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DE CANA-DE-AÇÚCAR
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Luís Augusto Barbosa Cortez
Coordenador

Blucher FAPESP

SUGARCANE BIOETHANOL

R&D FOR PRODUCTIVITY AND SUSTAINABILITY

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Rua Pedroso Alvarenga, 1245, 4º andar
04531-012 – São Paulo – SP – Brazil
Fax 55 11 3079 2707
Phone 55 11 3078 5366
editora@blucher.com.br
www.blucher.com.br

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ABOUT THE COORDINATOR

Luís Augusto Barbosa Cortez

University degree in Agricultural Engineering from Unicamp, M.Sc. from Université Laval in Quebec, Canada and PhD from Texas Tech University in Lubbock, USA. Titular Professor at Unicamp Agricultural Engineering University. He was a Coordinator of Nipe/Unicamp (1998-2002) and a Coordinator of Unicamp International Relations (2002-2009). Currently, he is the Assistant Coordinator of Fapesp Scientific Board of Directors and Directorship Adviser in the Bioethanol Science and Technology National Laboratory (Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CTBE).

ABOUT THE ORGANIZERS

André Tosi Furtado

Doctorate in Economics from Université Paris 1 (Panthéon-Sorbonne), France (1983). Currently, he is a Professor at Unicamp Geoscience Institute.

Antonio Bonomi

A Chemical engineer. PhD in Chemical Engineering from University of Minnesota, USA, 1977. Technological Evaluation Director of the Bioethanol Science and Technology National Laboratory (Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CBTE), since 2008. Senior Researcher of the Technology Research Institute (Instituto de Pesquisas Tecnológicas – IPT) – São Paulo, from 1983 to 2008. He has been working in the development of ethanol production technology for over 20 years, counting on several publications in the area. Nowadays, he is the Biofuel Director of the Brazilian Automotive Engineering Association (Associação Brasileira de Engenharia Automotiva – AEA).

Arnaldo Walter

University degree in Mechanical Engineering from Unicamp in 1980. Mastership and Doctorate in Energetic Systems Planning from Unicamp in 1994. Doctor Assistant Professor at the Mechanical Engineering college at Unicamp. At present, he is the Coordinator of the Sustainability Program at the Bioethanol Science and Technology National Laboratory (Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CTBE).

Luís Augusto Barbosa Cortez

University degree in Agriculture Engineering from Unicamp, M.Sc. from Université Laval in Québec, Canada, and PhD from Texas Tech University in Lubbock, USA. At present, he is a titular Professor in the Agriculture Engineering College at Unicamp. He was a Coordinator of Nipe/Unicamp (1998-2002) and a Coordinator of International Relations at Unicamp (2002-2009). At present, he is the Adjunct Coordinator in the Scientific Board of Directors at Fapesp and a Director Adviser in the Board of Directors at the Bioethanol Science and Technology National Laboratory (Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CTBE).

Manoel Regis Lima Verde Leal

University degree in Aeronautics Engineering from ITA in 1964. PhD in Mechanical Engineering from Kansas State University in 1971. He carried out Research and Development activities in engineering in the sugar alcohol sector at the Sugarcane Industry Technology Center (Centro de Tecnologia Canavieira – CTC) from 1986 to 2004. Currently, he is the Coordinator of the Ethanol Sustainability Program at the Bioethanol Science and Technology National Laboratory (Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CTBE) and also the Research and Development Director of the Alternative Energy and Environment Center (Centro de Energias Alternativas e Meio Ambiente – CENEA).

Oscar A. Braunbeck

Industrial Engineer with mastership and doctorate in agricultural engineering, MSU/USA. He has supervised 25 dissertations and theses as a professor at Feagri/Unicamp. He has been dedicating his expertise to research and equipments project for sugarcane mechanization since 1980 and has operated in the Copersucar Technology Center at Unicamp. At present, he is the Director of the Low Impact Agriculture Program in the Bioethanol Science and Technology National Laboratory (CTBE) with focus on direct planting, raw sugarcane crops and straw.

Paulo Sérgio Graziano Magalhães

Titular Professor at Unicamp Agricultural Engineering University, university degree in Agricultural Engineering from Unicamp in 1979 with doctorate in Agricultural Engineering from University of Cranfield, England, in 1986. He has been working in this area with emphasis on project and development of agricultural machinery and precision agriculture in the area of sugarcane industry.

Rodrigo Lima Verde Leal

University degree in Electrical Engineering from Unicamp (1995), Postgraduation in Administration and Business from FGV (2002) and Mastership in Technological and Scientific Policy from Unicamp (2007). At present, he is a researcher at CPqD Foundation. He counts on background in the area of innovation management where he has been working mainly in the following subjects: Information Technologies and Communication (Tecnologias de Informação e Comunicação – TIC), viability analysis, prospection and technological planning, regulation and public policies.

ABOUT THE AUTHORS

Ademar Hakuo Ushima

Researcher at the Energetic and Environmental Technology Center (Centro de Tecnologias Ambientais e Energéticas – CETAE), Technology Research Institute (Instituto de Pesquisas Tecnológicas – IPT). University degree in Chemical Engineering from EPUSP; MSc in Thermal and Fluids from the Mechanical Engineering Department at Unicamp. He has been working at IPT since 1978, developing activities in biomass gasification, industrial and municipal residues, and energy conservation in the industrial sector. Professor invited to the courses of Distributed Generation and Cogeneration: Technology and Management – MBA/USP, Industrial Combustion (IPT), Environmental Management and Businesses in the Energy Sector (IEE) as well as Strategic Management in the Environment (MAUÁ).

Adriano V. Ensinas

Assistant Professor at the Engineering Center, Modeling and Applied Social Sciences at ABC Federal University (Universidade Federal do ABC) and Collaborator Researcher in the Chemical Engineering Department of Campinas State University (Universidade Estadual de Campinas). Research areas: thermal systems analysis, modeling and industrial processes integration, energy utilization of agribusiness and urban residues.

Alceu de Arruda Veiga Filho

An Economist, a scientific researcher of São Paulo Agrobusiness Technology Agency (Agência Paulista de Tecnologia de Agronegócios – APTA) and a master in PC&T from Unicamp. He carries out studies on sugarcane economy. He has worked in the elaboration of agricultural development programs and has also taken over several management positions in the Agriculture and Supply Board (Secretaria da Agricultura e Abastecimento – SAA).

Alexandra Pardo Policastro Natalense

University degree in Theoretical Physics with Mastership and Doctorate from Unicamp in the area of electrons scattering through molecules, and post-doctorate in chemistry from Texas A&M University in the molecular photoionisation area. Currently, she is the director assistant at the Bioethanol Science and Technology National Laboratory (Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CTBE) and carries out researches concerning breaking of hemicellulose through electrons impact.

Alexandre de Sene Pinto

Agronomy Professor at Moura Lacerda University Center (Centro Universitário Moura Lacerda), Ribeirão Preto, SP. Member at the Bug Deliberative Council (Conselho Deliberativo da Bug). University degree in Agronomic Engineering and mastership in Entomology from Unesp/Jaboticabal and doctorate in Agrarian Entomology from Esalq/USP. He has been working with plagues biological control since 1989, especially sugarcane cultivation, citrus, corn and soybean, insects biology and agrochemicals selectivity to insects and pollination as well.

Alfred Szwarc

Mechanical engineer, M.Sc. in environmental pollution control, expertise in prevention and control of pollutant emissions in the transportation sector. Currently, he is the Director of ADS Technology and Sustainable Development, operating in the energy and environment areas. He is also a technical consultant of the Sugarcane Industry Union (União da Indústria da Cana-de-açúcar – Unica). He takes part in the Board of Directors at the Brazilian Automotive Engineering Association (Associação Brasileira de Engenharia Automotiva (AEA).

Amanda Pereira de Souza

University degree in Biological Sciences from the Methodist University of São Paulo (Universidade Metodista de São Paulo) and mastership in structural and cell biology from Campinas State University (Universidade Estadual de Campinas). She has been attending doctorate at USP (University of São Paulo) in the Botany Department and carries out researches in the area of physiology and biochemistry in vegetables with sugarcane.

André César Vitti

University degree in Agronomic Engineering from Viçosa Federal University (Universidade Federal de Viçosa – 1993). Mastership (1998), Doctorate (2003) and Post-doctorate (2006) both concluded at the Center of Nuclear Energy in Agriculture (Centro de Energia Nuclear na Agricultura – CENA/USP). At present, he is a Scientific Researcher for São Paulo Agrobusiness Technology Agency (Agência Paulista de Tecnologia dos Agronegócios – APTA) – Expertise in crop science, soils and plant nutrition.

André Meloni Nassar

University degree in Agronomic Engineering from Esalq/USP, Doctorate and Mastership in Economics, Business and Accountancy at USP. Currently, he's been operating as the general director of the Trade and International Negotiations Studies Institute (Instituto de Estudos do Comércio e Negociações Internacionais – ICONE) since 2007, where he has been general manager since its foundation in 2003. He counts on several years of background, rendering technical assistance to Brazilian agrobusiness trade associations in topics related to international trade, international negotiations, trade barriers and environmental affairs. He is the coordinator of the ICONE modeling project for land use.

André Tosi Furtado

Doctor in Economics from Université Paris 1 (Panthéon-Sorbonne), France (1983). Professor at the Unicamp Geoscience Institute (Instituto de Geociências da Unicamp).

Andres da Silva

Agricultural Engineer and Master in Mechanical Engineering (Thermal and Fluids) from Unicamp. He has been working with protected tillage and several hydroponic productions in Canada, USA and Mexico for the last 15 years. Expertise in integrated projects conception and in the management of high technology agricultural greenhouse complexes in Brazil through the company Estufas Agrícolas Comércio e Assessoria Ltda (EACEA).

Anete Pereira de Souza

University degree in Agronomic Engineering from Esalq/USP in 1984. Doctorate in cell and molecular biology from Université de Paris XI (Paris/Sud) in 1992. At present, she is a titular professor at the Unicamp Plant Biology Department (Departamento de Biologia Vegetal da Unicamp) in the field of plant genetics. She works especially in the areas of plant genetics and molecular biology, with focus on molecular genetic mapping, genetic diversity analysis and structure and expression of proteins connected with phyto-pathogenic genetic characteristics.

Antonio Augusto Franco Garcia

Master and Doctor in Genetics and Plant Improvement from Esalq/USP. He has concluded post-doctorate in Statistical Genetics at the Bioinformatics Research Center, Department of Statistics, at North Carolina State University, in Raleigh, USA. His main researches are based on developing and/or adapting genetic-statistical procedures.

Antonio Bonomi

Chemical engineer. PhD in Chemical Engineering from University of Minnesota, USA, 1977. He has been the Director of Technological Evaluation at the Bioethanol Science and Technology National Laboratory (Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CTBE), since November 2008. He was a Senior Researcher at the Technological Research Institute (Instituto de Pesquisas Tecnológicas – IPT) – São Paulo, from 1983 to 2008. He has been working in the ethanol production technology development for over 20 years counting on several publications in the area. Currently, he is the Director of Biofuels at the Brazilian Automotive Engineering Association (Associação Brasileira de Engenharia Automotiva – AEA).

Araken Alves Lima

Economist with expertise in Agro-industrial Economics from UFAL, mastership in Economic Development, Space and Environment, and doctorate in Applied Economics, both titles obtained at Unicamp. Currently, he works at the National Institute of Industrial Property (Instituto Nacional da Propriedade Industrial – INPI) where he takes over the position of mastership coordinator in intellectual property and innovation.

Arnaldo Walter

University degree in Mechanical Engineering from Unicamp in 1980. Mastership and Doctorate in Energetic Systems Planning from Unicamp in 1994. Doctor Assistant Professor at the Mechanical Engineering college at Unicamp. At present, he is the Coordinator of the Sustainability Program at the Bioethanol Science and Technology National Laboratory (Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CTBE).

Beatriz Acquaro Lora

Biologist, expertise in Environment Management, M.Sc. in Energy, researcher at the Biomass Reference National Center (Centro Nacional de Referência em Biomassa – Cenbio – IEE/USP).

Brigitte J. Feigl

Doctor Professor at the Nuclear Energy Center in Agriculture (Centro de Energia Nuclear na Agricultura – CENA/USP). He operates in research lines concentrated on evaluating emission rates from greenhouse effect fumes by the farming and stockbreeding sectors, and the effects of changes in the use of land and manipulation of soil over the carbon dynamics and the microbial biomass of soil as well as its functional diversity.

Camila Martins Garcia

University degree in Chemistry from Unicamp in 2003, Mastership in Inorganic Chemistry from Unicamp in 2006. Currently, she is licensed in the Doctorate course in Inorganic Chemistry at Unicamp and works as the Chief of Biomass Biodiesel Laboratory.

Camilo Sixto López Garzón

Chemical Engineer from Universidade Nacional de Colômbia, he concluded Mastership in Chemical Engineering from Unicamp, and has background in Biochemical Processes. He operates mainly in fermentation processes and bioreactors. At present, he develops doctorate in Biotechnological Processes at the Technical University of Delft, Netherlands.

Carlos Clemente Cerri

Titular Professor at the Nuclear Energy Center in Agriculture (Centro de Energia Nuclear na Agricultura – CENA/USP). He develops research programs collaborating with national and international institutions in the following areas: Alteration of carbon stocks from soil; emission of greenhouse effect fumes and the relations with environmental sustainability; and interactions of Biofuels with Global Warming.

Carlos Eduardo Pellegrino Cerri

Agronomic Engineer graduated from Esalq/USP, mastership and doctorate from University of São Paulo. Currently, he is a professor at the Soil Science Department of Esalq/USP (Departamento de Ciência do Solo da Esalq/USP) where he carries out researches related to the dynamics of soil organic matter under tropical climate conditions.

Carlos Eduardo Vaz Rossell

University degree in Chemical Engineering from Universidade de La República, Uruguay in 1970. M.SC (1972) and Dr.Sc. (1976) in Food Processing Engineering at Unicamp. In 1980, he joined the Copersucar Technology Center (Centro de Tecnologia Copersucar) and stayed there from 1980 to 2005, working as a Process Engineer, Process Coordinator, Chief of the Industrial Processes Division and Expertise Engineer. At present, he is the Coordinator of the Industrial Program at the Bioethanol Science and Technology National Laboratory (Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CTBE).

Carlos Henrique de Brito Cruz

University degree in Electronic Engineering from ITA, and Doctorate in Sciences from Unicamp Physics Institute. He was a Director at the Physical Institute, Dean at the Research Office and Provost of Unicamp. He was President of Fapesp where he is currently the Scientific Director. He is also a member at the Brazilian Science Academy.

Cássia Regina Limonta Carvalho

University degree in Industrial Chemical Engineering from Ribeirão Preto University (Universidade de Ribeirão Preto) in 1980, with mastership in Analytical Chemistry from the Chemistry Institute of Campinas State University (Instituto de Química da Universidade Estadual de Campinas) in 1996. Currently, she has been working as a Scientific Researcher for the Agronomy Institute in Campinas since 1994. She is also an expert in Analytical Chemistry and Plants Chemistry.

Cristiane Sanchez Farinas

Chemical Engineering from UFSCar (1992), mastership (2001) and doctorate (2004) in Chemical Engineering from Unicamp and post-doctorate in Chemical Engineering from UFRJ COPPE (2006). Nowadays, she is a researcher at Embrapa Farming and Stockbreeding Instrumentation (Embrapa Instrumentação Agropecuária) and a professor with credentials at the UFSCar Post-graduation Program in Biotechnology (Programa de Pós-graduação em Biotecnologia da UFSCar). She has background in Biochemical Processes and primarily operates in the following topics: fermentation, bioreactors, enzyme production and protein purification.

Cristina d'Urso de Souza Mendes

University degree in Chemical Engineering from EQ/UFRJ and M.Sc. from UFRJ Chemistry School (Escola de Química/UFRJ). Currently, she's been attending doctorate in the area of Management and Technological Innovation. She works as a Researcher at the National Institute of Industrial Property (Instituto Nacional da Propriedade Industrial – INPI), in the Division of Studies and Programs (Diespro), developing prospection studies and technological monitoring, making use of patents as a source of information.

Cylon Gonçalves da Silva

University degree (UFRGS), Mastership (UCBerkeley) and Doctorate in Physics (UCBerkeley). He has worked in the areas of magnetism and theoretical physics of semiconductors. He has already been the Director of the National Laboratory Luz Síncontron (Laboratório Nacional de Luz Síncrotron), Secretary National for Policies and Programs of Planning and Development in the Ministry of Science and Technology (Ministério da Ciência e Tecnologia – MCT), Director of the Genius Technology Institute, and nowadays he operates as the Fasesp Adjunct Coordinator where he advises the Scientific Board of Directors. He is a member at the Brazilian Science Academy (Academia Brasileira de Ciências) and is also an Emeritus Professor at Unicamp.

Edgardo Olivares Gómez

Mechanical Engineer from Universidad de Oriente in Cuba. Mastership and Doctorate from Unicamp Agricultural Engineering University (Faculdade de Engenharia Agrícola da Unicamp) in the areas of pyrolysis and biomass gasification. He has already been a professor at Itajubá Federal University (Universidade Federal de Itajubá – Unifei) and currently he carries out researches at the Bioethanol Science and Technology National Laboratory (Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CTBE).

Eduardo de Almeida

University degree in Agricultural Engineering from Unicamp, he has focused his studies on the biomass energetic utilization and by-products arising from the sugar and alcohol sector. He has also participated in courses, technological development projects and researches connected with the subject. Mastership student at the FEQ/Unicamp.

Eduardo Delgado Assad

Doctorate in Hidrologie Et Mathematique from Universite de Montpellier II (Scien. et Tech Du Languedoc), France (1987). Currently, he is the Research Chief at Embrapa Informática.

Eduardo Winter

University degree in Industrial Chemistry from PUC/PR; mastership and doctorate in Analytical Chemistry from IQ/Unicamp. At present, he takes over the position of professor/researcher in the professional mastership on Intellectual Property and Innovation at the National Institute of Industrial Property (Instituto Nacional da Propriedade Industrial – INPI), and operates in the areas of technological prospection and C&T&I indicators.

Efraim Albrecht Neto

University degree in Agronomic Engineering from São Carlos Federal University (Universidade Federal de São Carlos), mastership in Agricultural Machinery from Unicamp Agricultural Engineering College (Faculdade de Engenharia Agrícola da Unicamp). Currently, he is the Coordinator of the Innovative Research Project in Small Companies at Fapesp and a collaborator in projects connected with the Strategic Studies Management Center (Centro de Gestão de Estudos Estratégicos – CGEE), Ministry of Science and Technology (Ministério da Ciência e Tecnologia – MCT) and Projects and Studies Financier (Financiadora de Estudos e Projetos – FINEP).

Electo Eduardo Silva Lora

Doctorate in steam generators construction and reactors from Saint Petersburg Polytechnic University in Russia (1988). Adjunct Professor at the Itajubá Federal University (Universidade Federal de Itajubá – UNIFEI).

Euler Hoffmann Melo

University degree in Mechanical Engineering from Mackenzie Presbitarian University (Universidade Presbiteriana Mackenzie) in 2009, and a trainee at the Biomass Reference National Center (Centro Nacional de Referência em Biomassa – CENBIO) in 2008 and 2009, in the Bioethanol Project for Sustainable Transportation (Projeto Bioetanol para o Transporte Sustentável – BEST).

Evaristo Eduardo de Miranda

Agronomist, master and doctor in ecology from Montpellier University in France. He has coordinated several projects and research programs in the agriculture and environment areas, he also has over 200 scientific works. He has already been a professor at the USP Bioscience Institute (Instituto de Biociência da USP) and currently is a researcher of Embrapa Satellite Monitoring.

Fábio Luis Ferreira Dias

University degree from the Agrarian and Veterinary Sciences College – Jaboticabal Campus/Unesp in 1994, Master in Soil and Plants Nourishment from Luiz Queiroz Agriculture Superior School (Escola Superior de Agricultura "Luiz de Queiroz" – Esalq/USP) in 1997, Doctor in Plant Production from the Agrarian and Veterinary Sciences College – Jaboticabal Campus/Unesp in 2001. At present, he is a Scientific Researcher IV for the Agrobusiness Technology Agency in São Paulo (Agência Paulista de Tecnologia dos Agronegócios – IAC/APTA) and Director of the Regional Pole Center South (Pólo Regional Centro Sul – APTA).

Fábio Ricardo Marin

University degree in Agronomic Engineering from Esalq/USP where he concluded his course in 1998. He has mastership and doctorate in Physics of Agricultural Environment from the same institution. He has been attending doctorate at the University of Florida in a project about sugarcane modeling. He is currently a researcher for Embrapa, operating in research projects on climatic hazard evaluation, agricultural division into areas and plants growth modeling with focus on the sugarcane culture. He is a Tutor in the Agroenergy Professional Mastership of FGV/Esalq/Embrapa and in Environmental Engineering at PUC Campinas. He is also a tutor in the Post-graduation Program on Physics of the Agricultural Environment of Esalq/USP.

Fabíola Cristina Ribeiro de Oliveira

University degree in Economics from Unimep and master in Applied Economics from Esalq/USP. Nowadays, she takes part in the crew of the Labor Magistrature Study Group (Grupo de Estudos da Magistratura do Trabalho – GEMT), extension and research group of Esalq about the agricultural working market.

Francisco Rosillo-Calle

M.Sc., PhD., Researcher, Imperial College, England. He has approximately 30 years of background in the biomass energy area. He has published over 80 articles and books and has edited several books as well. He collaborates with many international research projects and counts on great knowledge on the Alcohol National Program in Brazil (Programa Nacional do Álcool no Brasil) – topic he has written his doctorate thesis about in 1985. He lectures classes on biomass energy in the mastership and doctorate courses in several countries.

George Jackson de Moraes Rocha

University degree in Chemical Industrial Engineering from Lorena University (Faculdade de Lorena – USP – 1989), Mastership (1995) and Doctorate (2000) from USP. Currently, he is a professor at the Lorena Engineering School (Escola de Engenharia de Lorena-USP) and an adviser in the implementation of processes and equipments in the Bioethanol Science and Technology National Laboratory (Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CTBE). He operates in the Plant Biomass Conversion.

Giampaolo Queiroz Pellegrino

Degree in Forest Engineering from São Paulo University (1991), expertise in Nuclear Energy in Agriculture (1989), mastership in Agronomy (Physics of Agrarian Environment from USP (1995) and doctorate in Agricultural Engineering – Water and Soil from Unicamp (2001). At present, he is a researcher in Global Climate Changes of Embrapa Informatics and Stockbreeding (Embrapa Informática Agropecuária). He operates in global climate changes and their impact over agriculture, trend analysis, environmental modeling, scenario simulation, watersheds, geo-processing and remote sensing.

Gilberto de Martino Jannuzzi

Adjunct Professor of Energetic Systems at Unicamp. He concluded doctorate in Energy Studies – University of Cambridge in 1985, and post-doctorate at California University/Berkeley. Nowadays, he is the Executive Director of the NGO – International Energy Initiative. He has published over 35 articles in specialized journals and 70 works in event analysis reports. He has four books published. He is the Coordinator of Nipe/Unicamp.

Glaucia Mendes Souza

Professor Associated to USP Chemistry Institute (Instituto de Química-USP) and Coordinator of the Fapesp Bioenergy Program (Programa de Bioenergia da Fapesp (Bioen). She has taken part in several inniciatives in genomics and functional genomics and has also been the Coordinator of Project Sucest about sugarcane genome sequencing since 2003. She studies regulatory networks of sugarcane, identification of associated genes to agronomical tracts of interest, bioinformatics and transgenic production.

Guido Zacchi

Chemical Engineering Professor since 1989 at Lund University, Sweden. His research is directed to the biofuel production field and chemicals obtainment from lignocellulosic materials. His research group counts on one process development unit for lignocellulosic ethanol investigation. He has oriented around 30 doctorate students and over 60 mastership students. He has also published around 150 scientific articles in scientific magazines. He owns 4 patents.

Heitor Cantarella

University degree in Agronomy from Unesp-Botucatu in 1974; M.Sc. (1981) and PhD. (1983) in Soil Fertility from Iowa State University, USA. Scientific Researcher for the Agronomic Institute (Instituto Agronômico – IAC), since 1975. Currently, he is an expert in soil fertility and plant nutrition.

Henry Joseph Jr.

Chemist with expertise in combustion, fuels, biofuels and automobile emissions. He has been working in the Products Development at Volkswagen do Brasil since 1981 and is currently responsible for the Automobile Emissions and Engine Laboratories. Nowadays, he is the President of the Environment and Energy Committee of the Automobile Manufacturers National Association (Associação Nacional dos Fabricantes de Veículos Automotores – ANFAVEA) and an Adviser for the Automobile Engineering Brazilian Association (Associação Brasileira de Engenharia

Hilton Silveira Pinto

Unicamp Professor. University degree from Esalq/USP with doctorate in Agronomy from Unesp and post-doctorate at the Guelph University in Canada. He has coordinated and still coordinates 23 research projects with financing in the areas of hazards and climate changes in agriculture. He has published scientific articles and book chapters in Brazil and abroad. He has also received 2 awards over scientific merit.

Isabel Cristina Serta Fraga

University degree in Chemistry from Maringá State University (Universidade Estadual de Maringá – 1983), Mastership (1989) and Doctorate (1997) in Inorganic Analytical Chemistry from PUC-RJ. Nowadays, she is a Researcher for Inmetro in the area of Chemical Metrology, with focus on Electrochemistry (pH and electrolytical conductivity).

Isaías Carvalho Macedo

University degree in Mechanical Engineering from ITA in 1967; PhD., Mechanical Engineering, University of Michigan, USA, 1971. Mechanical Engineering Professor at ITA and Unicamp since 1983; teaching and research in energy systems. He planned and coordinated research and development programs at the Copersucar Technology Center for 20 years (1981-2001). He has been working as an energy consultant (federal government and private companies) since 2001; he was a Principal advisor at Unicamp and coordinates biomass energy projects as a Visitor researcher at the Energetic Planning Interdisciplinary Center (Núcleo Interdisciplinar de Planejamento Energético – Nipe/Unicamp).

João Furtado

University degree in Economics from Unicamp in 1981, master in 1990 and doctor in Economics in 1997, Universidade de Paris XIII. Currently, he is a Professor in the Polytechnic School at the University of São Paulo (Escola Politécnica da Universidade de São Paulo). He has coordinated the Study Group in Industrial Economics (Unesp) and the Private Research Directory. He works with affairs related to Technology of Economics and Innovation and Industrial and Technological Policies. He is the Adjunct Coordinator of Fapesp Scientific Board of Directors in the Innovation area (programs PIPE and PITE). He has also founded Elabora Consultoria where he is a director-partner.

Joaquim E. A. Seabra

University degree in Food Processing Engineering from Unicamp with doctorate in Energetic Systems Planning from the same institution (2008). While attending doctorate he analyzed technological options for the whole utilization of sugarcane biomass, including evaluation of ethanol life cycle. Nowadays, he operates as a post-doc in the National Renewable Energy Laboratory (NREL, USA) in the area of Biorefinery Analysis dispensing special attention to sugarcane biomass. He is a researcher at the Bioethanol Science and Technology National Laboratory (Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CTBE).

Jorge Luis Donzelli

University degree in Agronomic Engineering from Unesp with expertise in Soil and Sugarcane Management. Specialization in Irrigation and Drainage from Esalq/USP. He has worked at the Campinas Agronomy Institute (Instituto Agronômico de Campinas – IAC) and is currently the Research and Development Coordinator for the Sugarcane Technology Center in the city of Piracicaba (Centro de Tecnologia Canavieira – CTC/Piracicaba).

José Antonio Bressiani

Agronomic Engineer with mastership and doctorate (Esalq/USP) in Genetics and Plant Improvement. Operation Area: Sugarcane genetic improvement.

José Carlos Feltan

University degree in Agronomic Engineering from Agronomic Sciences (Faculdade de Ciências Agronômicas/UNESP), with mastership and doctorate in phyto-techniques from Unesp. At present, he has been working as a Scientific Researcher III for the Campinas Agronomy Institute (Instituto Agronômico de Campinas – IAC) since 2004. He has background in the area of plant nutrition, management of root and tubercle production cultures, theoretical and applied knowledge on statistics and geoprocessing.

José Dílcio Rocha

University degree from Unicamp, mastership in Energetic Systems Planning from the Mechanical Engineering College (FEM) and doctorate in the Area of Materials and Manufacturing Processes also concluded in FEM at Unicamp. At present, he works at the new branch EMBRAPA-Agroenergy.

José Goldemberg

Doctor in Physical Sciences from USP where he was the Principal from 1986 to 1990. He has already been the President of São Paulo Energy Company (Companhia Energética de São Paulo – CESP); President of the Brazilian Society for the Progress of Science (Sociedade Brasileira para o Progresso da Ciência); Secretary of Science and Technology; Secretary of the Environment for the Republic Presidency; Minister of Education in the Federal Government and Secretary of the Environment in the State of São Paulo. He has coordinated the Bioenergy Committee in the State of São Paulo as well.

José Luiz Olivério

University degree in Production Mechanical Engineering from the Polytechnical School at USP. Nowadays, he is the Technology and Development Vice-President of Dedini S/A Indústrias de Base. He represents the equipment industry in the Biodiesel Sectorial Chamber, and has already represented it at the Alcohol and Sugarcane Chamber from 2004 to 2007, both institutions belonging to the Ministry of Agriculture. He is also a member at the Technology Council and in the Agrobusines Superior Council at the Association of Industries in São Paulo (Federação das Indústrias de São Paulo – FIESP), in the Orientation Council at the Technological Research Institute (Instituto de Pesquisas Tecnológicas – IPT) and in the International Consultancy Council (Conselho Consultivo Internacional – Fundação Dom Cabral).

José Roberto Miranda

University degree in Biological Sciences from USP and doctor in Applied Ecology from Université des Sciences et Techniques in Montpellier, and from École Pratique des Hautes Études, Paris Vième – Sorbonne, France. He has already been a professor at USP and is currently a researcher for Embrapa Satellite Monitoring where he carries out researches in the areas of Agroecology and Biodiversity. He counts on hundreds of technical and scientific works, several book chapters and books published.

José Roberto Moreira

University degree in Electrical Engineering from the Polytechnic School at USP. Doctor in Physics from USP. Currently, he is a Researcher in Princeton University in the US and a Researcher at Tohoko University in Japan. He is also a Professor of Physics and Energy at USP. Author and coordinator of the International Panel about Climate Changes in the United Nations (IPCC).

José Roberto Postali Parra

Titular Professor in the Entomology Dept, Phytopathology and Agrarian Zoology – Esalq/USP, member at the Brazilian Academy of Sciences, member at the Academy of Sciences for the Developing World (TWAS), researcher 1A for the National Council of Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq) and commander in chief at the National Organization of Scientific Merit – Republic Presidency.

Juan Harold Sosa Arnao

Doctor in Mechanical Engineering from Unicamp in 2007. Researcher for the company Equipalcool Sistemas Ltda. Research area: thermal systems analysis, water-tube boilers development for biomass and urban residues burn, bagasse drying, fluidized bed combustion.

Juan Miguel Mesa Pérez

University degree in Chemical Engineering from Universidade de Oriente, Cuba, doctorate in vegetal biomass thermal conversion system from Campinas State University (Unicamp). He is currently a partner at the company Bioware Technology.

Julio Maria M. Borges

Present partner and director of *JOB Economia e Planejamento* (Economy and Planning). He is a Professor at the Economics Department at USP and counts on articles published in Brazil and abroad. He was the economist responsible for the Copersucar Economics and Planning Assessorship for 14 years. Nowadays, he is a Counselor for alcohol and sugarcane plants in Brazil and is also a member of national and international institutions related to sugar, alcohol and energy.

Jurandir Zullo Junior

University degree in Applied Mathematics (1985) and Agriculture Engineering (1987), mastership in Applied Mathematics (1990) and doctorate in Electrical Engineering (1994); all these titles were obtained from Unicamp. At present, he has been working as a researcher for Cepagri/Unicamp since 1987, and was also the Director of the Center of Studies from august 2002 to august 2008. He has background in the areas of Agricultural Meteorology, Remote Sensing and Mathematical Modeling.

Katia Tannous

University degree in Chemical Engineering from UCS/RS (1985), Mastership from Unicamp (1989) and doctorate from the Institut National Polytechnique de Toulouse (INP), France (1993); post-doctorate at the University of Waterloo, Canada (1999-2000); expertise in education (2004) from PUC – Campinas. She is currently an Educator, Researcher and Professor associated to Unicamp.

Karine Miranda Oliveira

University degree in Biological Sciences from Unicamp (2001), and doctorate and post-doctorate in Genetics and Molecular Biology from the same institution (2006 and 2008, respectively). Nowadays, she is a Senior Researcher in the Sugarcane Technology Center (Centro de Tecnologia Canavieira – CTC). She has background in the Genetics area, with focus on Plant Genetics and Improvement.

Ladislau Martin Neto

Doctorate in Applied Physics from USP in São Carlos. Post-doctorate in Environmental Sciences from University of California, Berkeley, USA. Researcher for EMBRAPA Instrumentação Agropecuária. Supervisor of the Post-graduation

Program at USP – Chemistry Institute in the city of São Carlos. Researcher, Research Productivity of CNPq, level I-C. At present, he has been the Coordinator Embrapa Labex USA in Beltsville since 2009.

Leticia Ledo Marciniuk

University degree in Chemistry from Maringá State University (Universidade Estadual de Maringá) in 2003, and mastership in Inorganic Chemistry from Unicamp (2007), under orientation of professor Dr. Ulf Schuchardt. She is currently a doctoral student in Chemical Engineering at São Carlos Federal University under orientation of Professor Dr. Dilson Cardoso in the area of heterogeneous catalysis for biodiesel production.

Lúcia Carvalho Pinto de Melo

University degree in Chemical Engineering from UFPE in 1973, Master in Physics from UFPE in 1976, Master in Energy and Environment from University of California in 1980, post-graduation courses in the Massachusetts Institute of Technology – MIT. Nowadays, she has been the President of the Center of Management and Strategic Studies (Centro de Gestão e Estudos Estratégicos – CGEE), desde 2005. She has already been an Adjunct Executive Secretary of the Ministry of Science and Technology (MCT). Science and Technology State Secretary of the state of Pernambuco and President of the Foundation for Research Support of the state of Pernambuco (Facepe). She is a titular researcher for the Joaquim Nabuco Foundation (Fundação Joaquim Nabuco – Fundaj) and Chief Commander of the National Scientific Merit.

Luciana Rossini Pinto

University degree in Agronomic Engineering from FCAV/Unesp, with mastership from FCAV/Unesp and doctorate in Genetics and Plant Improvement from Esalq/USP. Currently, she is a scientific researcher for the Sugarcane Center at the Campinas Agronomical Institute. Operation Area: Biotechnology.

Luís Augusto Barbosa Cortez

University degree in Agriculture Engineering from Unicamp, M.Sc. from Université Laval in Québec, Canada, and PhD from Texas Tech University in Lubbock, USA. At present, he is a titular Professor in the Agriculture Engineering College at Unicamp. He was a Coordinator of Nipe/Unicamp (1998-2002) and a Coordinator of International Relations at Unicamp (2002-2009). At present, he is the Adjunct Coordinator in the Scientific Board of Directors at Fapesp and a Director Adviser in the Board of Directors at the Bioethanol Science and Technology National Laboratory (Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CTBE).

Luiz Augusto Horta Nogueira

University degree in Mechanical Engineering from Unesp Guaratinguetá; Master and Doctor from Unicamp. He was a Director at the Oil National Agency (Agência Nacional de Petróleo – ANP), Professor from the Latin America Memorial. He is currently a titular Professor at UNIFEI where he works in the biomass area for energetic purposes.

Luiz Carlos Corrêa Carvalho

University degree in Agronomic Engineering from Esalq/USP, post-graduation at FEA/USP and Vanderbilt University (USA). He was an Executive in public and private associations connected with sugarcane and alcohol; President of the Sectorial Chamber of Sugar and Alcohol Production Chain for the Brazilian Government from 2003 to 2007; Advisor at the Sugarcane Technology Center (Centro de Tecnologia Canavieira – CTC) from 2004 to 2007. Nowadays, he is a Director at Canaplan and Director of Plants from the Alto Alegre Group; Vice-President of the Agrobusiness Brazilian Association (Abag).

Manoel Regis Lima Verde Leal

University degree in Aeronautic Engineering from ITA in 1964, PhD in Mechanical Engineering from Kansas State University in 1971. He has developed Planning and Development activities in engineering in the sugarcane/alcohol sector at the Sugarcane Technology Center (CTC) from 1986 to 2004. At present, he is a Coordinator of the Ethanol Sustainability Program at the Bioethanol Science and Technology National Laboratory (Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CTBE). Planning and Development Director of the Alternative Energy and Environment Center. (CENEA).

Marcelo Khaled Poppe

University degree in Electrical Engineering from UFRJ in 1972); Master in Innovation Economics and Energetic Systems Economics from Université de Paris IX – Dauphine and Institut National des Sciences et Techniques Nucléaires in 1985. Director and then Energetic Development Secretary of the Ministry of Energy and Mining from 2001 to 2003. Nowadays, he is an Advisor at the Management and Strategic Studies Center (CGEE) where he leads studies in the areas of energy and climate change.

Marcelo M. R. Moreira

University degree in Economics from PUC-RJ, and with mastership in Economics of Institutions and Development from the University of São Paulo. He has been a researcher for the Institute of Trade and International Negotiation Studies since 2007 where he operates as an expert in economic modeling of the sugarcane energy sector, biofuels and direct and indirect change in soil usage.

Marcelo Valadares Galdos

University degree in International Agricultural Development in Kansas, USA. Master in Agroenvironment Management from Campinas Agronomic Institute and doctor in Soil Science from Esalq/USP. Nowadays, he carries out researches at the Center of Nuclear Energy in Agriculture (Centro de Energia Nuclear na Agricultura – CENA/USP) about agricultural products Life Cycle Evaluation with focus on greenhouse effect fume emissions and carbon capture in the soil.

Márcia Justino Rossini Mutton

University degree in Agronomic Engineering from FCAV/Unesp, with mastership in Plant Production from FCAV/Unesp, doctorate in Soils and Plant Nutrition from Esalq/USP. At present, she has habilitation degree (livre-docência) as a Professor at the FCAV/Unesp Technology Department and operates in the areas of Quality Raw Material Production for the Sugar and Alcohol Sector, Fermentation Biotechnology and Sugar Production Technology, Alcohol and By-products.

Marco Aurélio Pinheiro Lima

Theoretical Physician with a university degree and mastership in Atomic and Molecular Physics from USP and doctorate in Chemistry from Caltech, USA. Currently, he is a Titular Professor at Unicamp. He has published over 120 articles in categorized magazines and counts on over 1.600 citations. He is one of the editors of the magazine European Physical Journal D. He is also the Director of the Bioethanol Science and Technology National Laboratory (Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CTBE).

Marcos Guimarães de Andrade Landell

University degree in Agronomic Engineering from FCAV/Unesp; mastership and doctorate from FCAVJ/Unesp in Plant Production. Currently, he is a scientific Researcher in the Sugarcane Center at Campinas Agronomic Institute. Operation Area: Sugarcane Genetic Improvement.

Marcos Silveira Buckeridge

He has been carrying out researches on native plants and plants cultivated in Brazil in relation to their responses to climate changes since 1998, studying their photosynthesis, growth and metabolism. He is one of the creators and coordinators of the program BioEn – Fapesp, a Coordinator at the Technology and Science National Institute (Instituto Nacional de Ciência e Tecnologia – INCT) for Bioethanol and the Scientific Director of the Bioethanol Science and Technology National Laboratory (Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CTBE). Currently, he is a plant physiology professor at USP Bioscience Institute and an editor of international magazines on bioenergy.

Maria das Graças de Almeida Felipe

University degree in Exact and Technological Sciences, Teaching Degree in Biology from UFV in 1981, Master in Agricultural Microbiology (UFV-1988). Doctorate in Biochemical-Pharmaceutical Technology in the area of Fermentation Technology from USP in 1994. Nowadays, she is a Professor and Researcher at EEL-USP and operates in the field of Industrial Biotechnology with focus on plant biomass especially agro-industrial by-products.

Maria Valnice Boldrin Zanoni

University degree in Chemistry from FFCLRP/USP, Mastership and Doctorate in Physical Chemistry from IFQSC/USP, Post-doctorate at the University of Loughborogh/UK. Teaching degree in Analytical Chemistry (FFCLRP/USP), Professor Visitor at the University of Wisconsin/USA and University of Oxford/UK. Currently, she is a Professor at IQ/Unesp.

Marie-Anne Van Sluys

University degree in Biological Sciences from Rio de Janeiro State University (1983) and doctorate from Paris University XI (Paris-Sud) (1989). She is a titular professor at USP and responsible for the laboratory GaTE-LBMP. She operates in the genetics area with focus on molecular biology. Currently, she is an Adjunct Coordinator and a Member in the Program BIOEN of Fapesp.

Martial Bernoux

Agronomic Engineer, doctor from the universities of São Paulo and Orléans (France). He has been a researcher for the Institut de Recherche pour le Développement (IRD) in France since 1999. Co-worker in the Group “Carbon and Global Changes” (Carbono e Mudanças Globais) of the Research Unit Eco&Sols.

Mats Galbe

Senior Researcher for the Chemical Engineering Department at Lund University in Sweden. He accomplished his MScChE and Ph D at Lund University. He has over 20 years of background in ethanol production from lignocellulosic materials. He is currently responsible for the development of one national process unit for ethanol production, located in Lund where he also operates as a doctorate supervisor for doctoral students.

Mauro Alexandre Xavier

University degree in Agronomic Engineering from UFSC. Mastership from FCAV/Unesp in Plant Production. Researcher for the Sugarcane Center in the Agronomic Institute (IAC) in Campinas. Operation Area: Sugarcane Genetic Improvement.

Miguel Angelo Mutton

University degree in Agronomic Engineering and master in Plant Production, both titles obtained from FCAV/Unesp; doctorate in Soils and Plant Nutrition from Esalq/USP. Assistant Professor Doctor for the Plant Nutrition Department of FCAV/Unesp, and operates in the areas of Production and Sustainable Management Systems of Sugarcane cultures.

Miguel Taube-Netto

PhD at The University of Michigan, 1972/3, Department of Industrial and Operations Engineering. Bachelor in Aeronautic Engineering at Instituto Tecnológico de Aeronáutica, 1963, Brazil. Retired Professor from Unicamp- State University of Campinas, Department of Applied Mathematics of the Institute of Mathematics, Statistics and Scientific Computing. President and founder of Unisoma, a Brazilian company operating in the area of mathematical modeling for business decision making. Author winner of the “1995 Franz Edelman Award” delivered by Iinforms – Institute for Operations Research and the Management Sciences.

Mirna Ivonne Gaya Scandiffio

Doctorate and Mastership in Energetic Systems Planning from Unicamp. She has worked at the Bioethanol Science and Technology National Laboratory (CTBE) in areas related to Sustainability. As a researcher for Nipe/Unicamp she has participated in the Ethanol Project. In the academic area, she has coordinated the Administration superior course. She teaches subjects in the areas of Strategic Administration, Renewable and Nonrenewable Energies, Sustainability, Quality and Environment, for graduation and post-graduation courses .

Nelson Ramos Stradiotto

University degree in Chemistry from FFCLRP/USP, Mastership and Doctorate in Physical Chemistry from IFQSC/USP, Post-doctorate at the University of Southampton/UK. Habilitation degree (Livre-docência) in Analytical Chemistry from FFCLRP/USP. Professor Visitor at the University of Loughborogh/UK and University of Oxford/UK. Titular Professor in Chemistry (FFCLRP/USP). He is currently a Professor at IQ/Unesp.

Nilson Antonio Miguel Arraes

University degree in Agricultural Engineering from Unicamp, expertise in Economy of the Agriculture Feeding System (Cefas), mastership in Systems Engineering, doctorate in Sanitation and Environment from Unicamp. Nowadays, he is a Professor at Unicamp Agricultural Engineering College. He develops teaching, research and extension activities in the rural management area; particularly in production management and environmental management (private) as well as in the management of peri-urban rural areas (public).

Orlando Melo de Castro

Doctorate in Soils and Plant Nutrition from Esalq/USP. He has been a researcher for the Soil Center at the Agronomic Institute (IAC) since 1978. He was Director General of IAC from 2004 to 2008. Currently, he has been a coordinator at the Agrobusiness Technology Agency in São Paulo (APTA) since 2008.

Oscar A. Braunbeck

Industrial Engineer with mastership and doctorate in agricultural engineering, MSU/USA. He has supervised 25 dissertations and theses as a professor at Feagri/Unicamp. He has been dedicating his expertise to research and equipments project for sugarcane mechanization since 1980 and has operated in the Copersucar Technology Center at Unicamp. At present, he is the Director of the Low Impact Agriculture Program in the Bioethanol Science and Technology National Laboratory (CTBE) with focus on direct planting, raw sugarcane crops and straw.

Patrícia Maria Guardabassi

Chemical Engineer, M.Sc. in Energy. Researcher at the Biomass Reference National Center (Cenbio) and Electrotechnics and Energy Institute of São Paulo University (IEE/USP).

Paulo Paschoal Borges

University degree in Metallurgic Engineering from UFRJ in 1983. Mastership in 1989 and Doctorate in 1999 in Metallurgic and Materials Engineering from UFRJ-RJ. He is currently a Researcher for Inmetro with background in the area of Chemical Metrology with focus on Electrochemistry (pH and coulometry).

Paulo Sérgio Graziano Magalhães

University degree in Agricultural Engineering from Unicamp in 1979, with doctorate in agricultural engineering from University of Cranfield, England, in 1986. Titular Professor in the Agricultural Engineering College at Unicamp. He works in the area of agricultural engineering with focus on Agricultural Machinery Project and Development and Precision Agriculture in the sugarcane area.

Paulo Sérgio Machado Botelho

University degree in Agricultural Engineering. Mastership, doctorate in Entomology and post-doctorate from Esalq/USP. Professor Associated to the Plant Biotechnology Department of UFScar. He worked for the extinct IAA/Planalsucar from 1975 to 1990. He has dedicated his background to sugarcane plague studies and plague biological control in agriculture.

Pedro Ramos

Economist, Master and Doctor in Economics Applied to Administration from Eaesp/FGV. Professor/Researcher for the Agriculture and Environmental Economy Center at IE/Unicamp. He works with the subject of evolution and structure of Brazilian farming and stockbreeding, as well as with Bazilian Economic History. Author of the book "Sugarcane Agroindustry and land property in Brazil", having also organized other books on similar subjects.

Raffaella Rossetto

University degree in Agronomic Engineering, Esalq/USP, mastership in Nuclear Energy in Agriculture from Cena/USP, doctorate in Soils and Plant Nutrition, Esalq/USP. Scientific Researcher level VI for the Agrobusiness Technology Agency in São Paulo (APTA) – Sugarcane Program of Campinas Agronomy Institute (IAC).

Renata Marcheti

University degree in Law from Fadisc. She owns teaching habilitation (Licenciatura Plena) in Arts and Literature from FFCL at Barão de Mauá. Master in Constitutional Law from PUC – Pontifícia Universidade Católica de São Paulo, Doctorate in Law of International Economic Relations from PUC – Pontifícia Universidade Católica de São Paulo. Professor, Doctor in Law at the Economics, Accountancy and Administration and Business College (FEARP) at USP. She works as a lawyer and has already been a Legal Manager at Grupo Nestlé Brasil Ltda., as well as a General Legal Manager at Votorantim Metais Ltda. Her background in Law is focused on Entrepreneurial Law, M&A, Tax and Bioenergy.

Renata Martins

University degree in Administration and Business in 1995. She has been attending mastership in Energy at Universidade Federal do ABC. She has been a Scientific Researcher for the Agricultural Economy Institute (IEA) since 2005, for the Agrobusiness Technology Center in São Paulo (APTA), and for the Agriculture and Supply Board of the State of São Paulo (SAA). She operates in the technology management area and in the innovative processes area with focus on biofuels.

Renata Torres Gomes de Souza

She has been attending mastership in Agricultural Engineering from Unicamp, winner of the award CREA-SP, with professional background from the same institution. She operates as a PMO (Project Management Officer) in the area of

Supply Chain of Whirlpool S.A. She has worked as a consultant in the sugar alcohol sector and as a Project Engineer of DEDINI. In this company, as a member of Development Engineering and New Businesses, she was directly involved in straw analyses for energy co-generation. Expertise in technical and economic viability analysis of projects and elaboration of business plans.

Ricardo Yassushi Inamasu

University degree in Mechanical Engineering and Doctorate from São Carlos Engineering College – USP. He has concluded post-doctorate in Biosystem Engineering from University of Nebraska. At present, he is a researcher at Embrapa Instrumentação Agropecuária and also a collaborator professor at University of São Paulo. He has operated maily in the following subjects: Instrumentation for Precision Agriculture, Agricultural Robotics, High Resolution Sensoring and Electronics Embarked in Agricultural Machinery. He is a member at Força Tarefa Isobus Brasil.

Roberto Campos Giordano

Universtity degree from Poli-USP, master from Unicamp and doctor from EPUSP in Chemical Engineering. Post-doctorate in Biochemical Engineering at MIT, USA. Professor at UFSCar since 1980. He is currently a Titular Professor at UFSCar and a Coordinator of the Bioprocess Automation and Development Laboratory. His research activities aim the development of nonconventional bioreactors, modeling, simulation, optimization and validation of bioprocess control strategies.

Rodolfo Hoffmann

University degree at Esalq/USP in 1965. He was a full time professor in that institution from 1966 to 1996. Nowadays, he has been a Professor at Unicamp Economics Institute since 1997. His main subjects of study and research are: poverty and social inequalities measurements, income distribution in Brazil and agriculture modernization process.

Rodolfo Quintero-Ramirez

University degree in Chemical Engineering from UNAM (1972), Master from MIT (1974), and Doctor from Universidad de Manchester (1977). At present, he has been a Professor in the Process and Technology Department in the Engineering and Natural Sciences Division at Universidad Autónoma Metropolitana, Mexico, and a National Investigator, level III, del SNI since 1989.

Rodrigo Aparecido Jordan

University degree in Agricultural Engineering in 1998 and Master in Agricultural Engineering in 2000, both titles obtained from UNIOESTE University (Universidade Estadual do Oeste do Paraná). Doctor in Agricultural Engineering in the area of Rural Construction and Surroundings from the Agricultural Engineering College (FEAGRI/Unicamp) in 2005.

Rodrigo Gazaffi

Doctor in Genetics and Plant Improvement (Esalq/USP). Currently, he attends post-doctorate in Statistical Genetics under supervision of Dr. A. Augusto F. Garcia. He works with plant improvement and QTLs mapping in experimental populations and progenies of complete siblings (diploid and polyploid).

Rodrigo Lima Verde Leal

University degree in Electrical Engineering from Unicamp (1995), post-graduation in Administration and Business from FGV (2002), and mastership in Scientific and Technological Policy from Unicamp (2007). Nowadays, he is a Researcher at the CPqD Foundation. He has background in the innovation management area, and mainly operates in the following subjects: Communication and Information Technologies, viability analysis, technological planning and prospection, regulation and public policies.

Rogerio Cezar de Cerqueira Leite

Professor Emeritus at Unicamp, Member at the National Council of Science and Technology, President of the Administration Council at the Technology Brazilian Association Luz Sincrotron (ABTLuS), Member at the Editorial Council of the newspaper Folha de São Paulo.

Sabrina Feldman

Communication Coordinator at the Institute of Trade Studies and International Negotiations (Instituto de Estudos do Comércio e Negociações Internacionais – ICONE).

Sabrina Moutinho Chabregas

Doctorate in Genetics and Plant Improvement from Esalq/USP (2002). Expertise in Agroindustrial Technology of the Cooperative Society for Sugarcane, Sugar and Alcohol Producers – Sugarcane Technology Center (Cooperativa de Produtores de Cana, Açúcar e Álcool – Centro de Tecnologia Canavieira – CTC).

Sérgio Tamassia Barreira

University degree in Agronomical Engineering in 1975 from Luiz Queiroz Agriculture College (Escola Superior de Agricultura "Luiz de Queiroz" – Esalq/USP), and MBA in Entrepreneurial and Finance Management from ESAMC. He has started his activities at Codistil S/A. in 1976 as a Project Engineer in the Ethanol and Sugar Division, and has taken over the positions of Engineering Manager and Director in his career background. Currently, he works at Dedini in the position of Executive Director in the Business Division (BIO) – Equipments and Plants. He also works as a Director Superintendent at DAP (Dedini Automação de Processos) – Dedini Process Automation.

Silvana Creste

University degree in Agronomical Engineering from FCA/UNESP with mastership in Biological Sciences from Unesp and doctorate in Genetics and Plant Improvement from Esalq/USP. At present, she is a Scientific Researcher for the Sugarcane Center at Campinas Agronomic Institute. Operation Area: Biotechnology.

Silvia Azucena Nebra

Researcher for Nipe/Unicamp. Retired Titular Professor from Unicamp Mechanical Engineering College (1980-2005). Research Areas: diagnosis/optimization of thermal systems, drying of agroindustrial products.

Sílvia Maria Stortini González Velázquez

University degree in Chemical Engineering from Fundação Armando Álvares Penteado in 1985, Mastership in 2000, and Doctorate in Energy in 2006 from the Inter-union Program of Postgraduation in Energy (Programa Interunidades de Pós-Graduação em Energia – PIPGE) at USP. Professor in the Engineering College at Fundação Armando Álvares Penteado, Professor at Mackenzie Engineering College (Escola de Engenharia da Universidade Presbiteriana Mackenzie), Researcher for the Biomass Reference National Center (Centro Nacional de Referência em Biomassa – CENBIO), operating mainly in energy generation from renewable sources, particularly biomass, and in the utilization of liquid biofuels.

Silvio Cezar Pereira Rangel

University degree in Economics from Mato Grosso Federal University, and degree in Law from Cuiabá University. Post-graduation in Entrepreneurial Management from University of São Paulo (USP), Administration Foundation Institute (Fundação Instituto de Administração – FIA). Now, he has been operating as the manager of the biodiesel division at Usina Barralcool S/A since its initial project until its implementation and posterior functioning in 2006.

Suani Teixeira Coelho

Doctorate in Energy from USP, Professor in the Inter-union Program of Postgraduation in Energy at USP, Coordinator at the Biomass Reference National Center (Centro Nacional de Referência em Biomassa – CENBIO) – Electrotechnics and Energy Institute (Instituto de Eletrotécnica e Energia – IEE/USP), Adjunct Secretary of the Environment – Geraldo Alckmin Government – State of São Paulo.

Tamás Szmrecsányi (1936 – 2009)

Philosopher. Mastership in Economics from New School for Social Research. Doctorate in Economics from Unicamp. Post-doctorate from University of Oxford (England). He taught at Esalq/USP and had teaching habilitation (Livre Docência) at Unicamp. Titular Professor of Social History at C&T/Unicamp, Professor Visitor at Université de Toulouse I (France) and at Facultad Latinoamericana de Ciencias Sociales (Ecuador). Author of several publications out of which we can refer to the book "O Planejamento da Agroindústria Canavieira do Brasil (1930-1975)" – The Agroindustry Sugarcane Planning in Brazil – and an organizer of collections by Editora Hucitec. He founded and presided the Brazilian Association of Researchers in Economic History.

Telma Teixeira Franco

University degree and mastership from Pharmaceutical Sciences College and doctorate in Biochemical Engineering from University of Reading, England. Currently, she is a Professor with teaching habilitation (Livre Docência) in the Chemical Engineering College at Unicamp and a Coordinator at the Biochemical Engineering Laboratory, Biorefinery and Renewable Origin Products. She has background in Bioprocesses. She operates in the biomass utilization to obtain molecules for industrial usage, characterization and application of chitosan/biopolymers in intelligent recipients, enzymatic technology, biorefinery, fermentative processes and photobioreactors.

Teresa Losada Valle

University degree in Agronomic Engineering, mastership in Genetics and Plant Improvement, and doctorate in Agronomy from Esalq/USP. Scientific Researcher VI for Campinas Agronomic Institute (Instituto Agronômico de Campinas – IAC) since 1982. She has a background of 27 years in science and technology development with the cassava culture. She is also an adviser in national and international projects and has developed several cassava variations with high impact on agriculture.

Thomaz Fronzaglia

University degree in Agronomic Engineering in 1999, and Mastership in Administration and Business from the University of São Paulo in 2003. Nowadays, he has been operating as a Management and Strategy Secretary Board Analyst of the Brazilian Farming and Stockbreeding Research Company – Embrapa since 2007. He was a Researcher for the Agricultural Economy Institute (Instituto de Economia Agrícola – IEA/Apta) between 2005 and 2007. He operates in prospective analysis, strategic planning, innovation management and economy of the organizations and institutions.

Ulf Friedrich Schuchardt

University degree in Chemistry from Marburg University, Germany, in 1973, Doctorate in Inorganic Chemistry from Muenchen University, Germany, in 1975. Post-graduation at the Max-Planck Institute, Germany. He has been a Chemistry Professor at Unicamp since 1976. Retired and Senior Researcher for CNPq since 2007.

Vadson Bastos do Carmo

University degree in Chemistry and Expertise in Quality Engineering, both titles obtained from Unicamp. Specialization in Entrepreneurial Management from USP, mastership in Production Engineering from Unimep, mastership in Information Systems Management from PUC. He has been attending Doctorate in Chemical Engineering from Unicamp. Over 25 years of Background in multinational and national companies (Dow, Degussa, Elekeiroz, Sebrae, Fatec, Dedini) in the areas of Research and Development, Technological and Entrepreneurial Management.

Vanderléia Radaelli

Economist, attending doctorate in Scientific and Technological Policy (IG/Unicamp).

Wanderley Dantas dos Santos

Doctorate in Cellular Biology from Maringá State University on his research about ferulic acid allelopathic mechanisms. Nowadays, he investigates the phenylpropanoids role in the recalcitrancy to hydrolise of the sugarcane cell wall in the Bioscience Institute at USP.

William Lee Burnquist

Agronomic Engineer, PhD and improver. Currently, he is the Strategic Development Manager at the Sugarcane Technology Center – CTC. He counts on wide background in genetic improvement and sugarcane biotechnology. He has coordinated research groups and developed over 40 sugarcane variations, which collectively occupy 50% of the Brazilian Market. He is currently an active member at the International Society for Sugarcane Technologists (ISSCT). In 2010 he was elected the Society Vice-Chairman (2010-2013).

PREFACE

SUGARCANE BIOENERGY IN BRAZIL:

SUSTAINABILITY, REDUCED EMISSIONS AND ENERGY SECURITY

Carlos Henrique de Brito Cruz
Scientific director of Fapesp

In 2007, sugarcane ethanol provided 16.3% of the energy for ground transportation (excluding railways) and 37.6% of the overall energy supplied via liquid fuel for Otto cycle engines in Brazil. This last figure was 51% in 1988.

In addition to the energy extracted and stored in ethanol, burning the sugarcane bagasse is used to generate heat for the mill. Bagasse has been increasingly used as raw material for generating electricity resold to distributors. In 2007, the total energy generated from sugarcane in Brazil reached 15.9% of all the energy generated in the country; this figure makes sugarcane the second major energy source in Brazil, second to petroleum and above hydroelectricity.

On top of having the world's lowest production costs, ethanol from sugarcane produced in Brazil has another important advantage: in the country's Center-South region, one unit of fossil energy is used for each 8-9 units of energy produced from sugarcane ethanol. Reduced carbon emissions are another benefit from sugarcane ethanol: for each cubic meter of sugarcane ethanol used as fuel, there is a reduction of 2.1 to 2.4 tons of CO_2 issued to the atmosphere.

Sugarcane landed in Brazil in 1532. In the "Brazilian model", sugar and ethanol are jointly produced, which has brought some technical benefits and a noticeable increase in the competitiveness of both products in the international market. Approximately 50% of the saccharose produced in Brazil from sugarcane is used for producing sugar; the other half being used to produce ethanol. Industrial and academic R&D helped to continuously increase ethanol productivity, especially during the past 33 years, at a rate of 3.2% per year. Increased productivity made possible to reduce the planted area by a factor of 2.6.

In 2007, the area planted with sugarcane for producing ethanol was 3.4 MHa, corresponding to 1% of the total cultivable area in Brazil. 63% of the ethanol produced in Brazil comes from the São Paulo state, which has the highest productivity, beyond 7,000 liters per hectare. Most of the expansion is taking place in the Center-West region of the country, in degraded grazing lands.

The world interest in biofuels, especially since 2004, created important opportunities for Brazil, while it also posed great challenges. It is worth noting that the world market for gasoline in 2002 was 1.17 trillion liters, so to supply a 10% demand of this energy it would be necessary to produce about 150 billion liters of ethanol fuel. This is equivalent to 10 times the Brazilian production.

Since 1975, with the start of the Proálcool Program, Brazil had been developing the use of biofuels, practically without any competition (and also without much interest from the rest of the world). High petroleum prices prevailing until 2008 and the growing attention to hazards from greenhouse gas emissions changed this comfortable, almost monopolistic, situation. On one hand, scientific breakthroughs led decision-makers in the US and Europe to believe that it will be possible to produce biofuels in an economically viable way by processing cellulose, using hydrolysis and/or gasification techniques. The price of petroleum, that reached US$ 120 per barrel in mid-2008 (though it dropped since the beginning of the current economic world crisis) helped to strengthen this conviction, favorable to the feasibility of cellulosic ethanol. On the other hand, from the IPCC Scientific Report, published in 2008, stating that global warming has solid scientific grounds, it is therefore essential to take action to reduce the emission of greenhouse gases.

Since the Proalcool launch, Brazil had been the great, and practically the sole actor in this field. The scenario has changed: today, more developed countries decided to adopt the use of biofuels and they are investing into making this goal feasible, in terms of financial and corporate resources, as well as a significant part of their R&D capabilities. From 2007 on, Brazil lost its world's leadership in the production of ethanol to the United States. The American ethanol production is based on corn, which is less efficient than sugarcane in several aspects. The speed of technological advance tends to increase and the likely breakthroughs may result in significant changes, either positive or negative, for Brazil.

Simultaneously, in the new scenario, the likely increase of the world production of biofuels brought two relevant issues to the debate. The first is the increase being perceived as a potential competition factor for cultivable areas, which would raise the cost of food. Second, issues related to the sustainability of biofuel production were emphasized, especially those connected to studies on the Life Cycle Analysis.

All these recent changes stress the importance of research for acquiring new knowledge in the bioenergy area. Furthermore, they highlight the need for the research on biofuels in Brazil to shift level, from a relatively comfortable situation where external competition was virtually nonexistent into one where competition now includes the major scientific powers on this planet.

To face these challenges, action is required from the various parties involved in national science and technology policies. Fapesp, watchful on this subject, has been running debates since 2005 among the São Paulo state research community about bioenergy research. The approval of the project Guidelines for Public Policies for the Sugarcane Agriculture in the São Paulo State, led by Prof. Luís Augusto Barbosa Cortez, from Unicamp, within the Fapesp Research Program in Public Policies, was an important step in this direction.

The studies and the conclusions developed in this project are introduced herein. The job involved 18 workshops on specific themes and mobilized over 500 researchers.

The scientific and technological research agenda that came from this encompassing and systematic study shows the importance of studies associated to the sustainability of energy production from sugarcane. It also shows how possibilities for improved efficiency and productivity may result from scientific breakthroughs and the relevance of the interconnection between these challenges.

It is essential that Brazil and the São Paulo state take the necessary steps to intensify R&D activity in universities, institutes and companies regarding the issues covered herein. Brazil's leadership position in the use of bioenergy depends on that, especially when scientific progress points to a second generation of biofuels, based on processing sugars extracted from the cellulose in the biomass. For this purpose, Fapesp announced in 2008 its Research Program on Bioenergy, Fapesp's Bioen.

The Fapesp Research Program on Bioenergy, Bioen, aims at articulating R&D in this area, using academic and industrial laboratories and, in doing so, to expand and apply the knowledge in the fields related to ethanol production in Brazil. The Fapesp Research Program on Ethanol has a solid center to support academic research related to the exploration of these themes. It is expected that such exploratory activities generate new knowledge and qualify the necessary scientists and other professionals for advancing the industrial capabilities in ethanol-related technologies.

Additionally, the Fapesp Research Program on Ethanol establishes partnerships with industry for co-financing cooperative R&D activities between industrial and academic laboratories in universities and research institutes. For each of these collaborations, details and themes are specified according to the interest of private partners and in accordance to Fapesp's commitment to promote research in the São Paulo state. Other research agencies from the federal government and other states were invited to participate in Fapesp's research program on ethanol: CNPq has already approved a co-financing regime, with significant resources from Pronex, which was used in the calls published in 2008. The Minas Gerais Research Support Foundation (Fundação de Amparo à Pesquisa de Minas Gerais – Fapemig) has already approved a cooperation agreement with Fapesp for co-financing R&D, for the collaboration between researchers from both states.

Fapesp's Bioen comprises five major divisions:

a) Sugarcane plant science and technology, including genomics, improvement and technologies for growing and harvesting sugarcane.
b) Industrial ethanol production technologies.
c) Ethanol applications for vehicles: Otto cycle engines and fuel cells.
d) Biorefinery technologies.
e) Overarching themes: social and economical impacts, environmental studies and land usage.

The first calls for research proposals were published by Fapesp in 2007 and 2008, jointly representing R$ 89 million in investments for the next four years. New calls will be issued this year.

Professor Cortez's and his team's work, presented herein, is a rich contribution from Fapesp's Bioen for the R&D development of bioenergy in Brazil. We hope it will stimulate the research community to continue searching for new scientific and technological challenges and that it means a milestone in overcoming them.

INTRODUCTION

Luís Augusto Barbosa Cortez
Coordinator of Fapesp PPP Ethanol project

The book *Ethanol: Research and Development* is the result of a project carried out between August 2006 and March 2009 entitled "Guidelines for Public Policy for Scientific and Technological Research on Bioenergy in the State of São Paulo" (http://www.apta.sp.gov.br/cana/) also known as PPP Ethanol Project. It was funded by the São Paulo State Research Foundation – Fapesp.

The Fapesp PPP Ethanol Project also worked closely with the São Paulo Technology Agribusiness Agency – APTA, which includes institutions such as IAC, IEA and Ital). In addition, the following institutions were also involved in the project:

- Centro de Ciência e Tecnologia do Bioetanol – CTBE
- Centro de Referência de Biomassa – Cenbio
- Centro de Tecnologia Canavieira – CTC
- Dedini S/A Indústrias de Base
- Embrapa Brasileira Agropecuária – Embrapa
- Instituto de Pesquisas Tecnológicas – IPT
- Universidade Estadual Paulista – Unesp
- Universidade Estadual de Campinas – Unicamp
- Universidade Federal de São Carlos – UFSCar
- Universidade de São Paulo – USP

Contributors to this book include researchers and experts from a variety of areas ranging from policy, sustainability, or specific technological developments in the sugar-ethanol sector in Brazil.

There were 18 technology workshops covering a wide range of institutions and topics, as illustrated in Table 1. The objectives were to assess and develop scenarios for the development of proposals for RD&D and to propose strategies and policies for the sugar-ethanol sector.

The technology workshops covered the entire production chain from sugarcane to the end use of ethanol. The meetings were aimed at developing guidelines, by identifying the bottlenecks in the industry, spread across areas and expertise, integrating all the participating team. This included the encouragement of other experts not directly participating in the project and representatives of the production chain, in order to assess the potential for sustainability and growth of the industry and how to meet the demands of society.

These workshops allowed the authors of this book to develop indicators and measure the performance, make assessments, analyze the results and identify bottlenecks of the whole supply chain of the sugarcane ethanol sector. The book is, therefore, a collection of documents obtained through the workshops and papers of experts who took part in the project.

It is the hope that will help the policy-makers to define guidelines and strategies for the development of public policies for the sugarcane and ethanol industry. The research undertaken by this project should allow the development of research policies to improve the current production chain to the desired sustainable development path. To that extent, the Bioen Fapesp Program is a good example to stimulate research efforts and training of human resources in bioenergy. The Bioen-Fapesp Program, in addition of constituting a strong core of basic research, has also

TABLE 1 Technological Workshops conducted by the Fapesp PPP Ethanol project.

Topic	Responsible Institution	Date
Ethanol Production	EEL/USP	10 Nov. 2006
Cane Harvest, Transport, and Trash Recovery	Feagri/Unicamp	29 Nov. 2006
Hydrolysis	IPT	11 Dec. 2006
Sustainability	IEA/APTA	14 June 2007
Genetic Improvement and Biotechnology	IAC/APTA	28 June 2007
Biomass Production and Agricultural Modeling	Esalq/USP	17 July 2007
Sugarcane Pests	Esalq/USP	14 Aug. 2007
Energy Cane	FEQ/Unicamp	05 Oct. 2007
Vinasse	FCA/Unesp	10 Oct. 2007
Cogeneration	FEM/Unicamp	23 Jan. 2008
BTL (Biomass To Liquids)	IPT	26 Fev. 2008
Environmental Aspects	Cenbio/Cetesb	16 Apr. 2008
Sector Evolution Impacts	APTA/CATI	16 May 2008
Production of Ethanol: Quality of the Raw Material	EEL/USP	30 May 2008
Sugar-Ethanol Sector Agricultural Management	CTC	02 Oct. 2008
Use of Water in the Production of Sugarcane Ethanol	FEM/Unicamp	24 Nov. 2008
Instrumentation and Automation in the Sugarcane Ethanol Agriculture and Industry	Embrapa Instrumentações	28 Nov. 2008
Photosynthesis	Fapesp	18 Fev. 2009

industrial partnerships such as Dedini, Braskem and Oxiteno.

The involvement of the staff of APTA, universities and private sector, will enable the adoption of policies aimed at maintaining and improving the competitiveness of the sugar and ethanol industry in Brazil.

This book is divided into 5 parts, each one under the responsibility of a respective organizer:

- Public Policy Strategies for Ethanol in Brazil (Luís Augusto Barbosa Cortez).
- Sustainability of Biofuels Production and Consumption (Arnaldo Walter).
- A New Model for Sugarcane Mechanization System (Paulo Sérgio Graziano Magalhães and Oscar A. Braunbeck).
- A New Model for Industrial Production and Final Uses of Ethanol (Antonio Bonomi).
- Technological Roadmapping for Sugarcane Ethanol (André Tosi Furtado and Rodrigo Lima Verde Leal).

At the end of the project, a workshop was organised to assess the main findings and how to develop a Public Policy Guidelines for Ethanol production (should also say sugarcane).

CONTENTS

Part 4 A NEW MODEL FOR INDUSTRIAL PRODUCTION AND FINAL USES OF ETHANOL

Antonio Bonomi (organizer)

Part 1

PUBLIC POLICY STRATEGIES FOR ETHANOL IN BRAZIL

Luís Augusto Barbosa Cortez
(organizer)

1

INTRODUCTION

Luís Augusto Barbosa Cortez

Since the 1970s energy crisis and concern with the environment, energy efficiency was intensified and expanded, and interest on renewable energy sources which can contribute to reduce CO_2 emissions, intensified considerably. The Brazilian Agenda 21 and The Kyoto Protocol promoted further training, education, technical-scientific knowledge, and the substitution of fossil fuels for sustainable renewable energy sources.

This concern has grown significantly worldwide in recent years and countries such as the USA, which consumes roughly 40% of the world's gasoline (around 560 billion liters in 2008), is also adopting policies to reduce foreign energy dependence and the promotion of renewable energy.

Therefore, because global environmental concern (greenhouse gas emission reduction) or because the need to reduce foreign energy dependence, Brazilian ethanol, which overall is environmentally highly positive when compared to other options, represents a great opportunity for Brazil today and in the coming decades.

ETHANOL: A STRATEGIC PRODUCT FOR BRAZIL

Brazil is world's largest producer of sugarcane, ethanol, and sugar, with 572.7 million tons of cane harvested, 27.7 billion liters of ethanol, and 31.1 million tons of sugar. Sugarcane is produced in 101 countries, although the largest eight producers present about ¾-world production (FAOSTAT, 2008); accordance to the same source in 2007 Brazil accounted for 33% of such production.

Brazil's leadership in this sector was achieved thanks to significant reductions in production costs, mainly after *Proalcool* – Brazilian National Ethanol Program was launched in 1975, due productivity and efficiency gains, both agricultural and industrial, as illustrated in Figure 1.

For example, total recoverable sugars (TRS) increased from about 109 kg/ton sugarcane in the 1974/75 harvest to 144 kg/ton sugarcane in the 2004/05 harvest. In Central and South Brazil, especially in the State of São Paulo, the gains have been even greater. For example, between 1975 and 2000, sugarcane production increased 33%, saccharose content by 8% while fermentation efficiency reached 14%, and 130% in overall productivity. Such improvement has resulted in the South Center producing 5,900 liters/ethanol/ha compared to 2,000 liters/ha in 1975; and production costs roughly US$ 0.20/liter. The state of São Paulo, thanks to its competitiveness, accounts for about 60% of domestic sugarcane and alcohol production.

Brazil's worldwide leadership and competitiveness cannot be guaranteed in medium and long term because countries such as Australia and Thailand have also sugar production costs similar, or even lower, than Brazil, while they have considerable potential for sugarcane expansion. As for ethanol, many developed countries are investing heavily in ethanol production from lignocellulosic materials, using different routes [hydrolysis and gasification routes (Fischer-Tropsch and other)], aiming to achieve productions costs similar to Brazil's current costs, in the medium term. The USA position is very important as is it the world's

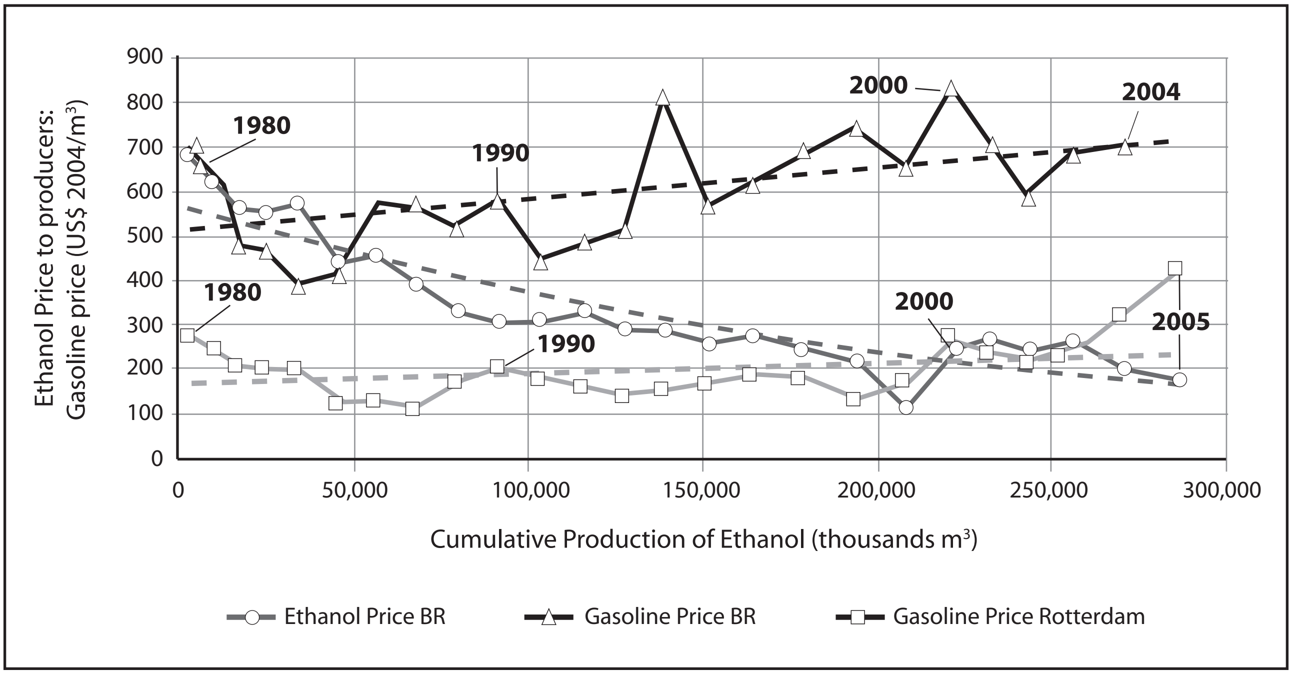


FIGURE 1 Learning Curve – Brazilian Ethanol.

Source: GOLDEMBERG, NIGRO and COELHO (2008).

largest producer and consumer of ethanol, with almost 30-billion liters produced in 2008 alone. In addition, the potential home market is about 60 billion ethanol liters annually, just with 10% ethanol mixture with gasoline. Investments and RD&D on such scale can be expected to lead to production in large scale and increased competitiveness that will impact the global market.

Concerning Central South Brazil, ethanol production costs are, on average, 65-68% raw material (sugarcane), 20-25% industrial process and the remains administrative expenses (sugar mill management, supplies, marketing etc.). This industrial efficiency gain has already led to conventional sugar and alcohol technology production to a high maturity level. However, the main gains are still in agricultural and investment, mainly genetic improvement on sugarcane and farming practices, must be prioritized by focusing RD&D resources. This does not means ignoring the industrial as there are still potential gains e.g. juice treatment, fermentation and distillation, surplus electric energy production; by-products, reduction of water consumption, energy and environmental impacts, among others.

Sugarcane is increasingly being seen as an energy source, in addition to as a food source. However, this far from being achieved since less than 30% of its original primary energy is converted into useful secondary energy (alcohol and electric power). This is new perspective for sugarcane since the potential for improvements is quite large e.g. some estimates indicate that agro-industrial productivity could increase from current 6,000 liters/ha/yr to at least 14,000 liters/ha/yr within 20 years.

Within the next 20 years, global demand for alcohol fuel could reach hundreds of billions of liters (e.g. some 200 billion liter per year would be needed to replace just 10% of the gasoline consumed worldwide in 2025). If Brazil provides half of this demand, it would mean more than US$ 30 billion/year in exports at today's price. This could more than double if one takes into account other sectors such as chemistry (ethanol chemistry), or the electricity generation.

The development of this sector in the last twenty years and growth perspective for the next years requires a very different position as has been the case so far (MACEDO, 2005b). In the case of the Brazilian sugarcane sector, the growing opportunities and sustainable development will increase our understanding on man's interactions with the environment and its social consequences, resulting from policy and economic actions in an interrelated world; this will increase the productive chain and competitiveness.

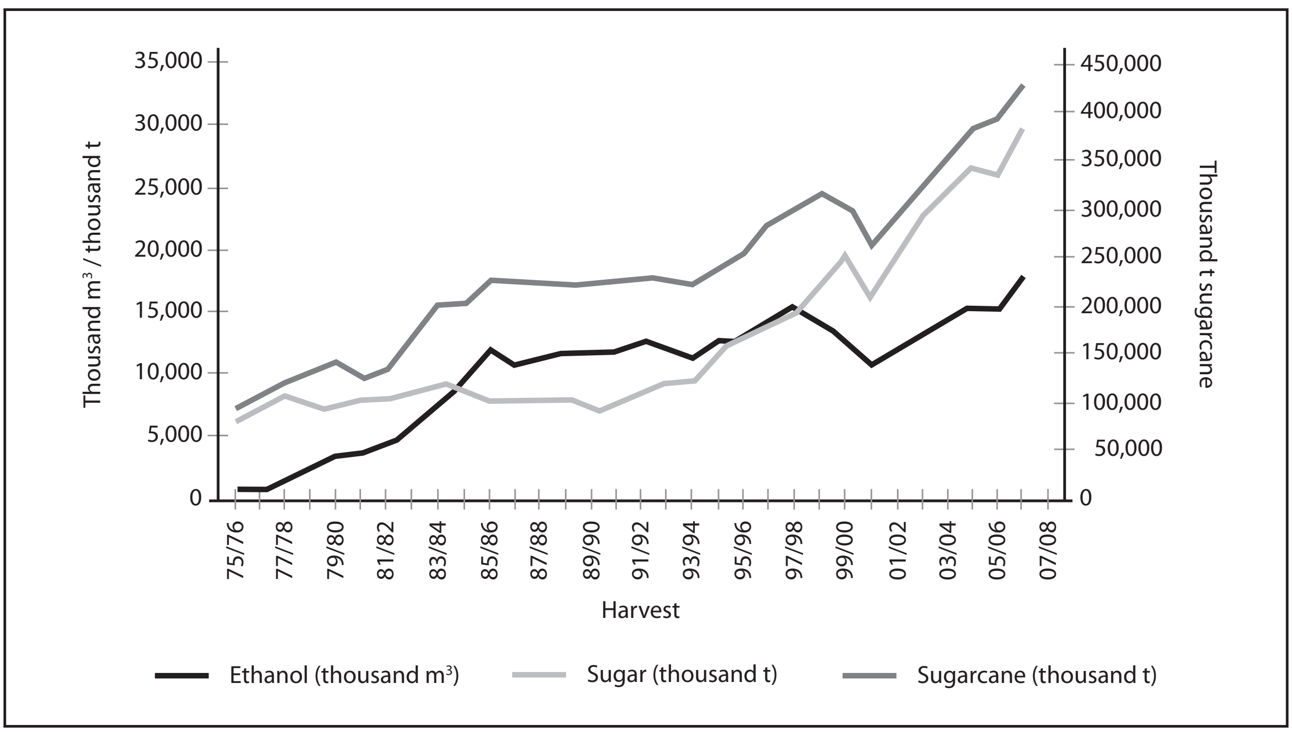
PERSPECTIVES OF ETHANOL PRODUCTION EXPANSION

The developed countries are increasingly searching for alternatives to oil and Brazil offers considerable advantages when it comes to sugarcane and ethanol production. However, to keep up with increasing the competitiveness, requires investing in research, human resource, and infrastructure. Brazil has excellent conditions when it comes to land availability, climate, or technology to produce ethanol in large scale. This will require more investment in RD&D from government and private initiative e.g. investment in new distilleries and alcohol pipelines, enabling producing and transport of ethanol to demand markets such as the EU and USA.

Industrial countries search for biofuels is the combination of various factors, but finding alternatives to oil is an overriding one. Oil is a commodity physically located in politically unstable regions, and is also the main responsible for greenhouse gas emission. The combination of supply and demand problems together with the environmental implications is forcing many developed countries to search for new strategies that include greater consumption of biofuels.

Brazil is the world largest producer of ethanol from sugarcane. This is due to the lower production costs of sugarcane and ethanol. Currently, Brazil accounts for c.40% of the world supply of ethanol fuel and this trend will continue in the near future; this consolidate Brazil as a world leader as ethanol exporter.

As can be observed in the Figure 2, Brazil's ethanol production has been strongly associated to sugar production. This combination has favored the competitiveness of both sugar and ethanol pro-



Source: BNDES and CGEE, 2008.

FIGURE 2 Evolution of the production of sugarcane, ethanol and sugar in Brazil (1975-2008).

duction thanks to the flexibility it offered. In the last 30 years, with exception of the 2nd phase of the *Proalcool* (1979-1985) when several autonomous distilleries were installed, ethanol production was in almost all production units associated to sucrose content. Unlikely many other sugar producers, Brazil uses cane juice and B molasses to produce ethanol, and this allows to produce a better quality and lower cost product than most competitors.

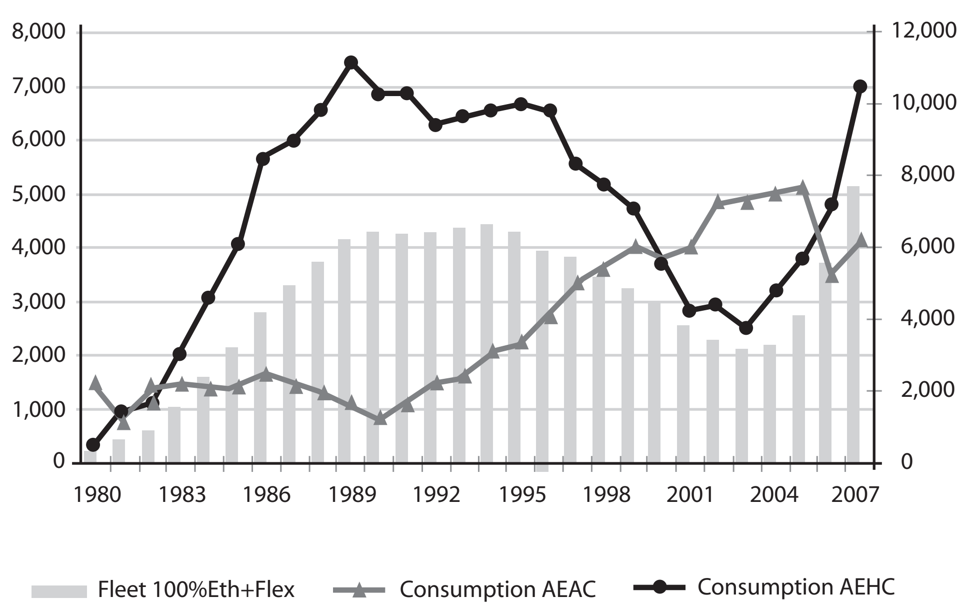
This model is known as "Brazilian model," and in this sense the expansion of ethanol production would be dependent on sugar production expansion. What happens is that today c. 50% of sucrose goes to ethanol and 50% to sugar. This percentage tends to increase driven by the rapid raise of flex-fuel vehicles (e.g. this represented 90% of the domestic market in 2008, circa 3 million of new vehicles).

Thus, a rapid ethanol production expansion in Brazil would need to overcome the sugar-ethanol production "shift" as the world demand for ethanol will be greater than sugar. For example, global demand for sugar tends to follow population growth (2-3% annually), but in many industrial countries there is a decline as people becomes more health-conscious, and other alternatives emerge.

Therefore, this ethanol expansion is very quickly, it will have to be in independent distilleries (e.g. 100% ethanol distilleries). This could largely be avoided if ethanol could be produced from sugarcane bagasse via hydrolysis in large commercial scale.

Such ethanol expansion shift has other consequences that go beyond the technological question. For example, in most cases those who control ethanol production are traditional mills owners that produce sugar and ethanol. This model has been very successful up to now, and also due to support from various governmental agencies, vehicles manufactures etc. However, this successful model was aimed primarily to the home market. The national consumer went through several crisis and changes e.g. changing fuel prices, technical difficulties with alcohol car etc. Over 30 years of learning, the consumer was often let down but eventually has been rewarded with a viable green ethanol fuel and flex-fuel vehicles (see Figure 3).

The future of ethanol fuel should not be restricted to the home market, even there is a further flex-fuel vehicles expansion in the next years. Ethanol production in Brazil needs to keep pace with the international market where there major



Source: Own development from data of Anfavea and BEN (MME).

FIGURE 3 Light Vehicles and Ethanol Consumption (hydrated and anhydrous).

opportunities, even it ix currently a protective market. The need to address climate change and reduce fossil fuel dependency will push the biofuel market development. Brazil is in a unique position to take advantage of these emerging opportunities.

One of the major difficulties is to channel much larger investments in sugarcane and ethanol research. It is necessary to create a sartorial fund ensuring investments in such area, i.e. what happen to oil, if the country is to maintain its leadership in this field. It would also be very important that such investment in research is done in a coordinated way with the private sector to ensure the quality of the results in reducing costs and increasing competitiveness.

To better understand of the expansion potential of ethanol production, the *Núcleo Interdisciplinar de Planejamento Energético – Nipe* (Interdisciplinary Center of Energy Planning – Nipe) of Unicamp, carried out a series of studies (phase 1, 2, and 3) with *Centro de Gestão de Estudos Estratégicos – CGEE* (Center for Strategic Studies and Management in Science, Technology and Innovation), with the purpose to analyze the impacts of a large expansion of ethanol production, to meet Brazilian and world markets. The study, coordinated by Professor Rogério Cerqueira Leite, one project investigated what would be necessary and the macro-economic impacts of substituting 5% and 10% of the worldwide gasoline consumed in 2025. The study shows that Brazil must take seriously the opportunity ethanol fuel offers. It seems also clear that this would require a coordinated action between the government and private initiative to define the necessary actions.

In 2005 a Nipe study projected that in 2010 the ethanol market will be c. 80 billion liters. The major markets were Europe and the USA, followed by Japan. In Brazil, there are currently 50 new distilleries in construction and a further 50 in a planning stage. It is highly important to plan this new expansion phase leads to greater and improve benefits such good quality jobs, more social benefits, economic development, better sugarcane verities etc.

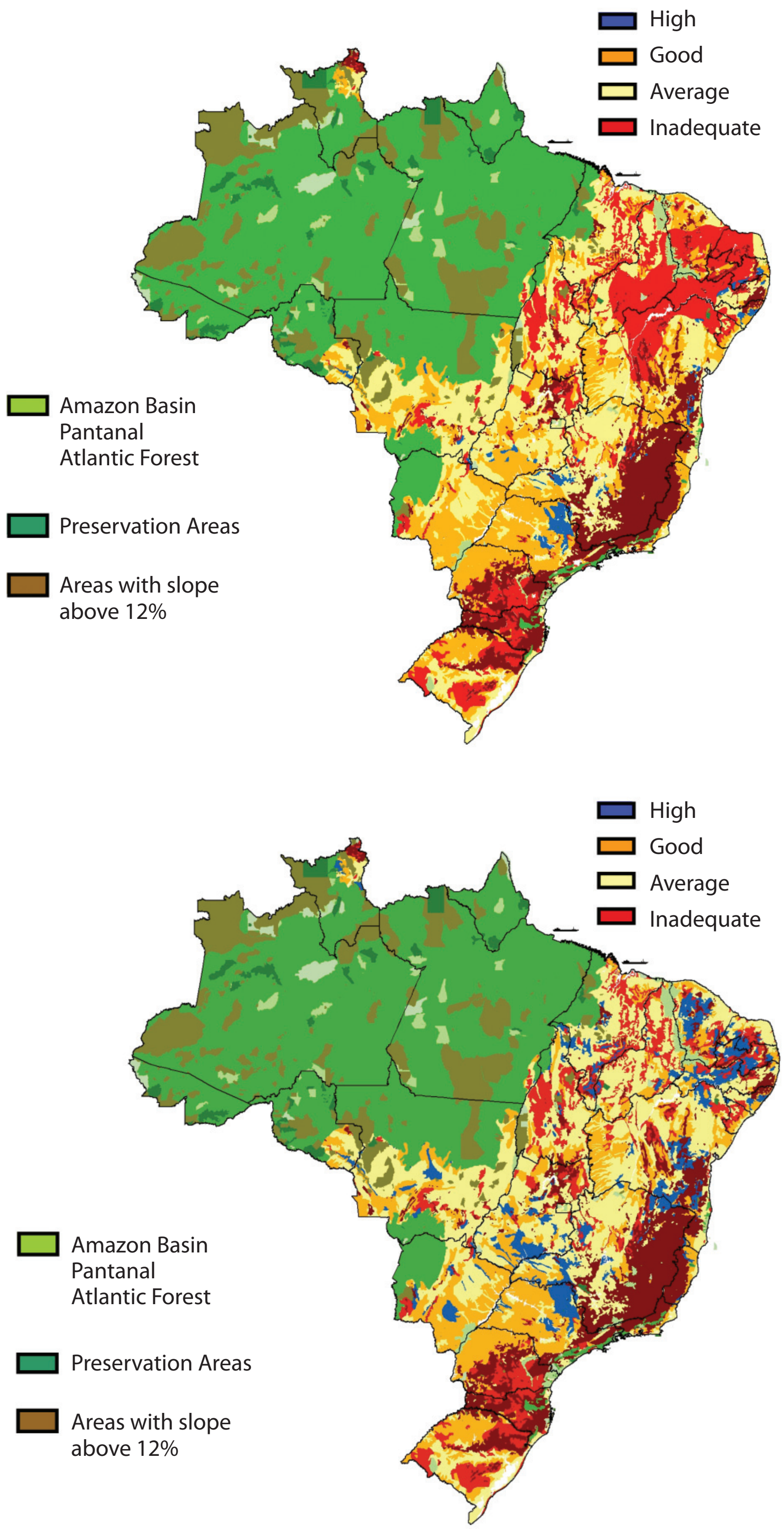
Environmentally, there are benefits from using ethanol fuel rather than gasoline. Among the benefits, perhaps the most important, is the reduction of greenhouse gas emission significantly, mainly the carbon dioxide (CO_2). It is also important to emphasize that the NIPE research group is also carrying out other studies on sustainability of sugarcane ethanol production in a large scale; involving socio-economic and environmental questions and the possible integration to produce sugarcane with existing production systems (see Figure 4).

An important outcome of this large study has been the creation of the Brazilian Bioethanol Science and Technology National Research Laboratory – CTBE of the Ministry of Science and Technology – MCT. The newly created Center will be focusing basically in three main themes considered decisive for bioethanol future: 1) development of agriculture for sugarcane with minimum impacts; 2) hydrolysis technology; and 3) sustainability of ethanol production.

OFFICIAL PROGRAMS SUPPORTING BRAZILIAN SUGARCANE AND ETHANOL

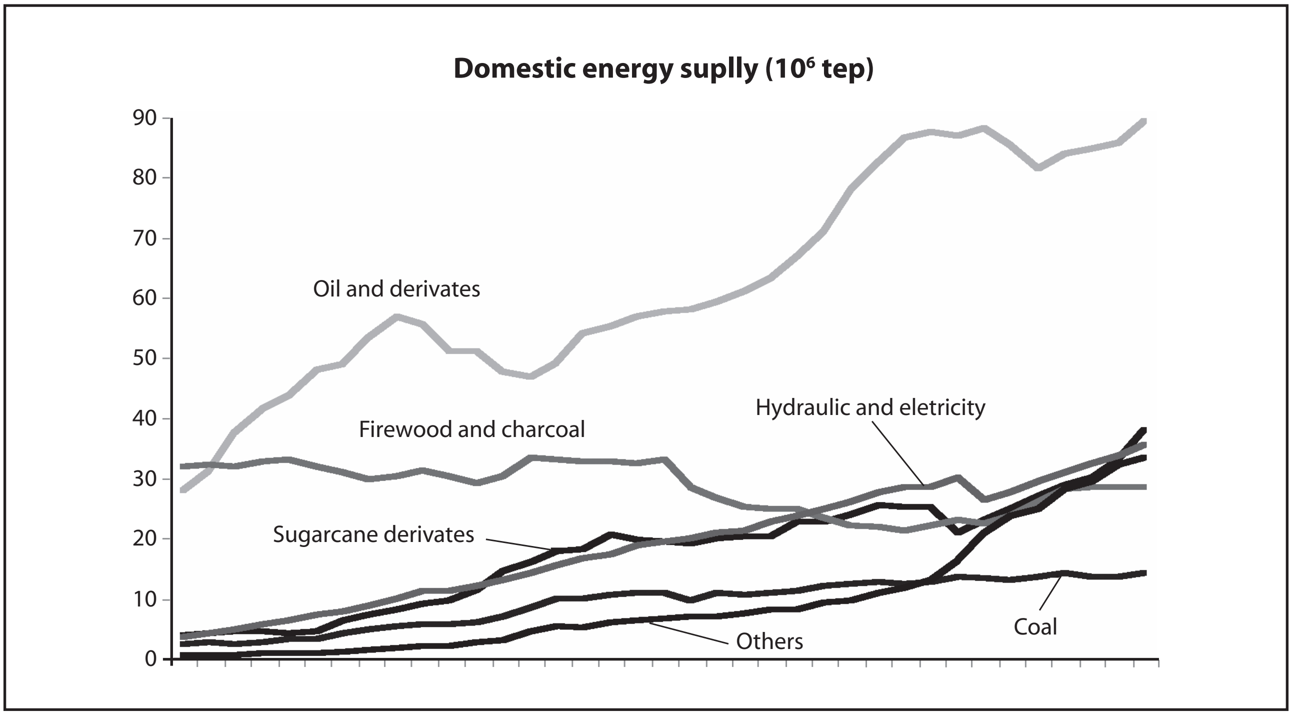
These consist of the following. The Federal Government, through the Ministry of Agriculture, Livestock and Supply – MAPA (2005), Ministry of Science and Technology – MCT, Ministry of Mines and Energy – MME, and Ministry of Development, Industry and Foreign Trade – MIDIC, who have produced the Guidelines of Agrienergy Policy 2006-11. This is a reference document for the Brazilian strategy aiming to articulate and channel actions by the various ministries involved. In addition, there are other governmental agencies involved such as Embrapa Agroenergia (http://www.cnpae.embrapa.br/) and the *Centro de Gestão e Estudos Estratégicos – CGEE*, as the above mentioned study.

Also, the State of São Paulo government created the *Comissão de Bioenergia – São Paulo Bioenergy Commission*, coordinated by Professor José Goldemberg, to define the state strategy (GOLDEMBERG *et al.*, 2008). For example this Commission identified the main opportunities and barriers for alcohol-sugarcane sector and its relations with electricity generation, logistic and research areas.



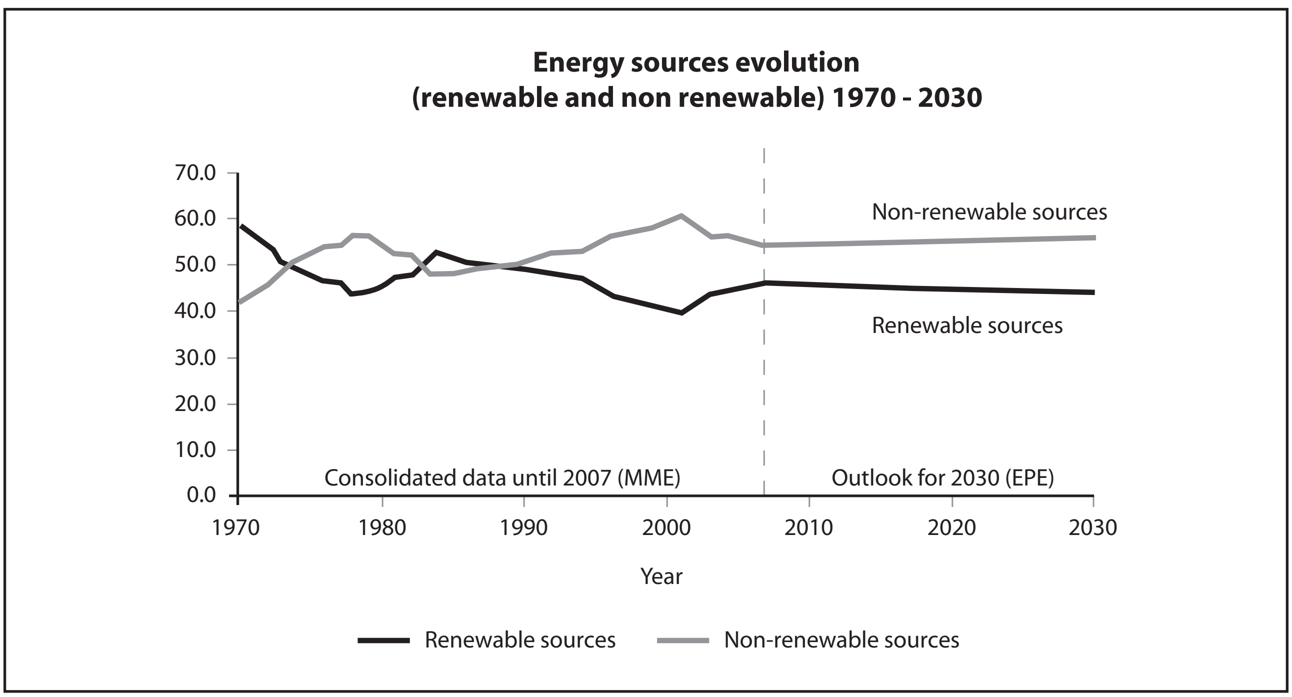
Source: LEITE, R. C. C *et al.*, 2005.
Areas excluded from the study: *green: Amazon and Pantanal, dark green: preservation áreas, brown: slope >12%.*
Areas included in the study: *blue: high productivity, orange: good, yellow: world average, red: inadequate.*

FIGURE 4 Sugarcane Production Capacity in Brazil; at left side without irrigation and at right side with survival irrigation.



Source: MME, 2008 (Year Base 2007).

FIGURE 5 Internal offer of energy in Brazil (1970-2008).



Source: Own production from MME and EPE data, 2008.

FIGURE 6 Energy source growing, renewable and non-renewable, from 1970 to 2030.

Obs.: The percentages of energy (renewables or non-renewables), from 1970 to 2007 are real values obtained from the *Balanço Energético Nacional – BEN*, Chapter 1, Table 1.12b, from Ministry of Mines and Energy – MME website. The values expected for the source contribution in 2030 are estimates provided by the *Empresa de Pesquisa Energética – EPE*, available in the document entitled *Plano Nacional de Energia 2030.*

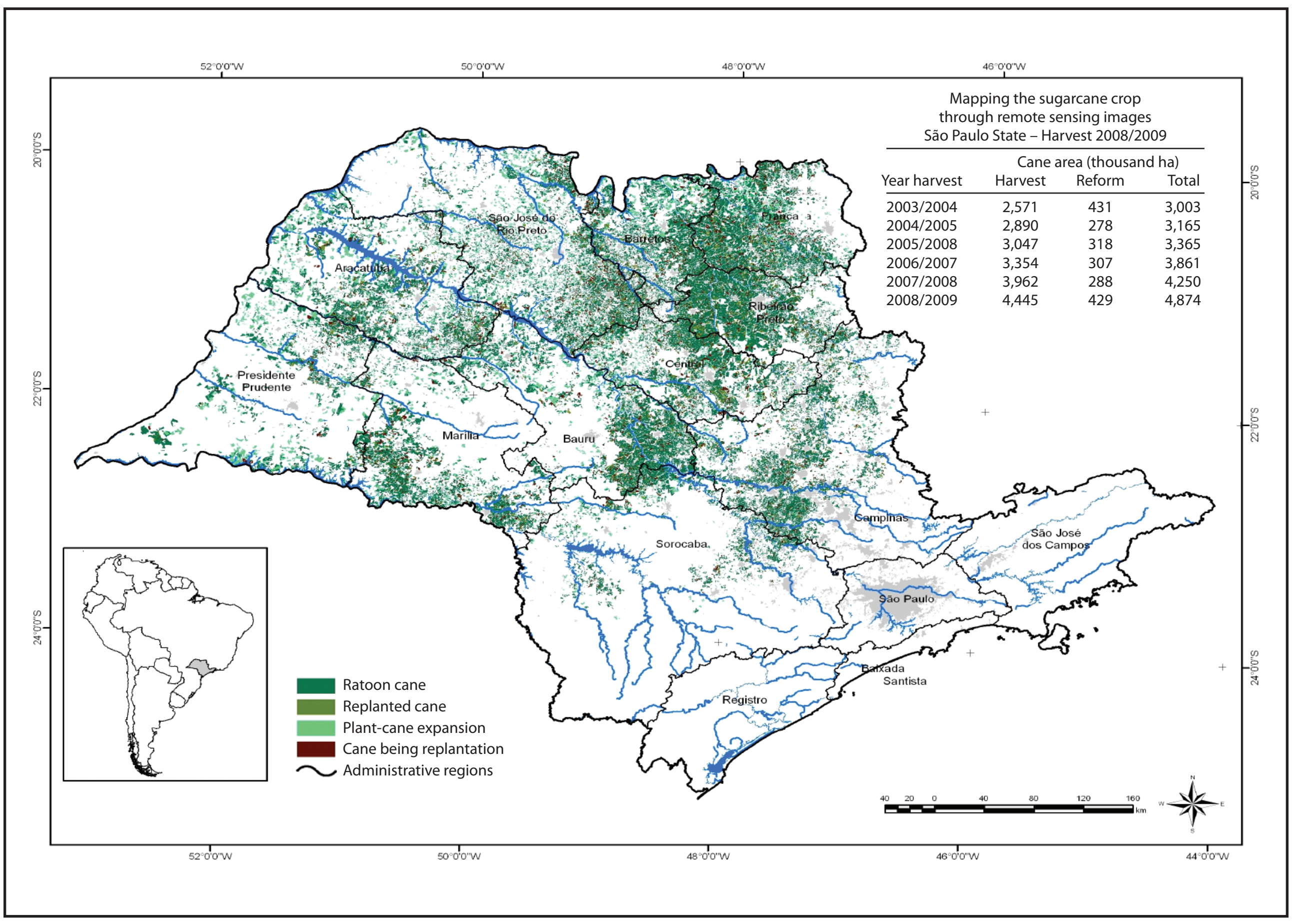
According to the *Brazilian National Energy Balance from MME* (2008), Brazil produced 45.9% of renewable energy in 2007, of which 14.9% is hydro, 15.8% was from sugarcane, 12% from wood and charcoal, and others, 3.2%, from other renewable sources. The Brazilian industry, woodfuels provide 7.4% and sugarcane bagasse for 19.7% of the energy needs (see Figure 4).

However, as illustrated in Figure 5, the non-renewable sources are gaining in percentage while renewables are slightly declining.

Current international interest in biofuels is one of the major driver in the expansion for sugarcane expansion in Brazil in general and in the State of São Paulo in particular e.g. there was a 6.5% extension in land area, 5.4% increase in production that led to 255 million tons of cane (CASER *et al.*, 2005).

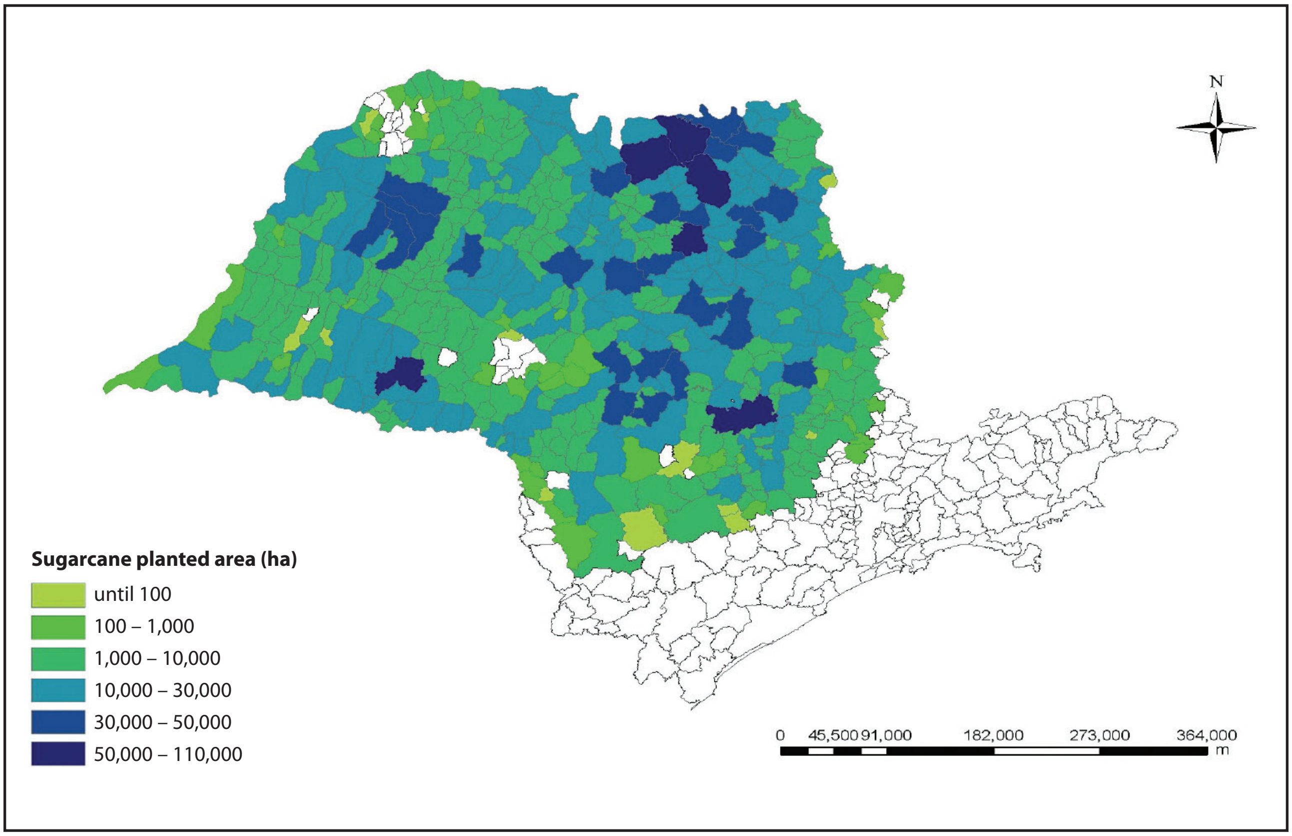
The State of São Paulo is also a leader in many other agricultural products and has the country largest agribusiness. For example, the Sate is responsible for 1/3 agro industrial GDP of Brazil representing 22% from ICMS collected. It has more than 190 thousand km^2 of agricultural land in addition to pasturage, and forests economically active. São Paulo is also the world second sugarcane and orange juice producer, and the fourth coffee producer. The agricultural activity in the State of São Paulo employs 973,000 people. The sugarcane sector, worth R$ 7.7 billion, is second after animal products (meat, milk, and eggs), worth R$ 8.3 (TSUNECHIRO, 2004).

In 2007/2008 harvest, sugarcane occupied 5.23 million of hectare in São Paulo producing 367.2 million of tons of cane (IEA, 2008). Figure 7 shows sugarcane location areas in 2008/2009 harvest in



Source: Map from INPE team using available data in the website CANASAT, 2009. (<www.dsr.inpe.br/canasat>).

FIGURE 7 2008/09 harvest sugarcane location areas in municipalities of the State of São Paulo.



Source: Map from INPE team by using available data in the website CANASAT, 2009.

FIGURE 8 2008/09 harvest sugarcane area density in municipalities of the State of São Paulo.

the municipalities of the State of São Paulo, while Figure 8 represents the density of the sugarcane area by municipality. This means a demand of 247,000 jobs in agricultural activity, (based on 7.01 jobs per 100 hectares (VEIGA FILHO, 2003), or 23% of the working population in the São Paulo's agriculture in 2004, or 1.058 million of people (BAPTISTELLA *et al*., 2005).

Commemorative 30 years of Proalcool: *Ethanol Combustível – Balanço e Perspectivas*, a study was carried out by UNICAMP (NIPE/UNICAMP, 2005), to assess its performance and to develop further Brazil full potential. It seems that energy from sugarcane can form the base of a national development project.

R&D BACKGROUND OF BRAZIL SUGARCANE AND ETHANOL

Sugarcane has been cultivated in Brazil for almost for 5 centuries. Although is first introduced in the State of São Paulo[1], it was in the Northeast where sugarcane took roots, primarily in the States of Pernambuco and Paraíba, mainly for exports to Europe. The production model in this period was based on small agricultural and industrial production, although the early centuries there were thousands of small family mills.

With the process of agro industrial modernization at the end of the XIX century conducted by Portugal until 1870, there was a revolution in production increasing the number of sugarcane suppliers and consenting production in largest mils, (EINSENBERG, 1977).

With the coffee crisis in 1929, the sugarcane started to expand in the State of São Paulo based in big properties and large industries. With this new model, more concentrated, it was possible to

[1] The introduction of sugarcane in Brazil was made by Martin Afonso de Souza in 1530.

apply new technology and management practices that allowed that the State of São Paulo to gain in competitiveness. As a result between 1930 and 1970, Pernambuco responsible for almost 40% of sugar production, dropped to 20%, while São Paulo increased its production from 10% to almost 50%.

Another important element was advances connected to the coffee crisis (disease that attacks plants) at the beginning of the 1920s. The State of São Paulo, as the first state affected by the disease, created the *Estação Experimental de Cana de Piracicaba – EECP* (Experimental Station of Sugarcane of Piracicaba) to select varieties more resistant to the disease (OLIVER E SZMRECSÁNYI, 2003). In 1935 was set up the IAC that witnessed a considerable expansion of the variety program and later coordinated a network of industries, improved extension services and provided technology to the São Paulo's industries.

In 1969 the Federal Government created the *Plano Nacional de Melhoramento da Cana-de-Açucar – Plansalsucar* (National Plan for Sugarcane Improvement), managed by the *Instituto do Açúcar e do Alcohol – IAA* (Sugar and Alcohol Institute) with a wide experimental network aimed at the production of new varieties of sugarcane.

In 1970 the private sector created the *Centro de Tecnologia COPERSUCAR – CTC* (COPERSUCAR Technology Center) in Piracicaba, State of São Paulo. The creation of the CTC (currently Sugarcane Technology Center), and the implementation of a program of genetic improvements, allowed important advances in the productive chain of sugarcane, including agricultural engineering and industrial technologies.

With the extinction of IAA in the 1980s, followed by PLANALSUCAR, was created the *Rede Interuniversitária para o Desenvolvimento do Setor Sucroalcooleiro –RIDESA* (Inter-university network for the Development of the Sugarcane Alcohol Industry), consisting of seven federal universities, is currently responsible for near 50% of new varieties of existing sugarcane in the country. A new initiative, *Canavialis,* a private company created by scientists in 2003, is targeting the production of new varieties based on the genome sequencing of the sugarcane.

Finally, another important factor in developing sugarcane alcohol industry in São Paulo was the creation of companies such as Dedini, Zanini, and Codistil which, starting from a small base turned into big suppliers of equipment and technological innovation. Such companies were very technologically innovative and were able to provide mills and distilleries during the expansion phases of Proalcool.

Thus, the competitiveness of the sugarcane alcohol industry, mainly in São Paulo, was not achieved by chance or recently, but rather the result of a deliberate investment policy to overcome the many difficulties facing the industry.

THE FUTURE OF ETHANOL AND BRAZILIAN NEEDS

As stated above, the Brazilian problem today is not to mitigate the greenhouse gases or increase the offer of fuel for the Otto cycle[2]. Rather, it can be stated that a lot of the gasoline is not used; besides ethanol, Brazil also uses, be it incorrectly, GNV (compressed natural gas), in the transport sector. As with diesel, biodiesel is being tried as a replacement but this is far from being economically attractive. To replace diesel by ethanol is technically possible and the Professor Moreira discusses this subject in one of the book chapters, although has its restrictions.

Another question is why sugarcane fiber is not used for the generation of electricity? This subject deserves particular emphasis in this book. Given the difficulties iN Brazil in obtaining approval for new large scale hydroelectric power plants in Amazônia, where there are the largest remaining Brazilian potential, it is difficult to understand why cogeneration from sugarcane bagasse is not given greater prominence. For example, the latest attempt to build a dam in the Amazon provoked a considerable debate and political difficulties, involving various ministries and the National Congress. Various studies have showed the potential benefits of using biomass and

[2] The need to mitigate GHG is, above all, an international agenda. In Brazil, possibly, the best way to reduce emissions is by eliminating forest burning in the North Region.

that demonstration studies should be financially supported immediately to:

- Develop and establish efficient routs for the recuperation, preparation and cleaning of sugarcane tops and leaves for use to generate electric power.
- Employ higher-pressure boilers (at first up to 80 bar) to establish and consolidate a better use of the full sugarcane potential.
- Develop modern technologies for low impact mechanization, and generate electricity by gasification.

This is area where Brazil has a great potential since the country will need a lot decentralized low cost electric power (especially in SE, CE, and NE) which would help to internalize the national economic development.

Finally, it is important to highlight that besides liquid fuels and electric power, there is also the possibility to convert sugarcane or its fiber (bagasse and straw) into feedstock for the petrochemical industry. Examples are products obtained from pyrolysis such as gas, bio-oil, and charcoal. This will allow the diversification of the sugarcane/ethanol sector. It is an option that opens up a lot of new opportunities both the domestic and international market. In all cases, however, research needs to be carried to enable:

- A new and more sustainable agricultural model.
- Full use of the sugarcane resources.
- New industrial models that allow in addition to ethanol generate more electricity and inputs to the petrochemical industry.

THE NEED TO FINANCE RESEARCH IN SUGARCANE-ETHANOL INDUSTRY

The production and use of ethanol fuel from biomass is a multidisciplinary subject. From development of new cane varieties through industrial process and the final use, research into the so-called sugarcane alcohol industry has wider implications in all fields. Research may include areas at the frontiers of knowledge such as genome, new materials, nanotechnology, automation, environmental medicine, as well as more traditional areas, directly connected to the manufacture process, e.g. agriculture and engineering.

The advance of knowledge on sugarcane-ethanol has depended primarily on governmental institutions (research institutes and universities), and less so on the private sector (mainly in the *Centro de Tecnologia Canavieira – CTC* and *Dedini*) efforts. There are research areas in which the private sector will more susceptible to funding, e.g. the development of the sugarcane varieties[1], software to optimization transport or a change in the milling, aiming to improve the extraction index. It can also be stated that a significative portion of resources that the sector invests in research is already aimed to this kind of short to medium-term development.

However, either by the need to reduce costs raises productivity or by sustainability indicators, there is an urgent need to finance more basic research and take higher long-term research risks, which is already growing. Such research should aim to:

- obtain higher agricultural and industrial productivity gain;
- optimize the use of inputs and resources, especially fossils;
- reduce the volume of waste;
- greater emphasis in the development of emerging technologies;
- assure the means to acquire renewable energy sources.

Thus, it should be expected that the government bodies responsible for promoting research will act more decisively in the financing basic research. The current situation in the sugarcane-ethanol sector, demand greater understanding of basic scientific knowledge of an interdisciplinary nature, and this it is fundamental that more funding is allocated to basic research.

Basic research is fundamentally important to support the technological development in the sector of which the development of enzymatic catalysts and its relation to hydrolysis technology which may allow increasing significantly ethanol production without the need to increase sugarcane planting area while demanding fewer inputs in production, is a good example.

However, there are also several other areas where basic research is needed in the sugarcane-ethanol sector. The transition from an oil-based economy into a biomass-based economy (e.g. sugarcane) requires fundamental research in production, conversion or final use. A further important point to notice is the high investment risk since generally it is less attractive to the productive sector given the low rate of investment return, normally inherent to this kind of research. Currently Brazil in going through a technological transition in the sugarcane alcohol industry; up to now, the increase in productivity has been achieved primarily by the improvement of known technologies, reduction of costs by a process of learning by doing. However, this current technological basis must change. The so-called "Brazilian model" of producing sugar and ethanol as co-products must give way to a new paradigm of ethanol production and full use of whole sugarcane dissociated from the sugar production.

The change of an industry traditionally producing sugar and ethanol must include the production of new products such as ethanol-chemistry, will be only possible through massive investment in basic research.

If Brazil aims is to increase significantly sugarcane energy production, taking advantage of the opportunity presented today, important technological transformations will be needed. To develop new technologies, an important knowledge base will be needed, chiefly in basic sciences, which could create the conditions for the development of greater applied research.

However, it is important to highlight *Programa Fapesp de Pesquisas em Cana-Ethanol – BIOEN* (Fapesp Program of Sugarcane-ethanol Research), which finance research that would not be financed by the private sector.

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2

THE BRAZILIAN STRATEGY FOR BIOETHANOL

Rogerio Cezar de Cerqueira Leite

The first intervention in the production of ethanol in Brazil was already in the early twentieth century with the 2% addition of ethanol into the gasoline. During these early decades, however, there was no concern with environmental impacts, including greenhouse gases. The main objective was national self-sufficiency/security in relation to fuels that were previously imported. The reason for this initiative was simply to create a buffer for the sugar sector, which absorbed excess production of sugar by converting it into ethanol. Although this percentage had grown slowly, even before the advent of the National Alcohol Program (Pro-Alcohol), a clear strategic only came to interfere later on. With the steep increase in international prices of oil dependency in Brazil, which was at the time of more than 80%, has become an excessive economic burden.

Concomitantly with the reversal of national policy for the oil that previously intended to protect our crude oil reserves for the future, turned interested to seek an increase in domestic production, was then deployed the National Alcohol Program. With the beginning of the Pro-Alcohol increased to 10% the participation of ethanol in gasoline and passenger car engine with ethanol were encouraged. However, at that time the only strategic concern was to reduce national dependence on oil.

Although some scientists knew the greenhouse effect since the nineteenth century, even in the academic world there was no perception of the importance of CO_2 emissions to the atmosphere. Nor was it taken into account any other consequence of an ecological nature of the use of fossil fuels or organic. More recently some steps taken by the government during the Fernando Henrique Cardoso and Luiz Ignacio Lula da Silva, may be considered as embryos of a future strategy. At first, initiatives related to the progressive reduction of open burning, early preferential financing of efficient production systems in particular with respect the cogeneration and better use of bagasse. Brazil has also sought to promote ethanol production in other countries with the aim of reducing the aversion to dependence on Brazilian ethanol, shown prematurely by future possible importers.

Although quite shy, the Ministry of Science and Technology has supported studies and integrated planning to increase production of ethanol. They have also been supported by studies on the full use of the cane, including the creation of a research center of bioethanol. Simultaneously, several aspects of sustainability have also been supported by the Ministry of Science and Technology.

Although the Government's attitude has been, with respect to ethanol production, mainly of a "laissez-faire", the studies conducted by the MCT has had consequences in the private sector and one of them is the perception that logistics is essential for production, not only economic and energy efficient, but also socially and ecologically positive. The concept of "clusters" came to be central to this perspective.

CLUSTER

The cluster concept is quite simple and follows from the fact that the transportation of ethanol is much cheaper using pipeline than by any other means of transport. However, this is true, of course, for large volumes. These two conditions require the clustering of plants around a collection point of ethanol. To make the ethanol economically viable is therefore necessary a minimum number of plants forming a "cluster". This would have the added advantage of being also socially beneficial, since according to the mentioned project, the cluster would contain about 200,000 inhabitants, which would facilitate the implementation of a socially important infra-structure composing a number of schools of all levels to universities and hospitals, and recreation. From the point of view of sustainability the cluster is highly desirable as it would reduce energy costs and contain the expansion of sugarcane cultivation in areas previously considered.

The project in question has also proposed a specific zoning for the production that take into account the distribution of wealth in the country, the preservation of important ecological succession and the implementation of investment that would be suitable for the country.

This study also provides for the elimination of manual harvesting and consequently the burning, which are certainly extremely damaging to the environment. Also included is the production of electric energy cogeneration and adoption of high-pressure boilers for better use of bagasse. In parallel with this project has also prepared a study on the optimum use of bagasse and straw (trash) by hydrolysis, also under the aegis of the Ministry of Science and Technology. The same group from Unicamp, in collaboration with various universities and research centers in Brazil, has been studying measures to improve productivity in the Northeast and Rio de Janeiro, now considered in decline.

However, all this does not means that Brazil has established a strategy or even on to the fuel ethanol and the main reason for this is that unlike what is happening in other areas of energy, the production of ethanol refers to the various ministries. Initially the Agriculture because sugarcane is a crop, the Ministry of Mines and Energy because fuel ethanol is an energy, the Ministry of Development, Industry and Foreign Trade because it is an industrial product, the Ministries of Economy and Planning for may soon become a commodity and so on. This caused the federal government to take a disastrous decision by deciding to centralize the studies in the Office of the President who does not have the necessary expertise. It is a ministry that works in the Policy Sector and is overwhelmed with a multitude of tasks. This excessive centralization and obvious technical inadequacy prevent any attempt at elaboration and adoption of a strategic or even a single development plan for the ethanol industry.

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3

THE STATE OF SÃO PAULO STRATEGY FOR FUEL ETHANOL

José Goldemberg

The strategy of the State of São Paulo for the expansion of ethanol production is based on a sustainable expansion with low environmental and social impacts. The main components of this strategy are:

1. Improve the efficiency of 1st generation technology presently in use. It is estimated that the average productivity over the next 10 years will increase by nearly 30%.
2. Increase cogeneration of electricity using bagasse from sugarcane.
3. Phase out manual harvesting of sugarcane and accelerate mechanization in areas with slopes less than 12%.
4. Guide the expansion of the cultivated area of sugarcane – which currently stands at 4.34 million hectares – to degraded pastures of which there are about 10 million hectares only in the State of São Paulo.
5. Promote the construction of pipelines to reduce the cost of transporting ethanol from producing regions to major consumer centers and ports for export.
6. Ecological-economic zoning – EEZ and creation of new conservation areas.
7. Introduction of advanced 2nd generation technologies for the production of ethanol.
8. Promote the development of alcoolchemistry.

We discuss below in some detail the proposed measures, some of which are already being implemented.

IMPROVING THE EFFICIENCY OF 1ST GENERATION TECHNOLOGY

Currently the production of ethanol from sugarcane in Brazil is based solely on “1st generation technology” in which the sucrose is fermented. This sucrose, however, represents only 1/3 of the energy content of sugarcane as shown in Figure 1.

Bagasse is used to produce heat and electricity required for production of ethanol, creating an additional surplus electricity that can be feed into to the grid.

The use of bagasse for this dual purpose is the reason why the energy balance of ethanol production from sugarcane is highly positive, since no fossil fuels are used in except those that are embedded in the fertilizers and pesticides in addition to the diesel oil used (in agricultural equipment) in the transport of cane from the feeds to the distillery. The energy balance in ethanol production, i.e. the ratio of energy contained in a given volume of ethanol to the fossil energy used in its preparation, is 8-10:1. In the United States energy balance for the production of ethanol from corn is only 1.3:1.

The productivity in the production of ethanol in the country has grown enormously in the last 29 years, at an average rate of 3.77% per year. (Figure 2).

This is due to improvements in the agricultural stage by selecting the best strains as well as other gains in other stages of the process:

- Increase in recoverable sugar: 1.45% per year.

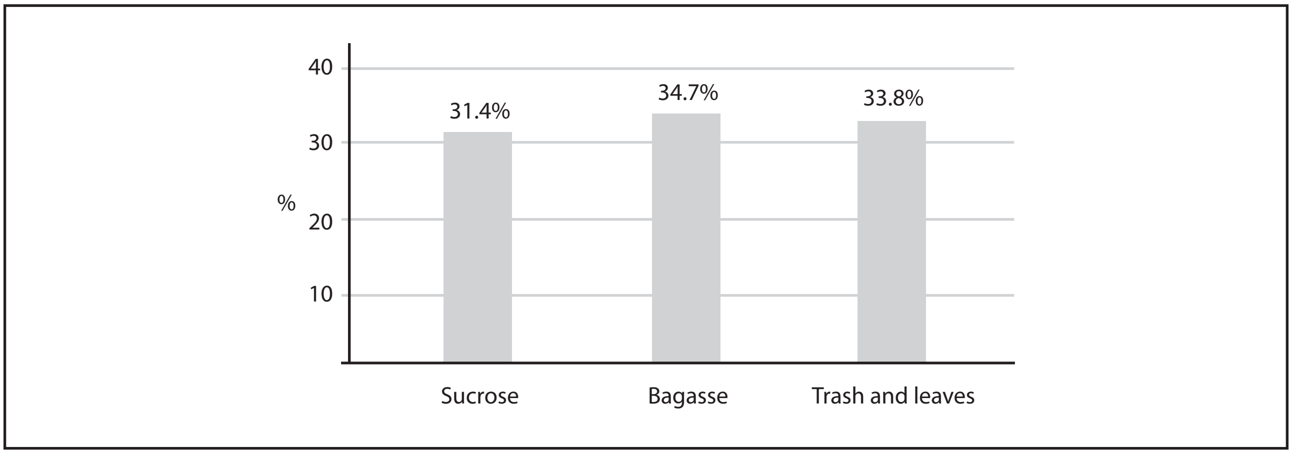


FIGURE 1 Energy contained in sugarcane.

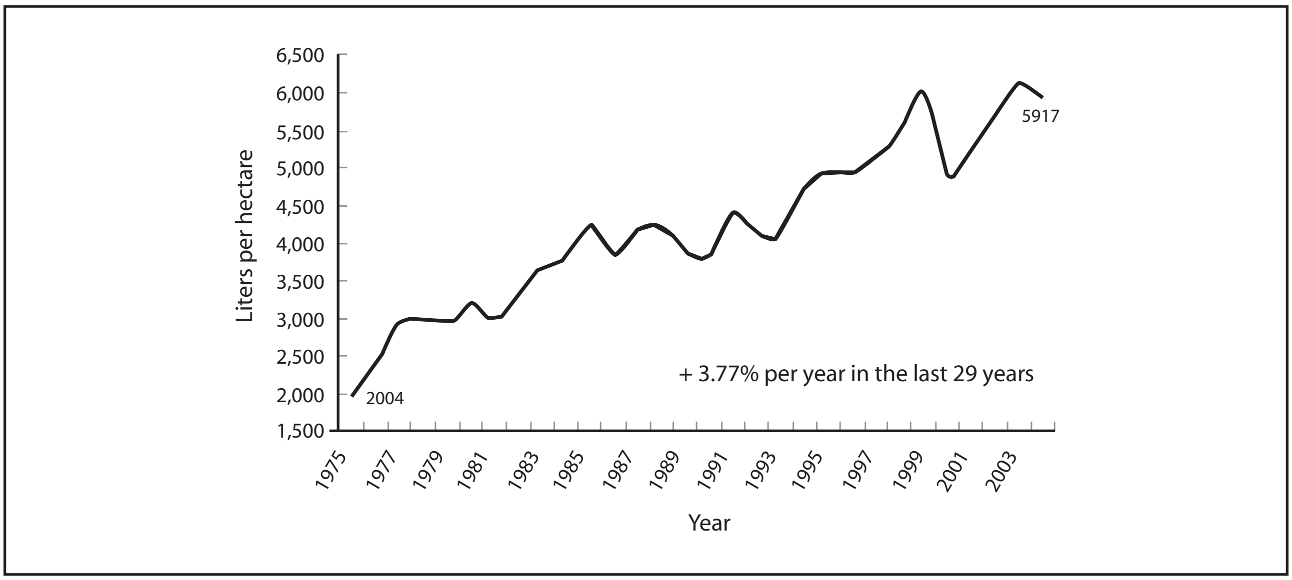


FIGURE 2 Productivity in the production of ethanol (liters/ha/year).

- Extraction of sugar: 0.3% per year.
- Increase the volume of sugarcane: 0.73% per year.
- Improvements in fermentation: 0.3% per year.

Figure 3 shows the agro-industrial productivity of a sample of 116 plants in Central-South Brazil, whose average value is 8,000 to 8,500 liters of ethanol per hectare. There are other plants with lower and higher productivities. The challenge that the State of São Paulo is facing at the moment is to increase the productivity of less efficient plants.

It is believed that there are still gains to be achieved in the next 10 years:

- 12% in the volume of cane;
- 6.4% in recoverable sugar;
- 6.2% in the fermentation process; and
- 2% in the extraction of sugar.

The efficiency of existing plants is shown in Table 1.

It is estimated that "state of the art" distilleries would cost about 20% more than the "new" distilleries.

The main potential gains may occur in the following areas:

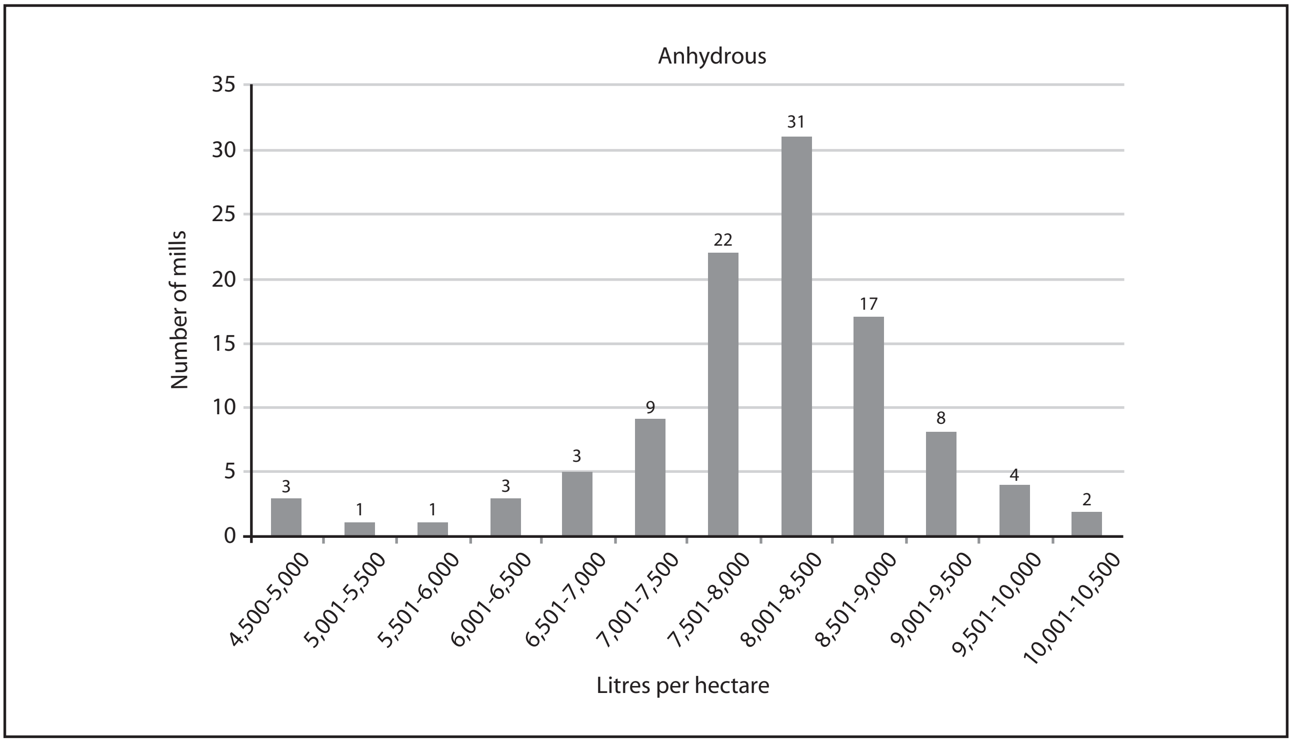


FIGURE 3 Yields at brazilian distilleries.

TABLE 1 Overall efficiency of ethanol distilleries.

Current distilleries	75%
New distilleries	81%
"State-of-the-Art" distilleries	88%

- Fermentation: current may rise 85% to 92%
- Extraction: current may rise 97.5% to 98.6%
- Distillation and dehydration: current may rise 99% to 99.7%

INCREASE THE COGENERATION OF ELECTRICITY PRODUCTION

In the past the boilers used to produce steam for the sugar processing and evaporation of fermented cane mash were of low efficiency (typically 20 bar). The amounts of bagasse found in a distillery are immense and the use of inefficient boilers was justified by the need to incinerate the bagasse which left in the fields gave rise to environmental problems. With the gradual implementation of mechanical harvesting of sugarcane the amount of biomass available for cogeneration has increased even more.

Steps taken by the Secretaria do Meio Ambietne of São Paulo led the BNDES to develop mechanisms that encourage plant owners to upgrade their boilers, creating a differential in interest rates of BNDES for more efficient cogeneration equipment for electricity and steam production.

A problem to be solved is the interconnection with the utility companies that distribute electricity. Possibility splitting the generation of electricity from the production of sugar and ethanol, exempting from taxes the exchange of energy and bagasse between the two companies.

The Department of Energy of the State of São Paulo is working on the planning of interconnections, to create transmission subsystems serving various distilleries thus reducing its costs.

The ethanol plants in operation today are providing the electricity grid with about 1,000 average megawatts, which complements the hydroelectric generation in the Southeast in the "dry season" (April-November) which is when the ethanol plants are operating at full steam. This power could be increased fourfold if all the plants in the state were modernized and the period in which electricity is produced (6 months) could be extended with the use of cane trash.

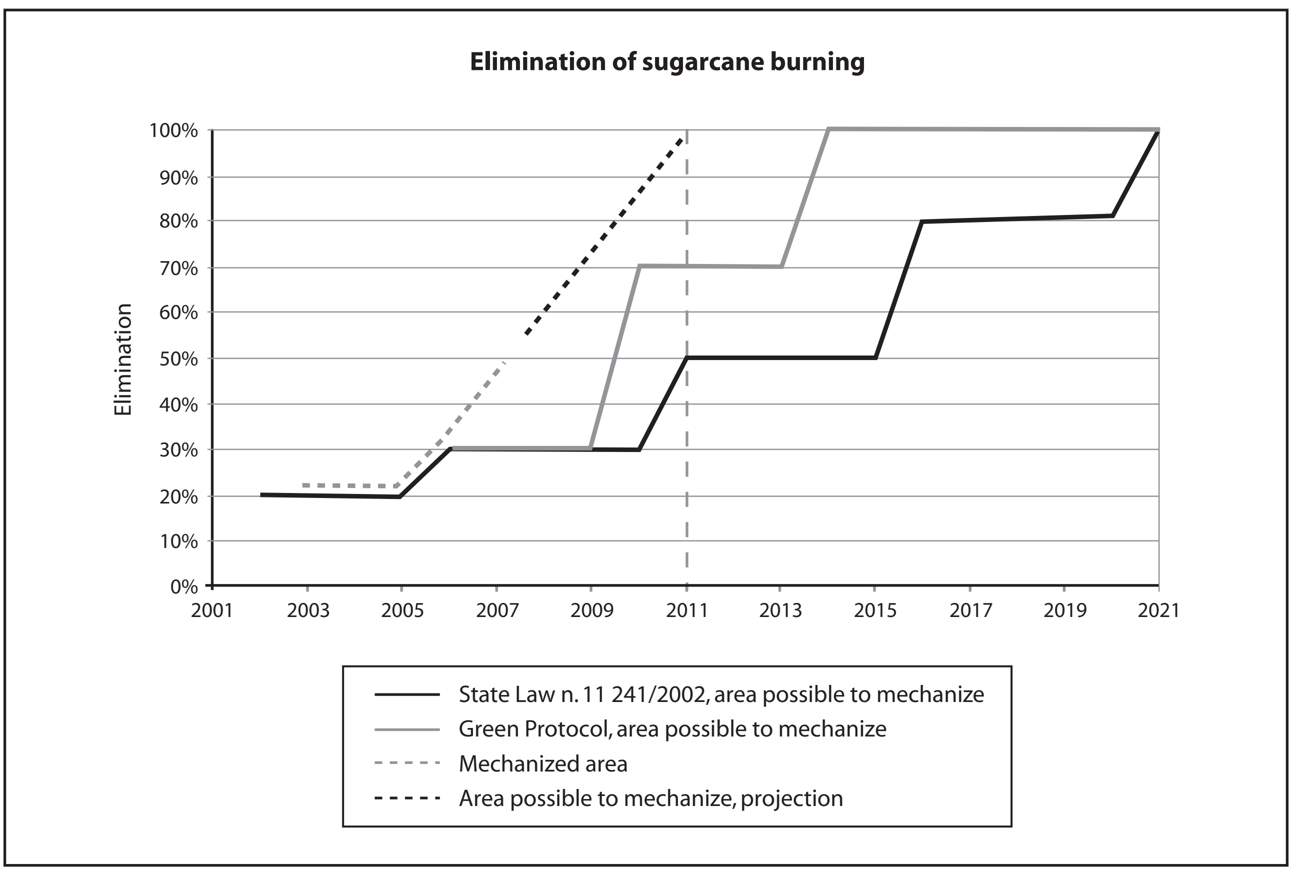
GRADUAL ELIMINATION OF MANUAL HARVESTING

The burning of the cane before harvesting is an ancient practice to facilitate cutting and eliminate animals such as poisonous spiders and snakes. But the burning can damage the tissue of sugarcane, increasing the risk of disease in the cane, causing the destruction of organic matter and damaging the soil structure due to lack of moisture increasing the risk of soil erosion.

The open fires also result in risks to the electricity lines, railroads, highways and forest reserves and cause undesirable air emissions such as CO, CH_4, non-methane organic compounds and particulate matter. The burning of sugarcane is also responsible for the increase in tropospheric ozone concentration in areas where it occurs.

For these reasons, for years attempts were made to introduce mechanized harvesting, which finally became a reality with the approval of the São Paulo State Law n. 11 241/2002. What the law has established was a timetable for the introduction of mechanized harvesting as shown in Figure 4.

In practice mechanical cutting is occurring faster than anticipated in the Law. In 2007 more than 40% of sugarcane was cut by machines and by 2009 this percentage exceeded 50%.



Source: Available at: <http://homologa.ambiente.sp.gov.br:80/etanolverde/resultado.asp>.

FIGURE 4 Evolution of mechanized harvesting for sugarcane.

In 2007 the Secretaria do Meio Ambiente and UNICA signed a voluntary agreement with the goal of rewarding good practices in the field of sugarcane. About 145 distilleries (89% of plants established in the State of São Paulo) agreed to bring forward the timetable for the complete elimination of manual cutting for 2014 in areas with scopes of less than 12% and by 2019 for higher scopes. The same protocol was also signed by Orplana, association representing 13,000 small sugarcane suppliers, in March 2008 committing the whole chain with the elimination of burning.

It is, therefore, a problem being solved in the State of São Paulo.

THE EXPANSION OF SUGARCANE IN THE STATE OF SÃO PAULO

Figure 5 shows the evolution of the area devoted to sugarcane in São Paulo since 1990.

The areas used to food production decreased very little, since the expansion of sugarcane is occurring mainly in pasture land. Moreover, sugarcane yields have increased thanks to the selection of better and more resistant cane varieties and better adapted to different climatic conditions.

The number of ethanol plants and expansion plans for the State of São Paulo are shown in Table 2 and indicate that there was an increase of

TABLE 2 Evolution of sugarcane crop and sugar and ethanol Mills in the State of São Paulo.

	Harvest 2005/2006	Harvest 2006/2007	Harvest 2007/2008	Harvest 2008/2009
Number of mills	154	166	177	190
New mills	4	12	11	13
Production of sugarcane (million tons)	243	264	296	340*

* Estimative by UNICA.

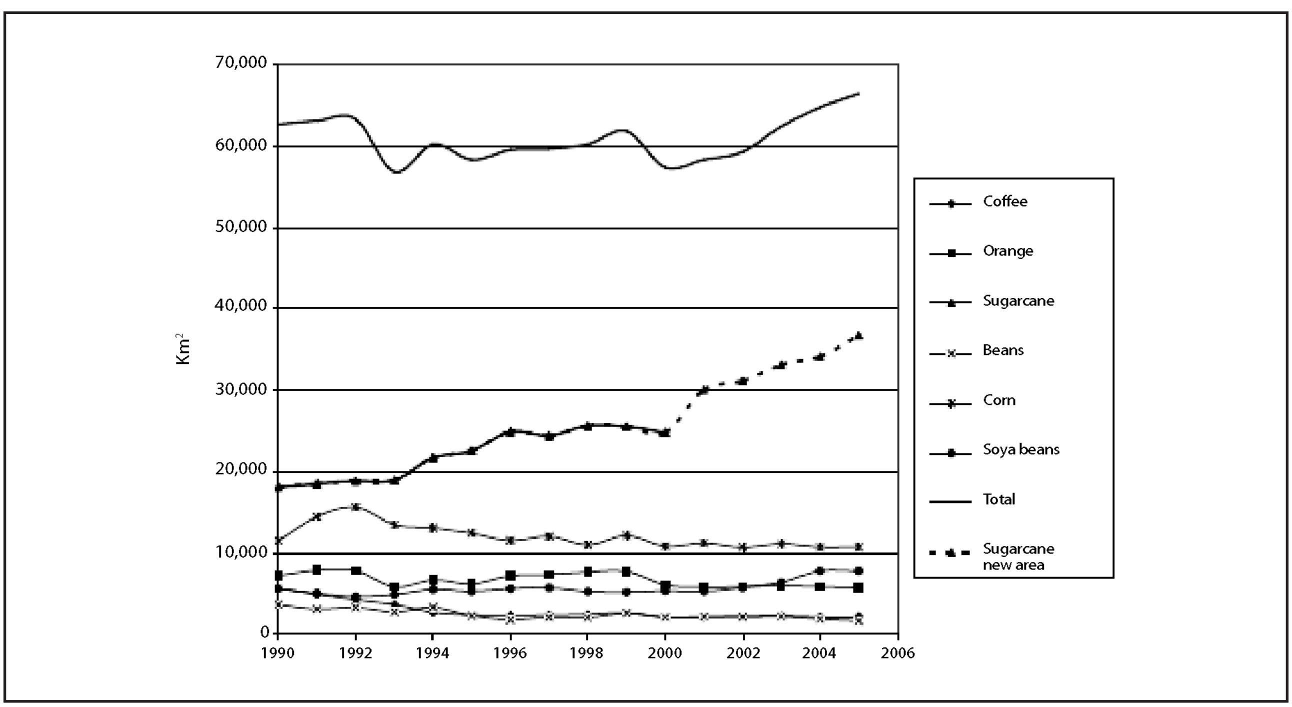


FIGURE 5 Evolution of area occupied by sugarcane in the State of São Paulo.

about 30% in the last two years in the State. The Secretaria do Meio Ambeitne – which licenses the construction of new ethanol plants – is required to comply with environmental legislation in all the new ventures.

THE CONSTRUCTION OF ETHANOL PIPELINES

The transport of ethanol from production areas to major consumption centers (mainly the metropolitan area of São Paulo) and export through the port of Santos – which requires about 500,000 truck trips per year – ends up increasing by 20% the cost of products delivered or in the port of Santos.

With the anticipated increase in production and exports of ethanol this problem will get worse, making it imperative to build ethanol pipelines from the region of Ribeirão Preto, São Paulo (and Santos), or from the new agricultural frontiers.

The TRANSPETRO and a private group organized by UNICA have conducted studies and proposals for the construction of one or more pipelines, using in part the Tietê-Paraná waterway.

Two Protocols have been signed with the São Paulo State Department of Transport with TRANSPETRO and UNICA for studies on ethanol pipelines in order to find a form of collective action, to make the project viable. It is important to allow the use of the waterway, the connection between the waterway and Paulínia and the easy access of the pipeline, to remove the truck traffic from roads of São Paulo.

One factor that delays the implementation of these agreements is the fact that groups who wish to build the pipeline how required long-term supply commitments from ethanol plant owners to enable the return on their investments. As the transactions in this sector are usually made on the spot market these conditions are difficult to achieve.

ECOLOGICAL-ECONOMIC ZONING AND THE CREATION OF NEW CONSERVATION UNITS

The first agricultural zoning of São Paulo State was made in 1974 and complemented in 1977, when remote sensing satellites were not available there were only meteorological stations in the state, against the current 450. Moreover, at the time the socio-environmental aspects were not considered. The new reality of reducing the cost of remote sensing resulted in improvement in weather monitoring, providing information on weather conditions, water availability in the soil, the likelihood of disease, drought and hail.

As a result agricultural zoning studies will be conducted, through coordinated action by the São Paulo State Department of Agriculture, so that patterns of land use, climate and risk conditions are incorporated as important instruments of public policy decision support to agribusiness and the expansion of sugarcane crops.

In addition to that it was proposed, the creation of 14 new protected areas in the state, totaling approximately 90,000 hectares, which were identified by the BIOTA FAPESP project as priorities for the conservation of biodiversity of both flora and fauna in the regions of were sugarcane is expanding.

INTRODUCTION OF 2ND GENERATION TECHNOLOGIES

"2nd generation technologies" are identified as "disruptive" because they could leads to a new level production of bioethanol. The most important "2nd generation technologies" are:

1. Gasification of biomass, which could delivers suitable fuel for efficient generation of electricity and/or the synthesis of liquid fuels (biorefineries). Expectations for the commercial viability of such projects are between 2015 and 2025, but there are a few pilot units being listed around the world there is the need for further research efforts in this area.
2. Acid hydrolysis and enzymatic hydrolysis or the combined acid/enzyme process, which allows the conversion of cellulose into sugars and from there, the production of ethanol and other products. It is expected that the first units will be operating commercially between 2010 and 2020.

There are major efforts in research and technological development in this sector in Europe, the United States and Asia.

3. Genetically modified varieties of sugarcane, which could significantly increase productivity. From the mapping of the genome of sugarcane in Brazil there are several research groups working with dozens of transforms varieties. One expects of gains in yield from greater disease resistance, precocity, sucrose, total biomass etc. Just as an example, increasing the sucrose content of 13.5% to 14.5%, – feasible in a short period of time – would produce the same amount of sugar and ethanol in an area of 300,000 hectares smaller or increase production ethanol in São Paulo State nearly 2 billion liters. It is difficult to estimate the time required for implementation of these efforts because it is not just a technical problem. The release of these new varieties (even for field testing) depends on approval from federal agencies. The groups working in the area are both private (CTC, Allelyx) and public research institutions.

STIMULATING ALCOOLCHEMISTRY

Increased production of sugarcane in the São Paulo State leads naturally to the possibility of the production of chemicals (monomers and polymers) from renewable raw materials derived from sugars, ethanol, biomass, glycerol and other by-products of the production of biofuels.

An example of the interest that exist in this area is the agreement between FAPESP and BRASKEN which aims to invest 50 million reais (US$ 1 = R$ 1.75 at the end of 2009) in numerous studies in this area. Examples of are as follows:

- Development of routes for obtaining ethylene, propylene, butene-1, hexene-1 and octene-1 from renewable raw materials.
- Production of synthesis gas from the gasification of glycerol.
- Production of propanol from synthesis gas.
- Production of biopolymers in plants, bacteria and fungi.
- Catalysts and kinetics of hydroformylation of ethylene production of n-propanol.
- Catalysts and kinetics of dehydration of alcohols to olefins.

FINAL CONSIDERATIONS

The expansion of ethanol production from sugarcane in the State of São Paulo is occurring at a rapid pace to meet growing domestic demand and eventually to overseas demand. The strategies adopted by the State Government intended are aimed to prevent this expansion with insurmountable bottlenecks of various types and, negative social and environmental consequences.

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CHALLENGES IN RESEARCH, DEVELOPMENT, AND INNOVATION IN BIOFUELS IN BRAZIL

Lúcia Carvalho Pinto de Melo and *Marcelo Khaled Poppe*

Three quarters of the world's energy consumption is represented by fossil fuels. They are responsible for a great deal of local pollution, and for most of the emission of greenhouse gases (GHG) on the planet. The scale in which they have been used will quickly, lead to their rarefaction; considering that global energy consumption should grow, as result of progress in various areas undergoing development. Industrialized countries were not successful in reducing energy consumption without compromising quality of life, in spite of knowing that this can and should be done. The present challenge is to promote the use of renewable energy sources, and to increase the efficiency in energy generation and usage in an unprecedented scale. Sugarcane bioethanol, and other biofuels that may be developed in a sustainable way, could contribute significantly to this end. . However, this will require an unprecedented global research effort.

In Brazil, the sugarcane agro-industry has been transforming itself into an energy agro-industry, replacing fossil fuels and opening the possibility to be, in the near future, an important source of renewable materials (plastics and chemical products). Its participation in the national energy matrix has been growing, currently representing about 15% of the total energy consumed in the country, comprising both bioethanol for transportation, and bagasse for electric, thermal, and mechanical power generation. Better use of sugarcane waste and efficient co-generation may significantly increase electricity power generation. And the development of new processes for obtaining bioethanol from bagasse and trash, can increase power generation by up to 40%, using the same quantity of sugarcane.

The Brazilian experience demonstrates that sugarcane bioethanol represents an actual possibility for reliably supplying part of the world's fuel market. Significant progresses in domestic and international research, development, and innovation capabilities will determine the success of such endeavor.

However, it is necessary to consider that innovation is a complex process, not exclusively limited to the research and development dimension. This point is very relevant to discussions in terms of domestic and global outlook regarding biofuels expansion, as innovation processes assume interaction among the various players and segments of the society that make up what is usually called the "innovation environment". This encompasses universities and research centers, and definitely industriey; however, it also covers other aspects such as regulatory benchmarks and domestic and international rules. It is a socio-technical process by nature, which must be considered in all its various dimensions to develop with the required vigor.

Historically, Brazilian breakthroughs in biofuels research are obvious: productivity gains in all production steps, either agricultural or industrial, or even environmental controls, are evident. Bioethanol and bioelectricity production and distribution costs were reduced by advances in technology and management, in addition to investments in infrastructure. Nowadays, producing bioethanol and bioelectricity in the most efficient plants is competitive with all other sources of fuel production and electric power generation.

At the same time, Brazil is still a very uneven country, though all of the recent indexes show improvement, and this unbalance is also reflected on employment quality and production capacity, which require special attention to reach levels capable of ensuring competitiveness and sustainability of biofuels in the domestic and international energy commodity markets.

The widespread adoption of the most efficient and available technologies may further reduce costs, and this holds considerable potential using technologies that are still being developed, including precision agriculture, new transportation systems, genetic improvement, and improved industrial processes.

Therefore, it is necessary to face the challenge of improving the whole production chain as well as the value chain associated to biofuels production. The research and development theme is challenging, pervades all links in the chain, and should consider not only the amassed knowledge and previously incorporated, visible innovations; it also has to consider the potential of new transforming technologies that may have impact on various links in the chain, such as biotechnology, new materials transformation technologies, and nanotechnology. Such technologies create opportunities at every step of bioenergy generation, and must be exploited.

Brazil stands out from other sugarcane producing countries for the progress it has achieved in sugarcane biotechnology, having non-commercial transgenic varieties since the 1990s. In 2003, Brazilian laboratories completed theidentification of 40,000 sugarcane genes, and dozens of research teams are working on the functional genoma; their data being used in genetic improvement experimental programs, which should bring commercial results in the next few years. Furthermore, a growing number of sugarcane varieties are used in Brazil, providing considerable assurance regarding the resistance to exogen diseases and predators. Over 500 sugarcane varieties have been mapped, and 50 of them are currently in commercial use. The 20 leading varieties make up 80% of the harvested area; however, no single variety covers more than 13% of the area.

Water catchment for use in the industrial process has decreased substantially, as well as the quantity of fertilizer used is reduced in comparison to other countries and cultures. Nutrient recycling has been improved by ferti-irrigation, and by the use of production process waste, which has increased considerably.

The use of sugarcane bioethanol as fuel for vehicles, either jointly with or replacing gasoline, contributes substantially to the improvement of air quality in urban areas, and to reduce GHG emissions; in addition sugarcane culture can also be employed for recovering degraded agricultural soils, in deforested areas, or in areas underused by extensive animal breeding.

In Brazil it was possible to responsibly expand the biofuels production area, at the same time freeing important agricultural areas which, were it not for the productivity gains attained, would have been used much more intensively in terms of requirement for such production. A considerable part of the Brazilian territory is adequate for agricultural production, preserving forests and biological diversity. Sugarcane culture expansion has occurred mostly in extensive grazing lands and degraded areas.

This issue of extension and adequacy of land, climate, and soil has been well researched, as demonstrated by the works carried out by CGEE[1], also in partnership with the Interdisciplinary Centre for Energy Planning of the Campinas State University – (Núcleo Interdisciplinar de Planejamento Energético – Nipe/Unicamp), coordinated by Professor Rogério Cerqueira Leite. It is also worth highlighting works developed by Embrapa and other public and private institutions, which examined complementarity and synergy in the production of food, energy,

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[1] "Biocombustíveis" study, published in the NAE section #2 (NAE, 2005); Studies in partnership with Nipe/Unicamp between 2005 and 2008, published in "Bioetanol combustível: uma oportunidade para o Brasil" (CGEE, 2009); Study "Bioetanol de cana-de-açúcar: energia para o desenvolvimento sustentável" (BNDES, 2008).

and materials in Brazil. Contrary to the perception of many who see as a conflict in land usage, studies have confirmed the availability of this input, with soils and climate favorable for considerable growth in sugarcane production, which opens an opportunity to create a Brazilian strategic agenda, also in partnership with other countries situated in the humid tropical regions of the planet.

Doubtlessly, one extremely important aspect for Brazil is to have been able to consolidate its position as a major player based on a strongly rooted sugarcane bioethanol production. By means of knowledge accumulated over the years, as well as actual indicators of growing productivity, Brazil's privileged condition has been reaffirmed. The aforementioned studies draw attention to the Brazilian competitive advantages, such as the issue of Brazilian sugarcane bioethanol yield compared to European beets, American corn, Thai cassava, or wheat in the European Union, as well as sugarcane in India.

Indeed, the Brazilian agro-business has demonstrated an expressive productivity increase from the 1970 to the present, which has not been exhausted yet, having a significant potential for further growth. In terms of energy balance, another competitive edge, Brazilian sugarcane bioethanol has currently comparative advantage, compared to all other biofuel cultures: a ratio of almost 10 to 1 renewable energy units produced for each unit of fossil energy consumed in its production.

Thus, Brazil presently also holds a leadership position in utilization and knowledge dissemination. There is a remarkable collection of know-how in universities, companies, and qualified human resources. Additionally, there is now in Brazil an important effort towards incorporating new knowledge and enhancing innovation throughout the whole bioethanol production chain. Equally important are the available fostering instruments, adequate for supporting the various stages of innovation, from basic research and technology development to direct support devices for innovation in companies, such as economic subsidies enabled by the Law of Innovation.

This new environment has favored the development of innovation cycles in companies, also for building corporate excellence centers, either alone or in partnerships, focusing on issues that are precompetitive by nature, and that may render the breakthroughs the world needs in the sustainable production of liquid biofuels for transportation.

It is important to point out that some of the experience accumulated in Brazil could be shared with other countries. For instance, in terms of competence and qualification for the production of sugarcane varieties, programs like Ridesa's- a successful cross-institutional university network for research and development, currently organized all over Brazil, and actually a university-industry partnership- is allowing the development and utilization of new sugarcane varieties in regions where traditional production behooves gains in efficiency, or in regions deemed promising for expanding production.

Embrapa, together with Ridesa, plays an important role, with chances of obtaining short-term results in expanding overseas a sugarcane variety research and development agenda, in the same way as done in Brazil for regions with lower productivity with traditional varieties. This type of experience can easily be shared with other countries by integrating programs of the National Scientific and Technological Development Council of the Ministry of Science and Technology (CNPq/MCT), such as ProSul and ProAfrica, and of the Ministry of Foreign Affairs (Ministério das Relações Exteriores) – ProRenova; as well as through partnerships with multilateral organizations, such as ECLAC (Economic Commission for Latin America and the Caribbean), IADB (Inter-American Development Bank), CAF (Corporación Andina de Fomento), relative to Latin American and Caribbean countries, and UN-ECA (United Nations Economic Commission for Africa) as well as regional UN offices for food and agriculture – FAO.

Regarding countries that, unlike Brazil, do not have yet explicit and policies for biofuels, especially those having both a natural inclination and a competitive advantage in terms of sugarcane (cultivated in over 130 countries) production and use, joint efforts should be made to promote greater cooperation around relevant knowledge. The reason is that though bioenergetic routes may be envisioned (and they are extremely important), as well as the implementation of advanced technology in each step of the production chain, there are some issues that are not being treated with the required priority. This includes the strong dependence on technology that even Brazil has to face e.g. fertilizer options, extremely important to render bioethanol more renewable than it is currently the case. Credit should be given here to the endeavors by Embrapa and other research institutions in developing alternatives for these inputs, which are at one end of the chain, and should be strengthened.

Many Latin American and Caribbean countries, like Brazil, may obviously exceed by far their own needs in bioethanol from sugarcane production, and may become important players in the global biofuels market. Surplus production can certainly be exported to Europe, North America, and other countries, as it has been done in Brazil, whose bioethanol exports surpassed five billion liters in 2008 over 40% increase in relation to the previous year. This is a global scenario that creates opportunities for countries located on the humid tropics, particularly Brazil and its neighbors in Latin America and the Caribbean.

However, Brazil a relevant player in the international biofuels arena, must pay attention to the next steps to be taken, considering the world scenario. If other countries actually adopt diversification strategies in the use of liquid fuels, with environmental concerns related to GHG emissions and air quality in urban centers, Brazil will be the leading player in terms of sugarcane bioethanol production capacity, as its global demand has been growing.

Yet another segment to be considered, in terms of international cooperation, concerns experiments at the development stage, by companies that are introducing more radical technological innovations in new processes and products. Such companies may find qualified partners in Brazil, in universities, research centers, and other companies, so that they may complete the development of such products and processes, reaching new levels much sooner, towards the next-generation bioethanol. Indeed, Brazil now has outstanding capabilities to attract international research centers and foreign companies for them to carry out, with Brazilian partners, all the development steps, in an environment where basic inputs production is complete; there is also qualified personnel available to develop new technologies.

In terms of an international cooperation agenda, different guidelines may be foreseen regarding the developing and industrialized countries, however they cannot clearly preclude, in both cases, some kind of cooperation that Brazil already keeps, but which needs to be strengthened in qualifying human resources. This should take place by means of existing – or to be created – graduate programs, on subjects related to the borderline between knowledge on biofuels and all the knowledge chain around them.

In this context, the public-private partnership is fundamental for the innovation process to take place with overflowing intensity, necessary for the development process. This comprises setting up networks with institutions and researchers, the development of cooperative projects, implementation of strategic alliances, and assembling strategic R&D agendas. It is a challenging process, with many difficulties to be overcome, but certainly very important to be implemented in Brazil.

The challenge in research nowadays is huge, and organizing a research agenda is much more complex than it was a few decades ago. The current scenario is different, not only in Brazil, but worldwide. The generation of knowledge, and the speed this knowledge is taken in by society and industry, the dimensions society today demands that be built in a decision-making process relative to strategies to be adopted, or, meaningfully, the investments to be made, put into the building of research, development, and innovation agendas, variables not yet properly perceived or embedded in corporate and public policy decision-making processes.

Thinking and planning a research agenda assumes a wider and more diversified view of the dimensions associated to it. Furthermore, the way in which this research effort will be organized must be responsive to the identified challenges. This response is no longer provided by scattered action of people or restricted research groups, but by sharing knowledge through collaboration networks in a competitive environment.

In Brazil, the concept of a research agenda must consider the t extent to which it really creates opportunities, causes problems, and how it intends to solve them. Considering the country's vast territory and soil and climate diversity, specific research agendas are needed for each one of these areas. Research agendas for different kinds of institutions in bioethanol production are also required. Most likely production plants in São Paulo and Minas Gerais have their relationships with sugarcane suppliers structured in a different way than their counterparts in the more traditional regions in the Northeast, and in the northern part of the Rio de Janeiro state.

The sugar and alcohol production from biomass, extraction under pressure, fermentation, distillation, and production are issues well settled in Brazil for many years, which were doubtlessly reinvigorated by Proalcool, leading to the learning and knowledge available as of today. The new technological routes, the agendas that are being developed today for the future production of next-generation biofuels and new production processes, show the dimension that this issue will present, considering production from cellulosic biomass.

Cellulosic biomass utilization is an intense worldwide race, enlarged by mastery of this specific niche. So this niche, where the enzymatic hydrolysis issues and other variations are found, is driving a worldwide research agenda. Brazil has competence in several of the dimensions involved, but not in all of them as yet, nor does the country has the strong investment in research required to take the lead in this game. The existence of some qualified excellence research groups providing important results is great news as well as a necessary condition; however it does not suffice to advance on this level at the required speed to ensure that Brazil finds, in time and at an affordable cost, an exclusively Brazilian solution for this issue.

The technology route, from the primary input production stage y through the final step of the energy vector, the dimension of technologies offered, the technology intake, the efficient water usage, are all issues to be dealt with in a research and innovation agenda for bioethanol. What are the implications and relationships between the different uses of land for producing food, materials, and energy? What answers are being given to this question? What are the needs in studying the water usage issue? And the issues related to plant nutrients? What are the issues with fertilizer availability? If, for instance, there are fertilizers available only for producing food nowadays, what are the options? What if we are overly dependent on imported fertilizers? Finally, what is the Brazilian capacity to overcome some of, or all, these challenges? All these elements must be considered. Yet there is the dimension regarding new knowledge areas, which bring information specific to bioethanol, such as biotechnology, and even the development of social and economic policies, upon encompassing these dimensions.

In the conversion phase, that involves electricity or multiple generation, there are several research and development items that behoove some attention. In the first generation, as it is usually named, there are, for example, combustion processes, most of them are already well understood. In the next biofuels generation, including enzymes, catalysis, gasification, pyrolysis and other technologies, it is obvious that the required infrastructures are differentiated, complex, requiring immediate technological servicing capacity.

There is also a false dilemma between the first and the next biofuels generations.

There is room for improvement in every step, and challenges ranking from incorporating some technologies to the capital goods industry itself (e.g. intelligent machines, machines embodying new production methods) to environmental issues and rules established in a global scenario..

Finally, regarding the final use of energy vectors, it is necessary to examine not only the research issue, but also production scale and its possible integration with others.

This big and complex picture helps to illustrate the dimension of the problem in defining a research, development, and innovation agenda for bioethanol. Various groups have been studying and working with the CGEE to define and select an initial agenda that could be shown as the priority for research on bioethanol, covering from conventional genetics improvement issue to genetic engineering; production models and infrastructure, technological routes, biotechnology, precision agriculture; mechanized harvesting, and all their subdivisions, among others.

As we saw, the points to be considered are many: fermentation, distillation,management; the water and energy issue, how surplus energy generation capacity can be increased, how to integrate electricity distribution networks, and how to optimize this system in order that ethanol production can be part of an energy vector, that can be used as a fuel or diverted to feed the electric power distribution network. All this is possible, the technology is already available, but still requires further research to become a commercial reality.

The issue of mechanized harvesting without damaging the soil or the plant, for instance, is a challenge requiring the use of knowledge in robotics, sophisticated instrumentation, and thinking of a new mechanization concept and its relationship with the soil and the plant.

As mentioned before, there is also the bagasse hydrolysis and gasification issue, and high bagasse content sugarcane, known as energy cane. The integration of such innovation leads to the idea that when Brazil fully masters the know how for the full utilization of sugarcane, it will be primarily about chemical sugarcane, rather than bioethanol-bioethanol will become just another product.

Therefore, innovation cycles must be observed, and the chemical and thermochemical routes that may be taken varied. On the other hand, all this process also assumes the rapid evolution in cultural, political, and social discussions on the use of bioenergy and its implications.

It should be clear that there is still a lot of room in Brazil to reduce costs, to improve production sustainability, and to incorporate new technologies and incremental innovations in production, which may keep Brazil competitive for some time, in some market niches and under certain conditions. It is possible to establish a competitive margin with petroleum around a certain price range, or have a margin with the exchange relationships within a certain system; however, this is definitely not enough if Brazil wants to be a competitive global player.

Controlling new technology generations will require a more daunting agenda. It will be necessary to integrate synergically and intensively the domestic efforts, in the public and the private sectors. This support and involvement of both sectors will be of utmost importance to ensure that existing initiatives – and the new ones – are at the edge of scientific knowledge; like a new paradigm that guides and contributes to the production process, in terms of new technological routes such as the aforesaid biotechnology and nanotechnology. The bioethanol chain is strongly tied up to these agendas, as it is associated with biotechnology, nanotechnology, the use of advanced materials, and the intensive use of information and communication technologies. In other words, it is no longer possible to think that the bioethanol issue is restricted to the chemical or mechanical engineering departments, which know all about unit operations. Not any longer, a system vision is required.

Within this context, the Brazilian Bioethanol Science and Technology Laboratory (CTBE) was set up in Campinas, in the state of São Paulo, to carry out basic research and technological innovation, both internally and in strategic partnerships, representing a major investment by the Brazilian federal government in science and technology linked to sugarcane bioethanol. Through this center, the expected result is to aggregate the Brazilian scientific efforts to make feasible a renewable source of energy that merges high productivity with optimum raw material usage with sustainability.

A research, development, and innovation agenda for the bioethanol chain must consider the advantages and challenges for Brazil in this area. The advantages are remarkable: the availability of land, lack of competition with food production, and the considerable know-how. It is noticeable that Brazil's know-how on the whole bioethanol production chain finds no match in any other country.

On the other hand, there are threats that the nation will face, and should be alert. It begins with the technology control issue. Who will control some of the key technologies in the future? Who will have ownership of this knowledge? Who will have resources to invest in acquiring such proprietary domain? And who will have the capacity to follow all the advances in scientific knowledge, to include them with the required intensity and speed, throughout the whole production chain?

Another important threat is to acknowledge the degree of competition in this trade. The energy industry, be it biofuels or any other source of energy, is a big business, which requires working with different parameters. If Brazil acts as an international player, the competition business game includes variables like industrial property and marketing devices about which academic sector still has the greatest learning needs. It is still necessary to learn how to deal with this business dimension in the academic environment, which is a considerable challenge.

Obviously, the possible repercussions of the current financial crises should not be disregarded, as it may reduce investments, redirect strategies, diverting not only public investments, but private ones as well. Thus, another challenge for Brazil is to monitor the global landscape, in a difficult credit scenario, or financing difficulties, or problems in obtaining resources for investment.

Finally, it is not a market reserved for Brazil only; this is a world game where Brazil has some advantages. In order to preserve and expand these advantages, it is necessary to add knowledge to the whole chain, to mobilize and identify areas of competence in all technologies and synergies, and, above all, to have a clear vision of the future. To accomplish this, it is necessary to consider together all issues covered here. It is also necessary to realize that this challenge is not to be faced by the government alone, but by the whole society, a partnership between public and private endeavors becomes significantly relevant. Summing up, Brazil must explore the advantages it holds and to benefit from upcoming innovations as o a window of opportunity for the nation to act as a global player.

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CLIMBING MOUNT TERAWATT

Cylon Gonçalves da Silva

INTRODUCTION

In this book, the reader will find an extensive and rather complete compendium on the scientific, technical, social and economic challenges and opportunities for Brazilian sugarcane bioethanol, written by experts on the subject. This chapter, by a non-expert, is aimed at those readers who may still be asking themselves, but why sugarcane bioethanol? But, first, let us learn about Mount Terawatt.

It is no use searching in the old school Atlas or in Google Earth. Mount Terawatt (or simply TW) does not correspond to any geographical or geological landmark on the surface of our planet. It may still come to grace some mountain in a yet to be discovered planet, like those being discovered every day now, in which a small fraction of Mankind may seek refuge and a new start, far away from our old rock, eons from now. Mount Terawatt, for the moment, is simply one trillion (ten to the power twelve, one million million) Watts, a convenient unit to measure the amount of energy used by humans every second, because otherwise we would have to use very large numbers. (One Watt equals one joule per second, roughly one thousandth of a BTU per second.)

The 6.6 billion human beings use about 15 TW, i.e., on average, per person, 2,300 Watts (2.3 kW). This is about the power used by a large domestic electric oven, or, in poorer countries, a very good electric shower. Power, like wealth, is very unevenly distributed in the world. So, averages are almost meaningless. The average (North) American uses 10 kW – but she is also a fiction – while a poor African will use no more than a few tens of Watts. Mount Terawatt is important for us because it is tall – the amount of power it represents is too much for us to have a simple intuitive representation of it – and because we use fossil fuels to climb it. As is well known, about 80% of all power generated in the world comes from fossil fuels.

It is not easy to generate 1 TW of electrical power or liquid fuels. One TW of electricity requires the generating power of 1,000 "standard" nuclear power plants. So, if we took today the decision to generate 1 TW of nuclear electricity by 2050, aiming at replacing coal fueled power plants and avoiding CO_2 emissions, we would have to open a new nuclear power plant every three days for 40 years! After all this, we would, sadly, find out that there is not enough uranium to fuel them for very long, but because the reasonably accessible uranium supplies in the world are rather small.

One TW of ethanol is equivalent to the consumption of 1.4 trillion liters in a year (370 billion gallons a year) or, if you like to think in 3D, a cube with a 11.2 km (7 miles) edge. This is roughly 65 times the Brazilian bioethanol output in 2008 and a bit less than that of the US output. To generate 1 TW of bioethanol by 2050, the Brazilian output would have to grow at an average annual compound rate of 11%, that is, to double every six and a half years. This is not an impossible goal to achieve, as this book shows, but it is a huge challenge. Climbing Mount Terawatt is not easy.

But the race to reach the summit of Mount Terawatt with carbon neutral or even carbon negative power sources is on. Many believe, like the editors and authors of this book that the survival of our type of civilization and life style depends upon the success of this climb.

TWO DISTINCT LIFE FORMS

Two distinct life forms share the Earth: one natural, of which our species is part, and one artificial, created by us and without which we no longer know how to live. Using the term "life" here is a bit strong, because we normally associated it with organisms capable of reproduction and evolution. It is true that most of our machines do not share these potentialities with our pet dog, but this is not an essential limitation of the techno-industrial world. There are machines/organisms that already today straddle the gap between natural and artificial. What is a genetically modified organisms if not a machine capable of reproduction and evolution? Where is the essential difference between extracting a piece of iron ore from the ground and processing it into a ship, and extracting a piece of a gene from an organism, combining it with a piece of a gene from another and producing a third one? The processes, results, or risks may be very different, but it is the same scientific-technological-industrial view that governs these manipulations. The separation between natural and artificial is becoming smaller and smaller in our civilization and may have to disappear altogether, if we are to survive as a species on this planet. The natural world can no longer accommodate the demands of our insane and invasive species.

The point of this argument, however, is that the inhabitants of the artificial world share with us, humans, one fundamental characteristic: they only function thanks to a continuous flow of energy. In other words: they only function if they are well fed.

A normal adult requires about 2,500 kcal of energy per day. This translates into approximately 120 Watts. Assuming that all the 6.6 billion human beings fall into the "well fed" category (if only!), they would use 0.8 TW of power to feed themselves. In this number, we are not taking into account the many other TW's needed to produce, process, preserve, transport, distribute, and prepare our food, nor the power needed to deal with the waste products resulting from all these processes. In comparison, the inhabitants of the parallel artificial world require 15 TW of power, that is, about 20 times the human demand. The slaves eat more than the masters, but, then, they work harder.

When we talk about the competition between food and bioenergy, we are talking about the competition between humans and machines for energy. This is a very unequal competition, because the machines need much more than we do. Maybe, one day, they will take over and put us on a very strict diet.

A SINGLE SOURCE OF ENERGY AND ITS CONSEQUENCES

In the natural world, there is only one source of power: the Sun. (We are excluding some minor sources of power, which, although extremely interesting from a fundamental point of view, do seem to be of no practical importance for the moment being.) Plants and other organisms capable of photosynthesis, which transform electromagnetic into chemical energy, directly use this power. All the rest of us, natural or artificial heterotrophs, live mostly off photosynthesis.

The solar power incident at the top of the atmosphere is of the order of 170,000 TW, that is, more then 10,000 times the present needs of our machines. Only about 70% of this power (120,000 TW) reaches the surface of the Earth, the remainder being reflected back to outer space. On the solid portion of the surface, the amount is about 40,000 TW. Still an ample quantity of power compared with our needs. However, this power can only be metabolized by photosynthetic organisms. So, we are in the same position as the Ancient Mariner, dying of thirst (for power) in an ocean (of power). One tenth of a percent of the solar power incident on land would be more than enough to satisfy the present and foreseeable needs of Mankind. This book tries to teach us ways in which we may drink from this ocean of power by harnessing the photosynthetic good will of plants.

Undoubtedly, machines capable of converting heat into work (and work into electricity) are the great discovery of Mankind. The proper feeding of these machines depends, at the present moment, on the existence of immense reservoir of solar power metabolized and stored under the form of reduced carbon atoms (carbon atoms with a lot of chemical energy to spare, usually by being bound to hydrogen atoms). Coal, oil, and natural gas are the fossilized remnants of photosynthetic organisms that lived tens to hundreds of millions of years ago, and that now feed our machines. As we do not like to eat this sort of deteriorated food, there is no competition between them and us. And that is good. But, there is a price to be paid for this convenience. Eighty percent (12 TW) of the power used by them in 2008 came from fossil fuels, which once consumed by our heat machines become low grade compounds of reduced carbon, mostly CO_2 that increasingly litter the industrial civilization atmosphere. Although an essential ingredient in the photosynthetic synthesis of new biomass, the natural world cannot transform all of this CO_2 back into reduced forms of carbon as fast as the artificial world breathes it out. As it accumulates in the atmosphere, it leads to more and more scientific and diplomatic meetings, to more and more concerned statements by governments, and more and more announcements of oil discoveries by oil companies. But very little meaningful actions, such as those which this book proposes to alleviate the risks of major climate changes.

A phenomenon similar to the one just described already happened on our planet. Until photosynthesis came along, organisms that drew their energy from chemical sources and lived without oxygen inhabited the natural world. Photosynthesis, on the other hand, has as a metabolic by product a potentially toxic gas: oxygen. As the concentration of oxygen in the atmosphere grew, the new life forms slowly smothered the old ones, which had to retreat to places like municipal solid waste disposal sites. Today, artificial organisms, with our complicity, are busily changing the composition of the atmosphere, but try as they might, CO_2 concentrations will never reach the proportions of present day O_2 concentrations, because there is not enough fossil fuel at their disposal. But they can do a lot of damage, if increasing temperatures lead to the release of vast quantities of methane stored in colder parts of the planet.

The fact is that we can no longer envisage life without machines, but also, it is becoming more difficult to envisage the continued use of fossil fuel fed machines. So, it is a matter of utmost urgency to find a healthier diet for them. This is where bioenergy, rather biomass energy, comes in. Instead of using fossil reduced carbon, biomass energy aims at providing us with plentiful freshly reduced carbon, whose return to the atmosphere as oxidized carbon will not alter the overall concentration of CO_2. Let us take a brief look at the two major energy vectors that feed our machines: electricity and fuels.

ELECTRICITY

Electricity generation is responsible for one third of the energy emissions of CO_2. Instead of being generated by fossil energies, mainly coal, electricity can be generated by hydro, nuclear, wind, solar, wave, and biomass energy. All of which can have a lesser impact on emissions of greenhouse gases. With all these different alternatives, why persist with coal and other fossil sources? In the first place, because coal is cheap (not taking into account the cost of cleaning up afterwards), easily available in the countries that most need it, and the technology for burning coal efficiently is available. In the second place, because there are limitations for the other choices: available resources, expensive technologies, or intrinsic to the source, such as low power density or intermittency that can make the climbing of mount Terawatt rather challenging.

To begin with, we can exclude geothermal and wave resources. They are too local and limited to have a global impact. Next, wind and solar suffer because of their intermittency – the wind does not always blow in the right direction with the right intensity and the Sun does not always shine. So, the utilization factor (ratio of average power actually generated over the installed generating capacity) of these sources tends to be low. It can be better for wind than for solar, something to be kept in mind! But, no country can depend on its electricity exclusively on such sources. Anyway, the Achilles' heel of electricity is storage. Unlike liquid fuels that we can put into a tank and withdraw on a need to use basis, electricity has to be used as it is generated. There are schemes for storing electricity, but either they are cumbersome and inefficient or only work for minute quantities, in relation to actual needs. Whoever solves the problem of storing a TWh of electricity shall inherit the Earth.

The projections for 2030 indicate a worldwide need for 33,000 TWh of electricity. This means some 20 TW of generating capacity based on wind farms, which would occupy about 3.3 million sq. km. (1.27 sq. mi.), at a cost of 40 trillion dollars for the generators alone. But, we would also need a vast intelligent grid capable of mining the necessary power among all the generators, switching from one site to another quickly, depending on the local wind conditions. Similar considerations apply to solar electricity, be it photovoltaic or thermal. We are left with nuclear, hydro, and biomass electricity.

Nuclear has the great advantage of a large utilization factor (larger than 80%) to supply base loads. But, it has the disadvantages of nuclear waste that needs to be stored for centuries. To supply the same 33,000 TWh, in 2030, with modern day and foreseeable technologies, we would need 4,700 new nuclear plants, that is, a new one every three days, for 40 years! The known uranium resources could feed these plants for a couple of decades, at best, much less than their operational lifetimes. It is true that the technology can change and that the challenges of dealing with nuclear wastes can be tackled successfully, but this is very unlikely to happen soon. Electricity from nuclear fusion is the first cousin of electricity from nuclear fission. It has the advantage of abundant fuel supplies (it uses basically hydrogen nuclei and H is the most abundant chemical element in the Universe), but the technology is simply not there. Even the most ardent supporters of fusion, recognize that it will not be able to make an appreciable contribution to the world supply of electricity before the 22^{nd} century. And, the skeptics do not believe that it will happen even then.

Hydropower is clean, based on an established technology, can supply base load electricity, but… the resources are not enough. At most, we can count on 2 to 3 TW worldwide, enough to supply 7,000 to 10,000 TWh; far from the projected demand. In addition, lately ecologists have been fiercely opposing new hydroelectricity projects on the grounds of protecting biodiversity and the local environment. Between the little critters and the human species, they wisely settle for the former. In the long run, it is a safe bet.

Biomass is a nice option to supply carbon neutral base load electricity. To generate 33,000 TWh of electricity, we will require something of the order of 100,000 TWh of thermal power. Assuming 10 GJ/ton for biomass, this implies 36 billion tons of biomass per year. Taking sugarcane as an example, at 80 tons per hectare and 7.5 GJ per ton, we would need 600 million hectares or 6 million km^2 (2.3 million sq. mi.) of sugarcane plantations around the world. This is roughly a hundred times the present cultivated area in Brazil. This number is only approximate, it may be smaller or larger depending on the assumed energy densities and productivities, but it gives us a fair estimate of the area needed for generating 33,000 TWh of electricity from biomass in 2030. This is a very schematic reasoning, though, as the countries that will most consume electricity are also countries that have most severe restrictions to produce biomass (think China and India). But, for a country like Brazil, there would be no real difficulties to have all of its energy coming from renewable sources, provided Petrobras could live with that.

Electricity is expensive from the energetic point of view, and the electric car, a very bad solution (which does not mean that it will not be a popular success). None of the existing carbon neutral or carbon free alternatives for electricity generation can push out fossil fueled electricity in the near future. Local, cleaner, solutions are always very welcome. But, climbing mount Terawatt is not an easy task. The numbers shown are not going to be altered by small is beautiful, however. They might even get worse, as they depend only on the laws of thermodynamics and the availability of primary energy resources.

In spite of these somewhat gloomy numbers, there is still hope for fossil fuels. Let us capture and sequester, for many centuries, the final metabolic waste from our machines: oxidized carbon. But here, also, there are some "minor" difficulties. These technologies can only be employed for large fixed installations, not for the transportation sector, which contributes with a quarter of the total energy emissions. Unfortunately, these technologies are far from the deployment stage. Demonstrations plants for a million tons a year exist, but we need to sequester several billion tons a year. Storage for many centuries is an open question. Not to mention the overall costs.

FUELS

Liquid fuels move Mankind. In 2005, 144 EJ of oil (exajoules; 1 exajoule is equivalent to roughly one Quad – one quadrillion BTU) were used by the transport sector. This represents 60% of all the oil consumed in that year. In annualized power, 4.6 TW out of the total 15.3 TW of primary power, were used to move people and goods around. In 2007, non-fossil fuels contributed mere 1 EJ to the same tasks. Thus, we can say, supported by solid statistics, that the living are more and more moved by fossils. A notion of much wider application than merely to the transport sector, unfortunately.

With 60% of all the oil, and with 40% of energy emissions being due to this primary source, the transport sector was responsible for 24% of the 27 billion tons of CO_2 emitted in 2005. That is the price of our material and psychological dependency on mobility. Until the 2008 financial crisis, the demand from transport sector was projected to grow at 1.5% a year until 2030. As it seems that this crisis has not affected the largest developing countries so badly, we will keep the projection. Growth is good. But, 50% of this growth is expected to come from fossil fuels, leading to an increase in emissions. Emissions are bad. Fifty percent? Is the glass half full or half empty? The other half of the growth will come from biofuels, the largest contribution being from bioethanol, a little from biodiesel, reaching something of the order of 5 EJ in 2030. This book is a contribution to getting these projections out of the paper (sorry) and into the market. Hopefully, even increasing more substantially the contribution from biofuels to the transport sector.

The 10% solution, a relatively modest proposal being examined in this book, is the energy equivalent concentration of bioethanol in gasoline that could be adopted worldwide in order to reduce slightly gasoline consumption and emissions by 2030.

The volumetric energy density of ethanol is roughly 2/3 that of gasoline. Hence, 10% of gasoline energy corresponds to about 14.3% in ethanol volume. In 2007, the United States consumed 540 billion liters of gasoline. Globally, we can estimate for the same year a consumption of about 2.2 trillion liters. The 10% solution would require, in 2007, 318 billion liters of ethanol, compared to the world production of 50 billion liters. In 2030, if the projected world economy growth materializes, the 10% solution would require 430 billion liters of ethanol. A productivity of 7,000 liters per hectare, currently achieved by the Brazilian producers, leads us to an estimate of 61.4 million hectares (614.000 km^2) of land needed for feedstock production. If, as expected, improvements in current processes and new technologies result in a 10,000 liters per hectare productivity in the future, then 43 million hectares of land (430.000 km^2) would be sufficient for the 10% solution. This shows how critical productivity is to reduce land use. A 100% solution, which is not being contemplated, would require as much land as the one needed to supply global electricity demand exclusively from biomass (a solution which is also not being contemplated).

According to data from IEA World Energy Outlook 2008, it is possible to estimate that to increase the world production capacity of biofuels by 1 GJ it is necessary to invest US$ 60. Hence, to increase production of bioethanol from 50 to 430 billion liters, at 22 MJ/liter, US$ 500 billion would be required. This investment, spread over a period of 20 years, would mean US$ 25 billion/year. A small number as far as worldwide energy investments are concerned.

According to FAO (United Nations Food and Agriculture Organization), Brazil has about 550 million hectares (Mha) of potential agricultural land, of which 300 Mha are classified as "without major restrictions". That is, there are no major social or environmental restrictions on the use of this land for agriculture, as well as there is enough water for cultivation. In 2005, the cultivated area in Brazil was a mere 58 Mha, of which about 6 Mha dedicated to sugarcane (roughly half of this area for bioethanol production, the remainder for other products, mainly sugar). Hence, the 10% solution looks perfectly feasible in terms of available land and investments. The production of 430 billion liters of bioethanol would occupy about 14% of the area considered “without major restrictions”, not considering further improvements in agricultural and industrial productivities. This means 9.5 EJ of biofuels to replace gasoline consumption. Or, in power terms, 300 GW. It is not a huge amount, but it brings us one third up Mount Terawatt.

FINAL CONSIDERATIONS

The real challenges for bioenergy, as we tried to show briefly above, are not the numbers. They are social perceptions and the environment: sustainability, effective reduction of greenhouse gases, and the perceived competition with food production. This book looks into all of these aspects, in the hope of contributing to making modern bioenergy a realistic option for a cleaner world energy matrix in the near future.

6

ENVIRONMENTAL (LOCAL AND GLOBAL IMPACT) AND ENERGY ISSUES ON SUGARCANE EXPANSION AND LAND OCCUPATION IN THE SÃO PAULO STATE

Evaristo Eduardo de Miranda

INTRODUCTION

Agribusiness land management is in the current agenda. All scientific, social, economic, and environmental matters related to expanding ethanol production in the São Paulo state border on land issues. For Brazilian society and abroad, such issues linked to the agricultural use of the land dominate the debate on the expansion of agro-energy and the production of biofuels. Scientific knowledge is yet insufficient due to the considerable time-space dynamics of sugarcane in the São Paulo state, and the diversity of existing agro-environmental situations. Among the issues connected to the sugarcane territorial expansion, there are the following:

- What are the impacts of the sugarcane space-time dynamics on the overall agricultural production in the São Paulo state?
- Does sugarcane expansion induce a reduction in food (grain or meat) producing areas?
- What are the impacts of this sugarcane dynamics on areas with natural vegetation? Does it favor or reduce them?
- Could change in the sugarcane production systems technology profile (elimination of burning, innovative waste management, electric power co-generation etc.) lead to a retraction in sugarcane areas in certain territorial circumstances?

The results from some studies on the time-space dynamics of land occupation and use in the São Paulo state have brought some relevant information; yet, they are still insufficient to span the whole breadth of this issue and its resulting impacts. However, focusing research only in sugarcane areas land use monitoring is not enough. Research should cover all types and classes of land use. To monitor land occupation and use, and its time-space dynamics, emphasizing sugarcane, research has to develop and use methodological tools based on geographic information systems, remote sensing and modeling.

This chapter, based on research of the expansion of sugarcane land in the Northeastern region of the São Paulo state, provides pointers on the subjects, methods, and scientific procedures to be developed mostly to supply the need for knowledge in this process' dynamics, capable of supporting agricultural land management and investments in infrastructure. The text also points out the most urgent research results, which public or private policy decision-makers need to bestow improved sustainability to the land ordinance of the São Paulo state, due to the expansion of agro-energy.

A HISTORIC SUMMARY OF SUGARCANE AND LAND USAGE

Initially, São Paulo lost its importance in this scenario. In 1590, there were six sugarcane mills in Rio de Janeiro. In 1600, sugarcane occupied some 6,600 hectares. In 1728, the number of sugarcane mills rose to 32, and, in 1797, they were 120. Rio de Janeiro city toponymy still recalls this cycle, with places named Engenho Novo, Engenho de Dentro, Usina da Tijuca, Engenho Velho, Engenho da Rainha, Engenho da Pedra etc.; "Engenho" being the Portuguese word for "sugar mill". Brazil increased its exports, and in 1700 it shipped 19,000 tons per year; after some oscillations, this figure reached 24,000 tons in 1800.

Circumstantiated scientific studies observed that, during the Portuguese domain period, the average cultivated area per year was 9,000 hectares, reaching a maximum of 16,000 hectares at the outset of the Empire. In a maximalist scenario, the total deforestation for sugar production over more than 220 years, at the time of Independence, was close to 140,000 hectares. If compared to the extension of the Atlantic Forest, deforestation caused by sugarcane during a period of over 200 years by its population, can be considered negligible[1]. Currently, in one year alone, Brazil produces much more sugarcane than it did throughout the whole period of colonization by the Portuguese[2].

After the introduction of the Alcohol Fuel program in the 1970s, sugarcane gained new territorial dynamics in São Paulo, expanding its area in both traditional cultivation areas in, for example, Piracicaba and Ribeirão Preto, as well as in regions further West, such as the Assis area, occupying mostly *cerrado* lands dedicated to animal breeding, and seasonal cultures, having varied impacts[3].

In the 1970s, a crew from Terrafoto S.A., a land study and airborne survey connected to the São Paulo state government, taking into account restrictions of remote probing and geographic information systems existing at that time, made breakthrough surveys on this issue. They mapped land usage in a great deal of the São Paulo state, emphasizing sugarcane on two dates: early 1960s, based on air photos and later, the updated situation in the late 1970s, based on different surveys[4].

When Terrafoto S.A. was privatized in 1980[5], this work was discontinued, as it was interesting for public policies, but not for air survey private activities. Public institutions did not require such services either. Nowadays, access to this data is difficult for reasons linked to Terrafoto's records destination, and the very geo-processing technology employed at that time.

Nowadays, the sugarcane industry maintains, by means of União da Indústria de Cana-de-Açucar – Unica (Sugarcane Industry Union), keeps an exclusive monitoring of areas planted with sugarcane (Canasat) in cooperation with Funcate and Inpe[6]. Figures from the 2007-2008 harvest season indicate the constantly growing area and sugarcane harvest in the Center-South region, which represents 86% of the domestic production. There was 414 million tons of sugarcane, compared to 366 million in the previous harvest season: a 13% growth. It is estimated that 29 new mills will start operating in the region, being 13 of them in the São Paulo state, which implies another increase in cultivated area and production, around 10%[7].

THE CASE OF THE NORTHEASTERN REGION OF SÃO PAULO STATE

The Northeastern region of the São Paulo state is an example of Brazilian agribusiness territorial development, being the national productivity leader in the major agricultural segments, mostly based in sugarcane expansion. Its Gross Internal Product, above USD 25 billion, is higher than Uru-

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1 CASTRO, C. F. A. **Gestão florestal no Brasil Colônia**. Brasília: UnB, 2002.

2 In 2008, sugarcane production reached almost 500 million tons in the São Paulo state.

3 PAMPLONA, C. **Proalcool**: impacto em termos técnicos – econômicos e sociais do programa no Brasil. Belo Horizonte: SOPRAL, 1984. 93p.

4 SERRA FILHO R.; CAVALLI A. C.; GUILLAUMON JR. **Levantamento da cobertura natural e do reflorestamento no Estado de São Paulo** – Boletim Técnico do Instituto Florestal, 1974.

5 Available at: <http://www.al.sp.gov.br/staticfi le/integra_ddilei/decreto/1980/decreto%20n.15.471,%20de%2007.08.1980.htm>.

6 Available at: <http://www.dsr.inpe.br/canasat/>.

7 Produção em crescimento. **Agroanalysis**, São Paulo, FGV, vol. 28, abril 2008.

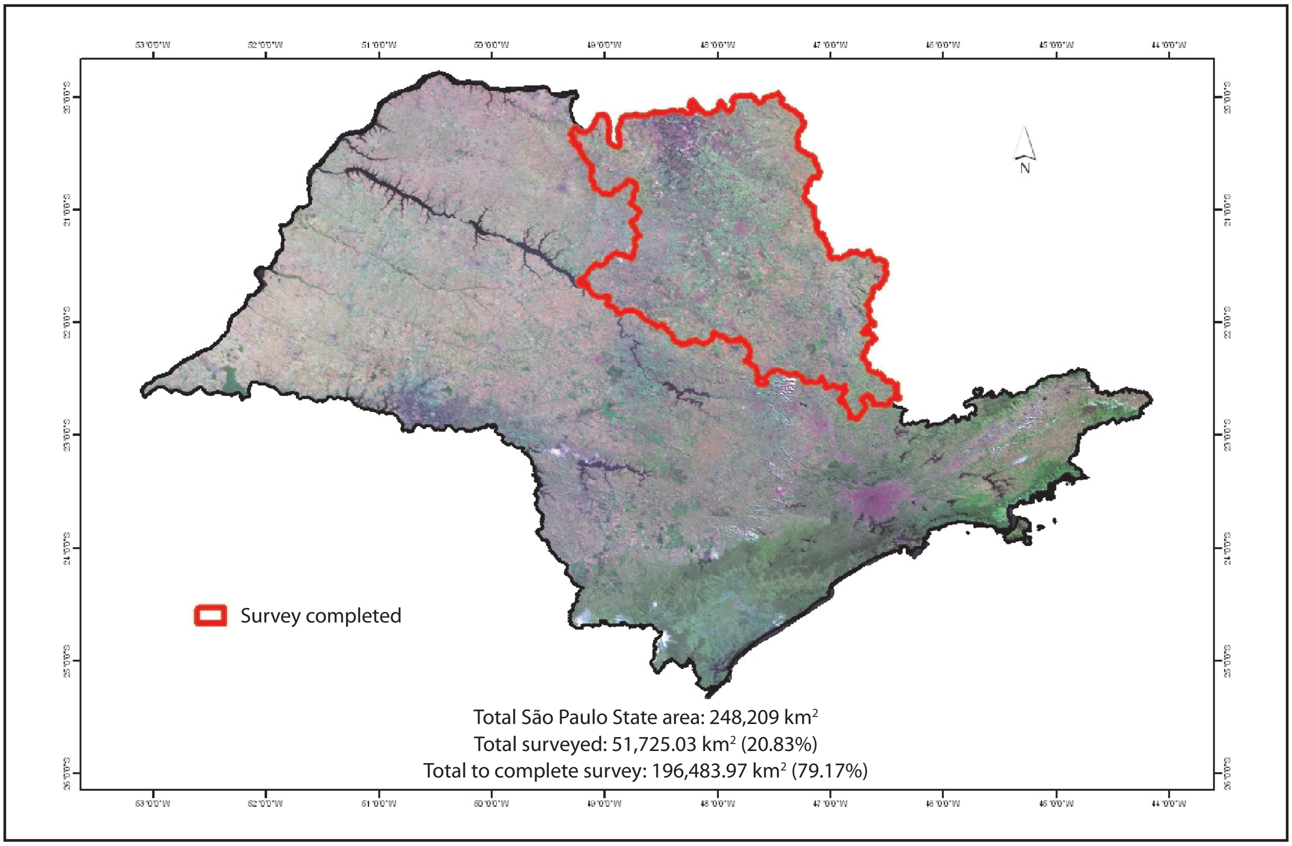

FIGURE 1 Location of the study area in the São Paulo State.

guay's, and its *per capita* income is twice as much as Argentina's[8].

A study of land usage and land management carried out by Embrapa Monitoramento por Satélite (satellite monitoring) covered 125 municipalities, approximately 51,725 km^2, and 20.83% of the São Paulo state (Figure 1)[9]. Town, regional and trade leaderships seek participation in public policies for land, and need updated information on agricultural land usage and spatial dynamics coverage, which, in partnership with the project *"Diagnóstico Ambiental da Agricultura no Estado de São Paulo: bases para um desenvolvimento rural sustentável – Ecoagri/ Fapesp"*[10] and the support of Abag-RP[11] (Brazilian Agribusiness Association of the Ribeirão Preto Area), structured an agribusiness land management system for this region.

Materials and key data used as grounds for usage mapping and land coverage work were images from satellites LANDSAT 7-ETM+, LANDSAT 5-TM, and the vector file with the municipal grid from Instituto Brasileiro de Geografia e Estatística – IBGE (Brazilian Institute of Geography and Statistics) (1999). Ortho-rectified aerial photos, on a 1:30,000 scale from 2001, and images from the satellites Cbers and Spot were used as support information. The main software packages used were Erdas Imagine and ArcGIS.

The land use and coverage map was initially obtained for 2003. Image interpretation was done on a 1:180,000 scale for representation in 1:250,000, considering 25 ha as the smallest

[8] ELIAS, D. **Globalização e agricultura**: a região de Ribeirão Preto/SP. São Paulo: Edusp, 2003.

[9] Available at: <http://www.cnpm.embrapa.br/publica/down – load/newsdownload/artigos_resumos%20anais%20eventos/ apc_44cbesrsober06_gestaoterrnesp_mir.pdf>.

[10] Available at: <http://ecoagri.cnptia.embrapa.br/indexphp>.

[11] Available at: <http://www.abagrp.com.br/>.

charted element. The same process was used for the 1988 mapping. The resulting key includes the following land usage and coverage categories: sugarcane, fruit, coffee, rubber, yearly cultures (corn, soy, peanuts, beans, rice), yearly cultures on irrigation pivots, pastures, natural and riparian vegetation remnants, urban areas, mining areas, and other uses/coverage (open soil, exposed rock etc.), and water bodies (lakes, rivers, dams etc.)[12].

Tables and charts on the land usage and coverage dynamics were obtained by crossing (intercept) of the 1998 and 2003 usage and coverage maps using geo-processing techniques. Data obtained were entered on a Geographic Information System, together with other information plans, such as: municipal division, hydrography, topography, basins etc.

A database containing agronomic, social, economic, and environmental data was built for each type of vegetation coverage mapped in the region from various information sources, and field surveys with farmers and technical support agencies. Each variable in this database may be spatialized within the region, and was used to structure other composite variables.

THE REGIONAL AGRICULTURAL DYNAMICS BETWEEN 1988 AND 2003

Land usage and coverage maps, obtained for 1988 and 2002/2003 are represented in a summarized form in Figures 2 and 3. The original maps are in a 1:250,000 scale and complete data may be found at CRISCUOLO *et al*., 2006[13].

From the intercepts by geo-processing of the maps obtained for each period it was possible to analyze the land usage and coverage dynamics for each category. Table 1 presents, in a cross-referenced way and summarized by usage and coverage category, the quantitative changes occurred in the area studied between 1988 and 2002/2003.

Table 1 summarizes each category's summarized quantitative data for each category mapped for 1988 and 2003.

From the intercepts by geo-processing of the maps obtained for each period it was possible to analyze the land usage and coverage dynamics for each category. Table 2 presents, in a cross-referenced way and summarized by usage and coverage category, the quantitative changes occurred in the area studied between 1988 and 2003.

SUGARCANE RETRACTION, PERMANENCE, AND EXPANSION

After the land usage and coverage maps in 1988 and 2003 were concluded, it was possible to make space and time analysis of the dynamics in the past 15 years, especially in the rural area. The time analysis of land usage and coverage pointed out the expansion of sugarcane, mostly over grazing lands and yearly cultures, like in other studies[14].

In 1988, sugarcane occupied 1,085,668 ha of the Northeastern region of the São Paulo state (21%), being concentrated around the central axis of the area studied, including the whole municipality of Ribeirão Preto as core area. In 2003, the area covered with sugarcane was 2,293,301 ha, which represented a leap from 21% to 44% of the area studied (Table 1).

One of the interesting features of a land management tool for agribusiness, based on the spatial knowledge of land usage and coverage, is in its capability of considering what took place in every hectare of sugarcane between 1988 and 2003. The figure shows sugarcane retraction, permanence, and expansion areas. Digital charting treatment of this information allows the quantification of sugarcane permanence area between the two periods: 989,523 ha, i.e., from the present 2,293,301 ha,

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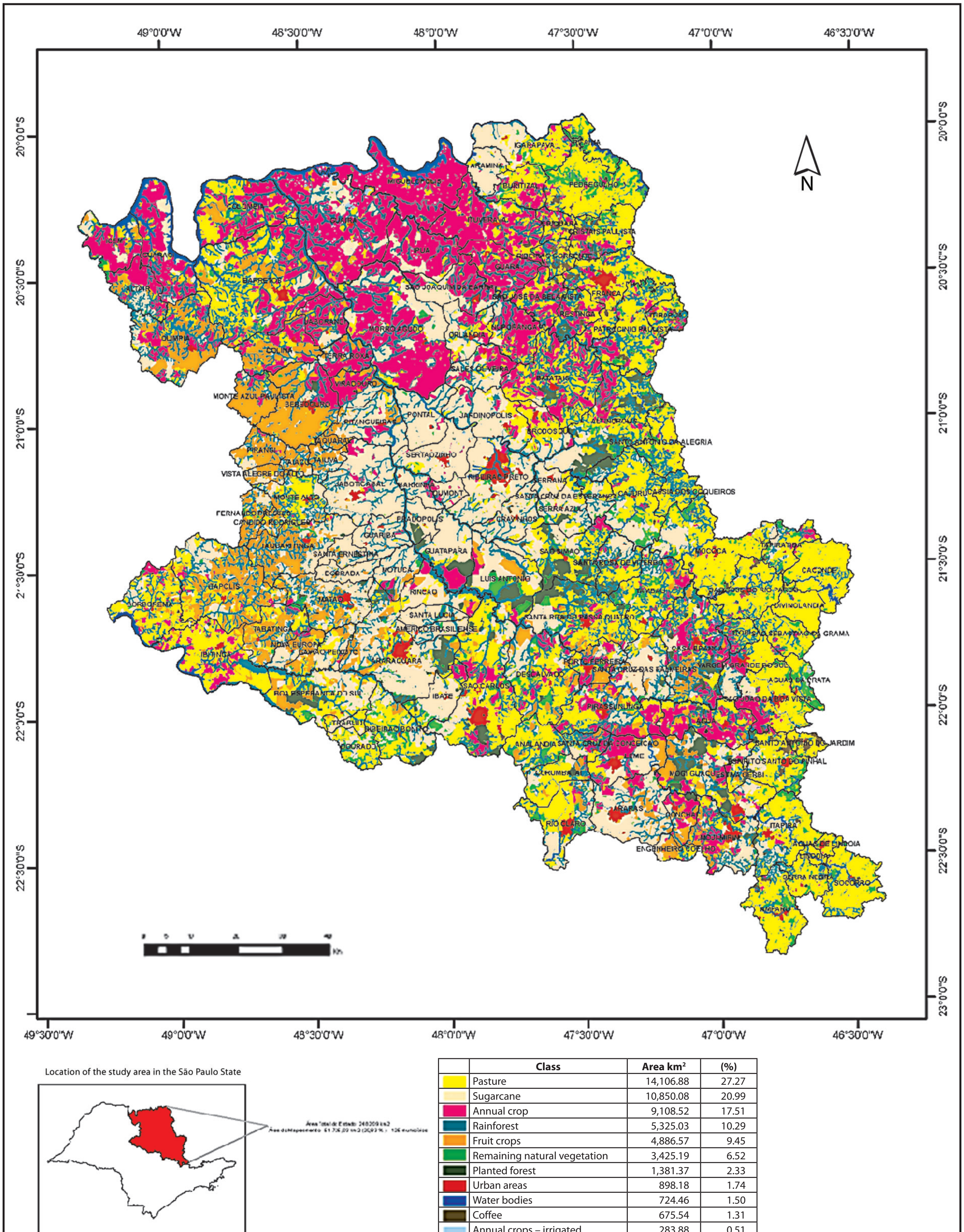
[12] DI GREGÓRIO, A.; JANSEN, L. J. M. **Land Cover Classification System (LCCS)**: Classification Concepts and User Manual. Rome: Food and agriculture organization of the United Nations, 2000. 179p.

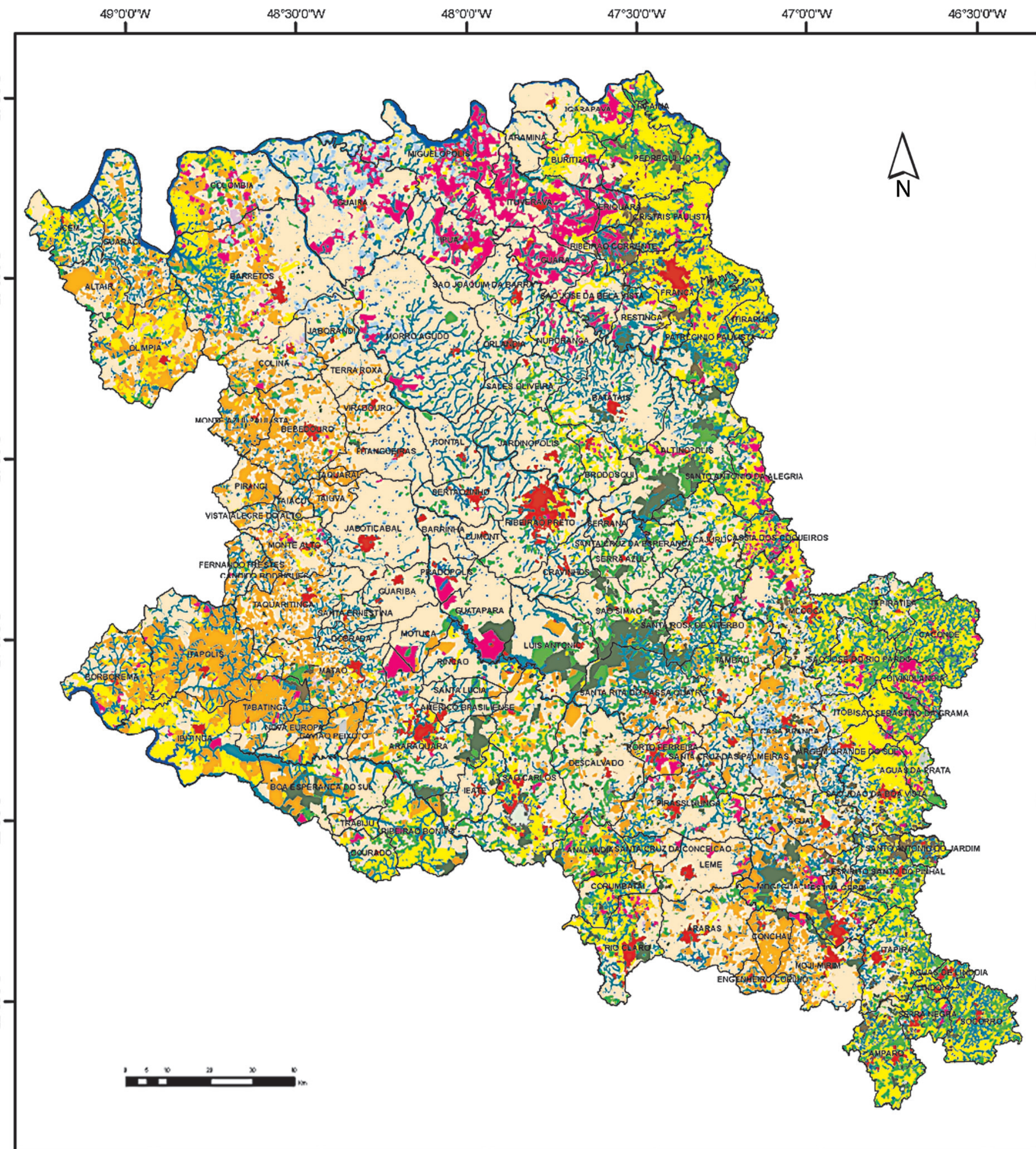
[13] CRISCUOLO C.; QUARTAROLI, C. F.; MIRANDA, E. E.; GUIMARÃES, M. **Dinâmica de uso e cobertura das terras na região nordeste do Estado de São Paulo**. Campinas: Embrapa Monitoramento por Satélite, 2006. 70 p., il. (Documentos, 46).

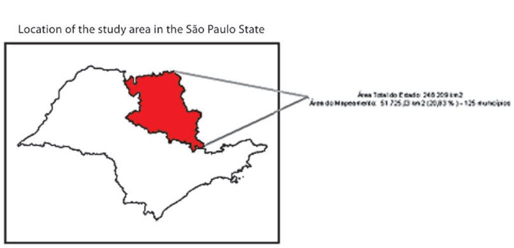
[14] COELHO S. T.; LORA, B. A.; MONTEIRO, M. B. C. A. **A expansão da cultura canavieira no Estado de São Paulo**. USP. São Paulo: Cenbio. Available at: <http://www.cenbio.org.br/pt/downloads/papers/expcana.pdf>.



	Class	Area km²	(%)
	Pasture	14,106.88	27.27
	Sugarcane	10,850.08	20.99
	Annual crop	9,108.52	17.51
	Rainforest	5,325.03	10.29
	Fruit crops	4,886.57	9.45
	Remaining natural vegetation	3,425.19	6.52
	Planted forest	1,381.37	2.33
	Urban areas	898.18	1.74
	Water bodies	724.46	1.50
	Coffee	675.54	1.31
	Annual crops – irrigated	283.88	0.51
	Others	32.21	0.36
	Mining areas	8.76	0.32
	Rubber trees	1.75	0.00
	Total	**51,726,03**	**100.00**

FIGURE 2 Synthetic map of land usage and coverage in 1988.





	Class	Area km²	(%)
	Sugarcane	22,935.16	44.34
	Pasture	7,981.20	15.44
	Rainforest	5,441.70	10.52
	Fruit crops	5,191.86	10.05
	Remaining natural vegetation	3,321.62	6.42
	Annual crop	2,294.25	4.44
	Planted forest	1,351.81	2.63
	Urban areas	1,189.22	2.30
	Water bodies	805.36	1.56
	Coffee	588.40	1.14
	Annual crops – irrigated	485.53	0.94
	Others	64.23	0.12
	Mining areas	41.66	0.09
	Rubber trees	9.03	0.02
	Total	**51,726.03**	**100.00**

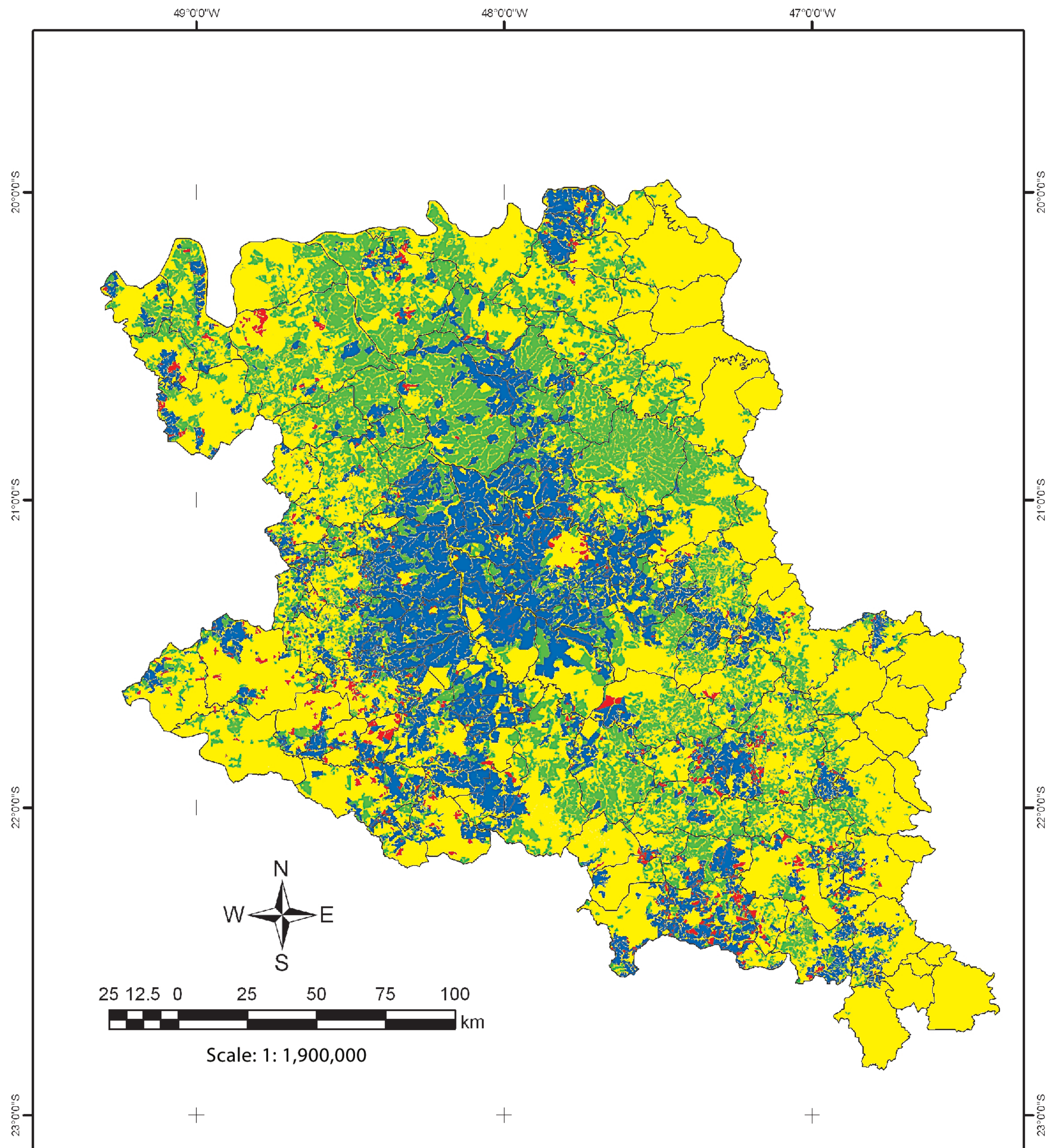
FIGURE 3 Synthetic map of land usage and coverage in 2002/2003.

TABLE 1 Quantificaion of land coverage in 1988 and 2003.

	1988		2002/2003	
Category/class	**4,126,120**	**79.77**	**4,089,374**	**79.06**
Pasture	1,410,688	27.27	798,956	15.45
Sugarcane	1,085,668	20.99	2,293,301	44.34
Annual crop	910,852	17.61	229,455	4.44
Fruit crop	488,657	9.45	519,739	10.05
Planted forest	136,137	2.63	135,783	2.63
Annual crop – irrigated	26,388	0.51	48,566	0.94
Rubber trees	175	0.00	4,761	0.09
Coffee	67,554	1.31	58,823	1.14
Antropic areas	**93,915**	**1.82**	**126,217**	**2.44**
Urban areas	89,818	1.74	118,898	2.30
Others	3,221	0.006	6,416	0.12
Mining areas	876	0.02	903	0.02
Natural vegetation	**875,022**	**16.92**	**876,431**	**16.94**
Rainforest	532,503	10.29	544,091	10.52
Remaining natural vegetation	342,519	6.62	332,340	6.43
Water bodies	**77,446**	**1.50**	**80,480**	**1.56**
Water bodies	77,446	1.50	80,480	1.56
Total	**5,172,503**	**100.00**	**5,172,503**	**100.00**

TABLE 2 Land usage and coverage dynamics in the Northeastern region of the São Paulo state, by analysis categories (numbers in ha).

		2002/2003				
		Agriculture and livestock	**Natural vegetation**	**Antropic areas**	**Water bodies**	**Total (1988)**
1988	Agriculture and livestock	4,015,964	76,092	30,701	3,363	**4,126,119**
	Natural vegetation	70,745	795,125	2,032	7,121	**875,023**
	Antropic areas	527	100	93,195	94	**93,915**
	Water bodies	2,139	5,114	290	69,902	**77,446**
Total (2002/2003)		**4,089,374**	**876,431**	**126,217**	**80,480**	**5,172,503**



	Summary of areas	Situation in 1988	Situation in 2003	ha	(%)
(blue)	Permanence	Sugarcane	Sugarcane	989,773.0	19.1
(green)	Expansion	Other uses/coverages	Sugarcane	1,303,778.0	25.2
(red)	Retraction	Sugarcane	Other uses/coverages	96,144.8	1.9
(yellow)	Absence	Other uses/coverages	Other uses/coverages	2,782,807.2	53.8
				5,172,503.0	**100.0**

FIGURE 4 Sugarcane permanence, expansion, retraction, and absence areas in the Northeastern region of the São Paulo state, obtained from land usage and coverage mapping in 1988 and 2003.

only 989,523 ha were sugarcane in 1988. This indicates that in other areas there was either retraction or expansion of the culture, as shown on Figure 4.

Retraction of this activity took place on 96,145 ha, and the land management system allows to identify major cultures that replaced sugarcane in these places: 40,113 ha were occupied with fruit; 14,729 ha with grazing land; and 11,058 ha with yearly cultures. The remaining area, around 30,254 ha, was occupied by various cultures (coffee, rubber, and silviculture), by restoring riparian forests, and other uses (dams, urbanization etc.).

The sugarcane expansion area was 1,303,778 ha, mostly over 596,345 ha of yearly cultures, 474,743 ha of grazing lands; and 157,680 ha of fruit cultures. Knowing the socio-economic indicators of each one of these cultures, it is possible to assess the impacts of this land usage and coverage dynamics, in terms of employment, income and levied taxes.

EVALUATION OF SOCIAL, ECONOMICAL, AND TERRITORIAL IMPACTS

This agribusiness land management system allowed following the land usage and coverage dynamics in each section of that region. Contrary to census and numerical data, it is possible to know, in a circumstantiated manner, which cultures were replaced in the sugarcane expansion, or which replaced sugarcane where there was a retraction. The system calculated this dynamic for each category and land usage class. Having such information for the whole São Paulo state would be highly relevant to monitor what is actually taking place, and its environmental and socio-economic impacts.

To illustrate, here are the evolutions of some socio-economical indicators, such as direct employment, though the land management system also has data on indirect, induced, and total jobs in each of the productive chains. Likewise, only direct taxes levied will be presented to illustrate, though there is also information on indirect, induced, and total taxes in each of the Northeastern region of the São Paulo State productive chains. Figures for gross income are based on the best prices obtained in the region in 2003. Results obtained and commented are presented next.

Gross income

Culture replacements, both for sugarcane retraction and expansion, were duly computed, thanks to the land management system. In the case of areas where there was a retraction of sugarcane, being replaced by other cultures (78,333 ha), the current use generates about R$ 223 million in gross income, against a potential income – if sugarcane had been maintained in these places – of about R$ 219 million.

This represents a gain in gross income in these sugarcane retraction areas of about R$ 34 million. Agronomical and environmental reasons also explain such changes, and justify the rationale for this spatial evolution.

In the case of sugarcane expansion, this additional area (1,266,681 ha) generates a potential gross income of about R$ 3.5 billion against a theoretical gross income – had the previous usages been maintained – of around R$ 2.1 billion. This represents a gain, in terms of gross income, of about R$ 1.5 billion, i.e, an average gain of R$ 1,161/ha in comparison to the other uses.

Considering the positive and negative compensations in terms of gross income in the area currently occupied by sugarcane in the Northeastern region of the São Paulo state, there was a gain of around R$ 1.5 billion.

Direct employment

In the case of areas where there was a retraction of sugarcane, and its replacement with other cultures (78,333 ha), the land management system estimated that the current use of the land generates around 10,825 direct jobs, against a potential of – if the sugarcane had been maintained in these places – of about 5,483. This represents a gain in direct jobs, in these areas of sugarcane retraction, of around 5,342. Job qualification, the resulting income profile etc. are not the same, but the data indicates such evolution.

In the case of sugarcane expansion, this additional 1,266,681 ha area generates a direct jobs potential of about 88,668 against the theoretical – if the previous usages had been maintained – of around 115,484. This represents a loss in direct jobs of about 26,817. Globally, with this whole picture of change in land usage, there was a net loss of 21,475 jobs.

On the other hand, studies by Federação das Indústrias do Estado de São Paulo – Fiesp (São Paulo State Federation of Industries) show that the sugar-alcohol industry sector was responsible – until April – for about 80% of the vacancies opened by the São Paulo state industry in 2008. From the 127,000 vacancies opened in the first four months, slightly over 94,000 of them were in sugarcane mills or plantations[15].

Direct taxes

In the case of areas where there was a retraction by sugarcane, and its replacement by other cultures (78,333 ha), the current land usage and coverage represent a total of about R$ 6.7 million in direct taxes, against a potential – if the sugarcane had been maintained there – of about R$ 7.8 million. This means a loss in direct tax revenue of around R$ 1.2 million.

In the case of sugarcane expansion, this additional area of 1,266,681 ha generates potential direct taxes of around R$ 127.5 million against a theoretical direct levy – had the previous usages been maintained – of around R$ 65.6 million. This represents a gain in direct taxes levy of about R$ 61.9 million. Here too, as in the case of jobs, sugarcane favors local taxes, and not their concentration in remote agricultural products processing hubs. Overall, with this scenario of change in the usage of land, there was a net gain in taxes levied of around R$ 60.7 million.

FINAL CONSIDERATIONS

The sugarcane expansion, the land usage and occupation in the São Paulo state present unprecedented dynamics[16]. The scientific, social, economic, and environmental themes linked to the expanded production of ethanol require inexistent or insufficient land information. Considering the weight of these land issues – for both Brazilian and international society – connected to the agricultural use of land, new methods and research should be driven to enlarge the actual knowledge on the space-time dynamics of agro-energy and fuel production in the São Paulo state.

This chapter, upon having dealt with this subject, introduced the example of a new agribusiness land management system, structured by Embrapa Monitoramento por Satélite (satellite monitoring) for 125 municipalities located in the Northeastern region of the São Paulo state, in partnership with several institutions, with support from Fapesp and Abag/RP (Brazilian Agribusiness Association of the Ribeirão Preto Area). From the methodological standpoint, the land management system articulated three modules: land use and coverage; agronomical, social, and economical database; and the geographic information system.

Land mapping, usage, and coverage are remarkable tools to follow land changes in agriculture, and their methods behoove improvements. The dynamics observed in the last 15 years in the Northeastern region continues to occur in the São Paulo state. Every agricultural year there are changes in the spatial division of activities, and the satellite images provide a systematic record of these realities. From the satellite images to the final cartographic product there is a whole series of data gathering and processing, both in laboratory and in the field, which requires new surveys and operational resources.

From the conceptual standpoint, technicians and researchers always keep a double denomination: land use and coverage, or land use and occupation. In practice, this poses an actual difficulty due to

[15] Available at: <http://www1.folha.uol.com.br/folha/dinheiro/ult91u402320.shtml>.

[16] CAMARGO A. M. M. P. DE; CASER D. V.; CAMARGO F. P. DE; OLIVETTE M. P. DE A.; SACHS R. C. C.; TORQUATO S. A. Dinâmica e tendência da expansão da cana-de-açúcar sobre as demais atividades agropecuárias, Estado de São Paulo, 2001-2006. **Informações Econômicas**, vol. 33, n. 3, São Paulo: IEA, 2008. Available at: <(http://www.iea.sp.gov.br/out/publicar/ieant.php)>.

farming systems' nature and dynamics. In the case of fruit production, for instance, land usage and occupation or coverage, are equivalent. In the case of sugarcane, this no longer happens. In a certain area, 1,000 ha may be covered or occupied by sugarcane; however, yearly a little less than 20% of this culture **will be reformed**, probably with yearly cultures (peanut, soy etc.). In other words, occupation is by sugarcane, but the use, in that year, will be by **yearly cultures.** Depending on the manager's objectives, cartographic data may be reclassified, getting closer to the use of the land, getting the information nearer the themes of production systems, technology levels, short-term fluctuations etc. However they may be reclassified towards the sense of land occupation, or coverage, reflecting more accurately the mid-range issues, production structures, and the higher determinants of the agribusiness.

From this standpoint, considering sugarcane alone in terms of occupation or coverage, the area in the Northeastern region of the São Paulo state in 2003 was about 51%. If the sugarcane plantation retrofit indexes are applied, this figure drops to 44%, and a considerable part of this difference may be credited to yearly cultures. New research efforts should accurately evaluate the grain production actually occurring within sugarcane areas.

In all natural resources mapping, scale creates the phenomenon. Land usage and coverage mapping in a region will not provide the same qualitative and quantitative result if a different scale is used. The 1:250,000 scale has offered São Paulo state agribusiness managers an adequate compromise in terms of cost/benefit, between accuracy and the required speed in obtaining results for regional studies of this nature. However more and newer research studies may also deepen this dimension.

Finally, among the issues connected to sugarcane territory expansion, several questions trouble public policy makers, and various segments of our society await answers from research:

- What are the key changes in land use and occupation by water basins and governmental districts caused by sugarcane in the São Paulo state?
- What are the regions and towns in the São Paulo state that were most affected by the current sugarcane area expansion dynamics?
- What are the indirect impacts of this land occupation dynamics, and in the use of land in other regions in the São Paulo state that are unsuited for sugarcane?
- To what extent does sugarcane expansion compete with food production, and if so in what dimension, and in which towns and regions?
- What are the regions in the São Paulo state where sugarcane expansion competes with citrus cultures and energy forests?
- In which regions does sugarcane spacial dynamics lead to a reduction in the number of cattle?
- What has been the connection between reduced grazing lands and cattle head count?
- Does sugarcane expansion cause deforestation, thus compromising the preservation of natural vegetation, or does it favor – by exclusive mechanization of flat areas – the recovery of permanent preservation areas?
- What are the water basins most affected by sugarcane expansion, and what are the likely positive and negative impacts on water resources?
- What gains and threats do sugarcane expansion presents to the Guarani aquifer?
- What are the regions where sugarcane burning has had seen the greatest increase, decrease, or remained stable?
- To what extent can city and state laws favor or restrict agricultural land usage by sugarcane?

7

EVOLUTION OF THE SUGARCANE INDUSTRY IN THE SÃO PAULO STATE

Luiz Carlos Corrêa de Carvalho

INTRODUCTION

The evolution of the sugarcane fields in the São Paulo State in the 2000s shows an annual growth of 10.3% in products volume over the last eight years, demonstrating a significant investment in this industry. As far as products are concerned, sugar had a yearly growth of 10.3%, the same rate as ethanol! This was not by mere coincidence, as this analysis will show. Among the ethanol products, the anhydrous (which is a gasoline additive) grew 4.2% per year, and the hydrated (car fuel) increased 16% per year. This difference in growth is directly related to the breakthrough caused by the launch of flex-fuel (ethanol/gasoline) cars, in view of the impressive acceptance of this product in the Brazilian market. Between 2005 and 2008, forty new plants focusing on the production of hydrated ethanol were installed in the São Paulo state. The sugarcane products mix in this state varied around 50% throughout this period, exceptions made to 2007 (47%) and 2008 (42%). The figures show a trend toward increasing ethanol in the mix. However, it is something to be observed in the next São Paulo state harvest seasons, with a potential period (over the next two years) of higher prices for sugar and, very likely, a new reversion toward ethanol. This will happen until the time when it becomes a global commodity, eliminating these sugar-ethanol shifts.

This reality opens an important outlook for analysis and R&D to be done in the socio-economic and agro-industrial fields, always from the stance of sustainability and added value. The greenfields expansion has been showing internal return rates from such projects in São Paulo between 13% and 15%, depending on internal competitiveness (productivity/costs) of the projects, their technology, handling and logistics.

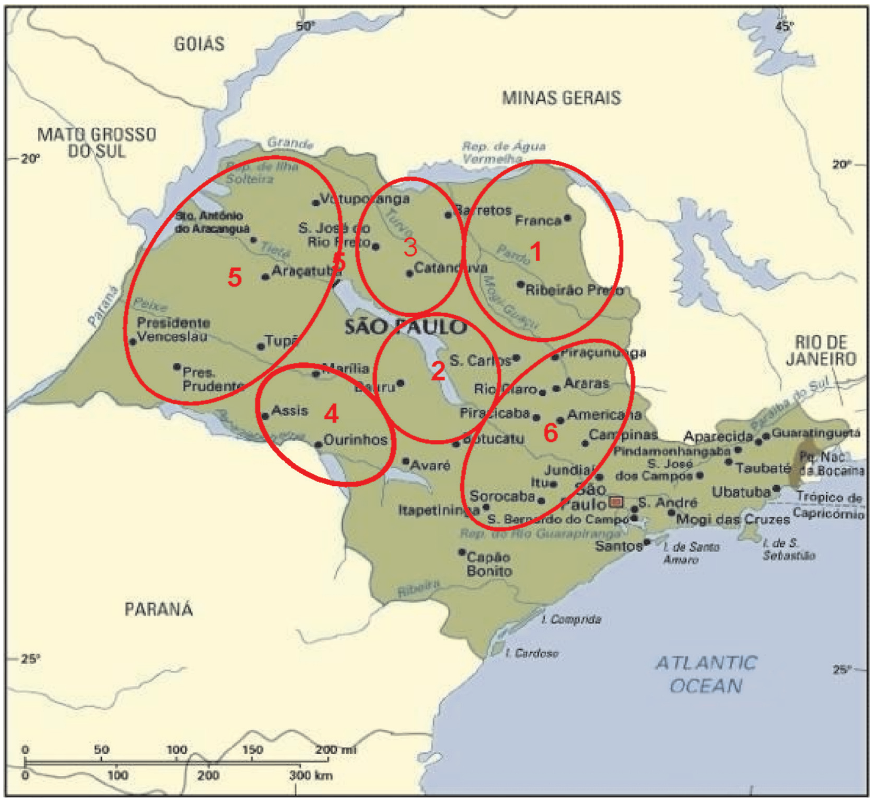
The effect on the whole industry production chain displays investments and expansions before the agro-industrial production, in the fuel distribution, in the co-generation of electric power and in the automotive chain.

THE SÃO PAULO STATE SUGARCANE FIELDS (PLANTATIONS WOULD BE BETTER)

The São Paulo state, responsible for 69% of the sugarcane milling in the Center-South Region, was divided in six large areas, as shown on Figure 1.

To show the evolution of the São Paulo state sugarcane fields, an attempt was made to use the TRS (Total Recoverable Sugars) index, which represents the end products placed in domestic and foreign markets, as shown on Table 1 below.

The two columns on Table 1 show the fantastic growth of the sugarcane fields and their products in the new expansion area in the Western São Paulo state (Araçatuba) area which, in a seven-year period grew its weight in São Paulo by 6%; on the other hand, the traditional regions of Piracicaba, Ribeirão Preto and Jaú lost their relative weight; Assis remained stable; and only Catanduva grew, in an impressive way.



Areas
1) Ribeirão Preto
2) Jaú
3) Catanduva
4) Assis
5) Araçatuba
6) Piracicaba

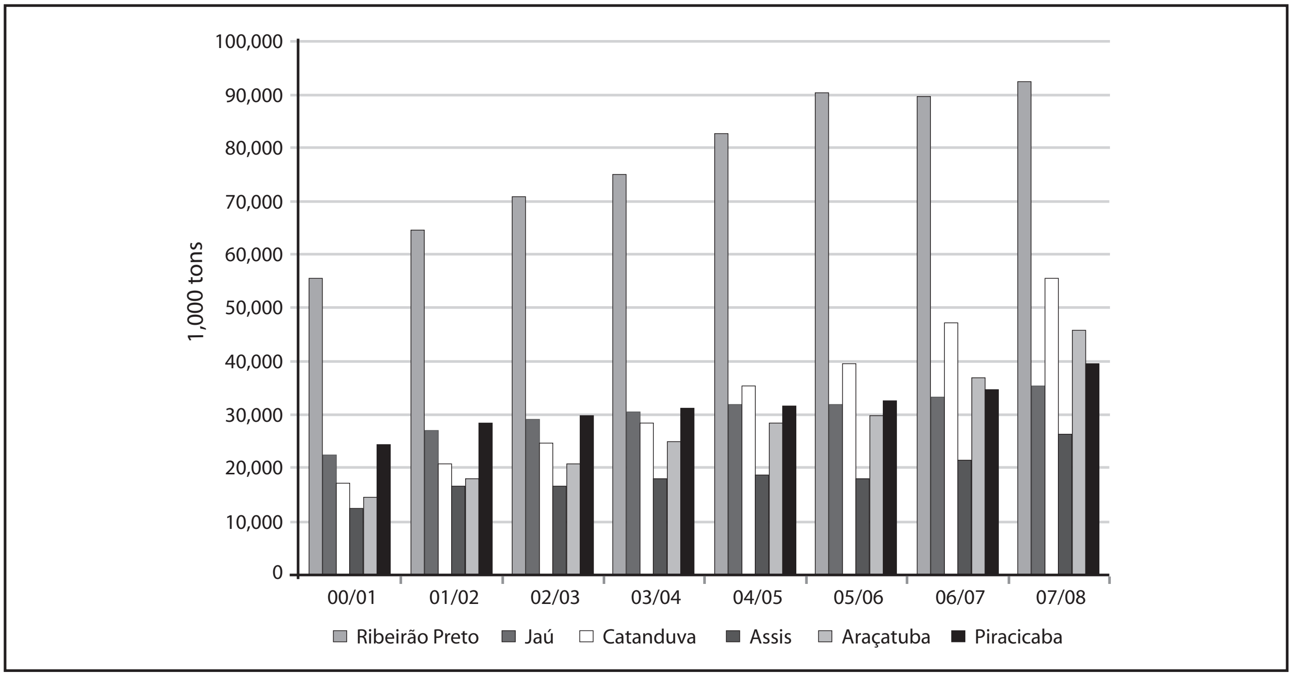
FIGURE 1 Regions from São Paulo State used in the present analysis.

TABLE 1 Growth in the great areas defined in the São Paulo state – TRS*.

Areas	Annual growth rate (2000/2001 – 2007/2008)	Weight in the total TRSs offered (%)	
	(%) – ATR	2007/2008	2000/2001
Assis	10.87	8.62	8.31
Araçatuba	18.19	15.39	9.49
Catanduva	17.52	18.93	12.14
Jaú	6.83	12.27	15.34
Piracicaba	7.19	12.87	15.71
Ribeirão Preto	7.17	31.91	39.01
São Paulo	10.29	100.0	100.0

* TRS – Total Recoverable Sugars.

Source: Producers database – production; Unica; compilation Canaplan.



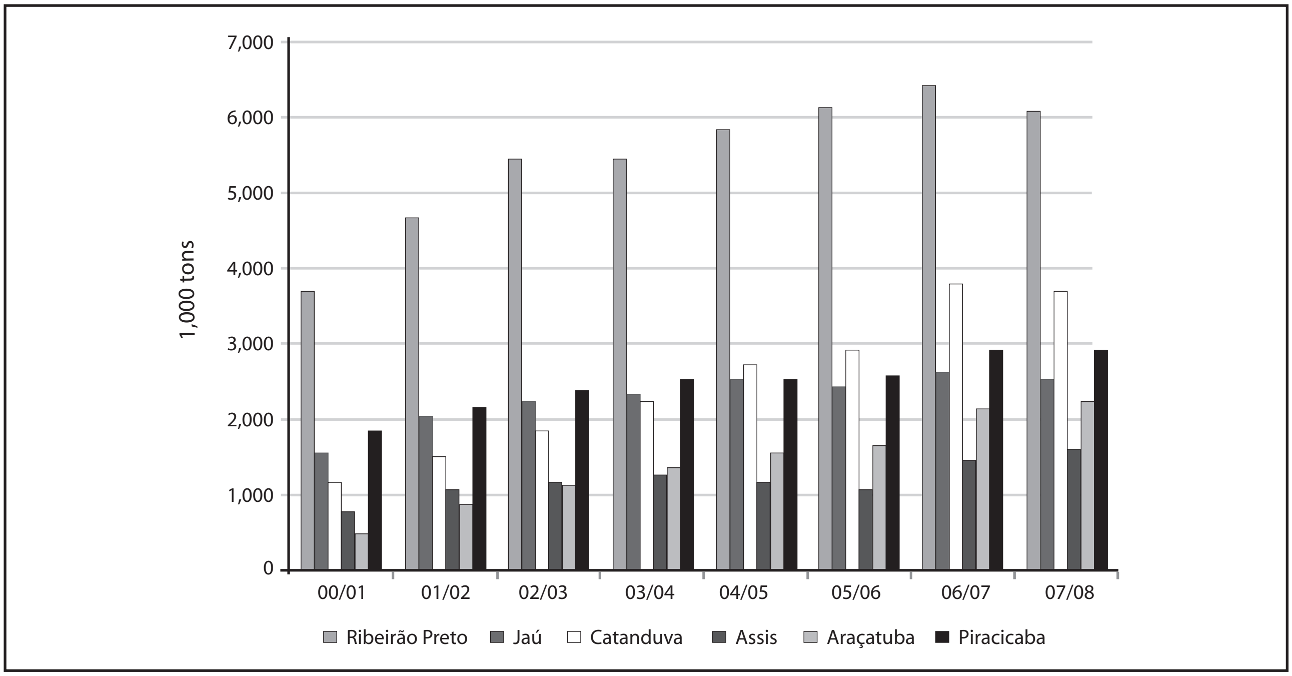
Source: Producers database – productions; Unica; compilation Canaplan.

GRAPH 1 São Paulo: sugarcane production per region.

TABLE 2 Evolution of offer of sugarcane products – São Paulo state.

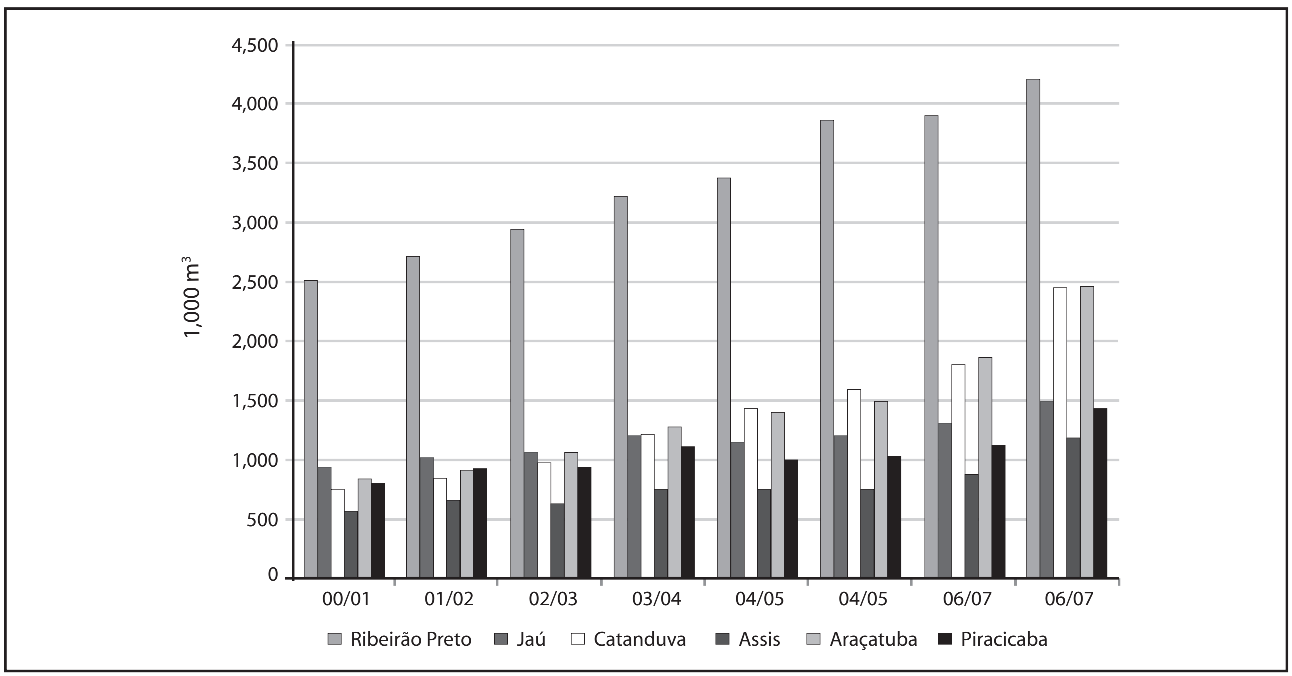
Areas/Harvest	Sugar (million metric tons)			Ethanol (billion liters)					
				Anhydrous			Hydrated		
	2000/2001	2007/2008	Annual rate (%)	2000/2001	2007/2008	Annual rate (%)	2000/2001	2007/2008	Annual rate (%)
Assis	0.79	1.68	11.38	0.60	0.70	2.23	0.39	1.29	18.64
Araçatuba	0.55	2.35	23.05	0.77	1.34	8.24	0.72	2.87	21.84
Catanduva	1.26	3.88	17.43	0.61	1.33	11.78	0.74	2.85	21.24
Jaú	1.64	2.66	7.15	1.03	0.97	(0.85)	0.62	1.60	14.50
Piracicaba	1.95	3.01	6.40	0.92	1.03	1.63	0.51	1.44	15.98
Ribeirão Preto	3.87	6.37	7.38	2.49	3.22	3.74	2.01	4.00	10.33
São Paulo	**10.06**	**19.95**	**10.27**	**6.43**	**8.59**	**4.22**	**4.98**	**14.05**	**15.97**

Areas/Harvest	Ethanol (billion liters)		
	2000/01	2007/08	Annual rate (%)
Assis	1.00	1.99	10.33
Araçatuba	1.49	4.21	16.00
Catanduva	1.35	4.19	17.56
Jaú	1.66	2.57	6.44
Piracicaba	1.43	2.47	8.12
Ribeirão Preto	4.50	7.22	6.99
São Paulo	**11.41**	**22.65**	**10.29**



Source: Producers database – productions; Unica; compilation Canaplan.

GRAPH 2 São Paulo: sugar production per area.



Source: Producers database – productions; Unica; compilation Canaplan.

GRAPH 3 São Paulo: alcohol production per area.

On every new harvest since 2000, it is possible to see the actual growth of each of the featured areas, as shown on Graph 1.

It is interesting to notice the logic in the growth of sugarcane products in the state, the relevant differences being shown on Table 2.

A few interesting facts may be observed from Table 2 about the options for products growth among the various areas in the São Paulo state. While the traditional sugar areas of Ribeirão Preto, Jaú and Piracicaba grew around 7% per year in sugar and ethanol, the Araçatuba and Catanduva areas showed considerably higher rates. In the early 2000s, Araçatuba had a small sugar production that increased more than four times, the ethanol offer increasing threefold; Catanduva, on its turn, increased both products threefold.

The sugar and ethanol offers are shown on Graphs 2 and 3.

The weight of the Araçatuba area in the ethanol offer is evidenced in this recent evolution of the São Paulo state.

Basically the increased products offer in the industry was accomplished by expanding the existing units. In most cases, growth took place in two stages, as it may be observed:

- Until 2003/2004 with the crises that resulted from ethanol-only fueled cars, when investments were focused on sugar and anhydrous ethanol.
- After 2004, shift to hydrated ethanol, mostly from the reality of flex-fuel cars and their amazing growth.

It was precisely from the new reality of the domestic market growth for hydrated ethanol, as well as the outlook for sugar and the potential represented by the growing international market for ethanol, added to the worldwide priority to fight global warming and the beginning of the astounding rise in oil prices, that new investments in sugarcane began to take place at considerable speed.

TABLE 3 Evolution of greenfields in the São Paulo state – 2005 to 2008.

Year	Number of units
2005	03
2006	13
2007	11
2008	13
Total	40

Source: Database – UDOP; compilation Canaplan.

The quantity of new units (greenfields) implemented in the São Paulo state from 2004 on is shown on Table 3.

It is interesting to note that – differently from what some might imagine – there were also investment only for sugar, sugar and ethanol and, as a majority, only for the production of ethanol, many of them also aiming at selling surplus electricity. In the recently closed 2008/2009 harvest season, 13 new units began the harvest milling 8.72 million tons of sugarcane, 368,000 metric tons of sugar, and 533 million liters of ethanol (76% for hydrated).

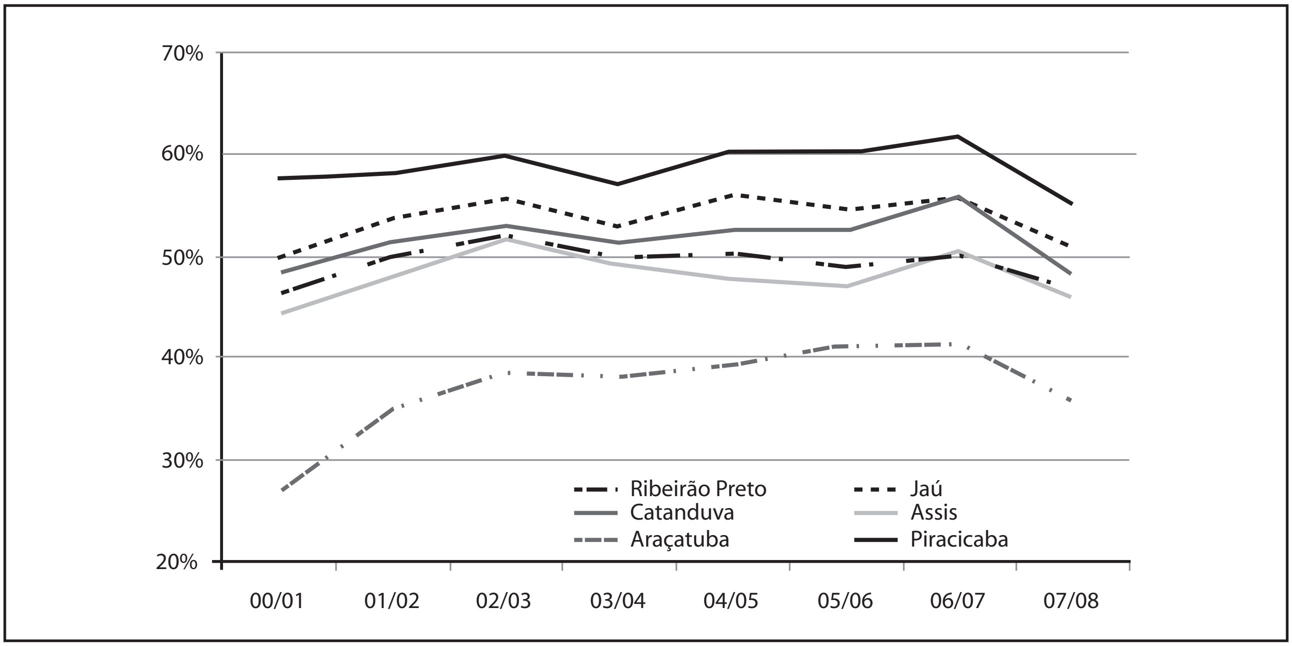
Examining the mix (different products obtained for each ton of sugarcane processed), it is noticeable that for the period under study (harvest seasons 2000/2001 through 2007/2008) in São Paulo began and ended with 46.9% for sugar. The maximum for sugar was 52.2%, as well as there is a clearly visible drop in the offer of anhydrous ethanol (from 29.94% to 20.17%) and the increase in hydrated ethanol (from 23.21% to 32.99%) in São Paulo. Nevertheless, the mix for alcohol went from 53.15% to 53.16%!

This simple analysis allows us to observe that, among the states in the Center-South Region, São Paulo keeps, in fact, a "sugar" pattern. Even so, it is known that the 2008/2009 harvest season showed 61% for alcohol in the mix, after two years with ethanol prices better than those for sugar, as shown on Graph 4.

On Graph 4, it may be observed that – except in the new Araçatuba sugarcane expansion area – the other areas use, in average, above 50% of milled sugarcane to produce sugar.

TRENDS IN PRODUCTION EXPANSION IN SÃO PAULO, PRODUCTS, TECHNOLOGY AND PRODUCTION SCALE

Overall, the stages of the sugarcane agroindustry in São Paulo, since the Proalcool (1970s) are initial investment in ethanol, followed by the implementation of a sugar plant, and later, the co-generation of electric power. In the late 1990s, plummeting hydrated ethanol sales led to sugar; with the increased sales of flex-fuel cars and better



Source: Producers database – productions; Unica; compilation Canaplan.

GRAPH 4 São Paulo: sugar mix per area.

prices for hydrated ethanol, the expansion toward ethanol and electric power took place. It is worth noting that there were investments focused on exporting ethanol.

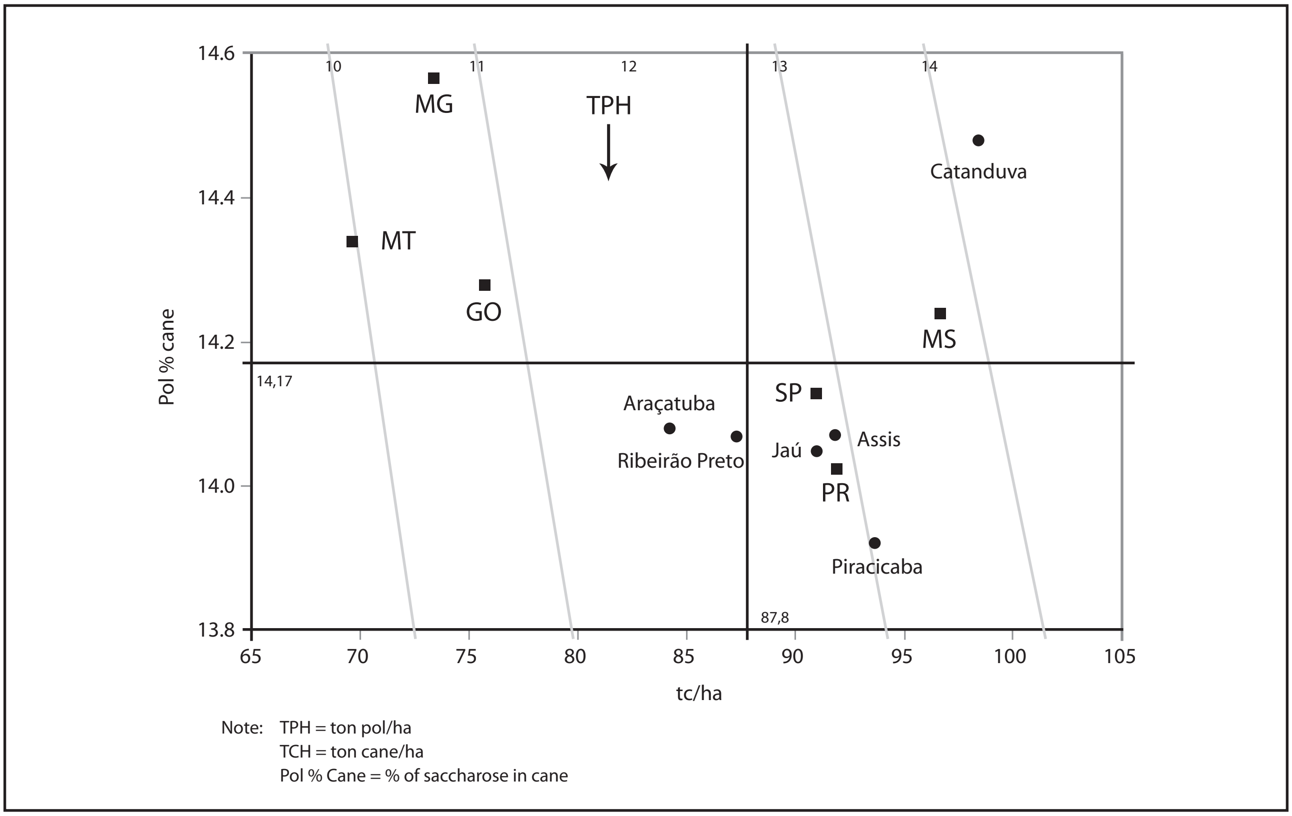
The continued positive growth of the Brazilian GNP began to raise some clear concern over a potential electric power crisis, due to the scarce investments to increase the offer to face the demand growth. The possibilities of expanding electric power supply by means of co-generation in the sugarcane industry became part of the governmental program for this purpose: Proinfa. The expansion of sugarcane fields in São Paulo would allow, in addition to ethanol, a considerable increase in the offer of electric power during the dry season, supplementing hydroelectric power. The fact is that, based on the success of increasing the sugarcane offer, its products became the second most important source of primary energy, after oil products.

The analysis of the facts and the reality of improved infrastructure and logistics conditions in São Paulo state ports – both for sugar and ethanol – will take producers, as a trend, to seek plant flexibility and, in future development, to diversify and add value to the products and sub-products of the sugarcane industry.

A few areas in the state are still capable of further expansion of sugarcane fields. These areas, mostly in the West of São Paulo state and located between the Tietê and Paranapanema rivers, show this capability. Likewise for the mentioned areas, other areas should also display a likely clustering effect, with acquisitions and mergers, seeking a larger agro-industrial scale. As a trend, this has already been taking place, and may occur significantly faster in the next five years, post-crisis.

From the technological standpoint, the São Paulo state displays relevant variation in productivity, due to soil and climate diversity, resulting in different productive potentials, for which managerial efficiency and the use of proper technology will be essential.

In the 2008/2009 harvest, the final productivity results measured in TPH (metric tons of saccharose per hectare), dedicated to the production of sugar and ethanol, show the Greater Catanduva area as the most productive, followed by Piracicaba, Assis, Jaú, Ribeirão Preto and Araçatuba. The Mato Grosso do Sul state stands between the



Source: Canaplan.

GRAPH 5 Productivity x cane quality – harvest 2008/09 – Central-South – until December.

TABLE 4 Agricultural productivity – t/ha – São Paulo and Center/South Region (up to Dec. 2008).

Areas	1st cut		Ratoons					Average	Average number of cuts (index)
	Year/ Winter	Year and a half	2nd cut	3rd cut	4th cut	5th cut	Others		
North (Ribeirão Preto)	96.9	113.7	95.4	84.6	75.6	71.4	75.2	87.3	3.32
Central (Jaú)	101.1	126.9	100.7	83.1	79.5	67.9	80.5	91.0	3.44
Northwest (Catanduva)	116.8	126.5	103.5	90.1	77.6	69.7	78.4	98.4	2.86
Southwest (Assis)	97.0	122.4	100.1	90.4	75.8	74.1	73.7	91.8	3.35
West (Araçatuba)	102.4	106.4	90.5	77.4	67.5	64.0	70.8	84.2	3.13
Southeast (Piracicaba)	103.6	131.5	101.7	88.1	79.2	73.0	77.9	93.7	3.21
São Paulo	102.4	120.1	98.6	85.6	76.2	70.0	76.0	90.9	3.18
Center-South	101.5	115.9	94.7	82.7	74.4	68.0	73.0	87.8	3.20

Source: Canaplan.

TABLE 5 Pol (%) cane – PC – 2008/2009 harvest.

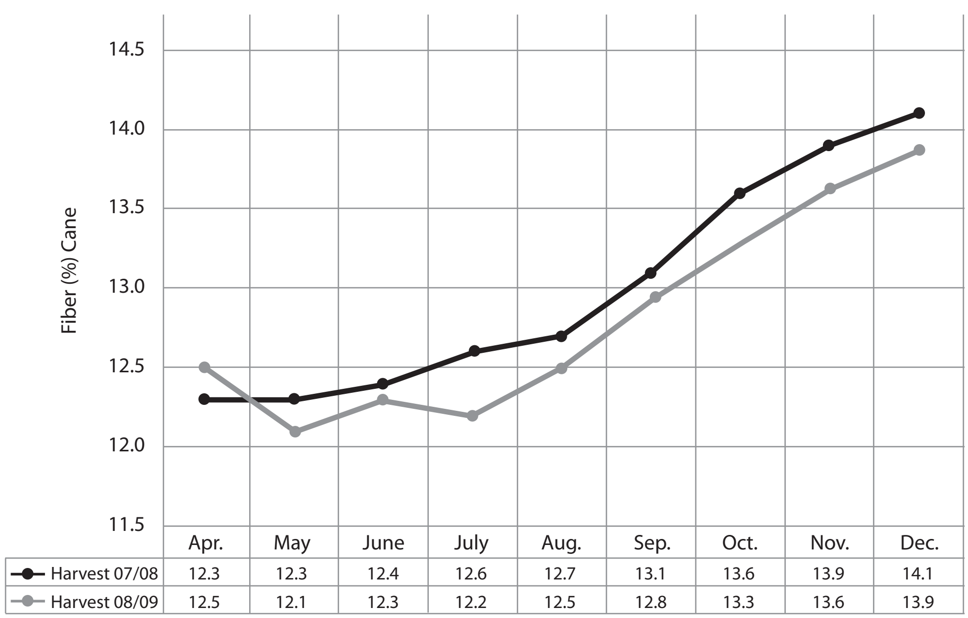
Areas	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Acc.
North (Ribeirão Preto)	–	10.64	11.59	12.87	14.47	15.09	15.87	15.38	14.06	13.38	14.07
Central (Jaú)	–	11.62	12.14	12.98	14.12	14.95	15.55	15.21	14.34	13.94	14.05
Northwest (Catanduva)	–	11.50	12.26	13.34	14.55	15.26	16.04	15.64	14.59	14.08	14.48
Southwest (Assis)	–	12.58	12.72	13.31	14.01	14.41	15.07	15.33	13.89	–	14.07
West (Araçatuba)	11.54	11.20	12.36	12.85	14.18	15.01	15.59	15.36	14.33	13.60	14.08
Southeast (Piracicaba)	–	11.60	12.66	12.99	13.94	14.53	15.07	14.77	14.13	13.55	13.92
São Paulo	11.54	11.36	12.15	13.03	14.28	14.97	15.65	15.31	14.28	13.72	14.13
Center-South	11.46	11.42	12.19	13.09	14.32	15.06	15.71	15.31	14.18	13.51	14.17

Source: Canaplan.

TABLE 6 TSR – 2008/2009 harvest (December 2008).

Areas	TSR (kg/ton sugarcane)
North (Ribeirão Preto)	138.9
Central (Jaú)	138.9
Northwest (Catanduva)	143.3
Southwest (Assis)	139.3
West (Araçatuba)	139.5
Southeast (Piracicaba)	137.4
São Paulo	139.7

Source: Canaplan.



Source: Canaplan.

GRAPH 6 Fiber (%) sugarcane – harvest 07/08 x 08/09.

first two, while the Paraná state is between Assis and Jaú, as shown on Graph 5.

Upon separating the agricultural productivity aspect, some areas become noticeable for their results below the São Paulo state average, in this case partially explained by a meteorological event in the year (Ribeirão Preto) and, in the case of Araçatuba, by actually higher water deficits in some months of the year, as shown on Table 4.

Considering the raw material quality, measured by pol % cane (saccharose), most areas are below the São Paulo state average, due to the outstanding performance of the Catanduva area:

However, considering industrial efficiency, TSR (total sugars recovered) results are lower than in the preceding years for each area in the state, for the 2008/2009 harvest in December 2008, as shown on Table 6.

Another relevant measurement (fiber % cane) also reflects regional differences, and will be an important source of energy, either as electricity or raw material (bagasse and trash) for producing cellulose ethanol.

FINAL CONSIDERATIONS

Sugarcane fields development in the São Paulo state, in view of productivity and logistic issues, tends to seek, among other aspects, scale, diversity and added value. If the industrial flexibility logic came to be for reasons including even the unbalanced growth of market opportunities and their price volatility cycles shifting between sugar and ethanol, the new order of competitiveness calls for focus, investments in technology and a vision of the agro-industry as a bio-refinery.

If the internal return on investment in standard ethanol and electric power projects is around 13-15% in the São Paulo state, only added value and agro-industrial efficiency will be able to improve this financial return.

The most relevant issues involve the search for more productive kinds of sugarcane, either for sugar or for power, resistant or tolerant to the major diseases and pests and responsive to drought and irrigation.

On the other hand, the planting mechanization process will tend to follow the one in harvesting, with precision agriculture, and using not only the stalks, but the tips and trash as well.

Biorefineries will be the delivery point of high agricultural yield, focusing on biotechnology and chemistry, adding value to the business.

The effect of these sugarcane fields on the local society and environment, under the logic of the production chain as a whole, should be measured more accurately. Certification of the products achieved will benefit exporters.

Carbon credits will be more valuable, as well as a source of funds and industry awards.

Efforts in R&D should be backed by essential investments in communication and industry image, in addition to pilot plants and fields for demonstrating new technology.

Major efforts in R&D would be:

a. High-yield varieties intended mostly for producing sugar and ethanol, but also for electricity or cellulose ethanol. Such effort shall encompass not only traditional breeds, but also GMOs, both for resistance/tolerance and for irrigation.
b. Efforts concentrated on natural enemies for pest control and biomass-originated herbicides.
c. Technically improved irrigation.
d. Planting and harvesting mechanization, exploiting all the biomass from the sugarcane.
e. Large-scale and lower-cost efficient transportation.
f. Biorefineries with value-adding processes, both in biotechnology and chemistry, including the conversion of carbohydrates into green hydrocarbons, and the use of by-products.
g. Intelligent investments in logistics and port infrastructure.

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8

THE ROLE OF THE STATE OF SÃO PAULO RESEARCH CENTERS ON BIOENERGY TECHNOLOGICAL INOVATION

Orlando Melo de Castro

INTRODUCTION

Generation and transference of scientific knowledge are strategic elements for a sustainable development of agribusiness in the state of São Paulo. State government invests money through agencies such as Apta – Agência Paulista de Tecnologia do Agronegócio – São Paulo Agribusiness Technology Agency, in order to amplify the competitive leadership of our state.

São Paulo is leader on bioenergy production in Brazil, and most of industries aiming bioenergy production are settled in the state. It is responsible for more than 60% of Brazilian ethanol production and represents around 30% of the state energetic matrix. In addition:

- São Paulo is responsible for 1/3 of Brazilian agribusiness and for almost 30% of exportations. Foreign sales of agribusiness products have reached a total of US$ 14.47 billions dollars in the year of 2008 (DIÁRIO OFICIAL, 2008).
- Farming and cattle raising production of São Paulo state in 2008 was nearly R$ 37.7 billions, which corresponds to an increase up to 11.6% in comparison with 2007, already discounting inflation (IEA, 2009).
- São Paulo's agriculture bears the greatest yield indexes: 2.3 fold the national average.
- Most part of the technological development on bioenergetic area takes place in public and private institutions of the state.
- Formal training in undergraduation and graduation courses in agro sciences in this state reaches the highest national levels.
- Each R$ 1.00 invested in agriculture and cattle research returns between R$ 10.00 and R$ 15.00 in values of the agricultural production, in the period from 1960 to 2000.
- Bioenergy contributes for the improvement of São Paulo environment. State environmental legislation concerning to the bioenergetic issue is the most modern and efficient among all Brazilian states.
- Agribusiness and familiar agriculture, on their economic, social and environmental dimensions, go on together in São Paulo, generating incomes and employments as well as promoting a regional development.

São Paulo's public policies aim to attend, through diffusion and popularization of science, the insertion of poor populations and also the increase of agriculture yield, as well as keeping State's leadership in the main productive chains of agribusiness. Policy for science, technology and innovation adopted by Apta are consonant with the public policies from São Paulo's Department of Agriculture and Food Supply.

Regional development is considered determinant for the enlargement of the State's economy. Thus, Apta is participant of the importance that science and technology represent nowadays in the process of regional development. Science and generation of technology are considered by Apta as social inclusion factors and, consequently, extension activities of knowledge and spread of new technologies are also considered major aims.

Capacity-building is another prior issue to Apta. It is intended, through the capacitance of agents, to collaborate with the generation of incomes and rural employment; gather value to products; collaborate with the adoption of new technologies and also help on the divulgation of the institutional mission for the society.

A new concept was recently introduced in São Paulo's public policies for the agricultural sector. Add to the generation of incomes, employment and social inclusion, certified quality or traceability is currently essential for the attendance of external market and also to ensure better life quality.

New opportunities and challenges are raised every day. The production of bioenergy and highly-productive biomass respecting the bases of sustainability, added to the avoidance of competition with food production, as well as preserving environments and forest areas, in a way that it is possible to generate jobs, incomes, social inclusion and regional development are major aims to be accomplished by Apta in the following years.

APTA'S INSTITUTIONAL MISSION

Apta's mission is "To generate, adapt and transfer scientific and technological knowledge for agribusiness, aiming for the social-economic development and environmental balance".

This mission is performed by the Research Institutes belonging to the Department of Agriculture and Food Supply in the State of São Paulo. Apta composing units are: Instituto Agronômico – IAC, head office in Campinas; Instituto Bilógico – IB, Instituto de Economia Agrícola – IEA and Instituto de Pesca – IP, all established in São Paulo; Instituto de Zootecnia – IZ located in Nova Odessa; Instituto de Tecnologia de Alimentos – Ital, seat in Campinas and also 15 Regional Poles of Technological Development, which action areas comprises several regions of the state. In addition to the head offices, which are also experimental farms, poles encompass other Research and Development Units, in a total of 34 Research Units (Experimental stations).

Regional poles reinforce Apta its strategically-distributed structure throughout the state, counting with scientific researchers in regions of agronomic frontier and/or close to productive chains which they are integrated in. Add to the programmatic action of Research Institutes (IAC, IEA, ITAL, IZ, IP e IB), the structure found in the Regional Poles confers strategic and competitive advantages ahead other Research Institutes in the State.

Generation of knowledge and technology is concerned to the adding of all actions, procedures and achievements used in a systematic way, linked to the basic knowledge or to applied science.

Transference of know-how and technology consists of actions that aim the dissemination and adoption of technologies. Traditionally, Research Institutes make public their research works in scientific and technical reports. Apta has many well-known scientific periodic magazines, which are under responsibility of the Institutes such as: Revista Bragantia, o Agronômico, Informações Econômicas, O Biológico, Boletim de Indústria Animal, Boletim do Instituto de Pesca and *Brazilian Journal of Food Technology*.

Other major actions for spreading technology is the organization of events, such as Field days, technical seminaries, among others, Apta also plays a role in capacitating people, through graduate courses (MSc at IAC, IP, IB & IZ and Ph.D at IAC), as well as organizing annually many short or long courses and trainings.

In the process of transference of knowledge, it is also relevant the production of strategic goods and specialized services that comprises goods and services derived from knowledge generated during the research process.

APTA AND THE RESEARCH, DEVELOPMENT AND INNOVATION STRATEGIC PROGRAMS

Apta joins government actions (public policies) with institutional goals. Within this perspective, it was defined for the Pluri-annual Plan, which is the government's instrument to the budget management and financial liberation, five great Strategic Programs for the period of 2008-2011. Programs were conceived aiming to orientate

RD&D for themes considered as priority in the present and future agricultural research scenario. This organization propitiates management mechanisms that facilitate programmatic actions of the Agency. Moreover, it is expected to create a more competitive environment in the sense of broadening the capacity of capturing resources and straitening Apta's relations with strategic partnerships.

Different productive chains are inserted in one or more strategic programs, e.g., research projects of sugarcane productive chain may be inserted in bioenergy programs, products and process strategic for agribusiness or even environmental sustainability.

Strategic programs defined for Apta are:

1. bioenergy;
2. environmental sustainability;
3. organization of rural and peri-urban areas;
4. food safety;
5. products and processes strategic for agribusiness.

To attend the strategic programs, Apta counts on with state budget resources, complemented with incentives from state, national and international founding agencies and also from private initiative. It also keeps scientific collaboration with other institutes, universities, private initiative, and agriculturalists, among others.

Apta counts within its dependency of around 20.000 ha of useful area belonging to the Research Institutes, encompassed among poles and some specialized centers under the supervision of the Research Institutes located in Campinas, Jundiaí, Cordeirópolis, Nova Odessa, Ribeirão Preto, Sertãozinho, among others. The sum of all these research units confers Apta its great capillarity in the State and the possibility to execute projects in an experimental network, in which one sole experiment may simultaneously be performed in different edapho-climatic conditions. These aspects consist in incomparable advantages to agronomic research.

Apta Institutes are organized in Research Centers. There are 35 Research Centers, comprised through 6 Institutes. These centers may be thematic or product-specialized, generating and developing most part of the agronomic research of the Institution and, many times, they coordinate or participate in the research performed in the Regional Poles.

Apta counts on its staff board with 2,491 employees, among researchers, administrative assistants or research support assistants, as shown in Table 1.

Scientific qualification of Apta research team is considered high. Around 42% of the technical board has already reached academic titles such as PhD or post-doctoral positions. Table 2 shows the percent distribution regarding the academic titles of Apta research team.

TABLE 1 Apta staff board.

Institute	Number or researchers	Number of assistant employees	Total
IAC	203	361	564
IB	126	116	242
IP	72	94	166
IEA	73	69	142
ITAL	96	108	204
IZ	60	166	226
Regional poles	213	734	947
Total	**843**	**1,648**	**2,491**

TABLE 2 Percent distribution of Apta's research team academic titles.

Researchers	%
PhD and post-doctorates	42
MSc	40
BSc	18
Total	**100**

Major aspects that characterize Apta are:

- Solid Institutes, reference in the history of national agronomic research.
- Well-distributed infrastructure within the state of São Paulo, that enables the assistance of regional demands and the formation of research networks, good capillarity.
- Technical board highly qualified.
- Diversified agenda of RD&I and multidisciplinary.

Some issues either limit or impair many RD&I actions in the Apta ambit and consist, therefore, in aspects to have efforts concentrated on them within the following years:

- Budget and financial resources are not always sufficient.
- Need for modernization of the infrastructure.
- Motivation, training and professional updating for technical and support board.
- Replacement of the support and administrative staff board, modernization and creation of new careers, e.g., professionals in the area of communication, informatics, administrative management, among others.
- New juridical model that ensures more administrative autonomy and self-management of the technological and physical patrimony.

Efforts must be made in order to broaden competence in research, development and innovation; also in the modernization of management, potentialization of opportunities for resources acquisition, improvement of the relationship with the productive sector and finally in transferring technology to the productive sector.

APTA AND BIOENERGY

Within the macro program bioenergy, Apta intends to found, generate research and suggest state actions for the various aspects of bioenergy, comprehending scientific and technological studies, in the areas of plant yield, biomass and residues application and even aspects concerning environmental, social and economic impacts.

Current portfolio in bioenergy projects is composed of 90 research projects comprising the following areas:

- Phytotechny, new cultivars, value aggregation, evaluation and use of wastes in oilseed plants.
- Phytotechny, new cultivars, value aggregation, evaluation and use of wastes in starch plants (manioc for ethanol).
- Phytotechny, new cultivars, value aggregation, evaluation and use of wastes in sugarcane for ethanol.
- Biofuels and agricultural engines functioning.
- Economic evaluations, production costs, competitiveness, food safety.

TABLE 3 Number of researchers directly involved in bioenergy studies and Apta units where they develop research.

Units	Number of researchers
IAC – Centro de cana-de-açúcar – Sugarcane Center	16
IAC – Centro de ecofisiologia – Ecophysiology Center	4
IAC – Centro de solos – Soils Center	3
IAC – Centro de irrigação e drenagem – Irrigation and Drainage Center	2
Polo – Piracicaba	4
Polo – Jaú	5
Polo – Votuporanga	2
Polo – Colina	4
Polo – Ribeirão Preto	5
ITAL	13
Instituto biológico – Biological Institute	7
Total	**65**

TABLE 4 Number of researchers directly involved in bioenergy studies and their major area of actuation.

Areas of actuation	# of researchers
Value aggregation and food engineer	9
Biochemistry, ecophysiology and plant physiology	5
Biotechnology and molecular biology	3
Climatology	1
Biological control of pests	2
Biological control of diseases	3
Pests and diseases control – Phytossanity	6
Conservation, conservationist practices, direct planting	3
Production costs	1
Phytotechny and plant yield	8
Irrigation and drainage	2
Weed management	2
Genetic breeding	6
Plant mineral nutrition and soil fertility	5
Agro environmental planning	1
Wastes, sustainability and environmental issues	4
Zootecny – animal nutrition with biomass production wastes	4
Total	**65**

Research on the bioenergetic area is performed by several Apta units and involves hitherto 65 researchers.

Apta develops research in genetic breeding and phytotechny for biomass yield aiming energy production within the following productive chains: sugarcane, manioc and other starch plants, peanut, soybean, castor oil plant and physic nut.

IAC leads one of the three sugarcane breeding programs in Brazil, performing activities in eleven Brazilian states, yet Mexico, Angola and other South American countries. This fact has allowed high adaptability of IAC's sugarcane cultivars to different edapho-climatic conditions.

Tables 3 and 4 relate the researches directly involved with the bioenergetic issue, Apta units where they can be found and main topics discussed.

EXAMPLES OF PROJETS – BIOENERGY APTA

IAC sugarcane program

The Agronomic Institute (Instituto Agronômico, IAC) initiated sugarcane research in 1892, with the Austrian scientist Franz Wilhelm Dafert, who was hired to establish an Imperial Station in 1887, with an essay of 42 noble cane cultivars in two cultivation conditions. In the 1920´s, a mosaic virus crisis stimulated the creation of genetic breeding programs through the introduction of imported cultivars and their adaptation to the environment. Thus, IAC genetic breeding program started in 1933 along with the creation of the former Seção de Cana-de-açúcar (Sugarcane Section), motivated by the mosaic virus crisis. In the following decades, IAC has developed many researches on phytotechny, which lead to the use of fertilizers, spacing and candidate cultivars to be adopted for São Paulo conditions.

However, from 1970 to 1990, its action was drastically reduced by being considered not essential for the state, since Copersucar program activities were just beginning (current CTC and former Planalsucar). In the year of 1992 IAC Sugarcane Program was reestablished, and in 2005 IAC Sugarcane Center was created, settled in the city of Ribeirão Preto, São Paulo state. Main research line of this center is genetic breeding, aiming for the development of sugarcane cultivars adapted to different environments. IAC Sugarcane Program is virtually managed by a configured network, involving a multidisciplinary research among many Research Centers and State Universities. In the last 10 years, IAC Sugarcane Program has released 17 cultivars develop under the concepts of regional selection exploitation of the particularities of the different production environments mainly within the state of São Paulo.

Add to the release of new cultivars, IAC has provided important advances in phytotechny. As an example, the qualification of production environments, a concept widely used by breeding program in which the parameters developed by IAC, are currently adopted either by other research groups or producers. Project Ambicana aims the characterization of production environments using pedology and phytotechny criteria, as well as promoting the socialization of such knowledge, capacitating specialists through training for this aim. Benefit of the project reaches over one million of hectare of Brazil's Center-South region.

This way, pest and nematode management is deeply based on research developed by IAC, which lead to the setting of an integrated management program of some of the most important pests in the Center-South region of the country. Currently, research on such area is focused on the management of sugarcane borer *Diatraea saccharallis* and the beetle *Sphenophorus levis*, which have been shown significant increases in both populations, mainly in sugarcane expansion areas.

IAC also coordinates the Sugarcane Fertilizer and Nutrition Group, responsible for many research works lately, aiming to define a new calibration for crop's nutritional management.

Within the biotechnology area, IAC Sugarcane Center develops research on germplasm characterization for parental selection, genetic mapping, gene expression and genetic transformation of sugarcane. Additionally, the Center also offers a diagnostic analysis of ratoon stunting disease and varietal fingerprinting. Moreover, the center counts with *in vitro* propagation of IAC cultivars.

At present, IAC Sugarcane Center coordinates the organization of a public germplasm collection which will gather efforts from many research institutions (Unicamp, USP and Unesp) on its management and strategy definition.

There are still some research works about physiology of sugarcane involving the evaluation of maturation phase and biomass accumulation. Such studies, in addition to the bioclimatic network coordinated by IAC Ecophysiology Center propitiate the possibility of projecting production scenarios through mathematical models.

The Engineering and Automation Center has been responsible for several studies in the area of mechanization of planting operation, cultivation and harvesting of sugarcane.

The organization of IAC Sugarcane Program is based in a virtual management set as a network of efforts, counting not only with a multidisciplinary vision, but still an organized action that allows a scope of the application of such model in many regions where this crop is very expressive or shows potential to increase.

An important element of this management process is the Sugarcane Phytotechny Group coordinated by IAC since April 1992. This group is a great prospector for sugar-alcohol research demands, used as reference by many researchers from Institutions such as Esalq, Ufscar, Unesp and CTC which participate together with the productive sector of the seven annual meetings that take place in Sugarcane Center in Ribeirão Preto, for the discussion of relevant issues for this crop. Some important projects have been elaborated as a result of these meetings. The creation and consolidation of the Phytotechny Group enabled a closer partnership with the sugar-alcohol sector, since it made possible a bigger participation by the technicians that work for the private sector on the definition and suggestion of paths and phases of IAC's sugarcane research programs, making them acting participants and also co-responsible.

Currently, besides all main regions of São Paulo state and Brazil, where sugarcane cultivation shows or gains expressiveness, IAC Sugarcane Center has widely spread its technologies for countries such as Mexico, Paraguay, Peru and Angola, with high future possibilities of helping other countries such as Mozambique, Sierra Leone, Tanzania etc.

Some technologies developed by IAC Sugarcane Program over the last decade are mentioned below:

- 16 sugarcane cultivars for ethanol and sugar production that are found in the majority of the Brazilian companies.
- One sugarcane cultivar for animal nourishment (forage).
- Training and maps of the production environments in more than 30 Brazilian companies comprising over a million ha.
- Integrated pest control such as nematodes, *Sphenophorus* and spittlebug.

- Innovative varietal management concepts using environmental matrixes.
- Experimental harvesting methodologies via biometrics.
- Methodologies for studying sugarcane root systems.
- Methodologies for harvest predicting through associative climate modeling methods.
- Text book: Sugarcane Services performed by IAC Sugarcane Center are cited below.
- Course: topics in sugarcane cultivation, which has oriented over 200 technicians for phytotechny production during the last three years.
- Performing the diagnosis of ratoon stunting disease.
- Characterization of production environments.
- Strategies for varietal management.

Data bank in bioenergy

Due to the great importance and demand for precise information about bioenergy, the Governor of São Paulo state, José Serra, in 22 of October 2007, through Decree n. 52 284, conferred to the Apta's Agronomic Economy Institute the responsibility for creating a bioenergy data bank. Initially, information about the area, productivity and price for sugarcane, grains and oilseed plants of São Paulo are available. Furthermore, there are also laws, decrees, emends and articles available about the bioenergetic issue, as well as the regular publication entitled "Etanol: A experiência paulista", which brings current numbers about ethanol in São Paulo and Brazil, concerning economic, social and environmental aspects.

IEA intends to make available a bioenergy data bank with a fast updating and easy utilization system, in a way to make it a dynamic tool, helpful for the several researchers from different areas interested on this topic. Thus, this data bank will be improved and systematically updated.

Physic nut program

The utilization of physic nut as raw material for oil extraction and biodiesel production is an option to be researched due to some advantages facing others oilseed plants, such as presenting a favorable energetic balance, low input use production, possibility of planting in declivous areas, regional alternative for job generation and social inclusion.

Main focuses are on subjects such as: botanical characterization; phytochemical characterization of present compounds; setting a germplasm collection; genetic characterization of materials obtained from many countries and/or Brazilian regions; evaluation of behavior of native and exotic material from different regions of the state, crop phytotechny management, spacing, fertilization, pests, diseases and seedlings production.

Castor oil plant program

Castor oil plant is distinguished by presenting high oil levels within its seed, and therefore is of interest for biofuel production. IACs intends to morphologically characterize its castor oil plant germplasm collection; obtain progenies and castor oil lines for the development of new cultivars, installing fields for the genetic purification of IAC's castor oil commercial cultivars (IAC-80, IAC-226 e IAC-Guarani); developing new management practices and adapt the ones already existing to the new cultivars, among them: new spacing, plants population, seed and harvest time, spatial array of plants and production of genetic seed s of new cultivars.

Elephant Grass program

Elephant Grass is the ideal raw material for obtaining electricity through biomass burning, because of the high caloric power around 4,500 kcal/kg dry matter and also because it leaves low ashes level after combustion. Hybrids from elephant grass *x* pearl millet (seed reproduction) as traditional cultivars for elephant grass are excellent to generating energy. It is intended to evaluate the selected genotypes of a hybrid population from elephant grass *x* pearl millet (PC e P8P) and the inter-varietal hybrid andropogon grass.

Also, it is necessary to optimize the chemical scarification of elephant grass *x* pearl millet and andropogon hybrid seeds, aiming to efficiently eliminate the aristas without harming the quality of seeds.

Diesel and biodiesel mixes and durability of engines

It aims to study the prolonged use of a mix from castor oil biodiesel in an agricultural engines. The mechanical performance of the agricultural engine is compared, in a dynamometric balcony, using alternatively castor oil diesel and a mix of fuel constituted of 95% diesel and 5% castor oil plant biodiesel (B5). Yet, it is intended to analyze the B5 mix effect in the characteristics of lubricating oil during 1,000 hours of engine functioning as well as analyzing the effect of B5 mix in the inject pump and inside the engine, after 1,000 hours of engine functioning.

Environmental impacts of wastes derived from ethanol production

Vinasse is one of the wastes derived from ethanol production in which the environmental impact comes from the quantity generated. It is produced 13 liters of vinasse for each liter of ethanol, resulting in over 230 billions of liters annually. This residue has some applications such as fertirrigation in the cultivation of sugarcane, where it totally replaces potassium and part of nitrogen necessaries for the crop. Agronomic efficient issues has been researched in detail in the past, and currently research is focused on topics concerned to the monitoring of soils and groundwater, in order to verify the risk of pollution through dragging of ions from soils and vinasse itself. Finally, it is aimed to verify if the recommendation of vinasse doses, that is currently done based on potassium levels (present at vinasse and soil) in a manner that it does not overpass the 5% soil CTC limit (Cetesb, norma 4 231) is environmentally suitable.

Program of biological control of sugarcane pests

Spittlebug

Since its publication, in 1997, the state Decree-Law n. 42 056/97 legislate that sugarcane harvesting in São Paulo state without burning the straws is a reality. This process, along with the increase of the mechanized harvesting area, has transformed the sugarcane agro-system and, in some cases, has favored the attack of some pest, e.g. sugarcane spittlebug, causing huge damages in agronomic productivity and industrial quality of the raw material.

The Biologic Institute – IB has performed actions to foment the use of the fungus *M. anisopliae* to control the increase of sugarcane spittlebug in the state. For that, IB has selected some isolates of this fungus and obtained in lab and field conditions, virulent products to spittlebug and high-productive in pre-baked rice medium. Such action involved researches for the obtainment of isolates more efficient for the control of this plague, as well as for suitable concentrations of the bi- insecticide and propitious period for its application.

It is important to outline that the isolates, resulting from the selection process, are nowadays used by the majority of fungus-based bio-insecticide producers located in Brazil. Thus, new companies and industry labs have been set up in order to increment the bio-insecticide offer in the market and, therefore, stimulate the use of this fungus.

As an example we can remind that between 2004 and 2008 around 10 thousand tons of bio-insecticide were used to treat an area of about 1,200,000 ha, generating an estimated economy of about R$ 240 millions in control costs. At present, besides the generation of knowledge about the subject, technicians from the Biological Institute assist the sugarcane sector on the development and implementation of plant factory inside and outside the state.

The development of biological control for spittlebug is of extreme importance to the economy of the sector, considering that the cost of this method is much lower than the chemical control, it is non-polluting, it does not cause biological imbalances, it is durable and takes advantage of the biotic potential of the agro-system. Moreover, it is not toxic for man and animal and may be applied with conventional machines with small adaptations.

Sugarcane borer

A biological insecticide capable of combating sugarcane borer (*Sphenophorus levis*), a pest that can destroy as much as 30 tons of plants per ha causing high risks to sugarcane cultivation, is being developed by the Biological Institute and will soon be able to be industrially produced.

Ground level insects are of hard control through the use of chemical compounds, what makes way for the opportunity of evaluating alternative methods for microbial control through nematodes entomopathogens, with advantages mainly on the economical and environmental order.

In some works developed by IB, nematodes have been presenting potential use in soil control, and many advances have been achieved in researches focus on sugarcane borer control.

To explore nematodes as bioinsectices, IB has been looking also to develop techniques for the industrial production and formulation of these new agents.

In addition to the lower cost of biological product, when compared to chemical one, another advantage is the application of nematodes in sugarcane is the possibility the combat, by these agents, of more than one pest species.

FINAL CONSIDERATIONS

Apta's Institutes are responsible for most part of the technological heritage which supports the tropical agriculture in our country. As major features, we can outline the capacity of performing regional research contemplating an environmental diversity which widely represents São Paulo state and others states of Brazil's Center-South region. This happens due to the significant infrastructure that enables the formation of research network and a good capillarity. Multidisciplinary research favors a more contextual view of the demand, especially when the bioenergy are is considered. Apta technical board is highly qualified and is inserted in main productive chains of agro-energetic crops.

Some actions would stimulate this net to make it more efficient, among them, the re-structuring of the management model, which could make possible to achieve better interaction among actors from public and private sectors.

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9

SUPPORT INSTRUMENTS FOR R&D ON ETHANOL

João Furtado and *Vanderléia Radaelli*

INTRODUCTION

Brazilian alcohol, recently renamed ethanol, is typically a Brazilian development, though hardly recognizable as such. The Brazilians' self-image comprises being erratic, often discontinuity-prone, incapable of persevering to achieve long-range goals. Ethanol, along with such diverse cases as coffee and aircrafts, shows us precisely the opposite: conceived as one of the drivers in the national response to the oil price crisis in the 1970s (together with the nuclear power program and the shift of oil exploitation strategy by Petrobras for a new scenario), the program persisted, painstakingly, for over three decades, having even endured times when oil prices justified its immediate phasing out.

The fundamental reason for the Brazilian success in producing ethanol originates directly from this persistence. The path of the Brazilian ethanol can hardly be attributed to any specific event, capable of determining its currently notorious success. It is essentially the outcome of the accumulation of multiple scattered advantages, usually incremental and cumulative, gained on each step during three consecutive decades.[1] The most remarkable fact along this winning journey is precisely the inexistence of any specific milestone.

The recent growth path seems to be an extension of this logic, which was hitherto so successful. However, would it be adequate for the current stage? Having been a victory in building a production capacity compatible with the Brazilian market, on an efficient basis, would the industry and its supply chain as a whole be capable of moving, in a safe and effective manner, into the forthcoming stage, to create an international market with guaranteed supply and production standards consistent with the practices required by the major countries with potential demand?

This chapter lists and analyzes the key instruments for fostering scientific and technological development of the Brazilian sugar-alcohol complex. The perspective adopted in this analysis uses exactly the aforementioned background: the political instruments aimed at fostering the scientific and technological development of this activity can be consistent for an incremental expansion path such as the one this industry took for the past 30 years, however can they be considered adequate to the ambitions Brazil seems to exhibit in the international scenario of renewable energy, in connection with biomass production?

INSTRUMENTS TO FOSTER RESEARCH AND DEVELOPMENT

Nowadays there is a well-established consensus regarding the existence, in Brazil, of a numerous, diversified, and rich set of instruments and a relatively abundant volume of resources to stimulate the technological development and promote innovative projects. Since the mid-1990s, Brazil has made efforts to promote research and

[1] On this matter, see the paper: Comissão especial de bioenergia do Estado de São Paulo, coordinated by José Goldenberg, on *Desenvolvimento da cadeia produtiva industrial para biocombustíveis*.

development activities – corporate R&D. Taking into account the Brazilian economy's structural shortcomings and the restrictions associated to the macroeconomic scenario, companies were able to find a more varied repository of instruments, adapted to various purposes. Recently, after an initial period of severe restraint on the constitutionally allocated funds for technological development, the Ministry of Science and Technology and the Research Studies and Projects Funding Agency (Financiadora de Estudos e Projetos – Finep), had their budgets strengthened, and began to operate on significantly larger budgets.

Some enlargement of the institutions involved in this endeavor also seems to be taking place. In BNDES, after an initial attempt during President Lula's first term, with the creation (but not the operation) of the Technology Fund (Fundo de Tecnologia – Funtec) and the facilities for fostering innovation (Research, Development & Innovation; and Innovation – Production), the bank's new management seems to have given a different weight to this initiative, as expressed – among other actions – by multiplying the budget of the Technology Fund by a factor of three. The financial effort to foster technological development made by these two federal agencies still awaits a similar move by the two other federal banks: Banco do Brasil (which seems to be taking its first steps) and Caixa Econômica Federal (without any evidence so far). Along what has been traditionally practiced by developed countries, it seems that Brazil today has a clearly drawn regulatory milestone for supporting innovation, with various instruments. Being relatively new, many of these are not yet regularly used by Brazilian companies. However it has not always been so.

Instruments to foster research and development – historical background

The instruments in effect during the 1980s were basically focused on supporting engineering projects, implementation of quality control, and acquisition of foreign know-how. Support mechanisms were centered in financing one or another possibility for reducing monetary escalation. On the other hand, the 1990s featured the process whereby many industries witnessed the shrinkage of some governmental R&D structures, a few rather consolidated, others still incipient[2].

Medium and large-sized companies have access to an important array of incentives supporting innovation. To make it simpler to understand, the major financial mechanisms are split between tax incentives and conventional financing. In this work, the technical mechanisms, so important and that reveal themselves so frail when companies open up as institutions connected to certification, metrology, quality, standardization, intellectual property, calibration and gauging labs, will not be covered. The importance of such technical devices is not commonplace; on the contrary, it is in the competitive edge of companies that begin to embody the innovation and continuous learning culture.

The launch, in 1993, of the Industrial or Agricultural Technology Development Programs (Programa de Desenvolvimento Tecnológico e Industrial – PDTI; Programa de Desenvolvimento Tecnológico Agropecuário – PDTA)[3], which granted tax incentives to companies having technological innovation, underscores the acknowledgment that the organizational restructuring wave, mostly based on control and quality promotion activities, would not suffice to compete in the international market, in an open competition scenario.

In the transition from a R&D model associated to large state-owned companies to a prevalence of private companies, the government established an array of Industry Funds, inspired on the Oil Fund created in 1998 (by the ministers, then in office, Raimundo Brito and José Israel Vargas, on 12/01/1998). It was from the *Oil Fund* model that

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[2] ERBER, F. S.; AMARAL, L. U. Os centros de pesquisa das empresas estatais: um estudo de três casos. In: SCHWARTZMAN, S. (Ed.). **Ciência e tecnologia no Brasil, política industrial, mercado de trabalho e instituições de apoio**. Available at: <http://www.schwartzman.org.br/simon/scipol/summ2.htm>.

[3] Tax incentives prescribed by PDTI and PDTA were ruled out since 2006, with the migration to the regime set forth by Law n. 11 196.

several other *Industry Funds* were created in 1999, setting an important stage in consolidating the instruments for supporting innovation[4].

At the same time the discussion on Law n. 10 973 would begin, though it had a slow cruise through the Legislative system and, at the outset of President Lula's term, was neglected for almost two years, until it was finally passed in December 2004 (Law n. 10 973 of December 02, 2004). Later, though not without some legislative uneasiness Law n. 11 196 of November 21, 2005 was passed.

Instruments to foster research and development – elements from International experience

The experience with OECD countries shows that tax incentives to foster innovation are more important and effective than financial incentives to stimulate private investments in R&D. In most of these countries there is a perception that market incentives are insufficient to generate an adequate volume of investments in innovation.[5] By reducing R&D costs, tax incentives allow to raise the current value of the research at the same time that they allow allocating such investments to different industries, companies, and projects.[6] Generally, the leading actions connected to tax incentives involve reducing the Income Tax as a result of investments made in R&D. Most recent data indicate that 20 member countries grant tax incentives for R&D. In 1995, only 12 countries practiced this kind of incentive.[7] In 2005, waived taxes in some OECD countries were: US$ 5 billion in the US; US$ 2 billion in Canada; US$ 1 billion in both France and UK and between US$ 300 and 400 million in Mexico, Australia, Belgium and Spain.

TAX INCENTIVES

Law n. 11 196 of November 21, 2005 brought some important advances regarding the instruments for promotion and development.[8] The most important among them is the automatic application of tax incentives, which highlights a very significant difference from the previous devices, which depended on prior approval by the Ministry of Science and Technology, and associated, as seen by their users, to the technical difficulty of assessment, bureaucracy, slowness, and, at least in the times required by companies, subject to market requirements. In the time elapsed from the application to the approval, companies often alleged having given up on continuing with the project. In the system introduced by the new legal instruments, the company selects the project, and posts its investments (expenses) to a specific account. Afterwards, all it has to do is to send an annual report to the Ministry of Science and Technology, which on its turn will send the pertinent documents to the Federal Revenue, for auditing purposes.

Chapter III of Law n. 11 196, in its articles 17 through 26, sets the incentives granted to companies investing in technological innovation. The concept of technical innovation is quite broad: "the conception of a new product or manufacturing process, as well as adding new functions or features to the product or process that cause incremental improvements and an actual gain in quality or productivity, *resulting in more competitiveness*

4 List of industry funds: Aeronautics, Agriculture, Amazônia, Waterways; Biotechnology, Energy power, Spatial, Hydro, Computer Science, Mineral, Health, Transport, Petroleum; Infrastructure, Funttel, Yellow Green Fund, each one with their own sources for financing.

5 NELSON, R. The economics of invention: a survey of the literature. **Journal of Business**, University of Chicago Press, vol. 32, p. 101, 1959; ARROW K. J. The economic implications of learning by doing, **Review of Economics Studies**, n. 29, p. 155-73, 1962.

6 ROSENBERG, N. Why do firms do basic research (with their own money)? **Research Policy 19 (2)** p. 165-174, 1990.

7 OECD SCIENCE. Technology and Industry Scoreboard, 2007.

8 Law n. 11 196 was regulated by Decree n. 5 798/2006 and amended by Law n. 11 487 of June 15, 2007 by including article 19-A (known as the Rouanet Law of Innovation). This additional article covers financing by companies of research projects in Scientific and Technology Institutions (Instituições Científicas e Tecnológicas – ICTs) (as defined by Law n. 10 973/2004) previously approved by a permanent Committee (Ministry of Education and Culture – MEC, Ministry of Science and Technology, and Ministry of Development, Industry and Foreign Trade). ICT research projects have to be submitted to MEC for approval, by public call.

in the market". The major tax benefits set forth by this law are:

- exclusion, from the net profit and the Social Contribution over Net Profit (Contribuição Social sobre Lucro Líquido – CSLL) calculation basis, of the amount corresponding to up to 60% of the total disbursements classified as operational expenses by the Corporate Income Tax (Imposto sobre a Renda da Pessoa Jurídica – IRPJ) legislation, effected with R&D in the period;
- this exclusion may reach 80% if there is an increase in the number of researchers dedicated to research and development;
- if a *patent* or *a plant varieties registration* is granted[9], this percentage may be increased by 20%;
- therefore, the incentive may reach a 200% deduction (100% of expenses + 60% for the incentive to R&D + 20% for the increase in the number of researchers + 20% for the patent or plant varieties registration granted);
- reduction of 50% on the excise tax (tax over industrialized products) owed in purchasing machinery, equipment, or instruments for R&D;
- accelerated devaluation and amortization of equipment and intangible goods, respectively, for R&D;
- credit of 20% (until 12/31/2008) of the Income Tax withheld at the source levied on money sent abroad to pay royalties, technical support or specialized services used in R&D;
- Income Tax rate reduced to zero on money transfers abroad made with the purpose of registering and preserving brands, patents and plant varieties.

Data released by the Ministry of Science and Technology referring to the year 2006 show that 130 companies used tax incentives to technological innovation relative to Law n. 11 196. The Brazilian government waived R$ 229 million in taxes upon computing all tax incentives from Law n. 11 196, compared to R$ 1.44 billion in investments by companies. There are not yet estimates available on future gains in production, income, and tax collection associated to these tax incentives.[10] Expectations are that tax waivers will increase in the next few years as a result of changes in corporate strategies and increased knowledge by the companies on the implementation of Law n. 11 196, which unfortunately is as of today surrounded by legal uncertainties.

Among the OECD member countries, some important differences are found, and these apply to the Brazilian case. In the Netherlands and Canada, for example, tax incentives have been preferentially directed to smaller than large companies. Spain, Mexico, China, and Portugal grant incentives regardless of company size. In Brazil, only those companies that choose to pay taxes on actual profits may benefit from the tax incentives prescribed by Law n. 11 196. This implies in an additional effort to adapt the instruments existing in smaller companies, e.g., attaching such benefits to state taxes or social charges.

FINANCIAL INSTRUMENTS

The major federal agencies in terms of financial incentives, especially refundable loans, are Finep and BNDES. At state level, Fapesp, Fapemig, Fapesb and Fapitec have been on the rise.

Finep is a federal public company under the Ministry of Science and Technology, created in 1967.[11] Its mission is to promote and finance sci-

[9] A plant variety registration is understood as that plant subtype with specific features, originated from research. It is a cultivated plant variety, developed by means of systematic research and selection efforts, and not the original type found in nature.

[10] The recently finished survey by the Study Group on the Organization of Research and Innovation (Grupo de Estudos sobre Organização da Pesquisa e da Inovação – Geopi), on the incentive programs for technology innovation of Fapesp (Pipe) shows very favorable results, considering the extremely embryonic characteristics of most of the companies supported.

[11] FERRARI, F. A. O Fundo Nacional de Desenvolvimento Científico e Tecnológico – FNCT e a Financiadora de Estudos e Projetos – Finep. Revista Brasileira de Inovação, v. 1, n. 1, p. 151-187, 2002.

entific and technological research and innovation in companies, universities, research centers, and other public institutions and private organizations, *mobilizing funds and integrating instruments for the economic and social development of the country*.

Finep's action unfolds into two main fronts: 1) Scientific and technological research Fostering Agency; and 2) Technology development and innovation Fostering Bank. The first focuses on ICTs, with non-refundable resources. The second has a wide array of programs, with various instruments: refundable resources – loans, and non-refundable resources, as economic subsidies, partnerships with ICTs, and other instruments, and investments as venture capital.

Each one of these instruments is described below, as per their official characterization.

Refundable credit facilities

They comprise credit granted to institutions that demonstrate payment capability and conditions to develop RD&I projects. The grace and amortization periods, as well as interest rates and other charges, vary according to the features, the loan type, the project and the borrowing institution. Refundable credit types are the following:

a. Pro-innovation: loan at reduced interest rates for research, development, and innovation of goods, services or for technology empowerment of Brazilian companies. The loans of this type are made with financial charges that depend on the project characteristics. The focus of this program is on innovation in a product, process, or service that contributes to improving the organization's competitiveness.
   The Pro-Innovation is a loan with reduced charges for research, development and innovation projects involving a minimum amount of R$ 1 million, carried out by Brazilian companies with revenue above R$ 10.5 million. The program offers loans for undertaking RD&I projects with long-range interest rates, deducted in 5% and longer terms (up to 120 months):
   - to increase the company's competitiveness, within the scope of the present industrial policy;
   - that increase the R&D activities in the country;
   - having regional relevance or that are included in local production arrangements, covered by programs of the Ministry of Science and Technology;
   - that result in higher technology density and dynamic production chains;
   - that are developed in partnership with universities, research institutions, and/or other companies;
   - that consider the creation or expansion, in at least 10%, of the R&D teams, hiring graduate (MSc or PhD) researchers.

b. Zero interest: type of loan that prioritizes the speed of the instrument, with reduced bureaucracy, to support projects developed by small and/or micro innovative companies, within their scope, in their business, process or products/services aspects. The Program works as a cooperation between Finep and its statewide partners, specific for micro and small innovative companies, having been already implemented in five states (Bahia, Minas Gerais, Pernambuco, Paraná and Santa Catarina).
   - loan amount from R$ 100,000 to R$ 900,000;
   - simplified form, using digital signature up to the execution;
   - online processing;
   - waives collaterals;
   - payment in 100 monthly installments, without any actual interest (only IPCA escalation).

Non-refundable facilities: economic grant[12]

This type of support to innovation is widely used in most developed countries, being deemed

[12] The economic subvention considers four types: national calls to companies; with state partners, usually foundations that support research, hiring researchers; and Prime (first company) is under implementation.

compatible with the World Trade Organization rules (it is not treated as a subsidy; hence it is not actionable in international courts). It began to be used in Brazil with Law n. 10 973 of December 2, 2004 and it allows applying public funds directly on companies, as a way to share the risks associated to innovation activities or yet to subsidize 40% to 60% of company researchers' salaries.

So far, three public calls were made for innovation in companies. The last one, launched together with the government's new industrial policy, allocates resources around R$ 450 million in six areas chosen by the policy (at least 40% of them will be directed to small companies), among them bioenergy: information and communication technology, biotechnology, health, strategic programs, energy and social development. In the bioenergy area, no less than 157 projects competed.[13]

Other instruments: Research in Companies Support Program (Programa de Apoio à Pesquisa em Empresas – Pappe)

An initiative of the Ministry of Science and Technology, Pappe is a partnership between Finep and the state research support foundations. The program finances R&D activities for innovative products and processes undertaken by researchers who work directly or in cooperation with technology-based companies. The program provides direct support to the researcher, associated to an existing company or a company being created, so that the research project may be funded to result in the development of a new product or process. Recently, Finep renewed a partnership with Fapesp to finance the so-called phase 3 of emerging technology-based companies, that now allows to associate the typical support to technological development (phases 1 and 2) with the support to production and marketing development (phase 3).

Non-refundable facilities: partnerships with ICTs

Finep operates this type in scientific and technological institutions for carrying out research, technological development, and/or company-interest projects.

Investment: venture capital

Finep, through the project named *Inovar*, provides incentives to the entrepreneurial capital for the development of small and medium technology-based companies by means of the venture capital instrument as a mechanism to stimulate technological innovation.

All these loans, in their different types, are applicable – though not exclusive – to the bioenergy area, including ethanol.

BNDES also has presently several instruments to financially support innovation: "a former federal agency created by Law n. 1 268 of June 20, 1952, was classified as a federal public company, with legal status under private law and its own assets, by Law n. 5 662 of June 21, 1971. BNDES is an agency under the Ministry of Development, Industry and Foreign Trade, whose objective is to support enterprises that contribute to the development of the country". Over its path, it has already changed its priorities several times, in accordance to governmental guidelines. It was the bank of the power-transportation binomial, which in good part was the reason for its creation and of the industry that included in its actions the agriculture and export issues (in the 1980s-1990s). It played a prominent role as the financial agent for privatizations (1990s), and – very recently – incorporated the theme of technological development and innovation, after a long period of absence.[14]

The BNDES facilities for technological development and innovation comprise four main programs: innovation capital, innovation, seed capital, and, in a non-refundable scheme, a technology fund – Funtec.

[13] From the three facilities that made up the call on energy, two referred to bioenergy: palmatias and physic nut, with 59 projects and a total demand of R$ 212,879,187.75; and stillage and ethanol, with 86 projects and a total demand of R$ 337,658,009.85. Source: Finep – Financiadora de Estudos e Projetos.

[14] Throughout its long history, BNDES cared for the science and technology theme more actively in the 1970s, when it helped to sponsor some important experiments in implementing and consolidating graduate study programs. Available at: <www.finep.gov.br>.

Innovation capital[15]

The innovation capital is aimed at financing companies in terms of implementation and consolidation of their efforts in technological development and innovation. One of the problems in this type of financing facility involves drawing the separation line between technological development and routine engineering, which typically exists in many large companies, including those that periodically renew their technical features and the design and style of their products.

Technological innovation[16]

This is the redesigned version of a previously existing facility, with several important advantages regarding payment terms and conditions. Possibly, the only adverse condition involved in this redesign is the uncertainty regarding the required collateral: experience has shown that the expression at BNDES' discretion nearly always causes to require them. In case of more modestly-sized companies, unable to access BNDES' facilities directly (they have to go through financial agents, paying a double bank spread), this may mean a restricted access to public credit. This disadvantage for smaller companies is added to the restriction (mentioned on the item of Law n. 11 196) that these companies face in terms of tax benefits.

Technology fund – Funtec[17]

BNDES's Technology Fund has existed, by statute, in the BNDES for a long time, however it remained nonfunctional for a considerable period of time. It was reactivated during C. Lessa's term at the bank, however it remained devoid of relevant agreements during this and the two successive terms (Guido Mantega and Demian Fiocca) until very recently, when its resources were multiplied (by 3), and it became functional (L. Coutinho's term). The Technology Fund uses a part of BNDES' profit (which would otherwise be transferred to the Treasury) to grant non-refundable loans for scientific-technological activities. It will manage resources comprising a few hundred million reais yearly, aimed to the established priorities approved by the bank senior management. The priority facilities currently in effect[18] are: renewable energy, health, and pollutants emission.

Criatec Program[19]

BNDES' capital-only program is aimed at providing financial support, with capital transfer to newborn companies, deemed innovative by the bank. In most cases, small innovative companies would have great difficulties to fulfill the financial requirements of any financial institution, even a publicly-owned one, and they would hardly honor the financial commitments associated with any traditional loan. For this reason, the capital transfer (seed) is the type recommended for this initial stage of corporate development, mostly when it is associated to innovation. One of the features of the program is its operation by third parties, selected by BNDES.

The Foundation for Supporting Research of the São Paulo State (Fundação de Apoio à Pesquisa do Estado de São Paulo – Fapesp) finances scientific and technological development in the São Paulo state actually since 1962. The São Paulo state Constitution of 1947 determined, in its article 123, that "support to scientific research shall be sponsored by the State, through a Foundation, organized as to be prescribed by law", and added, in a sole paragraph, that "every year the State will endow this foundation, as income for its private management, an amount not lesser than one-half per cent of its ordinary revenue". In the State Constitution of 1989, art. 271 determined an increase to that percentage: "The State shall endow at least

[15] Available at: <http://www.bndes.gov.br/inovacao/linhas_inovacao.asp#capital>.

[16] Available at: <http://www.bndes.gov.br/inovacao/linhas_inovacao.asp#capital>.

[17] Available at: <http://www.bndes.gov.br/programas/outros/funtec.asp>.

[18] Facilities also included, though not being limited to: software, semiconductors, biotechnological solutions for developing Brazilian agriculture.

[19] Available at: < http://www.bndes.gov.br/programas/outros/criatec.asp>.

TABLE 1 BNDES – Funding instruments for innovation.

	Innovation capital	Funtec	Technological innovation	Criatec
Purpose	To support innovative efforts in line with company strategies and included in the Innovation Investment Plans (Plano de Investimento em Inovação – PII), including physical infrastructure and both tangible and intangible assets (comprising support to incubators and technology parks).	To financially support projects aimed at stimulating technology development and innovation with strategic interest to the country, in accordance with Federal Government Public Plans and Policies.	To support research and development projects, with technological risk and market opportunities, comprising the development of new products and/or processes (at least for the domestic market), or significantly improved ones.	To capitalize innovative small and micro companies with seed capital and provide them with adequate managerial support.
Minimum and maximum amounts	R$ 1 million and R$ 200 million.	Defined on a case-by-case basis.	Minimum amount: R$ 1 million.	Maximum amount: 1.5 million in companies with net revenue up to R$ 6 million.
Interest rate	Long-range interest rate (Taxa de Juro de Longo Prazo – TJLP) + basic BNDES remuneration + credit risk fee.	Non-refundable type.	4.5% per year.	
Term	Up to 12 years.		Up to 14 years.	10 years.
Level of participation in financed items	• Small, micro and medium sized entrepreneurs: Up to 100%. • Large companies: Up to 80%.	Limited to 90% of the total project value.	Up to 100%.	
Collaterals			Defined in the operation analysis.	

Source: BNDES, summary by authors.

one percent of its levied taxes to the Foundation for Supporting Research of the São Paulo State, as income for its private management, to be applied in scientific and technology development", and the sole paragraph of this same article determined, when the inflation rate was still very high, that "the endowment set in this article, deducted from the amount to be transferred to municipalities, in accordance to art. 158, IV, of the Federal Constitution, will be transferred monthly, the percentage being calculated on the collection month, and paid on the next month."

The certainty of sizeable and regular resources allowed Fapesp to develop effective programs to support scientific and technological research since its foundation, in 1962. The 1989 Constitution increased significantly these resources, and allowed Fapesp to launch a series of new support programs for scientific and technological research. So, sidetracking the regular programs for supporting scientific and technological research, for researchers with projects developed in the São Paulo state, Fapesp began to support also research developed in companies, either emerging or simply small (less than 100 employees), by means of the Innovative Research in Small and Micro Companies Program (Pesquisa Inovativa em Pequenas Empresas – Pipe); and in companies of any size, through the Support Program for Research in Partnership for Technological Innovation (Programa de Apoio à Pesquisa em Parceria para Inovação Tecnológica – Pite).

"The Pipe program exists since 1997, and is intended to support the development of innovative research, to be carried out in small companies headquartered in the São Paulo state, on important issues in science and technology that have a high potential of commercial or social return. Projects may be developed either by researchers employed by the small companies or associated with them for the project. The program offers companies located in the São Paulo state access to non-refundable resources for developing technology research projects. This program is based on experiments developed in other countries, and supports research for up to 30 months, with resources that may reach R$ 625,000, being up to R$ 125 thousand for an initial stage (six months), corresponding to the demonstration of the concept, and R$ 500,000 in a second stage (24 months) for achieving the actual objectives. Companies in any industry may submit their projects to the PIPE program, as there is no specific scope or exclusion. The merit of the proposal is the key element for analysis, however the consistency of the person in charge of the research and the company perspectives are also considered in the assessment.

"The Support Program for Research in Partnership for Technological Innovation (PITE) is intended to finance research projects in academic institutions or research institutes, developed in cooperation with researchers in the research centers of companies established in Brazil or abroad and co-financed by them. This Program aims to strengthen the relationship between universities/research institutes and companies, by the execution of cooperative and co-financed research projects. If the research project development is carried out in a cooperative manner, it is expected that its results will contribute to developing knowledge, or technological innovations of interest to the partner company, in addition to contributing to promote knowledge, and the development of highly qualified human resources. Partner companies have necessarily to contribute to financing the research project with some consideration of their own or third-party resources."

Differently from Pipe, Pite requires something in exchange from the companies, an amount that usually represents 50%. In case of more exploratory projects, therefore involving a higher risk, Fapesp's share may exceed 50%; and in case of more secure projects, it may be lower.

SPECIFIC PROGRAMS

In addition to general programs to support R&D and Innovation, there are specific programs aimed at the bioenergy industry development in Brazil.

Fapesp has recently launched a program dedicated to bioenergy: Bioen. Fapesp's Bioenergy Research Program (Programa de Pesquisa em Bioenergia – Bioen) "aims at stimulating and articulating research and development activities using both academic and industrial laboratories to further knowledge and its application in areas related to the production of bioenergy in Brazil". The program is structured in five "divisions": a) Biomass for bioenergy (focused on sugarcane); b) biofuels manufacturing process; c) biorefineries and alcohol chemistry; d) ethanol applications in automotive engines: internal combustion engines and fuel cells; e) research on socioeconomic, environmental, and land usage impacts. As stated by Fapesp, "it is expected that exploratory activities may generate new knowledge and develop highly qualified human resources, which are essential to improve the industry's capacity in ethanol-oriented technologies, and increase its internal and external competitiveness".

- Bioen includes academic research and, when appropriate, establishes partnerships for the development of cooperative research activities between universities and research institutes in the São Paulo state and companies, sharing human, material, and financial resources.

- In these partnerships, the specific details of the themes of interest are specified according to the interest of the private partner and the Fapesp commitment to foster research in the São Paulo state.
- Other agencies, both from the Federal Government and from other states, were invited to participate in the Bioen-Fapesp. The Ministry of Science and Technology, through the CNPq, and Fapemig have already expressed their interest in participating, and other agencies are analyzing their commitment with Bioen.

Embrapa Agro-energy

Embrapa Agroenergia was created in 2006 with the purpose of finding technology solutions for developing agro-energy in Brazil. This Embrapa unit now has 5 platforms of research, development and innovation: fuel alcohol, biodiesel, biogas, power forests and agricultural and forest wastes. The center will develop research with sugarcane, cassava, oilseeds that may be added to biodiesel and other alternative energy sources. The creation of this technology center cost around R$ 10 million. The transfer in 2007 was R$ 50 million. In addition to managing the research carried out by Embrapa, the Agroenergia will also have pilot plants capable of sealing-up laboratory experiments. This will enable the development of additional competencies, in addition to further investigation of the possibilities in partnerships with companies and external institutes. This initiative of Embrapa is an integral part of the National Agro-energy Plan of the Ministry of Agriculture for the 2006-2011 period.

Bioethanol Science and Technology Center (Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CTBE): The federal center was inaugurated in Campinas in early 2008, and will initially be a department of the National Synchrotron Light Laboratory (Laboratório Nacional de Luz Síncrotron – LNLS). The project considers that 150-200 researchers will work at the Center, which will focus its research on enzymatic hydrolysis for producing ethanol from bagasse and trash, in addition to research on low soil impact mechanization techniques to reduce costs associated to planting and harvesting.

Petrobras Bioethanol Project

The project launched in 2007 consists of the first bioethanol pilot plant in the country. The unit was developed by Petrobras' Research and Development Center (Centro de Pesquisas e Desenvolvimento Leopoldo Américo Miguez de Mello – Cenpes) and produces ethanol from sugarcane bagasse or castor bean cake. This is the first project of the company in second generation fuel, produced from agroindustrial waste, which does not compete with the agricultural production of food. The plant is capable of producing 220 liters of ethanol per ton of sugarcane bagasse, the objective being to reach 280 liters soon. Petrobras has already announced its intention to build, in 2010, a semi-industrial ethanol plant. To reaffirm the entrance of Petrobras in ethanol, a partnership was recently announced, with the objective of leveraging the foreign market with the Japanese Mitsui, for the production of 200 million liters of ethanol per year in Goiás. There are other partnerships for the production in the Mato Grosso state.

International comparison elements

In 2005, the US government passed the Energy Policy Act 2005[20], which appears as the first initiative since the previous legislature, from 1992, to list a series of initiatives in the energy area. The decree includes the support to research and production involving ethanol.

Other initiatives have come up in various countries, either having as line of action the efforts to fulfill internal energy shortcomings, or to promote concrete actions in policies for science, technology and innovation in these areas. In the various experiments and with different agents, at least two features highlight this scope: public policies are supported in mission-oriented organizations, focusing on great breakthroughs.

Some examples of dedicated programs:

[20] Available at: <http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=109_cong_bills&docid=f:h6enr.txt.pdf>.

a. National Renewable Energy Laboratory – NREL

The National Renewable Energy Laboratory, which since 1977 has been carrying out research in its field, has its US$ 1.3 billion budget increasing at a rate of about 6% per year. NLRE is the leading laboratory of the Department of Energy in the US, and it has been making several partnerships with the private sector, with the objective of producing ethanol from sources that do not compete with the production of food. DuPont and Genencor, for instance, have signed up a partnership with NREL, with an initial investment that will exceed US$ 140 million. By 2009, a pilot plant will be able to present the technology used and by 2012 production will move into industrial scale.

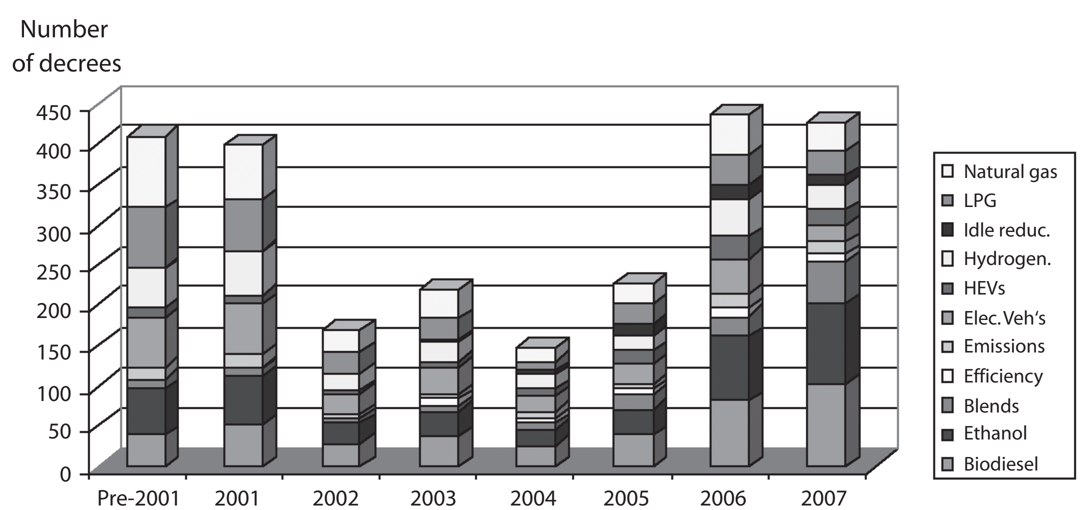
The activities performed by the Laboratory are in line with a series of incentives and provisions to increment renewable energy sources in the US. The graph below illustrates this incentive, quite expressive in terms of ethanol and biomass. In 2007, no less than 200 decrees involving ethanol and biomass were implemented in the US.

b. Biomass — Multi-Year Program Plan of the US Department of Energy

It comprises the actions that will guide the national policy for producing ethanol from cellulose. Last year's budget was US$ 1 billion, and it involved hundreds of projects led by companies, universities and public research laboratories under the Department of Energy.

c. Arpa – E – Advanced Research Projects Agency – Energy

This agency, under to the US Department of Energy, was created in 2007, using the pattern from the already consolidated Defense Agency (Darpa – *Defense Advanced Research Projects Agency*) to support the research projects connected to the development of technology capable of reducing energy imports by 20% over the next 10 years, gaseous emissions and increasing energy efficiency in several industries. The objective of this agency is to convert the advances in science towards technology solutions for the industries involved in energy. For the year 2008, the approved budget for the agency is US$ 300 million, and for 2009 it is "as much as needed". Since its inception, the agency has over 180 highly qualified and highly paid employees. To maintain a strong focus on the research projects and motivation, employees may not remain more than four years at Arpa-E. For managers, the limit is six years.



GRAPH 1 Laws of incentives by type of technology.

d. ecoENERGY

In July 2007, the Canadian government announced the most concrete initiative in biofuels in that country, involving a budget of US$ 1.5 billion, to be invested over 9 years. The program named ecoENERGY brings a whole array of incentives to involve in research companies interested in generating alternative energies in the country. One of the approved actions is that all gasoline sold in the country should contain an average of 5% of renewable energy by 2010. The country also has a program named ecoAgriculture Biofuels Capital, with a budget of US$ 200 million to be invested in companies that want to expand or build new biofuel producing plants.

e. European Bioethanol Fuel Association (eBIO)

The European ethanol association was created in 2005 and represents about 80% of the ethanol produced in that region. The theme is relatively recent in Europe, though most countries have already created programs for supporting the production on ethanol. France and Germany are the countries with the largest investments in plants and pilot plants. The goal of the European Union is to reduce its dependence on the international market, and make biofuels account for 6% of the fuels used in transportation by 2010, and for 10% in 2020.

Data from Global Subsidies Initiative show that there are 191 units processing alcohol and biodiesel being built in Europe and that by the end of 2008 their number should be 342. A considerable part of this thrust is strongly influenced by the subsidies policy.[21]

ASSESSMENT INSTRUMENTS

Will the political instruments intended to foster scientifically and technologically this activity be consistent to sustain and drive a globally expansive path, as it seems to be drawn from a convergence of economic and environmental circumstances?

[21] Available at: <www.globalsubsidies.org>.

FINAL CONSIDERATIONS

The wide array of existing instruments to foster the scientific and technological development of the fuel alcohol chain, unquestionably varied, constitutes a valuable tool for continuing the successful path taken by alcohol and bioenergy in Brazil. However, is it sufficient to face the challenge Brazil has ahead: to secure a solid position – maybe the leadership – in the global biofuels setting?

The current leadership was built from a path where gradualism and accrual lived together for a long period of time. Gains in yield per hectare were added to gains in saccharose content in the sugarcane, which were taken with the logistic gains to the mills, where the recovery indexes on juice, fermentation, distillation were improved... individual incremental gains, accrued one on each other, multiplied the production over three decades. The merit of this perseverance should not be ignored, despised nor underestimated.

Nevertheless, will this merit, hitherto so essential, suffice for the next phase? This new phase is defined by the perception widespread among a considerable number of countries, mostly those that have been leading the world's scientific and technological development and have occupied prominent positions in the economy, that there is an unavoidable need to shift into a new energy and environmental standard. There are objectives relatively well defined, and every country – or region, in the case of Europe – is seeking solutions that are adequate for their available resources, and their possibilities of using and developing them. In many cases, seeking these objectives is equivalent to a clearly defined mission, a mission similar to others when national security was challenged. The best example of these close akin concepts and policies is in the US, which created, for the energy field, a similar program, even in the name, to what rules the development of solutions for what is called *defense* or *national security*".

The protectionism that hovers over the field of biotechnologies and the international biofuel trade also reinforces the perception that developed countries, many of them having awakened dramatically late for the double problem of the possible exhaustion of fossil fuels and environmental endangerment, must withdraw – at least temporarily – from the liberal commercial flow while they gain time building their own solutions and renewable energy matrices. Were it not so, how could one explain that a renewable and clean replacement for petroleum, like ethanol, would be subject to trade restrictions that petroleum – pollutant and not renewable – never faced? Intensive, dedicated and coordinated programs by major countries and regions precede and prepare the solutions that may create local production bases for the energy and environmental issue.

The Brazilian advantage is, so far, important but insufficient. If computed exclusively by economic cost elements, it would be overwhelming, as shown by various studies, among them some chapters of this book. As it happens, the bases on which these advantages are seated mingle – no matter how sparsely – with elements that the world – for either legitimate or spurious reasons – vehemently rejects. A second important weakness is associated to product availability, to establishing a voluminous, growing and secure flow, which may render feasible the eventual decision of introducing ethanol in the fuel matrices of different countries. Finally, there is the challenge of using sugarcane and its energy fully. Put together, these are the challenges that we will have to face, if we want to translate the leadership position into biomass production, *partially* associated to natural factors, in a corresponding position to the next *steps* of the biofuel chains, multiplying their volumes by the rational and sustainable use of large territories that only Brazil has available.

It is possible to argue that the existing institutional setup, in terms of organisms, instruments and resources, is sufficient for the undertaking or that at least it is not far below the needs. However, the same cannot be said about the efforts coordination devices, split into levels (state and federal) and sectors (different ministries, departments, and industry agencies). This seems to be the main challenge.

10

MAPPING THE TECHNOLOGICAL CHAIN OF ETHANOL PRODUCTION FROM SUGARCANE FOCUSSING ON PATENT OF APPLICATIONS:

BRAZILIAN SCENARIO

Eduardo Winter, Araken Alves Lima and *Cristina d´Urso de Souza Mendes*

INTRODUCTION

Currently, there is an increase in the interest for biofuels and alternative sources of energy such as ethanol, biodiesel and hydrogen. The demand for energy increased substantially because of the growing demand for consumer goods and transportation leading to an increased use of fossil fuels. The major countries are experiencing great difficulties to meet their energy needs which has led to a greater participation of fossil fuels in the global energy matrix and the consequences have been for climate change.

The environmental concerns are causing major transformations in the world. Businessmen and government officials are recognizing the importance of policies regarding environmental sustainability, which in part has been finding an echo in the concerns of society that has demanded political and environmentally clean products. In contrast to this concern, the sustainable development of nations requires increasingly complementary and/or alternative forms of energy.

These changes have created a new and growing market known as carbon credits market. This has been the solution that industrially developed countries have found to maintain their productive activities operating without major changes. In this market, the nations negotiate carbon quotas launched into the atmosphere by the industrial activity with other less developed nations. This activity is so developed that today is exchange-traded in the stock market (SCHLITTLER, 2006).

Trading of carbon credits already benefits a number of companies in Brazil. Those are companies from various sectors such as steel, pulp and paper, sanitation and renewable resources, among others. These companies are accessing a market that, according to experts, expected to hit $ 10 billion a year, and Brazil will account for 10% of this amount (MIGUEZ, 2004).

Some countries, like Brazil, are taking mitigation measures regarding the air pollution, such as the decree of the State of São Paulo which aims to end the fires in the plantations of cane sugar by 2012, (SCHLITTLER, 2006), this will require the development of technologies from the planting and harvesting sugarcane to suit these new policies of cultivation.

In the productive chain of ethanol fuel (hydrated ethanol) the key steps are identified, they are: planting, harvesting and transport of cane sugar, the preparation of cane sugar, to obtain the substrate for fermentation, distillation and fermentation. Within each, there are smaller steps such as plant breeding, development of specific pesticides for the cultivation, development of new microorganisms and enzymes for fermentation processes etc.

Given the importance that ethanol fuel from cane sugar has been manifesting in the current context of global energy discussion, this study took place in order to map, in Brazil, the technologies used in the production chain of this fuel using the information in patent documents, because they provide the best indicators regarding the "status quo" of technology development. According to

OECD (1994), patents are excellent indicators of the innovative effort and can be used to measure the results of research and development (R&D) productivity, structure and development of a specific technology/industry.

Because of the relationship between the activities of R&D and the number of patent applications, is possible to compare, monitor and analyze the research activities in a particular subject area or a new sector (ALENCAR *et al*. apud MENDES 2007, 2008).

In this context, this paper presents an analysis of the search for patent protection in the ethanol production chain during the last three decades aiming to identify the changes in the technology landscape and its relationship to public policies, identifying the actors and countries that develop and/or developed these technologies or have interest in national technology market through marketing and/or use of the technology developed.

METHODOLOGY

The present study aims to analyze the patenting activity in the production chain of ethanol in Brazil. The data regarding patent documents used were recovered in two different databases: i) database of INPI: System database of the INPI (SINPI) (database of patents filled and/or granted in Brazil), ii) ESPACENET database, described below:

SINPI – Brazilian patent database, available in the Internet. This is a free database containing the summaries of patent applications filed and published in Brazil.

Espacenet – The patent database Espacenet contains references to patent applications that make up the documentation search of the European Patent Office – EPO. The database contains bibliographic data from over 60 million patent applications in almost every country in the world.

The search was carried out using keywords (ethanol, alcohol and sugar) and the International Classification of Patents. The search was carried out taking into consideration the period between the years 1974 and 2006, a period that covers the begining of the national government Pro-Alcohol, its deceleration in the mid-80 and the resumption of investments in biofuels at the end of 90s.

Using the search strategy above, 2,932 documents were retrieved that, after gathering the data were read in order separate those who did not relate to patent applications for ethanol fuel, eliminating the irrelevant papers. Thus, 2,276 documents were removed; leaving then a total of 656 patent applications filed relating to the chain of ethanol for analysis.

The reading step was followed by steps of adequacy of data and harmonization of information, followed by the development of a database in Microsoft Excel. After the data harmonization and the development of the database, it was possible to extract basic information about the object of interest in this study, such as the total number of documents selected, the main lines of the study, countries and companies that dominate the technology and life cycle technology.

The search strategy selected 656 patent applications filed in Brazil related to the productive chain of the fuel ethanol derived from cane sugar in the period 1974 to 2006. The applications filed in 2007 were not considered in this work because of the secrecy period (18 months) present in the process of examination of patent documents. Yet it is worth mentioning that the search in the patent databases was performed on 11.06.2008, therefore some documents filed in 2006 had not yet been published yet, and that year will probably have diferent result regarding the evolution of the technologies involved.

Finally, this study is organized in two steps. The first step presents an evaluation of the patent applications in the supply chain as a whole, from the plantation of sugarcane to the obtaining of the the hydrated alcohol. Sequentially, we performed a treatment of the data taking into account the main international classifications, allowing a difente analysis for each step of the production chain.

PATENT APLICATIONS AND/ OR PATENTS IN THE ETHANOL PRODUCTION CHAIN

An assessment of the number of filings of patents in Brazil by year (Figure 1) allows observing some peaks of deposits. It is possible to conclude that the number of patent applications in Brazil grows or shrinks according to the changing circumstances and the country's economic incentives from the government, as was the case with the Pro-Alcohol that has influenced significantly the investment in research and development (R&D) and technological development of ethanol production.

In the Figure 1 four distinct periods can be observed:

1st **Period** – 1974 to 1980: in this period, which coincides with the start of the Pro-Alcohol program, there is the highest growth rate in relation to the number of patent applications filed in Brazil, with an approximate five requests to year.

2nd **Period** – 1981 to 1989: The 80's, now known as the decade in which the technology, in general, was almost stagnant, there was the downturn in interest in ethanol. The dismantling of the government's ethanol program affected in the innovative effort and it is showed decreasing the number of patent applications filed in Brazil, with a rate of about -3 requests per year.

3rd **Period** – 1990 to 1996: in this period, the number of filings in Brazil remained stable, with an average of about 10 requests per year. However, during this period the debate on environmental issues intensified and Brazil played a great part of the discutions, as can be verified with the realization of ECO 92 in Rio de Janeiro. Another factor that interferes in this period is related to intellectual property with Brazil's signing of the TRIPS agreement, which culminated in the change of the existing Law of Industrial Property, culminating in the current Industrial Property Law (IPL – 9279/96), which dates from 1996. This new law, compared to the previous one, presents some important variations with respect to ethanol production chain, for example, matters related to biotechnology and chemicals.

4th **Period** – 1997 – present: in the late 1990s, in addition to the IPL comes into force, other factors took place that made Brazil and the rest of the World start a "race" for alternative energy sources, the main one being the high price of oil. Thus, the number of patent applications related to ethanol production strated to grow, with a growth rate of about three applications a year.

Regarding the origin of these documents (Figure 2), is possible to observe that the fillings are maily from residents (Brazilians), totaling ap-

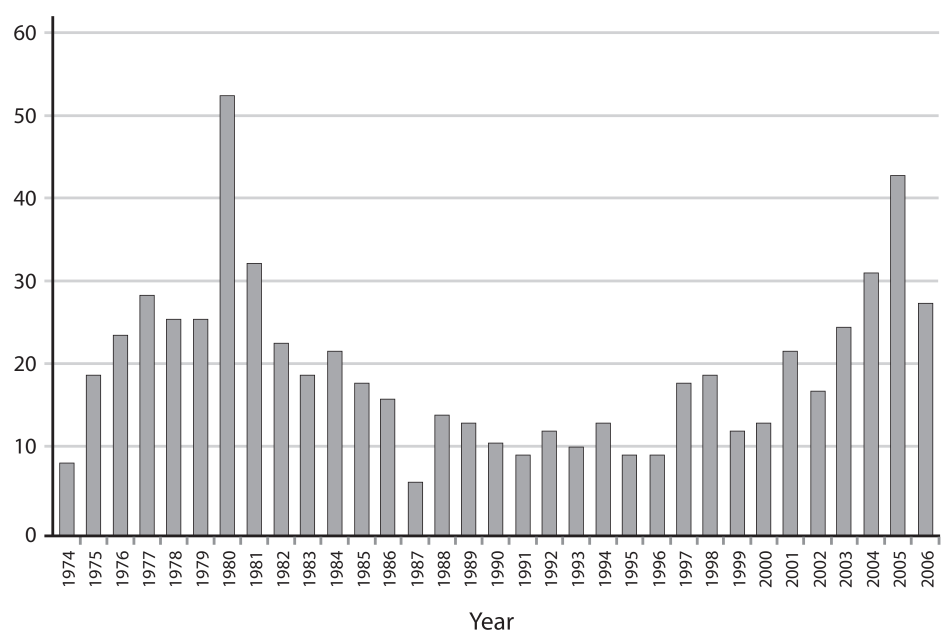


FIGURE 1 Evolution of the number of patent aplications from 1974 to 2006.

proximately 68% of the documents. The remaining 32% are non-resident applicants, maily patent applications made by the U.S. intutuitions, followed by Japan, Germany, Netherlands and Australia.

Subsequently, the participation of applicants involved in ethanol production chain (Figure 3) was evaluated. It is verified that the distribution of documents is well balanced and the main applicant (COPERSUCAR) has only 6.3% of the total, followed by Santal and Massey Ferguson. It should be noted that, of 656 documents, 459 are of different applicants, which shows an existence of a large number of actors involved in the processes of producing ethanol from cane sugar. Among the ten largest applicants, four are individuals and only two are non-resident applicants. Still, it is interesting to note that among the applicants with three or more documents filled, there can be found various educational institutions.

The COOPERSUCAR (Cooperative of Producers of Sugarcane, Sugar and Alcohol of the State of São Paulo) is a major producer of sugarcane, sugar and ethanol in Brazil. In relation to alcohol the company has sales office and tanks in Rotterdam, the Netherlands, from where the company exports to 10 countries in Europe, and should sell in the 2008/2009 crop, about 300 million gallons (c.2.27 billion litre) of ethanol fuel in the European standard. With tanks in Houston and New York, will put about 600 million liters in North America. The company also exports to Japan, India, Korea, Nigeria and the Gulf countries, among others.

Since the production chain of fuel ethanol from cane sugar is very extensive, involving equipment technology for planting and harvesting, through microorganisms and genetically modified plants, until the processes of fermentation, there was a need for a study detailing the distribution of patent documents regarding each specific technology. In this case, because of the use of patent documents, the best way to accomplish this separation is to use the International Patent Classification (IPC – the English International Patents Classification) (INPI) as shown in Figure 4 and Table 1, that show, respectively, the main classifications and descriptions of the classifications of patents.

Thus, seven classifications were selected for appearing over 100 times. They are: A01D, C12P, A01C, C12N, A01N, C13D, C07C. These classifications are described in Table 1.

Evaluating the classifications that predominate in the production chain of ethanol fuel and comparing with the information presented in

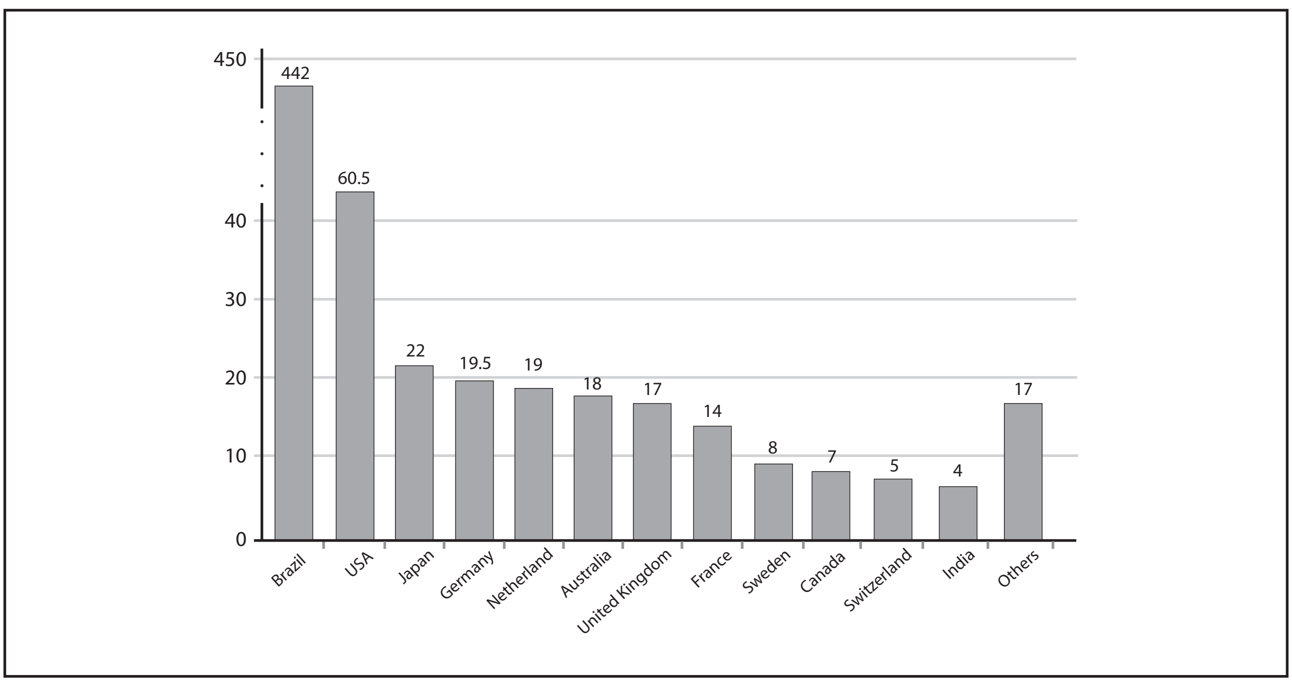


FIGURE 2 Distribution of patent documents filed in Brazil versus the country of the applicant.

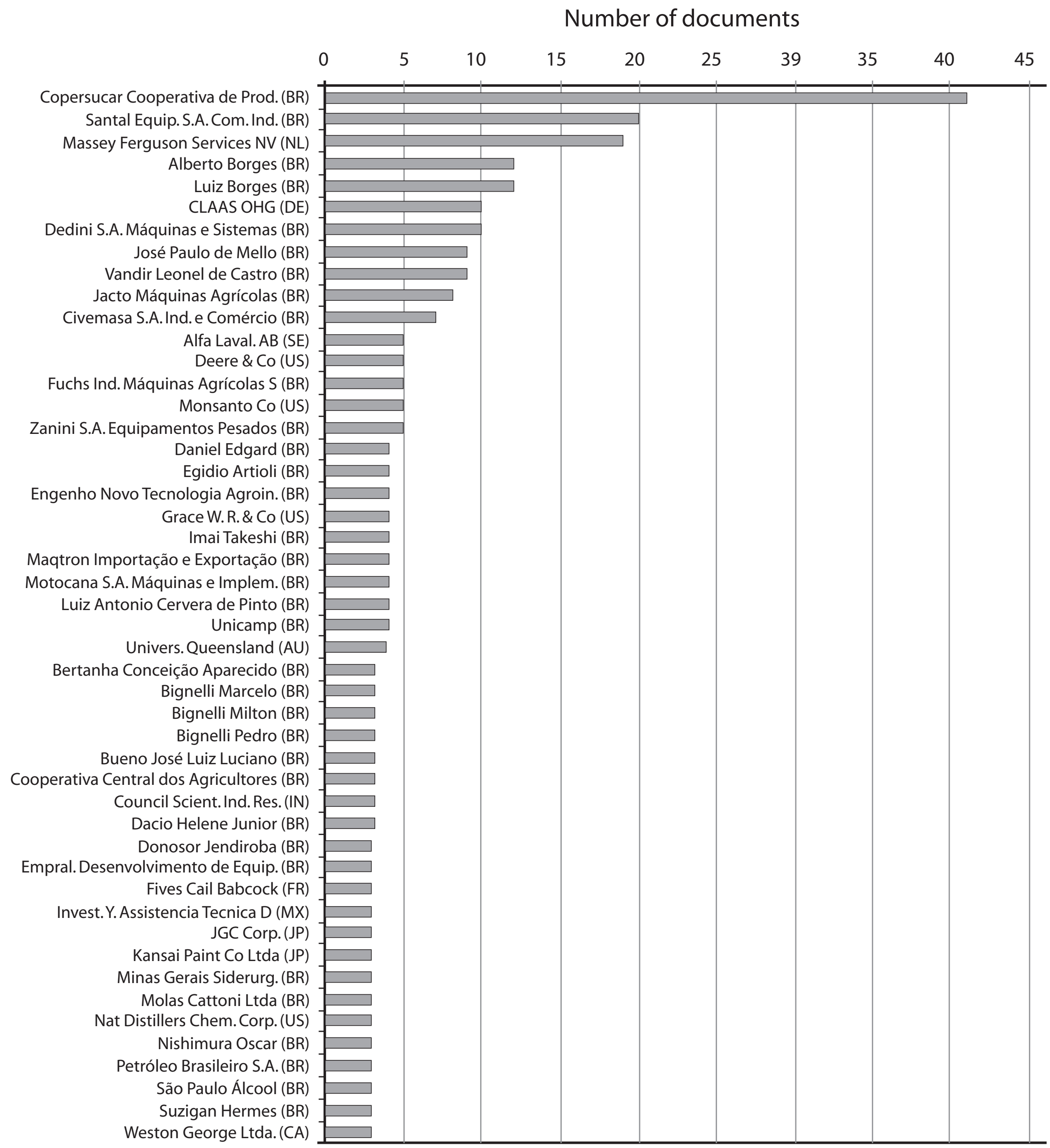


FIGURE 3 Distribuition of the main applicants of patent documents in Brazil.

Table 1, are found equipment designed for planting and harvesting (A01C and A01D), followed by biotechnological products/processes (C12P and C12N), such as fermentation. Still, there are classifications for the extraction of sugarcane juice (C13D), pesticides (A01N) and production of acyclic compounds (C07C). Because of the diversity of technologies involved the main classifications of patents involved in this chain were detailed, which enabled the identification of the main actors involved and the historical evolution of each step. The detailing took into account four main classifications (A01D, C12P, C12N and A01C), since these represent the two major technology groups, namely, processes and equipment for planting and harvesting (A01C and A01D) and fermentation processes, especially those involving biotechnology (C12P and C12N).

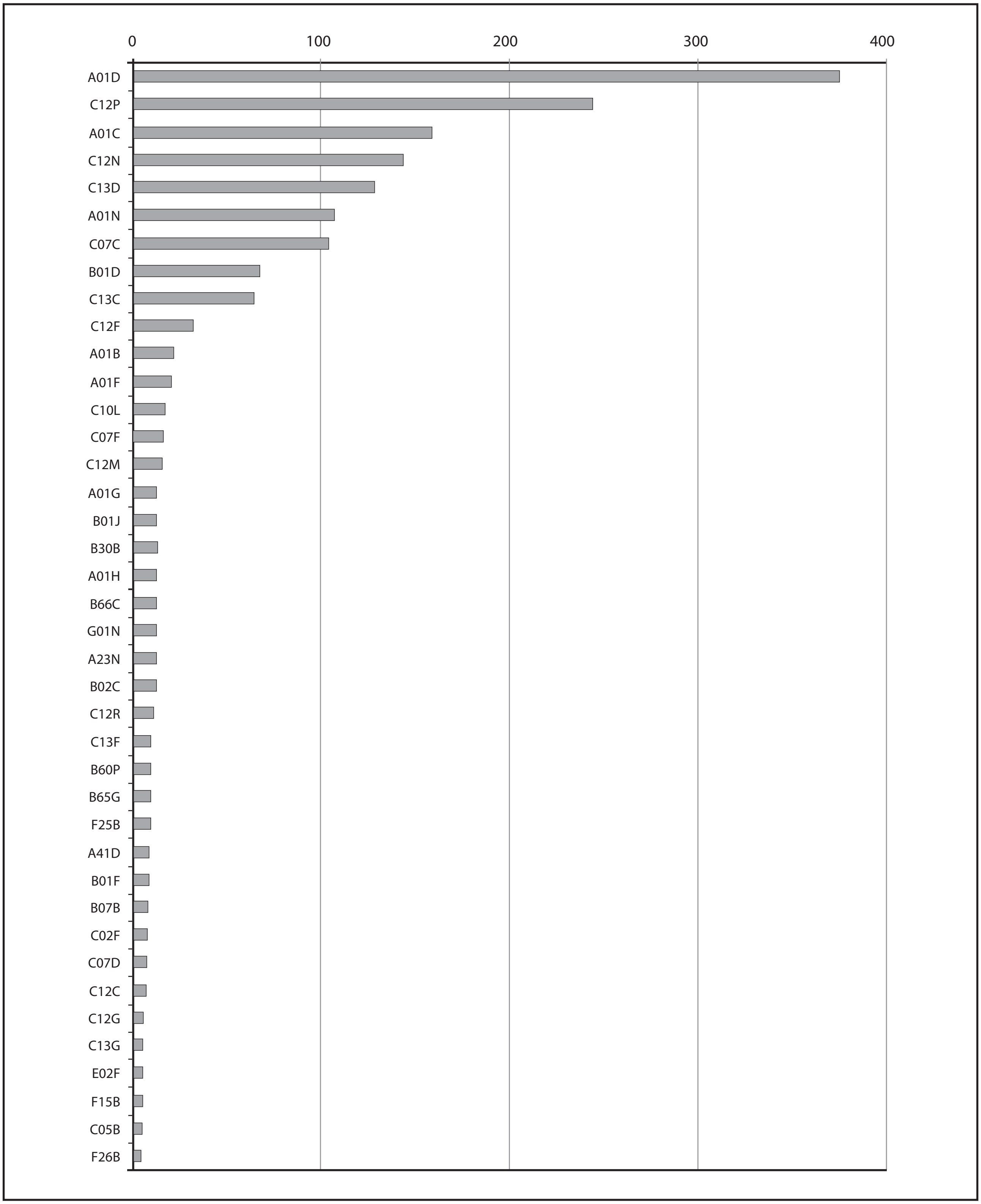


FIGURE 4 Distribuition of the main classifications (IPC).

TABLE 1 Description of the main classifications (IPC).

IPC	Description
A01C	Planting; Sowing; Fertilising.
A01D	Harvesting; Mowing.
A01N	Preservation of bodies of humans or animals or plants or parts thereof; biocides, e.g. as disinfectants, as pesticides or as herbicides; pest repellants or attractants; plant growth regulators.
C07C	Acyclic or carbocyclic compounds.
C12N	Microorganisms or enzymes; compositions thereof propagating, preserving, or maintaining microorganisms; mutation or genetic engineering; culture media.
C12P	Fermentation or enzyme-using processes to synthesise a desired chemical compound or composition or to separate optical isomers from a racemic mixture.
C13D	Production or purification of sugar juices.

A01D – HARVESTING; MOWING

This classification is intended to steps of harvesting and mowing, which involve mainly equipments for the harvesting of agricultural products, in our case more specifically, sugarcane.

First, it is interesting to evaluate the historical behavior of patent applications in this classification (Figure 5) and compare with the behavior shown in Figure 1.

Evaluating and comparing Figure 6 with Figure 1, it is possible to verify that there is much similarity in the behavior of both figures, but the highest peaks of applications occur on average two years before the behavior displayed in the Figure 1. This feature can be justified by the fact of referring to the initial stage of the production chain, which begins the process of innovation.

Regarding the country owning the technology filed in Brazil, it was examined the countries of origin of the applicants of the documents (Figure 6). In this case, it is verified that 68% of patent documents with CIP A01D filed in Brazil are from resident applicants, followed by the Netherlands, Germany and the United States. It is noteworthy that Brazil stands out as the largest producer of cane sugar in the world, therefore, it needs a lot of equipment adapted to working conditions in Brazil to harvest the cane, explaining their predominance in the documents filed.

C12P – FERMENTATION OR ENZYME-USING PROCESSES TO SYNTHESISE A DESIRED CHEMICAL COMPOUND OR COMPOSITION OR TO SEPARATE OPTICAL ISOMERS FROM A RACEMIC MIXTURE

The second IPC that stands out among the documents is the C12P, classification for the fermentation processes, the main process of production of ethanol using sugarcane as feedstock. First, it was evaluated the behavior of the patent applications in time (Figure 7). It is observed that the historical profile of existing patents in this technological niche has some differences when compared with the general behavior shown in Figure 1. It is noted that the first patent application regarding fermentation processes filed in Brazil occurred only in 1979, with peaks in 1980 and 1981, later going into decline.

This behavior may refer to different assumptions: i) the conditions of the fermentation process have little chance of variations, and the research in this area has saturated quickly, ii) the researchs are directed to the microorganisms used in fermentation processes, thus ltering the technological focus and therefore changing to the classification C12N iii) ther may be a change of the raw material used for production of ethanol, changing to other non-fermentative processes. It is possible that

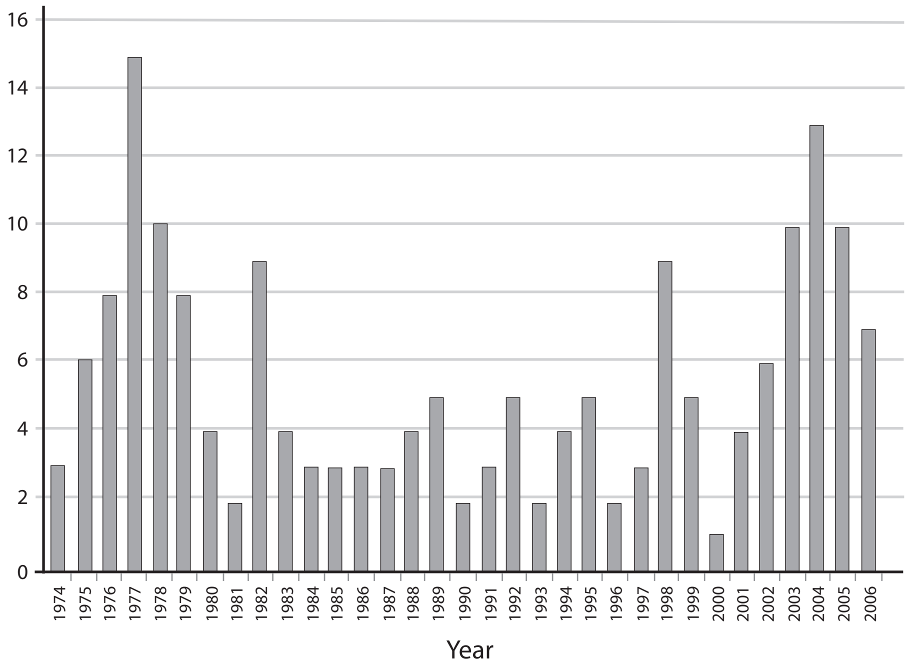


FIGURE 5 Evolution of the number of patent applications in the period between 1974 and 2006 refering to the international patent classification A01D.

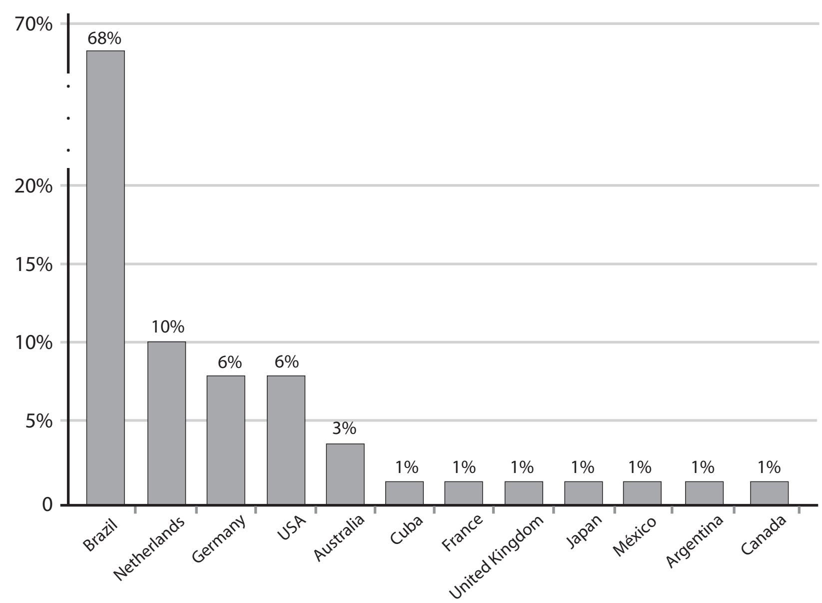


FIGURE 6 Distribution of patent documents filed in Brazil versus the country of the applicants in the internationa patent classification A01D.

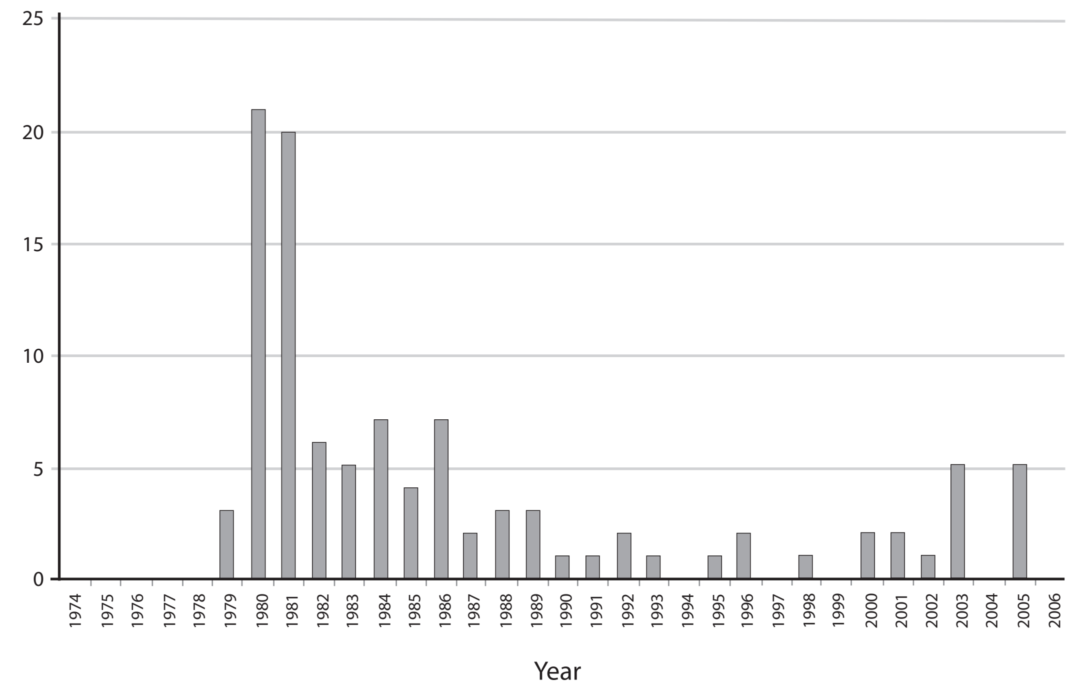


FIGURE 7 Evolution of the number of patent applications in the period between 1974 and 2006 refering to the international patent classification C12P.

these three cases are occurring simultaneously or separately.

Analizing the countries owning this technology filed in Brazil (Figure 8), it is observed that the percentage of documents filed by residents decreased when compared to all the documents, from 68% to 42%. However, Brazil still shows as the main holder of technologies involving the fermentation of sugarcane juice, but the U.S. and Japan have a significant share.

A01C – PLANTING; SOWING; FERTILISING

This IPC is also present in the early stages of the production of ethanol obtained from sugarcane and has great importance, since the process of planting of cane sugar has important features, either at planting or tillage.

Assessing the historical behavior of patent filling in Brazil in this classification (Figure 9), there is a behavior similar to that presented by IPC A01D and the behavior of the total number of documents in this study (Figure 1).

Later, as done in previous classifications, was studied of the countries within this niche of technology filed in Brazil (Figure 10).

It can be seen in Figure 10 that 95% of patent documents filed in Brazil are resident applicants, this can be justified due to the Brazilian peculiarities, especially the topography, climate and soil characteristics that need to be taken into account when developing technology cultivation for planting various types of plants.

C12N – MICROORGANISMS OR ENZYMES; COMPOSITIONS THEREOF PROPAGATING, PRESERVING, OR MAINTAINING MICROORGANISMS; MUTATION OR GENETIC ENGINEERING; CULTURE MEDIA

This IPC accounts for the the major advances in biotechnology for the production of ethanol obtained from sugarcane. Since the process occurs mostly in fermentative pathways, the existence of microorganisms for the conversion of carbo-

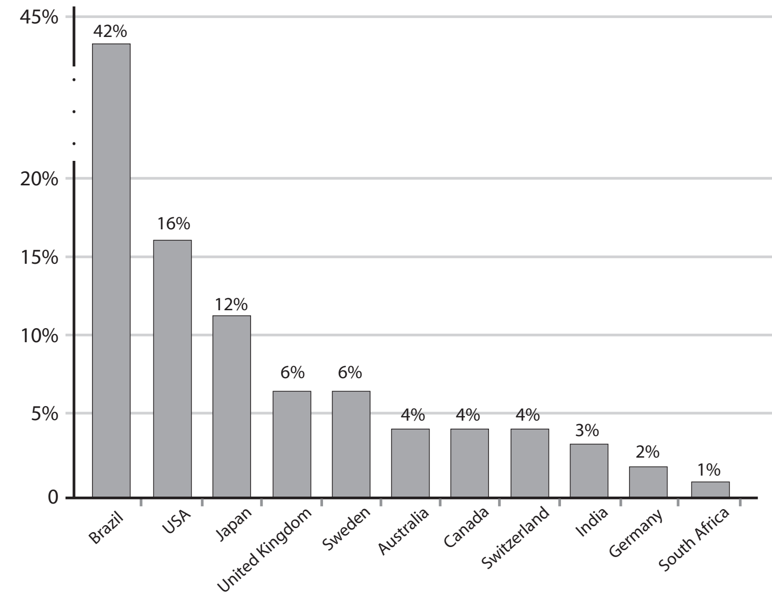


FIGURE 8 Distribution of patent documents filed in Brazil versus the country of the applicants in the internationa patent classification C12P.

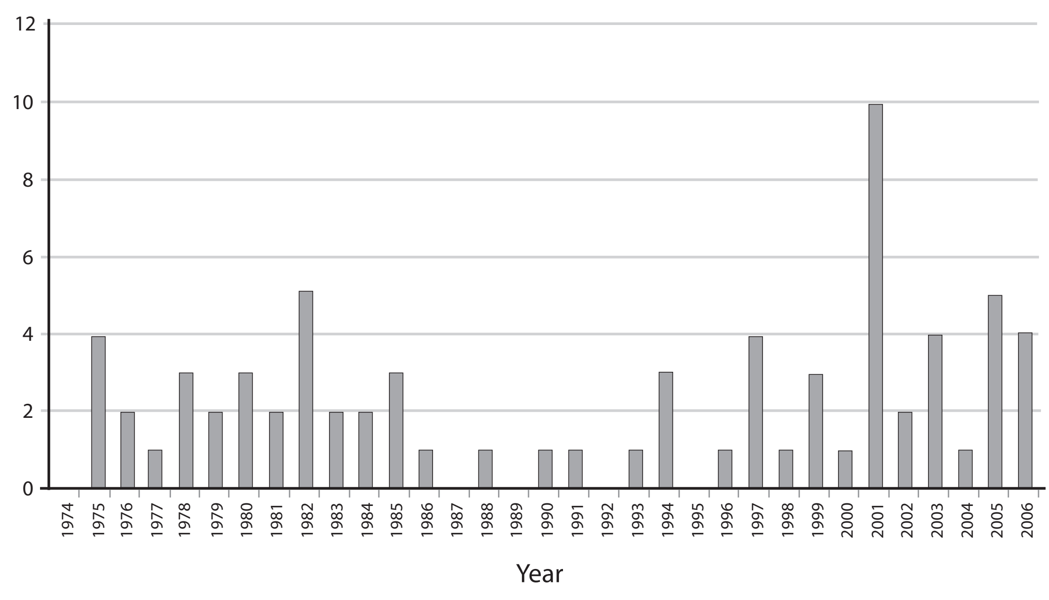


FIGURE 9 Evolution of the number of patent applications in the period between 1974 and 2006 refering to the international patent classification A01C.

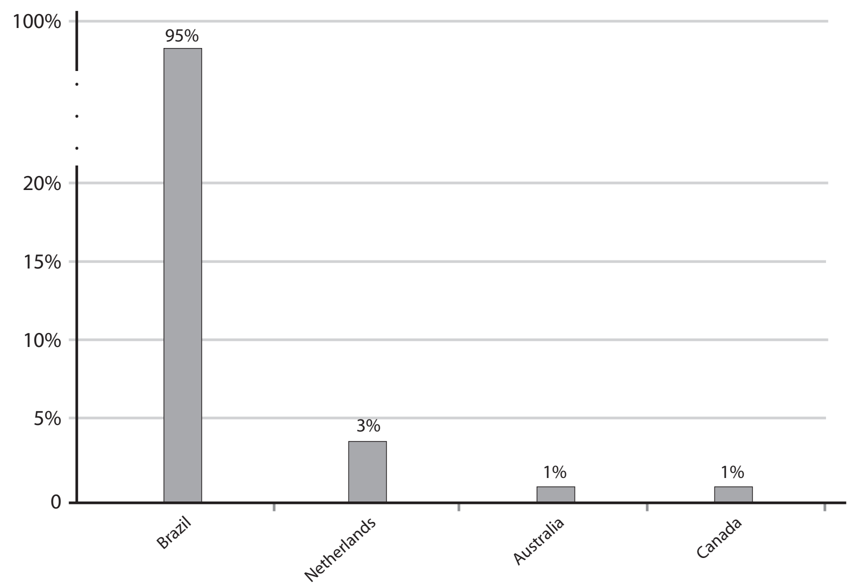


FIGURE 10 Distribution of patent documents filed in Brazil versus the country of the applicants in the internationa patent classification A01C.

hydrate to ethanol is necessary. Development of new microorganisms, mainly making use of genetic engineering has become a focus of research in several countries.

The historical evolution of patent applications in this IPC are shown in Figure 11. It can be observed, in this case, that the patent documents filed in Brazil had a higher concentration from the 90's, the largest peak of deposits in 2003 and approximately 45% of the documents filed in Brazil, occurred from 2000 to 2006. This profile is entirely different from the profile presented in the chain as a whole (Figure 1). This is probably due to the fact that biotechnology is a relatively new area, especially regarding genetic advances, what explains the predominance of documents in more recent times.

This result confirms the second hypothesis presented in the discussion of the classification C12P, because studies on fermentation processes had a drop in patent filling begining in the 90's and the applications regarding to microorganisms increased around that time.

Still, due to the complexity of the area, it is important to assess who owns this technology, mainly because it is one of the most important steps in the process of producing ethanol from sugarcane (Figure 12).

When evaluating the results shown in the Figure 12, it appears that the U.S. is alomost tied with Brazil, followed by Japan, United Kingdom and Australia. One hypothesis that could explain this result is that this technology niche has little regional dependency, and microorganisms developed for the fermentation of sucrose and other carbohydrates do not apply only to sugarcane and can be applied for the fermentation of sugars from corn, beets and other crops. Therefore, it is a technology that presents higher competitiveness and the countries with a more developed biotechnology research area of developed have more advantages.

FINAL CONSIDERATIONS

After evaluating the technology landscape of the production of ethanol fuel in Brazil in the last 3 decades, it is found the participation of various actors involved in the ethanol production chain, which reported over 400 different applicants in 656 documents filed in Brazil between 1974 and 2006.

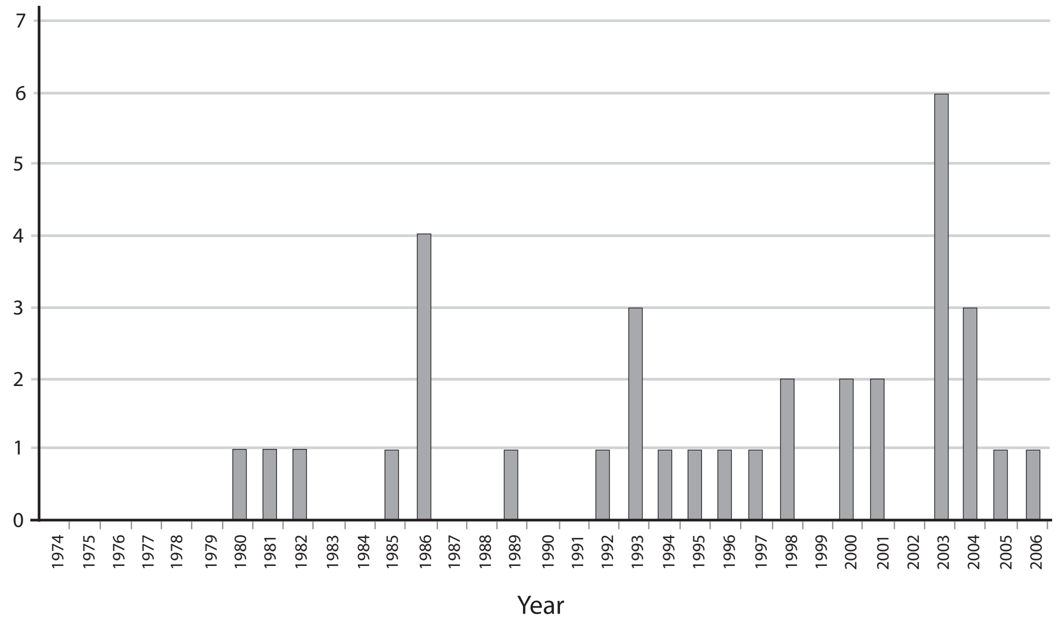


FIGURE 11 Evolution of the number of patent applications in the period between 1974 and 2006 refering to the international patent classification C12N.

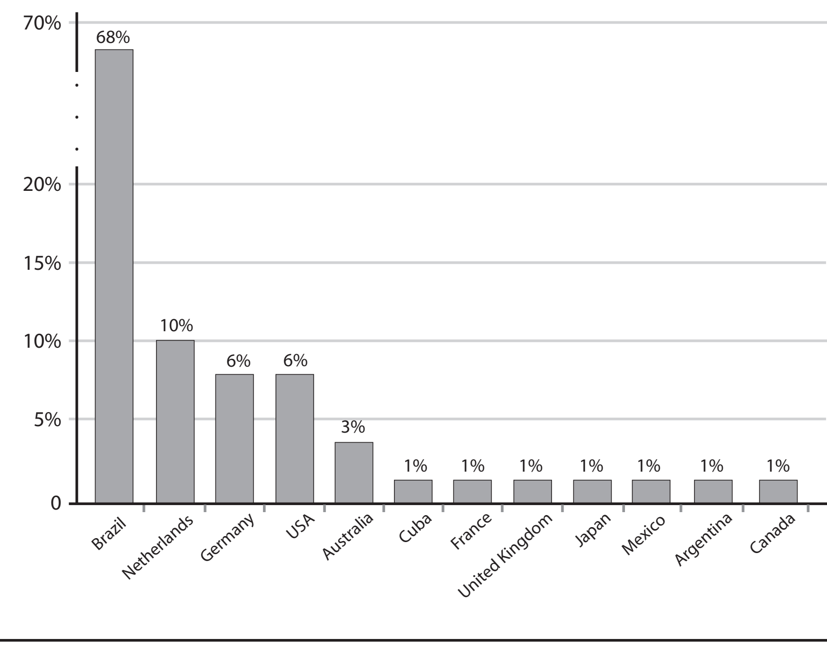


FIGURE 12 Distribution of patent documents filed in Brazil versus the country of the applicants in the internationa patent classification C12N.

Second, as in the case of Proalcohol, it is perfectly possible to see the impact of public policies on the behavior in the development and patenting of new technologies in production chain of ethanol from cane sugar.

Finally, that Brazil has a large percentage of the technology developed and filled in the country. However, it is worth noting that mosto of the documents relates mainly to equipments and processes of planting, harvesting and soil preparation. On the other hand, when it comes to the biotech industry, it appears that countries like USA and Japan gain market and become more competitive even in Brazil. This should serve as a warning to businessmen and authorities of the country, as these technologies are key to the so-called "second-generation ethanol," whose success is not only linked to the quantity of raw material that the country can produce, but also to process for the production of ethanol, especially the ethanol produced by biotechnology.

One conclusion to be drawn from this result is Brazillian reserch and development must not only seek the technologies already known, but rather, needs to intensify scientific and technological development and the protection of more complex technologies such as chemical and/or biotechnology in order to act competitively in this productive activity.

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11

FOOD *VERSUS* FUEL:

CAN WE AVOID CONFLICT?

Francisco Rosillo-Calle

GENERAL INTRODUCTION TO THE CURRENT FOOD VERSUS FUEL DEBATE

The aims of this chapter are: i) to present the main food versus biofuel debate arguments and the moral/ethical dilemmas, ii) assess the role of the agricultural sector and land use competition, iii) examine the impacts on food prices, subsidies, GHG and energy balance, iv) outline the potential implications of the second generation of biofuels, v) assess sustainability issues, and vi) identify major RD&D gaps.

There is an on-going debate on biofuels which has focused primarily on the overall social and environmental benefits, and land use competition. The food versus fuel debate is not, however, new (e.g. see Rosillo-Calle and Hall, 1987), but it has intensified significantly in 2007 and 2008 partly because the sharp increase in food prices largely blamed on biofuels. Also, new evidence has recently emerged on the overall GHG benefits of biofuels for which there is currently little consensus. In addition, there are widely diverging views on the sustainability of the current and future development of biofuels. These uncertainties are partly the consequence of lack of long term data which can only be addressed by investigating many of the existing R&D gaps, to gain better understanding of the full implication of biofuels.

Unfortunately the general press has highlighted primarily the potential negative effects, ignoring the fundamental message. A common feature of all these studies is that they lack rigorous long term scientific data to back up most of the claims. Production of biofuels is complex given the key role of agriculture, the potential impacts of climate change, increasing demand for food, feed, energy, and other biology-based products, and environmental scrutiny (see Rosillo-Calle and Johnson, 2010).

While biofuels were widely blamed for the surge on food price increases in 2007 and 2008, the reality is that there are complex reasons often little to do with biofuels expansion, e.g. lack of investment in agriculture, short term objectives, speculation, social injustice and poverty, to mention just a few. *Direct land competition* is a myth rather than a reality considering that merely 1% of the global crop land area is currently dedicated to biofuels. There are more than 2 Gha of underexploited land, plus 700 Mha of other type of land that could be used for non-food purposes without affecting food production. As Hazel and Wood (2007) put it "*... more food is produced than needed to feed the entire world population and at prices that have never been so low. The fundamental hunger problem today is one of income distribution rather than food shortages*".

For decades farmers have seen their income falling as the price of agricultural commodities has kept falling year after year[1]. Agriculture has

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[1] For example, in the UK if wheat prices kept pace with inflation over the past century, wheat would now be worth about $1200/t, rather than it current price of $ 190/t. See Biofuels-Some Myths and Misconceptions, National Farmers Union, UK (www.nfuonlie.com).

suffered from chronic under investment in most parts of the world e.g. in the 1980s about 17% of international development aid was for agriculture, but in 2005 this was just 3%. On the whole, the cost of the raw materials play a comparatively small role in the retail of food since price increases are largely determined by traders, speculation and the price of oil, among others.

True, while world demand for energy continues to grow, supply of cheap and clean energy are dwindling; at the same time population also continues to grow and so does the demand for improving living standards. What could therefore be the potential role of agriculture in meeting such demand without jeopardising its primary role of providing food? What would be the economic, social, political, and environmental consequences? How this increasingly complex situation is managed will be crucial in the future.

Biofuels have both the potential for providing many benefits but also many negative impacts if not properly managed. Biofuels are diverse as there are many different feedstocks from which they can be produced, each one with its own pros and cons. It is also fundamental to recognise that biofuels can only provide a fraction of our energy needs and thus any claim that they can provide the majority of our transport fuel needs is without a solid foundation, except in some specific circumstances e.g. Brazil. *Biofuels are not the problem but part of the problem and also part of the solution.* Unfortunately the debate has been driven mostly by politics, moral and ethical issues, and vested interest, rather than science.

THE THREE MAJOR ETHICAL/MORAL DILEMMAS OF BIOFUELS

There are at least three major ethical and moral dilemmas when it comes to biofuels, at least with regard to the first generation: i) should we produce food or fuel, or both and if so to what extent?, ii) to what extent do biofuels cause negative impacts on climate change?, and iii) to what extent do biofuels contribute or not to socio-economic development, wealth generation and distribution. None of these questions are easy to answer.

Should we produce food or fuel?

Opinions are divided and far from being scientifically driven in most cases. For many people it is simply unethical to use land to produce biofuels which benefit mostly the rich. A strong argument is that close to 2 billion people are undernourished in the world. This argument is, however, rather simplistic since the reasons why people go hungry are many and complex, and often have nothing to do with food and land availability or biofuels.

Generally, there is considerable amount of food available, and so if people go hungry is because they simply cannot effort to buy food, particularly the poorer. The root of the problem is social and economic inequality, with or without biofuels. At the same time it is obvious that, given the right conditions (i.e. financing, markets, skills etc.), farmers can deliver far more food than believed by the general public.

Therefore the answer should be yes, we can produce both food and biofuels to a certain extent on a global scale, without affecting food production, with good management practices.

Climate change

The greatest challenge facing humankind is perhaps the potential impacts of climate change. So the question we need to pose is, do biofuels make or not a net positive impact on global warming? On balance, it seems, the overall impacts are positive although evidence is still unclear simply because we do not have the methodology in place to make all the necessary calculations, and therefore much will depend on the specific feedstock and circumstances. The study by Searchinger *et al.* (2008) has raised new questions and challenges, but still leaves many unanswered questions that need to be investigated. Even the questions raised by Searchinger *et al.* are questionable.

The role of biofuels in wealth creation and distribution

For some people biofuels crate and distribute wealth while other disputes this. This argument is rather superficial and unbalanced because biofuels are not *intrinsically* better or worse than any other crop and therefore they need to be analysed within a wider social, economic and political context. For example, critics of biofuels often cite working conditions in the Brazilian sugarcane fields, without taking into account the overall social and economic reality prevailing in that country or region. Actually, in Brazil the working condition of workers in the sugarcane industry is much better than in similar industries such agricultural and forestry. While a very high standard is required for workers in the ethanol industry, the working conditions in other agricultural sectors are simply ignored or overlooked. This is a clear example of double moral judgement.

THE ROLE OF THE AGRICULTURAL SECTOR

Agriculture is extremely important, the key to our survival, not only as the source of our food, feed, energy etc., but also because for many, primarily in the developing world, their livelihood depends on agriculture. Land is finite while our demand on land is increasing continuously, beyond the famous seven “Fs”: Food, Feed, Fuel, Feedstock, Fibre and Fertiliser.

The agricultural sector faces therefore its greater historical challenge ever as demand for agricultural-based products and fuels continue to increase due to the combination of growing population, and cultural changes. Modernisation of agriculture, particularly in most of the developing countries, is essential to increase productivity and overall production. Agriculture’s increasing global role as potential provider of many raw materials other than food products could, at the same time, attract massive new investment, creating many new opportunities for innovation and diversification which could truly transform agriculture as we know it. For this to be achieved, massive investment is needed in new cultivation techniques, development of new crop varieties that require less water, fertilizer etc.; capacity building, skills, infrastructure etc.

It seems clear that if farmers are provided with the right conditions they will be able to produce far more food, energy and industrial products. Think of the poor African farmer, and specially women, only if he/she[2] could have access to the same conditions farmers have in the industrial countries! This requires many fundamental changes e.g. land ownership, fair land distribution, good educational level, availability of capital, skills, finance, marketing knowledge, and so forth. Farming cannot be seen as a backward activity, but as a science driven industry. Investment on modern scientific research for agriculture led to dramatic yield breakthroughs in the last century e.g. in England wheat yields took nearly 1,000 years to increase from 0.5 to 2 t/ha/yr, but just 40 years to increase to 6 t/ha/yr (Hazel and Woods, 2007).

It is unfortunate that most governments have neglected agriculture for so long. By transforming agriculture and fairer trade of agricultural products (including biofuels) it would be possible to produce far more food and also substitute between 5% and 20% of petrol in transportation by biofuels without affecting food supply. In addition, avoiding post-harvest loses, will be a key factor in increasing food production. What is needed is large investment on R&D, changes in land ownership and rights, the way we produce, transform, and distribute agricultural products and so forth.

Land availability

There remain many unanswered questions with regard to the total land availability that can be dedicated for energy crops and agricultural land due to lack of long term scientific data. Physical availability of land tells us very little without a full analysis of the wider factors. Additional uncertainties include the long-term productivity and sustainability of energy crops production, the effect of population growth and changing diets, global markets for food and animal feed; efficiency of biomass conversion technology, increased need for water and fertilizers, demand for other non-energy uses of land; and climate warming.

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[2] In Africa, most agricultural activities are carried out by women. These women have no capital, knowledge other than empirical, and above all, no governmental support. Empower the women farmer and productivity will increase dramatically. The role of these women is simple ignored.

The most productive land is already used (1.5 Gha[3] arable land, 3.5 Gha grasslands, 0.2 Gha for human settlements, 3.9 Gha forested land and 4.2 Gha consist of deserts, mountains and other unsuitable land for productive use). Doornnbosch and Steelblink, (2007) estimate that the upper technical limit of land for dedicated energy plantation in 2050 would be 440 Mha. However, Hausman (2007) estimates that there are currently more than 700Mha of good uncultivated quality land in 95 countries which could be used for bioenergy production[4].

Bergsma *et al*. (2007) have estimated that replacing 20% of oil (88 EJ) in 2020 by biofuels in the transport sector will require between 150 Mha to 1,000 Mha depending on the technological options adopted for its production. This large difference can be explained by the considerable uncertainty in biofuel production. But estimates by Moreira (2006) show that to meet 30% of ethanol demand in 2070, only between 80 Mha and 250 Mha will be needed, using advanced conventional biofuel production technologies, and sugarcane as the main feedstock. For comparison, current global sugarcane planted area is about 25 Mha while in 2007/08 harvest, about 260 Mha to 270 Mha were dedicated to wheat production (see www.fas.da.gov).

The main long-term difficulty facing bioenergy is not process technology but the costs of the feedstock e.g. for liquid biofuels still represents about 60-65% of total costs for sugarcane, over 70% for corn and more than 85% in the case of biodiesel. It is simply not possible to have a modern and efficient bioenergy industry until the feedstock is available cheaply and in large quantities. And this would not happen until the whole agricultural sector is also modernised to compensate for additional demand.

FAO statistics[5] show there are about 2 Gha of land considered degraded or abandoned which could partly be brought under cultivation with relatively low investment as land is often abandoned primarily due to low prices of commodities, poor management practices, lack of markets, infrastructure, lack finance, capital, skills and so forth.

The largest land area for biofuels could come from underutilised, pastures and grasslands (rather than from forested land as is often portrayed), combined with better utilization of residues. However, based on present trends, it is highly unlikely that large amounts of land would be available for dedicated energy crops without fundamental changes in the agricultural sector. The use of agricultural residues, integrated production and second generation biofuels would probably be the key factor.

The challenge will be how to achieve greater sustainable productivity per hectare/year with the lowest possible inputs. And an even a greater challenge, and uncertainly, is how to deal with the possible potential impacts of climate change. Other limiting factors may be lack of water, soil salinity and erosion, lack of investment, skills, fair play etc. The modernization of bioenergy must be in parallel with educational and agricultural modernization and capacity building.

The case of Brazil and the USA

Brazil and USA are very contracting cases, and the key to the future development of biofuels. Yes, the main feedstock used could not be more diverging, sugarcane and corn, respectively.

Brazil

Brazil is a country with an immense agricultural potential where, excluding a few areas, agricultural modernization is in its infancy. With favourable climatic conditions in large parts of the country and a large program of R&D, Brazilian agriculture will be able to increase productivity and overall production quite dramatically, if there is sufficient market demand, as discussed elsewhere in this book.

The availability of cheap and abundant land has led to extensive agricultural and husbandry practices and consequently to low productivity, thus achieving only a partial production potential.

[3] 1 Gha = 1,000 Mha.

[4] According to Hausman (2007) today's oil production represents the equivalent of 500 to 1,000 Mha (depending of the assumptions and productivity per ha, of biofuels.

[5] FAOSTAT – Food and Agricultural Organization, UN, Rome.

TABLE 1 Summary of land use impacts with varying estimates.

Corn yield scenario	2015 corn yield, bushel/acre	DG land use credit (percentage)	Range of US land converted, (Mha)
Informa	183.0 (16,459 l/ha)	31%	0.0-2.3
USDA	169.3 (15,225 l/ha)	31%	1.7-4.0
Informa	183.0 (16,459 l/ha)	71%	0
USDA	169.3 (15,225 l/ha)	71%	0

Source: DARLINGTON, 2009.

Take, for example, sugarcane which according to Ministry of Agriculture[6] data the average productivity per hectare increased from 61.5 t/ha in 1990 to 73.8 t/ha in 2005. For comparison, productivity in Colombia is close to 200 t/ha. And in the case of soy bean, based on the same source, productivity increase from 1.7 t/ha to 2.2 t/ha over the same period. Such productivity is low in comparison to major producers of these crops.

USA

The production of large scale ethanol from corn in the USA is the subject of a continuous bitter debate by the pro and anti biofuel lobbies, who continue to put forward a constant stream of arguments to support their views. Unlike sugarcane which offers many clear advantages as a feedstock, corn is far more controversial as the advantages depend on many factors which often depend more on politics than on science[7].

Yet, despite many uncertainties, it is clear that the potential for improving the benefits of ethanol from corn is quite large, either through improvements in the agricultural cycle or better use of by-products in the processing phase. For example, the argument put forward by many detractors of ethanol that most of the agricultural land of the USA would have to be converted to corn, does not stand scrutiny according to the latest studies. For example, (Darlington, 2009) affirms that the increase from *7.5 Bl/yr (2 Bgy) in 2000/01 to about 57 Bl/y (15 Bgy) in 2015/2016 would not result in new forest or grassland conversion in the USA or abroad (p4).* This would be possible throughout agricultural improvement (i.e. higher yields) and better use of by-products in the process phase. Table 1 summarises all land use impacts based on different assumptions and sources. The net land use for ethanol in the US for 2015 range 0 to 4 Mha, or less than 1% of the world's cropland.

The additional area devoted to ethanol would be offset by the reduction in other crops such as wheat and cotton and the CPR (the conservation Reserve Program). There are two fundamental factors. Firstly, increase in yield. According to the Table 1 above, yields will increase from 151.1 bushel/acre (13,590 l/ha) in 2007/08 to 183 bushel/acre (16,459 l/ha) in 2015/16 (Informa) and to 169.3 bushel/acre (15,225 l/ha) according to the USDA. Secondly, are the credits for distillers grains (DGs), a major co-product from ethanol fermentation processing used for animal feed. With the maximum land credit, no additional land is required for ethanol production even so there is a three-fold increase in ethanol production.

What this demonstrates is that even in the case of corn, there is considerable potential for increasing yields and better utilization of co-products if adequate R&D is put in place. If the same principle is applied to sugarcane, the overall potential will be far greater. Of course, it is impor-

[6] Agricultura Brasileira em Números, Secretaria de Política Agrária, Ministério da Agricultura, Pecuária e Abastecimento, March 2009.

[7] There is vast number of studies on this issue and thus this would not be taken any further.

tant to recognise that biofuels, and in particular first generation, have many limitations.

THE IMPACTS OF BIOFUELS ON FOOD PRICES

The potential impacts of biofuels on food prices came dramatically into light from 2007 to mid 2008, after which food price increases began to subside[8]. There has been sharp criticism against biofuels but without fundamental scientific proof. The reasons are many and complex, as there are many influencing factors, including (see Rosillo-Calle and Tschirley, 2010):

- Changed consumption patterns. Improved living conditions, particularly in developing countries such as Brazil, China and India, as growing wealth consumers move away from cereals to meat. This will require more land since, for example, it takes 8 to 10 kg of e g wheat to produce 1 kg of meat.
- Distorted agricultural sector in many countries, especially in the south, caused by rich countries dumping heavily subsidized surplus production on the world market led to very low prices and discouraged investment in agriculture.
- Lack of investment in the agricultural sector. For example, in the 1980s about 17% of international development aid was for agriculture, but in 2005 this was just 3%. This has been exacerbated in the last decade by low commodity prices as farmers struggled to survive and could not invest in new production.
- The increased interest from investors and traders in commodities makes price development much more sensitive. Speculation has been a major factor in prices increase.
- It is simply wrong to affirm that biofuels have played a major role in food price increases. Price increases due to *direct land competition* is a myth rather than a reality as merely about 1% of the global land area is currently dedicated to biofuels.
- Current situation of the agricultural sector. For example, the application of empirical rather than scientific principles, lack of skills, capital etc., are primary factors for low productivity, primarily in many developing countries and in particular in Africa.

Food price increases are therefore the result of a complex web of factors that need to be incorporated in any debate. For example, higher agricultural prices have both positive and negative impacts as higher incomes will allow farmers to invest more in agriculture and bring under cultivation new lands previously abandoned as uneconomic for lack of market. In Western societies consumers have been accustomed to a very low food prices for far too long, and this will become far more difficult to maintain in the future.

In conclusion, it seems clear that food price increases have been exaggerated by the popular press, a strategy often used by critics to scare off consumers. The greatest impacts are caused by oil price increases, as oil is used in the whole production and distribution chain, rather than by biofuels. At the same time, about 70% of the world's poor live in the countryside and could therefore benefit more directly from price increases. However, the urban poor face a grim future if prices are high but this requires, primarily, policy action.

Is goes without saying that this is an area that needs to be further investigated. We need to have a better understanding of the underlying causes of food price increases, rather than the easy solution of blaming biofuels.

SUBSIDIES

Subsidies have been at the core of energy production systems, both for fossil fuels and renew-

[8] While ethanol production in the US increased rapidly in 2007/08, American farmers delivered a bumper harvest for many crops in 2008 despite adverse weather conditions. For example, soybean crop reached 2.96 billion bushels, the forth largest in US history, 11% up from the previous year. As a consequence, agricultural commodity prices fell sharply. This shows that the previous year price increase of corn, who the anti-biofuels lobby blamed on ethanol production, was a myth (see Associate Press: Big harvest, weak demand bring down crop prices, 13 January 2009).

able energy sources. Pouring in vast subsidies is hardly the best way of expending taxpayer money. As with fossil fuels, biofuels development has been sparked off mostly by subsidies and other fiscal incentives rather than by market forces alone. However, the size of energy subsidies varies considerably from country to country.

For example, historically subsidies given by governments to fossil fuels and nuclear energy have been enormous in comparison for biofuels. Larson and Shah (1992) estimated that fossil fuel subsidies were to be more than $ 230 billion. Many these subsidies continue today under different hidden forms.

One of the major problems is how to identify many of the hidden subsidies that fossil fuels receive, directly or indirectly, in a multitude of forms. Take, for example, the US where a report by the General Accounting Office (GAO) shows that the petroleum industry received between $ 135 Bl to $ 150 Bl in tax breaks from 1968 to 2000 alone, excluding foreign investment tax credits estimated to cost de Treasury a further $ 7 Bl per year, compared to $ 7.7 Bl to $ 11.6 Bl given to the ethanol industry from 1979 to 2000 (GAO, 2000; WI, 2007).

US subsidies to the petroleum industry equal to approx. $ 0.003 cents/litre, but when indirect subsidies are included (i.e. military expenditure related to secure oil supplies from the Persian Gulf, which in 2003 amounted to c$ 50 billion), this represents an additional $ 0.30cents/litre of gasoline (see WI, 2007), excluding environmental damage of transport fuels[9]. In 2006 the US Federal energy subsidies totalled approx. $ 74 Bl, of which fossil fuels accounted for $ 49 Bl (66.2%) compared to $ 6 Bl for ethanol (7.6%); see Doornbosch and Steenblik, 2007; <www.earthtrack.net>. However, Pimentel *et al*. (2010) state that current direct subsidies per litre of ethanol from corn in the US is many times greater than gasoline.

Yet, one of the major criticisms against biofuels relates to the subsidies paid by governments to develop this industry which, critics say, distort the market. One would be inclined to think that subsidies provided to fossil would also distort the market. The scrutiny to which bioenergy is being subjected is unprecedented, and critics often forget that, historically, fossil fuels have received, and continue to receive, huge subsidies. While most of these fossil fuels subsidies still continue in different forms, there are increasing calls to remove or reduce subsidies to the bioenergy industry, which are very small by comparison. It is important that further research is carried out to ensure that subsidies are not seen as one sided, but that all pros and cons are fully accounted for, so that we can have a more balanced attitude.

BIOFUELS, CLIMATE CHANGE, GHG AND ENERGY BALANCE

Climate change is potentially the single most important challenge facing humanity. A key issue will be the vulnerability of the agricultural sector and its capacity to respond to climatic changes e.g. shorter growing season for some crops, severe droughts and flooding etc[10]. Climate change will, ultimately, be one of the main factors that will determine the success or failure of biofuels in the long term.

And we need to understand clearly the question, "do biofuels reduce GHG" to answer growing criticism. Further, we need to ask, if biofuels aren't as GHG positive as originally thought, should we reduce the speed of their introduction while allowing at the same time consumption of fossil fuels unchallenged? There is, simply, no perfect fuel!

As with the energy balance, the overall GHG benefits of biofuels are also increasingly being questioned, particularly after the study by Searchinger *et al*. (2008). This is because there are many and varying inputs that have to be accounted for which can lead to very different interpretations. But new studies are constantly challenging old

[9] For example, environmental damaged caused by diesel in the transport sector in 1993 (the year for which data is available), has been estimated at $0.31cents/litre (see WI, 2007).

[10] There is abundant literature on the potential impacts of climate change in agriculture. A particular international institution who is working in this area is the International Agricultural Research Centres. See for example, **Global Climate Change**: Can Agriculture Cope? Available at: <www.cgiar.org>.

persecutions. For example, a recent study carried out by researchers at the University of Nebraska Lincoln, which has quantified the impacts of recent improvements throughout the corn-ethanol production process, has demonstrated that corn ethanol emits about 51% less GHG than gasoline, therefore dismissing those critics who argue corn ethanol offers little potential for improvements[11].

GHG are constantly changing as they are the focus of significant efforts to increase the energy ratio and to reduce GHG. Further, many of the comparisons are with corn and wheat which compare unfavourably with sugarcane as if offers multiple benefits. For example, a study by S&T (2009) shows that GHG emission savings from ethanol production and utilization has more than doubled between 1995 and the projected level for 2015. The study indicates that *"there is a danger of making policy-decision based on historical data without taking into account learning experiences and the potential gains that can be expected as industries develop"* (S&T, 2009 p. iv). There are many ways in which GHG can be reduced as there are still many gaps in our understanding.

Biofuels, has been suggested, could largely be produced from set aside land particularly in EU and USA as a way of reducing competition with food production and reducing GHG. However, this option has also come under scrutiny (see Pineiro *et al*., 2009). The authors state that *"Depending on prior land use C releases from soil after planting corn for ethanol may in cases completely offset C gains attributed to biofuels generation for at least 50 years"*. Also, based on the results of 142 soil studies, soil sequestrated by setting aside former agricultural land was greater than the C credits generated by planting corn for ethanol on the same land for 40 years and greater or equal economic net present value (Pineiro *et al*., 2009).

The energy balance of biofuels production (the ratio of energy contained in the biofuel to the ratio of fossil fuel energy used to produce it), is still a contentious issue, particularly in the case of ethanol from corn, and this is despite numerous studies [e.g. see Wu *et al*. (2006), Shapouri *et al*. (1995), Wang, Wu and Huo (2007)]. It is also an issue often grossly oversimplified given the complex web of economic, social and political factors that need to taken into account; different assumptions/calculations can, therefore, lead to very different results. One of the difficulties is that often old data tend to be used while the continuous improvements in biofuels production and use are not always incorporated into the analysis.

There is also a need to have more comparative analysis of the energy balance of gasoline and biofuels. For example, a study by Sheehan *et al*. (1998), sponsored by the USDA and USDOE, found that the primary energy use for each 1MJ of petroleum diesel requires 1.2007 MJ, corresponding to 83.28% energy efficiency. Petroleum diesel uses 1.1995 MJ to produce 1MJ of the fuel product energy. According to the Greet Model[12] calculations, the fossil energy input per unit of ethanol is 0.78 MBTU[13] of fossil energy consumed per each 1 MBTU of ethanol delivered. This compares with 1.23 MBTU of fossil energy consumed for each MBTE of gasoline delivered (see www.transpsortation.anl.gov/)[14]. The S&T (2009) study shows that the net energy ratio (Joule delivered/J consumed) was for gasoline 3.7961 in 1995 and 3.1174 estimated for 2015; and 1.1851 for corn ethanol in 1995 and 1.9262 estimated for 2015.

Despite considerable disagreement, some consensus is emerging on the overall energy balance. For example for US corn, it is more generally accepted to vary from 1.25 and 1.35, which could be further improved to 2.9 if fossil fuels in industrial processes are switched to biomass-based fuels. The energy balance is not static but changing continuously. Major improvements (i.e. reducing energy consumption, greater energy self-sufficiency, developing new co-products etc.), will

[11] See Journal of Industrial Ecology. Available at: <http:dx.doi.org/10.1111/j.1530-9290.2008.00105.x>.

[12] Greet – The greenhouse gases, regulated emissions and energy e in transportation, was developed by Dr Michael Wang, Argonne National Lab's Centre for Transportation Research, with support from the USDOE.

[13] Million British thermal unit (one Btu = 1.05506 x 10^3J). In this case, 823 MJ for ethanol against 1,298 for gasoline.

[14] See document: Ethanol – The complete energy life cycle picture, 2007.

further improve the energy balance. US corn is, however, one of the least efficient feedstocks used in ethanol production e.g. sugarcane in Brazil has a ratio of 8.3 to 10 fold (see Macedo *et al.*, 2004; Walter *et al.*, 2008).

SECOND GENERATION OF BIOFUELS

Considerable hope is being pinned on second generation of biofuels. The current concern with the first generation of biofuels is catapulting RD&D toward the second generation in the hope that it would be possible to produce biofuels in large scale without affecting food production. This could be possible because the feedstock will be mainly cellulose-based, agro-forestry wastes such as straw. The hope is that they will provide clear advantages over the first generation, including:

- avoid direct competition with food crops;
- reduce the level of subsidies;
- provide clear advantages on GHG;
- provide clear environmental benefits;
- reduce deforestation;
- improve biodiversity;
- better utilization of resources e.g. lower quality land, water etc.

Although it remains to be seen if all attributes to the 2nd generation biofuels can become a reality. Firstly, it is not yet clear what impacts will have on land use, secondly the use of poorer land will be reflected in lower yields or higher inputs, thirdly process technology would be more expensive and possibly will have higher disposal problems, and four the overall costs may be much higher because the higher processing costs involved.

For example, currently there are two main conversion routes: i) biochemical (using enzymes and other microorganisms), and ii) thermo-chemical that uses pyrolysis and gasification technologies). None of these technologies seem to offer a commercial advantage despite many years of RD&D. Both pathways offer advantages and disadvantages (see Sims *et al.*, 2009). Thus, there are still serious technological hurdles to overcome not to mention economic ones. Within current financial climate and fluctuating oil prices, it is difficult for foresee when this technology will become commercially viable in large scale, but most probably no before 2020.

SUSTAINABILITY AND CERTIFICATION ISSUES

Considerable amount of work has been done on sustainability issues, but not on a global scale. It is necessary to have a more systematic approach which has greater international acceptance. The problem is how to create a global standard that allows for national and global activities, given the complexity of many of the issues involved. Any sustainability standard must include three key components: economic, social and environmental aspects. Although, a political and institutional new pillar has to be included as many of the issues implied in sustainability are regarded of a political nature (e.g. targets), see Diaz-Chavez and Rosillo-Calle, 2008).

Since the EU Directive on Biofuels in 2003 came into force, there has been a growing concern over the availability of resources and the increasing demand for energy crops to produce them. There has also been a concern for the increasing demand for biofuels imports from developing countries. This increment is expected to come mainly from sugarcane, soya, palm oil, rape seed, wood products and other biofuel feedstock (see Walter and Rosillo-Calle, 2008). It is important to be aware that vegetables oil market is driven primarily by demand for edible oil rather than for the biodiesel market. Often biodiesel is a by-product of the edible oil market.

Currently considerable efforts are being made towards the development of standard and certification systems specifically dedicated to biofuels. However, there are still considerable gaps in out understanding that need further investigation. The main ongoing projects are briefly explained below (see Diaz-Chavez and Rosillo-Calle, 2008 for further details).

1) ***Roundtable for Sustainable Palm Oil (RSPO) system***. This is a global multi-stakeholder initiative, originally produced for the palm oil production with focus on cosmetic and food industry.

2) *Round Table for Responsible Soya (RTRS)*. This is also a multi-stakeholder organisation created in 2004 including producers, industry, trade & financial organisations and civil society organizations. The RTRS is developing a set of standards for the production and sourcing of responsible soy and a verification mechanism to reinforce these standards.
3) *The United Nations Environment Program (UNEP)*. The Working group of UNEP is developing sustainability criteria and standards for the cultivation of biomass used for biofuels. To date this information has not been finalised.
4) *The European Commission with the new Energy Directive*. The recently approved EC Directive states: "Biofuels used for compliance with the targets laid down in this Directive, and those that benefit from national support systems, should therefore be required to fulfil criteria for environmental sustainability" (COM, 2008, p. 17).
5) *The Global Bioenergy Energy Partnership (GBEP)*. Partners include the G8 countries + 5 (Mexico, South Africa, China, India and Brazil) and other UN institutions and associations.
6) *The International Petroleum Industry Environmental Conservation Association (IPECA), Chain of Custody (CfC)*. IPIECA is a global association representing both the upstream and downstream oil and gas industry on key global environmental and social issues. This demonstrates that oil companies are also playing an increasing role in the development of sustainability and accreditation issues.

MAJOR RESEARCH AND DEVELOPMENT GAPS

There are still many gaps in our understanding of first generation biofuels, not to mention the second generation. One of the main reasons for the current agricultural difficulties lays on governmental policy. Many governments, and particularly in developing countries, have given priorities to industrialization and very low priority to R&D in agriculture. This has led, as stated above, to very serious R&D problems in many agricultural activities. These are many ranging from soil preparation to final product. This paper can only highlight the main ones related to implications to food and biofuels. It is clear that the main challenge is to modernize agriculture.

- *Human capacity building*. In many countries (exclude the most advanced ones), many farmers do not have the scientific knowledge to carry out their activities. Many practices are based on "empirical knowledge" which, as fundamental as it is, does not solve the needs of a modern agricultural enterprise. Farming must be scientifically-driven, and not regarded as a backward activity. This requires considerable attention for skills formation. And do not forget to role of women which in many developing rural economies, particularly Africa, are the key to success of failure as they are the backbone of the local economies.
- *Capital and investment*. Farmers need to have access to financial resources and investigating this need will go a long way in solving problems.
- *Marketing*. Often farmers know little on how to market their products leaving them exposed to exploitation by intermediaries and speculators. More R&D needs to be channelled to inform and prepare farmers to market their products.
- *Agricultural best practices*. There is considerable potential to improve agriculture to increase yields, reduce the use of fertilizers and pesticides, reduce GHG impacts and enhance sustainability and biodiversity.
- *Soil preparation*. This is very important, particularly when it comes to soil compaction. Often the machinery used is the wrong one e.g. too heavy for that particular soil. New R&D is needed to develop machinery more adequate to specific soils.

- *Harvesting machinery*. As with soil preparation, harvesters used in sugarcane, for example, are too heavy resulting in unnecessary soil compaction and losses. In many of the poor countries this is a serious problem.
- *Development of new crop varieties more adequate to energy*. Currently almost all R&D is channelled to food production crops.
- *The feedstock*. Feedstock is the main component of costs and thus ensuring the right feedstock is fundamental.
- *Disease and pest control*. Currently only major companies do have R&D in this area. There should be greater support for small farmers.
- *Transportation*. There are still many R&D gaps in the transportation of the feedstocks, particularly the method and costs as they constitute a major component of the final costs. The transportation of the raw material and distribution (end use), need considerable more R&D to avoid losses and reduce GHG emissions and costs (e.g. see Wakeley *et al*., 2009). Also, developing new form of long distance transport (e.g. pipelines, shipping) is essential for trade, particularly international biotrade.
- *Price increase of food*. Price increases have been blamed on biofuels. As we have seen in this paper, there are many diverse reasons, often nothing to do with biofuels. More research should go into this area so that the real "underlying reasons" are fully understood and explained to the wider audience.
- *Land use issues*. It is important to show that biofuels are not responsible for land competition with food crops. Currently only about 1% of the crop land is used for biofuels. The complex relationships between land use and biofuels need to be fully understood and explain to the wider public. Physical availability of land often tells us little, other factors such lack of skills, markets, injustice etc., are at the core of the problem.
- *Subsidies*. The anti-biofuels lobby has criticised the use of tax payer money to prop up biofuels. Subsidies have been, and still are, at the core of most government's energy policy. It is important that this is properly exposed to the general public.
- *Green housegases*. This is a sensitive area that needs considerable research. The pros and cons need to be understood beyond the specialist or experts. There are many ways in which the GHG can be improved in favour of biofuels e.g. using the right feedstock such as sugarcane, better utilization of co-products etc.
- *Energy balance*. There is still no general consensus on this issue for some feedstocks and thus the anti-biofuels lobby continue to argue that "we put more energy in than taken out". While this may be the case in some situations e.g. corn in the USA when new improvements are not taken fully into account, this is not the case if all potential improvements are taken into consideration. Further, sugarcane has a very high energy ratio and this needs to be explained much better than has been the case so far.
- *Co-products*. It is clear that there is a huge potential for the utilization use of co-products. New ways and markets should be investigated.
- *Sustainability and accreditation issues*. It is a major of concern primarily in the major biofuels consumer countries. Producers of biofuels need to have much greater involvement to ensure fair play, and that it is not another barrier to trade.
- *Biodiversity*. A hot topic which huge implications. Monopolistic cultures do not help. However, the system being implemented in Brazil of leaving 10-20% of cane field to preserve biodiversity should be given more prominence.
- *Innovation*. Often R&D fails to support innovative activities that can benefit more

directly the farmers, in this case those producing biofuels.

With regard to the second generation of biofuels, the following are some of the main gaps (far from exhaustive):

- Despite considerable increase in RD&D of recent years, and considering the complexity of the pathways, more RD&D is still need.
- More bridges between first and second generation of biofuels are needed to take full advantage of the transition phase, as this will be an evolutionary rather a revolutionary transition.
- More demonstration plants using greater diversity of feedstocks.
- Environmental performance and certification schemes would have to be developed. Obviously this could greatly be enhanced from current work on first generation.

FINAL CONSIDERATIONS

The food *versus* biofuels issue has been blown out of proportion, a debate driven by vested interests, moral and ethical stand rather than by science. It is important to go the core of the problem. Unfortunately there are still many gaps in our understanding that need to be investigated further.

It seems clear that biofuels, at worst, are only partly responsible of food prices increase, but not the cause. With over 2Gha of idle or semi-idle land and with only 1% of the crop land dedicated to energy crops, biofuels should be seen as part of the problem and also as part of the solution.

It is possible to produce all our food needs and a portion of biofuels without affecting food crops. The modernization of agriculture and good management practices can avoid land competition but fundamental changes are required in the agricultural sector, as explained in this chapter.

The debate on *food versus fuel* must go beyond the narrow confines of vested interests, misinterpretations, and over simplistic arguments. We need to have a balanced and realistic approach and not to overstate or underestimate the potential contribution of biofuels.

Also, it is important to ensure that concern with the environment, sustainability, and biodiversity issues does not lead to the imposition of requirements so stringent that will place biofuels in a considerable disadvantage with fossil fuels, hence hindering (or even preventing) rather than enhancing their development. We need an internationally agreed, traceable and realistic certification and accreditation system that allows a fair playing field for biofuels (Rosillo-Calle and Tschirley, 2010).

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12

INTEGRATING ESSENTIAL COMPETENCIES FOR SUGAR-ALCOHOL-CHEMICAL BIOREFINERIES

Vadson Bastos do Carmo and *Katia Tannous*

INTRODUCTION

The search for alternative feedstock from renewable sources to replace crude oil has become a worldwide concern. Among the known alternatives, the ethanol produced in Brazil from sugarcane is the most competitive on a global scale.

The sugar-alcohol sector has seen a constant increase in demand and production, mainly due to three factors that are taking place simultaneously: increased ethanol consumption on the domestic market caused by growing sales of flex-fuel vehicles; the potential growth of the foreign market due to concerns with global warming, leading to the use of renewable energy; and the increased consumption of sugar by the foreign market due to reduced subsidies by the European Union and other countries (CARMO and TANNOUS, 2007).

It is in this context that Brazil has been a leader in producing ethanol from sugarcane. The 2008-2009 crop produced 572,738,489 tons of sugarcane (MAPA (a), 2010), generating 27,681,239 m^3 of ethanol (18,050,758 m^3 of hydrated ethanol and 9,630,489 m^3 of anhydrous ethanol) (MAPA (b), 2010) and 31,297,612 tons of sugar (MAPA(c), 2010). This places Brazil among the leaders in the world ranking.

The sugarcane ethanol produced in Brazil is the worldwide leader in terms of production costs, making it competitive with gasoline obtained from crude oil. This leadership position has been achieved through technological innovation both agriculturally and industrially.

In terms of industry, we can point out incremental progress in the optimization of the production processes and the energetic integration obtained through the co-generation of the sugarcane bagasse, with production of steam and electricity to feed the ethanol and sugar production processes, in addition to generating surplus energy to supply the network. We should also like to point out improvements in the integrated management of the production chain.

However, these gains are reaching their limits, considering the current production processes, therefore a disruptive innovation that provides a new technological plateau is now necessary. The so-called second-generation technology makes use of other feedstock with much lower production costs, such as: agricultural residues, sugarcane bagasse, wood and other sources from cellulosic materials.

For this reason, a convergence and synergy should occur between the production processes for conventional petrochemical refineries and the production processes of the new biorefineries obtaining a variety of similar products to those of the petrochemical chain.

In order, for the supply the ethanol market's growing demand, new investments will be necessary, both towards stimulations the creation of a new technology and by the creation of new venture business. Thereby new incentive and financing mechanisms for producers, equipments and process suppliers, new investors and research institutions can represent a competitive advantage that will allow the country to remain the leader of this import production chain.

On the other hand, the petrochemical sector's production chain also represents a significant portion of the national production, with 23.1% of the Brazilian GDP, both in the production of fuel oils and in producing feedstock for other production chains, such as for plastics, textiles, packaging, auto parts and electro-electronics, among others.

This chain is considered a point of reference in the process of technological innovation for the fuel energy sector in Brazil, therefore it was chosen as a benchmark for this analysis, despite this chain's complexity, with innumerous possibilities for ramifications, it is possible to identify a sequence of transformation processes that begin with a small quantity of feedstock and obtain a variety of intermediary and final products.

In this sequence of processes, it is possible to see that the critical competencies necessary to establish competitive advantages are constantly changing. In other words, the initial stages of the process the fundamental elements the access to feedstock, the economies of scale and production costs, and advanced stages, there are innovation and differentiation capacities (FURTADO, 2003).

This article seeks to identify the essential competencies necessary for technological innovation and their stages on the business management of the sugar-alcohol-chemical chain. In this proposal, concepts from Project-based Learning are used as tools to assist in the methodology for managing competencies and providing collaborative learning.

ESSENTIAL COMPETENCIES

Businesses are becoming increasingly concerned with developing and managing their competencies, since in the current context organizations must have a competitive advantage, holding on to the intelligence of their processes and obtaining economy of scale in their production and logistics. Other wise, it is essential for there must be an integration to take place of all the essential processes held by each business in their production chain (ROSS, 1998).

This integration is an important factor towards gaining a competitive advantage and can occur in a variety of ways, from the verticalization of activities, the acquisition of companies across the chain, alliances with clients, suppliers and competitors (FURTADO, 2003). In order, resources to implement that, in addition to information technology resources, a standard of competencies that permeates all critical processes is necessary.

According to NOKATA and TAKEUSHI (1998), this knowledge can be classified as tacit or explicit. The first is related to the knowledge of employees in obtaining restrictive and individual results. The second has to do with the restructuring of information – both individual and collective – in routine work or in new projects, transmitted in a standardized language.

This being so, tacit knowledge should be avoided, since the biggest challenge faced by organizations lies exactly in transforming that knowledge into explicit knowledge, in other words, avoiding the organization's vulnerability and making it possible to manage and disseminate technological information.

Towards this transformation, those authors proposed four interconnected classifications within a continuous process, namely: externalization, internalization, combination and socialization (Figure 1).

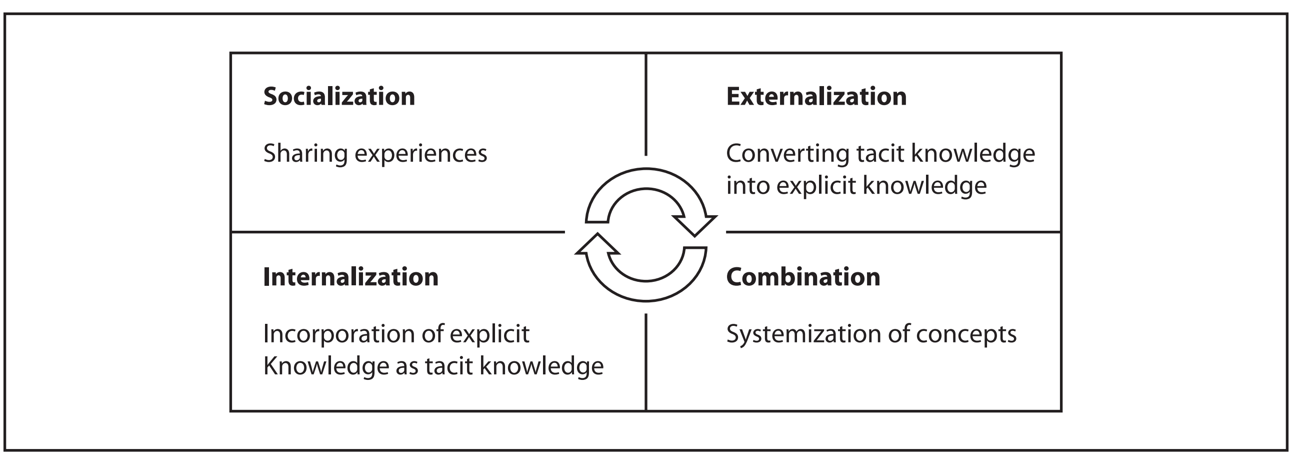


FIGURE 1 Knowledge Spiral.

TABLE 1 Essential competencies corresponding to each stage.

Stage	Example	Type of Competency	Essential Innovative Competency
1	Increase sugarcane processing capacity	Business	Management of manufacturing process performance
		Technical-professional	Development of equipment and engineering
		Social	Centralization of decisions
2	Sugar and alcohol production process optimization	Business	Knowledge of operating costs and performance control
		Technical-professional	Knowledge and maximum process performance
		Social	Decentralization, delegation
3	Sugar and alcohol production process energetic optimization	Business	Process control and strategic planning
		Technical-professional	Knowledge about energy efficiency
		Social	Systemic, holistic vision, autonomy
4	Agricultural and industrial integration (management and logistics)	Business	Complete view of supply chain, integrated management systems and performance indicators
		Technical-professional	Ability to operate in a multifunctional and integrated manner in the organization's many different processes and use of integrated management systems
		Social	Leadership in negotiation, articulation and persuasion in the production chain and community

Source: Table constructed using data from FLEURY and FLEURY (2001).

Socialization is the process that promotes the interaction between the tacit knowledge, where the sharing of experiences takes place. Externalization is where the tacit knowledge is transformed into explicit knowledge, while internalization represents the inverse process. Finally, there is a combination, in which a generation of new knowledge occurs through the systemization of concepts. With this interaction, a business can carry out collective and systemized tasks.

Through this fact, along with the choice of a competitive strategy and the application of a specific management model will make it possible to increase productivity and generate technological innovation. A business innovates when it is able to offer the market a competitive product, services or processes that did not exist previously.

Businesses, once they have incorporated this environment into their organizational culture, should have "intelligence" in a systematic way, in order to facilitate management and the development of essential competencies that will facilitate innovation and provide advantages over the competition. Table 1 shows the essential competences with innovation stages, respectively. Each stage has there types of competencies: business, technical-professional and social (FLEURY and FLEURY, 2001).

The first stage refers to organizational management with emphasis on the performance of its production processes. In this stage, the technological innovation of the sugar-alcohol chain is related to the need for increased quantities of sugarcane processed for alcohol production (Pro-alcohol government program) and the performance of the equipment used in the sugarcane preparation and extraction processes (OLIVÉRIO, 2004).

In the second stage, it is prioritizes the management focuses on optimizing the costs of manufacturing and related services.

In the third stage, management a focus is energy efficiency planning, involving all the internal processes that participate in the resources necessary for production.

In the fourth stage, a strategic vision of the entire supply chain makes it possible to plan and operate the production processes in an integrated manner (agriculturally and industrially) and with minimum resources.

TABLE 2 Types of strategies and essential competencies.

Competitive strategy	Operations	Product development function	Sales/marketing
Operational Excellence	World-class manufacturing/lean production	Incremental innovation	Convince the market that the quality/price ratio of the products/services is optimal
Product Innovation	Scale-up and primary production	Radical (Disruptive) Innovation	Prepare the market and educate potential clients towards adopting innovation
Client-oriented	Agile manufacturing	System development (products; specific services)	Develop client relationships to understand needs and sell solutions

Source: FLEURY and FLEURY, 2001.

Each stage can be related to the organization's essential competitiveness, which are classified by types of competencies: business, technical-professional and social. Examples of each stage are presented in Table 1 (FLEURY and FLEURY, 2001). We can see the development from an initial stage, in which the technical competencies are individual and specific to the production process, towards an advanced stage, where these become integrated in the different processes of the production chain. During this stage, it becomes even more important to use techniques and methods that facilitate the management competencies.

In this sense, aiming at identifying the processes which are essential for the development of competencies for a new plateau of innovation, this study chose the competitive strategy called "Product Innovation".

Table 2 shows the types of strategies and their related essential competencies

This kind of competitive strategy, product innovation, is characterized by the "scaling up" of the primary production and preparation of the market for radical innovation.

TECHNOLOGICAL DEVELOPMENT AND NEW PRODUCTION PROCESS TRENDS FOR THE SUGAR-ALCOHOL-CHEMICAL CHAIN

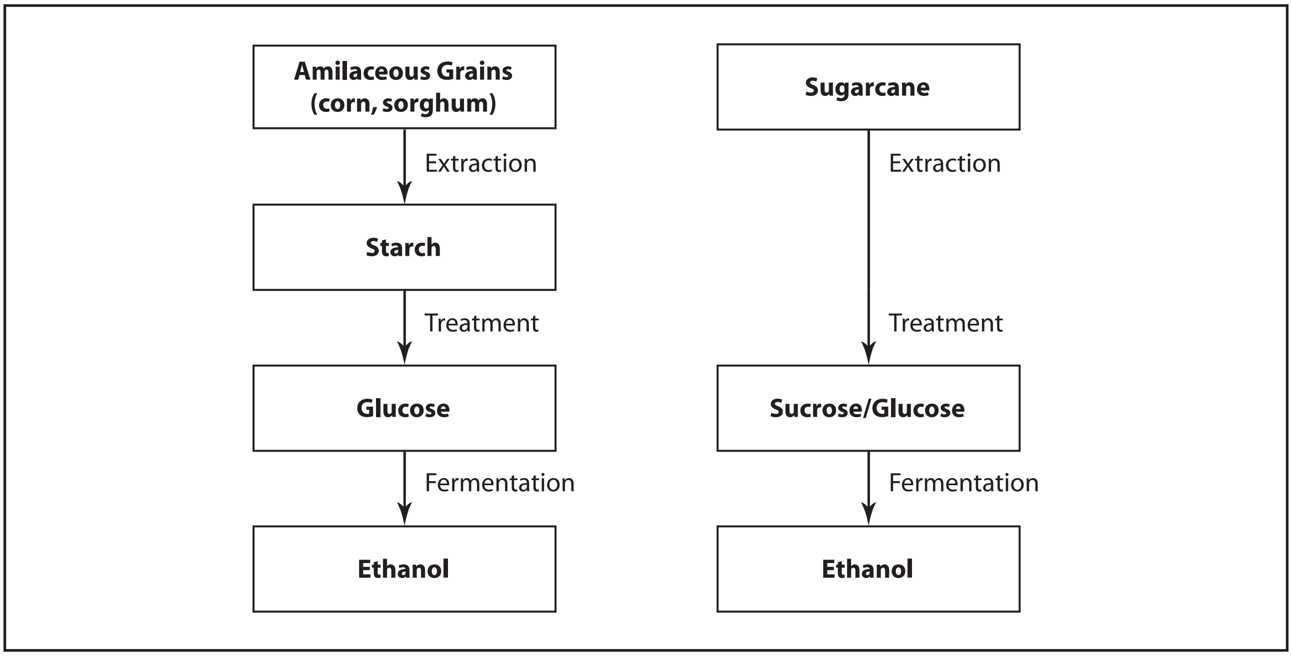
During the 1980s, ethanol, in addition to working in favor of reducing imports of crude oil and its derivatives, was also an important product on the agenda of Brazilian exports. However, starting in 1989, there was a period of net ethanol imports, as a result of the domestic supply crisis.

In recent years the trade balance was positive once again and there is a clear trend towards Brazil being a significant exporter of this product, due to the comparative advantages of producing in this country and the adoption of programs for the use of fuel alcohol in a variety of countries as a strategy for environmental improvement and emissions reductions.

Considering the fleet of vehicles powered by hydrated ethanol since 1980, and since 2003, with the inclusion of flex-fuel vehicles – those which can consume both gasoline with added anhydrous ethanol and hydrated ethanol directly – this fleet grew to 6,419,120 vehicles (ANFAVEA, 2009).

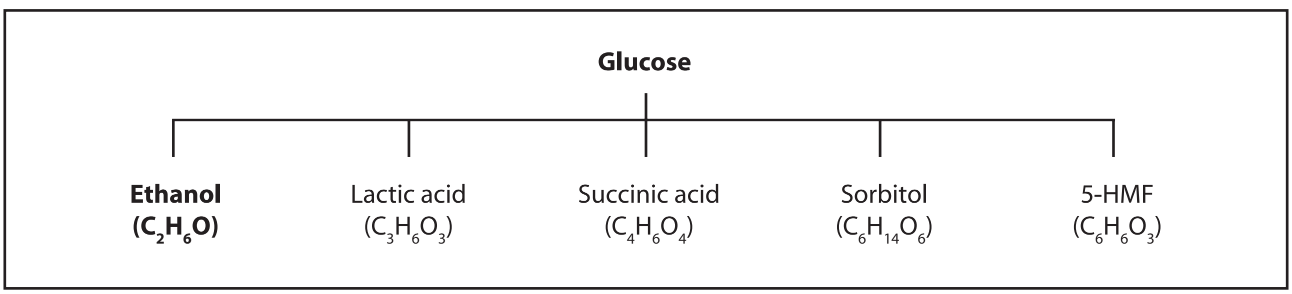
The sugar-alcohol production chain, which represents a significant alternative among Brazilian potentials, especially towards meeting the growing demand for fuel energy, is faced with the challenge to generate greater production of fuel alcohol as a substitute for gasoline, which comes from the petrochemical sector.

This ethanol production chain from biomass originates mainly from amylaceous grains (corn in the United States of America – the world's top ethanol producer) or from sucrose (sugarcane in Brazil – 2nd greatest ethanol producer), with the amylaceous grains being transformed first into starch and then into glucose, while from sugarcane sucrose is first extracted before being transformed into ethanol, as shown in Figure 2.



Source: BASTOS, 2007.

FIGURE 2 Main sources for obtaining 1st generation ethanol.



Source: BASTOS, 2007.

FIGURE 3 Sugar-Chemical Chain.

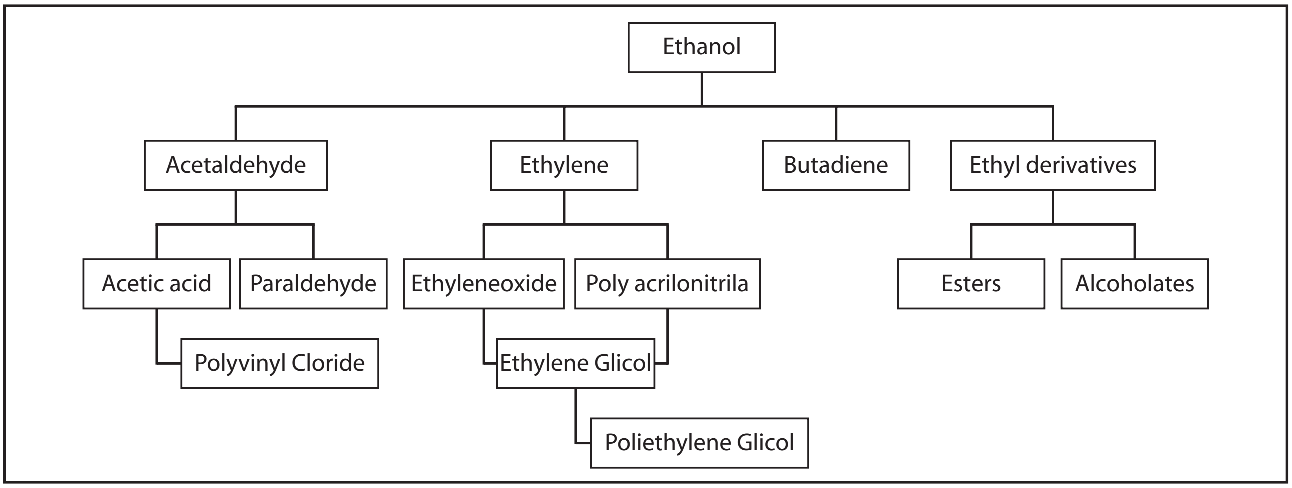
It is also possible to obtain many other products from the sugar-chemical chain starting from glucose as the feedstock and generating other products besides ethanol like lactic acid, succinic acid, sorbitol and 5-HMF (Figure 3).

In its turn, from the alcohol-chemical chain one can obtain the following products by using ethanol as the feedstock (Figure 4): acetaldehyde, acetic acid, polyvinyl chloride, paraldehyde, ethylene, ethylene oxide, polyacrylonitrile, ethylene glycol, polyethylene glycol, butadiene and ether derivatives (esters and alcoholates), among others.

The use of ethanol as a renewable source feedstock for the production of these different chemical products can serve as an alternative to naphtha, which comes from crude oil. This choice is the result of the production costs and price ratio for crude oil.

On the other hand, there is worldwide competition to obtain second generation ethanol (Figure 5) from cellulosic materials, which in this case would have production costs competitive with those obtained by the current processes and which would make it possible for other regions to enter the market as producers.

In addition to ethanol production, cellulosic materials or biomass would allow for the generation of energy by making use of the lignin, as well as the obtainment of oils, phenols and acetic acid, among others. From hemicellulose one can obtain furfural,



Source: Adapted from BASTOS, 2007.

FIGURE 4 Alcohol-chemical Chain.

maleic acid, xylose and mannose, among others. From cellulose, it is possible to obtain glucose and other fermentable sugars that can be transformed into ethanol or other products (YANG, 2006).

In this challenge to achieve the viability of these new processes, achieving new competitive levels, it becomes important to stimulate the development of innovative competencies in private and public organizations. And for this stimulus to take place, it is necessary to understand the process of technological and management evolution which has occurred in competitive sectors of Brazilian industry.

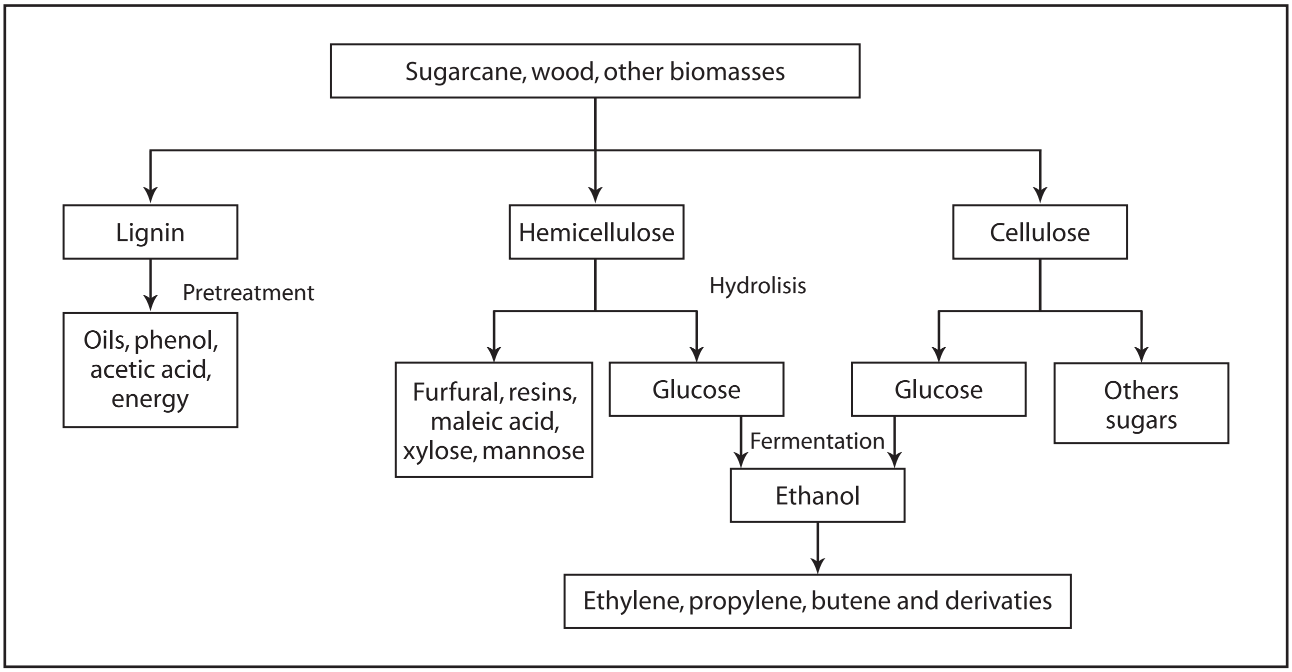
IDENTIFICATION OF ESSENTIAL INNOVATIVE COMPETENCE FOR THE SUGAR-ALCOHOL-CHEMICAL PRODUCTION CHAIN USING PROJECT-BASED LEARNING

After 30 years of constant technological development in the agricultural and industrial processes of the sugar-alcohol chain, it has become difficult to obtain further improvements in productivity and yield using the current production process. For this reason, it has become necessary to develop innovative competencies that will be able to break away from the conventional production processes, replacing them with alternative technological routes so as to achieve new levels of yield, efficiency, productivity and reduced production costs for all products (disruptive innovation).

In order to develop disruptive innovation (breakthroughs), it is possible to adopt the model of technological competencies that identifies different types and levels of innovative technological competencies according to the urgency and manner in which businesses accumulate these competencies and manage the process of learning over the course of time (FIGUEIREDO and TACLA, 2003).

The types of technological competencies are classified according to the stage of innovation and technological complexity, beginning at the basic level with technical, managerial and organizational competencies which are capable of operating existing technologies and passing to a higher level, with competencies in design, engineering, management and research and development towards the incremental innovation of products, processes and organizations. Next, on an even higher level, businesses have competencies for research, development and basic engineering and in project management to copy, implement and develop existing technologies and on the highest level, competency in research, development and engineering to develop and implement new technologies.

In this manner, we can map out these stages in traditional refineries that use crude oil as their feedstock source and compare them with biorefineries, which use biomass (sugarcane) as a feedstock source. As an example, we can cite, in the case of traditional refineries, that the naphtha, which will be used to produce ethylene, whereas in



Source: YANG, 2006.

FIGURE 5 Second generation ethanol production process.

biorefineries there is the obtainment of the ethanol which will be used to produce ethylene.

Alternative feedstock may make a new paradigm possible in the industry of conversion and crude oil derivatives, with these being replaced by ethanol derivatives. Figure 6 compares crude oil-based refineries with biomass biorefineries.

With this new concept of biorefinery, it becomes fundamental for chemistry and biotechnology to share competencies for the conversion processes and end products. In this sense, the use of a model capable of integrating competencies and providing synergy will be essential to make this viable.

In the most advanced stage of innovation, processes and projects are strongly integrated into the organization, emphasizing the acquirement of knowledge, creativity and the structuring of teams, which are supported through collaborative work, the use of information technology and innovation strategy.

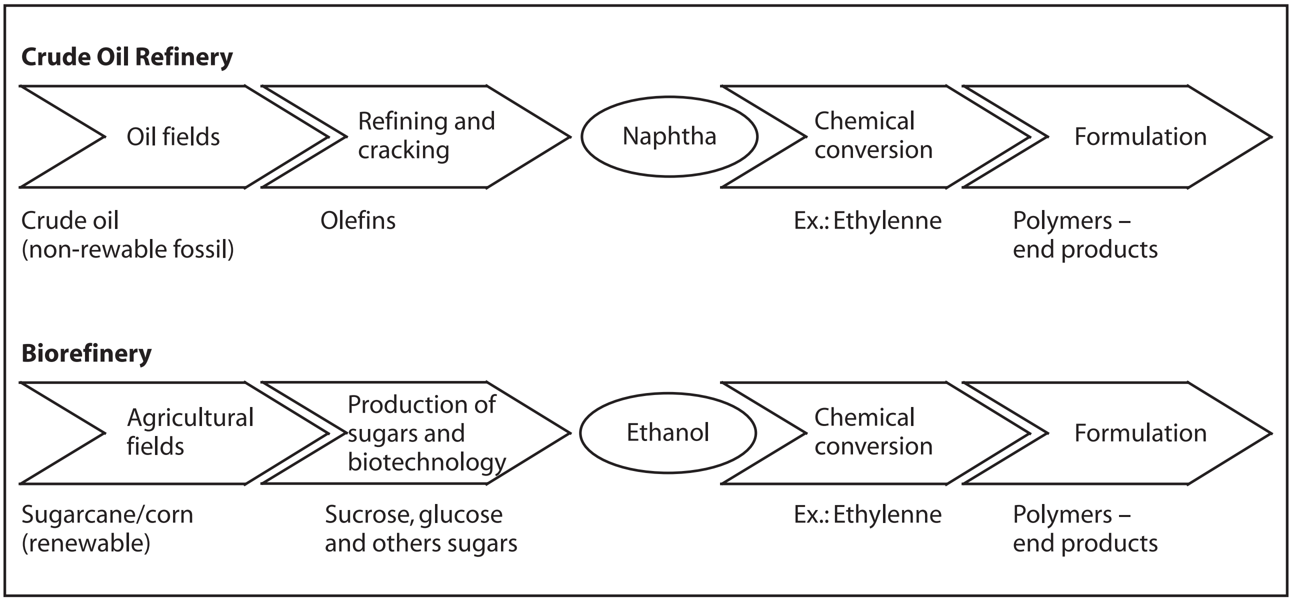
In this stage of development of essential innovative competencies, the proposal is to follow an innovation process model which consists of all the stages, from the creation of a new idea all the way to the commercialization of the product, as shown in Figure 7.

The dissemination of best practices identified in the essential processes can be facilitated through an environment of collaborative learning, which will allow for greater interaction between the different levels of activities and knowledge and can even facilitate the process of developing and acquiring essential innovative competencies.

To this end, the Project-based Learning – PBL method can be used, which aims to facilitate the learning process in a collaborative and multifunctional way, integrating different processes (TANNOUS, 2007). Each stage of the process will be sub-divided into sub-projects that are interconnected towards the reaching of the next stage, facilitating the development of competency management (Figure 8).

As an example, we can compare the competencies necessary for obtaining ethylene and develop a model to develop the essential competencies, especially the ones for innovation and engineering, starting from the stage of the creation of ideas, prototype development and feasibility plan, as shown in Table 3.

Next, the engineering competencies are shown, with their main production processes via the petrochemical route, using naphtha as the



Source: BASTOS, 2007.

FIGURE 6 Comparison of crude oil refineries and biorefineries.

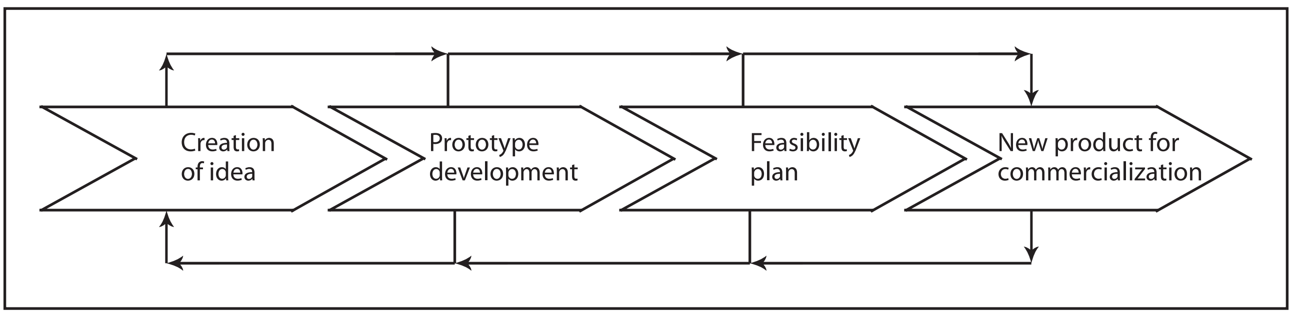


FIGURE 7 Stages of the innovation process.

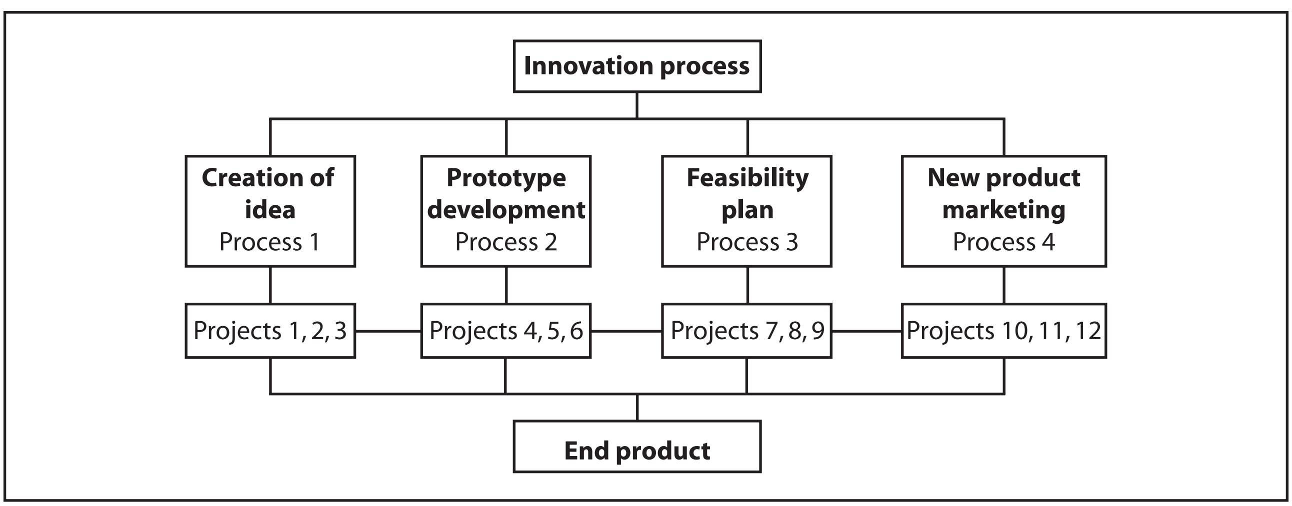


FIGURE 8 Project-based Learning for Innovation Process.

TABLE 3 Stages of the innovation process.

Stages	Innovation competencies
1 – Creation of idea	Capacity to prospect ideas internally and externally Knowledge and abilities in negotiation, persuasion and leadership techniques Capacity to identify and take advantage of opportunities
2 – Prototype development	Capacity for basic engineering, design engineering and product engineering
3 – Feasibility planning	Capacity for business planning Capacity for operational sizing Capacity for economic-financial analysis
4 – Product commercialization	Market research knowledge Capacity for market analysis Capacity and abilities for product commercialization

TABLE 4 Engineering competencies – crude oil refinery.

Stages (crude oil refining)	Engineering competencies
Exploration and extraction of crude oil (petrochemical refinery route)	Knowledge of prospection techniques Knowledge of extraction techniques
Crude oil refining and cracking (naphtha obtainment)	Knowledge of separation processes Knowledge of distillation techniques Knowledge of chemical catalysis

TABLE 5 Engineering competencies – biorefinery.

Stages (sugarcane biorefinery)	Engineering competencies
Sugarcane planting and harvesting (biochemical biorefinery route)	Knowledge of farming techniques Chemistry knowledge about soils and nutrients
Production of sugars, fermentation/distillation (ethanol obtainment)	Knowledge of separation techniques Knowledge of fermentation process Knowledge of distillation techniques

feedstock for the production of ethylene, as shown in Table 4.

In another way, we could describe the evolution of the main perspectives of innovation, from an initial stage in which innovation is individualized and has little interdependency, towards corporate innovation, with intermediate interdependency, all the way to distributed innovation, with strong interdependence and direct involvement of research and development integrated into strategic management (VEDOVELLO, 2006).

For comparison, we can also describe the engineering competencies in their main processes via the alcohol-chemical route, using ethanol as the feedstock in Tables 3, 4 and 5.

This being so, in order for technological capacity to succeed in provoking technological changes, it will be necessary to maintain funding, both towards using existing production processes and also obtaining funding to provoke these changes in the production processes and systems (VEDOVELLO, 2006).

These last competencies are the ones that are disseminated throughout the organization and production chain, including research centers, universities and external specialists.

FINAL CONSIDERATIONS

At the most advanced levels of innovative competencies, one must identify the development of new products and processes via engineering and P&D&I – Research, Development and Innovation with essential competencies for the management of world-class projects and the launching of innovative products.

Once the essential competencies are identified and adapted to the chosen production process, a plan for development and management of the innovative competence for the sugar-alcohol-chemical sector can be drawn up.

This competency development plan can be facilitated by means of a virtual learning environment, enabling, in addition to the development of competencies, that is, once the deficiencies and competitive advantages are known, management regarding the strong points that should be strengthened and the weak points that should be neutralized, it will become possible to strengthen and integrate other management methods, in the untiring search for competitive advantages.

With this model applied and the results being satisfactory, it can be replicated both for other processes and in-company departments and for other companies inserted into the chain, facilitating integrated management and contributing to the strengthening of the entire production chain of this new sugar-alcohol-chemical sector.

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13

ALCOHOL FUEL:

CONSOLIDATION OF THE DOMESTIC MARKET AND STRATEGY TO DEVELOP FOREIGN MARKET

Julio Maria M. Borges

INTRODUCTION

The theme covered in our article is relatively new, because only now there are reasons to discuss global markets for alcohol strictly on economic terms, at some distance from ineffective state protectionism.

Most of our considerations will be based on the recent Brazilian experience in producing and using alcohol as a fuel, initiated in the mid-1970s. Additionally, we will be taking into account the knowledge developed in research institutions like the Copersucar Technology Center (today Centro de Tecnologia Canavieira), Planalsucar (today Ridesa – Inter-University Network for the Development of the Sugar-Alcohol industry), CTA – Aerospace Technology Center, IEA – Institute of Agricultural Economics, Unicamp, USP, Federal University of São Carlos, UFRJ, just to mention a few among many others.

Finally, we are also using our professional experience at Job Economia, particularly in regard to foreign markets as consultants to BID and Unido.

ECONOMIC BACKGROUND

All the movement towards using alcohol as a fuel is owed to relatively expensive petroleum, currently around US$ 100.00 per barrel. This situation began in 2004, as shown on the graph below, referring to weekly light petroleum WTI prices in US$/barrel. Rates refer to the first market closing in the New York Futures Exchange.

Upon considering that:

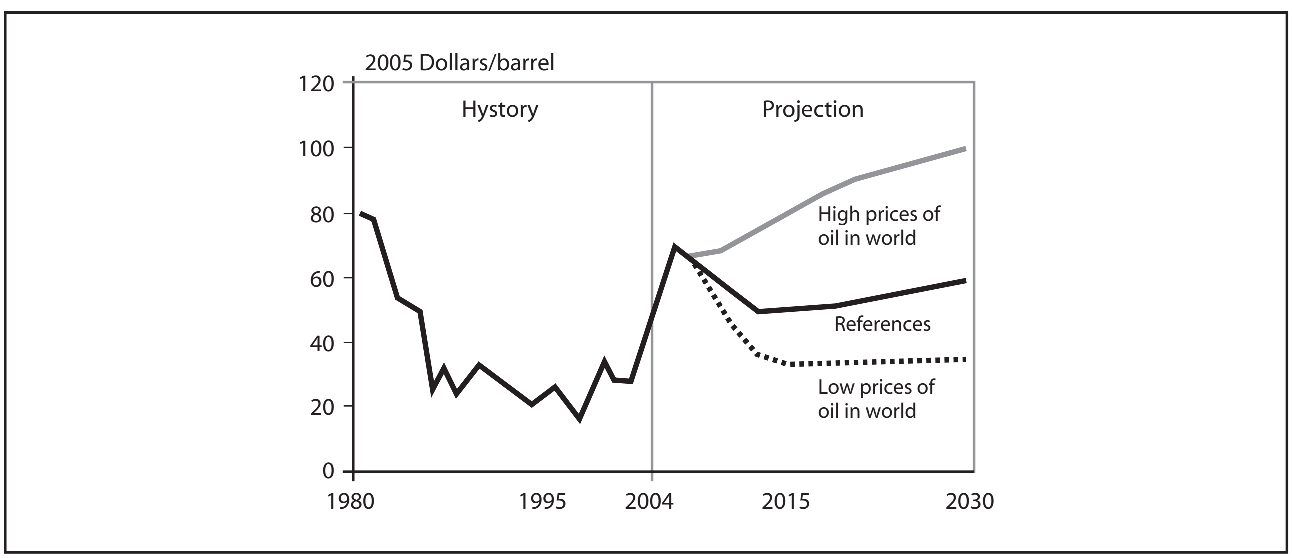
- Brazil, Russia, India, and China, should maintain an intense pace in their economic development and energy demand;
- OPEC is willing to provide oil at a price (US$ 100/barrel) that makes costly new discoveries viable, as they do not foresee supplying alone all the additional demand for the product, we can expect a well balanced global offer and supply of petroleum and its derivates, and therefore with relatively high prices. Everything leads to the fact that cheap petroleum – like it was in the 1980s and 1990s – will no longer exist.

The U.S. Department of Energy – in its *Energy Information Administration*, *Annual Energy Outlook*, 2007, Washington, DC – which has been conservative in their price forecasts saw, in 2007, three possible scenarios for petroleum in the 2005-2030 period:

- declining prices relative to the situation in 2005 and reaching US$ 40 per barrel over the next two decades;
- a reference scenario with prices also declining from the 2005 level and varying in the US$ 50-60/barrel range over the next two decades;
- rising prices from 2005 on, reaching US$ 100/barrel at the end of the period under analysis.

The study considered the US$ exchange rate of 2005. Keeping in mind that the average dollar

FIGURE 1 Variation of oil prices (ligh and oil) – from 2002 to 2008 in US dollars/barrel.



Source: Energy Information Administration (USA). *Annual Energy Outlook 2007*. DOE/EIA-0383(2007) (Washington, DC, February 2007. Website <www.eia.doe.gov/oiaf/aeo>.

FIGURE 2 Variation of oil prices (hystory and projections) from 1980 to 2030, in US dollars/barrel.

in 2005 (as compared to August 2008) devaluated 20% relative to the euro, and 33% relative to the real, it makes sense that the high prices scenario has prevailed.

Petroleum in the US$ 70-80/barrel range is enough to render the Brazilian anhydrous alcohol mixed to gasoline viable in the long run, considering an exchange rate within the US$ 1 = R$ 1.70-1.80 range and a refining premium around US$ 12/barrel. Furthermore, we should not forget that alcohol mitigates the negative consequences of the greenhouse effect, and that sugarcane alcohol, by means of co-generation of electric energy, accrues rights to carbon credits.

Therefore, fundamentally, Brazilian anhydrous alcohol, to be mixed to gasoline in a proportion of up to 20%-25%, represents a good investment and export opportunity, considering that petroleum has a high likelihood of its price reaching or surpassing US$ 70/barrel in the long run.

We are only considering anhydrous alcohol mixed to gasoline in this analysis, as the use of 100% hydrated alcohol in flex-fuel Otto cycle motors is less efficient on both performance and economical criteria. As we will see later, the global supply of alcohol might not suffice to cover a worldwide demand of 20% to be mixed to gasoline.

It is worth reminding those for whom fuel alcohol is not their everyday subject, that anhydrous alcohol mixed (up to 20-25%) with gasoline does not cause significant losses in engine performance (km/l or MPG). On the other hand, the use of 100% hydrated alcohol in flex-power motors causes a 40-45% increase in fuel consumption, as compared to gasoline.

OUTLOOK FOR THE DOMESTIC MARKET

The table below predicts a supply and demand scenario for 2015, developed using a model created by Job Economia. The baseline year is 2004, when the Proalcool fuel movement became strong.

Premises that support the alcohol supply and demand forecast are the following:

TABLE 1 Supply and demand scenarios for cane, ethanol, and sugar in Brazil.

Brazil		2015 Million	2004 Million	Annual growth 2004-2015
Supply				
Sugarcane total area	ha	13.7	5.7	8.3%
Sugarcane	ton	980	386	8.8%
Sugar	ton	38.3	26.6	3.4%
Total ethanol	m^3	59.8	15.3	13.2%
Total TRS	ton	143.7	55.2	9.1%
Demand				
Domestic demand	ton	12.0	9.5	2.2%
Sugar exports	ton	26.0	16.9	4.0%
Domestic demand of ethanol				
Fuel ethanol	m^3	50.0	12.7	13.3%
Others uses	m^3	1.7	1.0	5.0%
Ethanol exports	m^3	8.5	2.6	11.5%
Total TRS	ton	144.0	55.8	9.0%

1. GNP growing 4% per year.
2. Sales of automobiles and light commercial vehicles growing 5% per year.
3. Mix of anhydrous alcohol to gasoline of 25%.
4. Sales of flex-fuel vehicles should rise from 80% in 2006 to 90% from 2008 onwards, i.e.: 1.43 million in 2006 to 3.2 million in 2015.
5. Consumer price of hydrated alcohol ≤ 70% of the price of gasoline.
6. Vehicles Fleet: 31 million in 2015, compared to 20 million in 2006. Growth of 5% per year.
7. Average yearly scrapping of 6.6% of the fleet, against sales that represent 11.1% of the average fleet in the 2006-2015 period.
8. Global Otto cycle (gasoline, alcohol, and natural gas) consumption grows 8.3%. Fuel consumption increases from 1,700 liters year per vehicle to something close to 2,250 liters/year per vehicle, as a result of hydrated alcohol replacing gasoline, income and credit growth, and reduction of the average age of the fleet.
9. Alcohol demand for export admits that in 2020 the world will be using 10% of alcohol mixed in gasoline, and that the Brazilian share would be 12%-13% of this consumption, close to the forecast for sugar.
10. The model further considers that chemical industries will be having *business as usual* in their demand for alcohol. The model does not consider a more aggressive demand of chemical industries, as we have seen lately.

Some conclusions:

1. In 2015 Brazil will be milling something close to 1 billion tons of sugarcane per year, with a sugarcane cultivation area around 14 million hectares.
2. Sugar production will increase some 3%-4% per year in the 2004-2015 period, while alcohol production should grow some 13%-14% per year, getting close to 60 billion liters in 2015.
3. Sugar exports which were – over the past decade and the first half of the current one – the dynamic component of the

The mixture gasoline-alcohol up to 10%

Modifications in the engine not needed
1 liter AA = 1 liter of gasoline
Potential world demand: **120 billion liters/year**

Mixture from 10% to 25%

Need to adjust compression ratio
1 liter AA = 1 liter of gasoline
Potential world demand: **300 billion liters/year**

Flex fuel vehicle: 0% to 100% alcohol

Need to adjust the engine
1 liter AH = 0.7 liter of gasoline
Potential world demand: **1,200 billion liters/year**
Equivalent cost: 1 liter AH = 0.94 liter AA

FIGURE 3 Demanda potencial mundial de álcool para motores segundo diferentes porcentagens de mistura.

industry, having grown around 17% per year, will have a rather refrained growth, close to 4% per year.

4. Possible alcohol exports are predicted to be between 8 and 9 billion liters. If more volume is required, the domestic market will only be partially served with alcohol at relatively high prices for the Brazilian consumer.

OUTLOOK FOR THE FOREIGN MARKET

Considering the current world consumption of gasoline, the potential demand for anhydrous alcohol as fuel in the world may be estimated as shown in the Figure 3.

The world supply of fuel alcohol may be seen on the Figure 4.

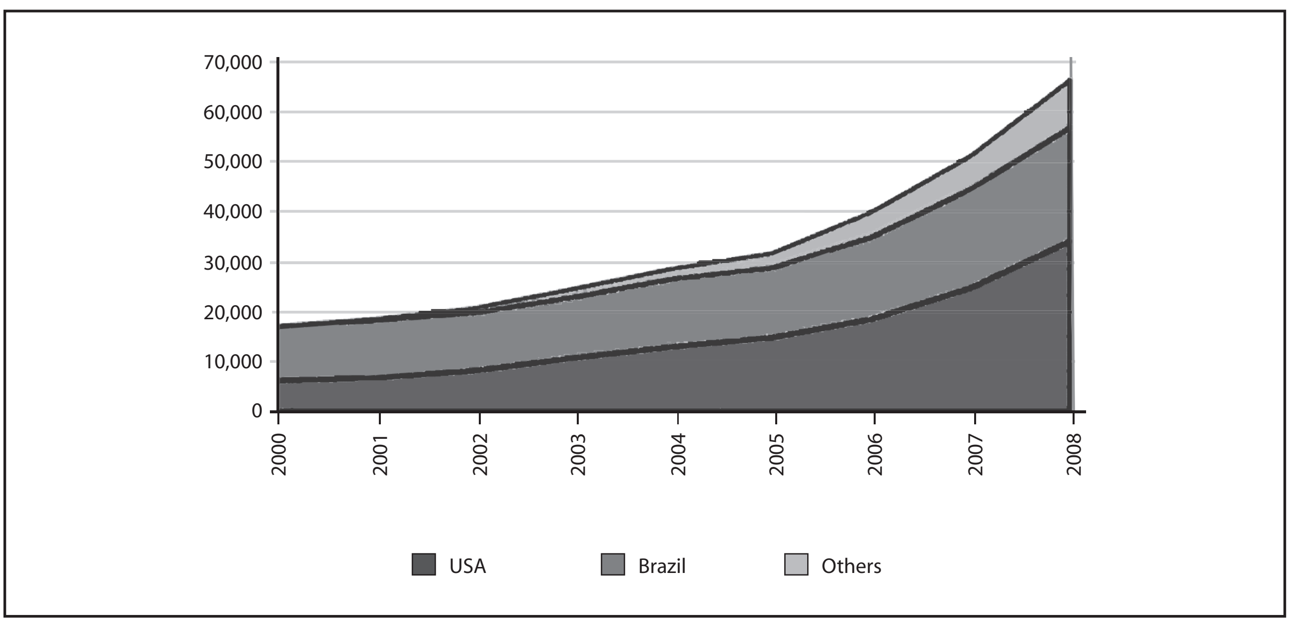
The growth of ethanol demand in the world has been expressive since 2004. World production more than doubled in the last four years. On the other hand, Brazil and the US still hold some 90% of this production. This means that the fuel alcohol issue for other countries is still more an issue for debating and taking stand than real action.

It is important to consider from the selling side that biofuels represent a good investment opportunity, mostly in the case of alcohol from molasses and sugarcane. Furthermore, it should be considered that perspectives for biofuels are very good, however limited by time and space. The use of food cultures for energy is limited by their high opportunity cost. The land available for significant increases in harvests for biofuels is limited to some regions in the world, like Brazil and Africa. Finally, it should be remembered that new technologies, in the long run, will take care of new energy sources, as well as their more efficient usage.

The International Energy Agency, in 2007, suggested a world energy supply scenario that can be summarized as shown on the table below.

Production levels predicted for Brazil and the US are conservative. In this latter case we are considering the new energy law, passed in December 2007. Making the expected corrections, we arrived at a world production of 140 billion liters per year or 2.4 million barrels per day.

As shown on the previous table, biofuels (ethanol and biodiesel) production will increase significantly until 2012: 19% per year. However their share in the market will be small. They will represent 2.5% of the petroleum market, and the alcohol-gasoline mixture may represent around 10% worldwide.



Source: International Sugar Organization – Market Trends, May 2008.

FIGURE 4 World production of bioethanol, Ml.

TABLE 2 Scenarios for world oil and biofuels supply.

	2006		2012	
	Billion liters/year	**Million barrels/year**	**Billion liters/year**	**Million barrels/year**
World oil	4,932	85	5,571	96
Biofuels, including biodiesel	50	0.86	102	1.75
USA	19	0.33	31	0.53
Brazil	17	0.29	31	0.53
EU	8.7	0.15	22	0.38
Others	5.3	0.09	18	0.31

This is a comfortable situation that causes little concern for OPEC. The gasoline market will have to undergo an adjustment, since its consumption will drop as alcohol is used more and more. However, by means of relative prices, it will be possible to fine-tune the supply and the demand of petroleum derivates.

OUTLOOK FOR BRAZILIAN ALCOHOL EXPORTS

We are considering that the worldwide production and consumption potential of fuel alcohol on a first stage to be something in the vicinities of 120-140 billion liters per year, i.e., 10% of the world's consumption of gasoline.

If Brazil maintains – like with sugar – a share of 40% of world exports, and considering exports as 30% of the world consumption, like in the case of sugar, which is a protected market, it is reasonable to conservatively expect Brazilian alcohol exports in the magnitude of 15 billion liters per year. We are currently exporting close to 5 billion liters per year.

How long would this take to happen?

From mid-range on, as on the short range there is some worldwide resistance to use fuel alcohol.

Such resistances are found mostly in the petroleum industry, as well as among the sugar producers, natural candidates to produce alcohol, initially from sugarcane molasses. In this case, producers intend to expand the existing protection in the sugar market to the new fuel alcohol market. This intent is politically difficult nowadays, as the markets are competitive and globalized, often regionally clustered, which prevents new commercial safeguards.

Next we will cover in detail the aspects that condition the development of the international alcohol market.

Commercial barriers

The countries now considering the adoption of fuel ethanol, such as the US and the EC, understood this move as an instrument to reduce dependency on imported petroleum and improve the environment, as well as an instrument to protect employment and income in the field, i.e. the initial idea was protectionist from an international trade standpoint.

This condition inhibits alcohol as a global commodity on the short term. On mid and long terms, it is possible that the degree of protection to domestic production of ethanol will be naturally reduced, as an outcome from a growing demand for fuel alcohol and restrictions on the supply side, particularly the competition with foods.

Alcohol in other countries and the interests of the petroleum industry

It has been observed in other Latin American countries and even in some developed countries that are considering using biofuels that economic interests connected to petroleum still raise barriers to using ethanol to replace derivatives from that product.

This condition also inhibits alcohol as a global commodity on the short term. As alcohol demonstrates its viability as an option – from technical, economic and strategic stances – to replace part of the gasoline, improving its quality and the environment, the petroleum industry will adopt this commercial option. Observe the cases of Venezuela and Nigeria, which are petroleum producers and exporters and that consider using Brazilian anhydrous alcohol mixed to gasoline.

Technology transfer would not be an obstacle to the entrance of other countries in alcohol production, considering it is available, either from governments interested in the use of fuel alcohol – like Brazil and the US – or from equipment suppliers.

Brazil's alcohol supplying capacity

Investment projects in the production of alcohol in Brazil point to a production level around 60 billion liters in 2015 and that about 20%-25% might be for export. This situation of exportable surplus as a fraction of the total production is not much different from the current one: we are producing some 24-25 billion liters and exporting 5 billion of them.

Our alcohol supply-demand scenario admits that the domestic market will continue being the larger destination of the production, based on a steady demand from flex-fuel vehicles, i.e., if in the next seven years, foreign demand exceeds our exportable surplus of 8-9 billion liters, there will be a need to increase the pace of investments in comparison to what we are witnessing now, or to partially supply the domestic market with higher prices for the Brazilian consumer.

Improvements in alcohol exportation logistics are taking place and should support growing volumes of international trading of this product.

Product specification

As long as there is a specification standard for fuel alcohol that may be accepted in the international trade, this will certainly foster and increase the dynamics of its acceptance as a global commodity.

The beneficial effect of this standard specification should be more effective in the mid term, when it is expected that the world will be more open and less protectionist to the international trade of fuel alcohol.

Business agreements and future markets

The availability of a solid reference for an alcohol export agreement is essential for the dynamics of its foreign trade. Furthermore, if we want the product to become a global commodity, an exchange negotiating alcohol in future markets is needed to avoid risks associated to market prices.

The beginning of the change in the world's energy matrix is benefiting Brazil, with sugarcane alcohol. Our country can also exploit this opportunity by developing conditions for our BM&F to become an international benchmark as future alcohol trade exchange.

The alcohol agreement at BM&F is a mature agreement, resulting from negotiations that began some 10 years ago. What they miss is an initial and temporary injection of liquidity, which depends on the market players themselves, if they want to turn Brazil into a world reference for fuel alcohol. After all, our country has the longest tenure in this matter, as we have been using fuel alcohol for 30 years already.

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14

SUGARCANE ETHANOL AND THE LATIN AMERICAN ENERGY INTEGRATION

Luiz Augusto Horta Nogueira

ABSTRACT

Most of Latin American and Caribbean countries, with a few exceptions, depend on imports to meet their energy needs; at the same time they present appropriate conditions towards the implementation of bioenergy programs for the production of bioethanol and bioelectricity within the sphere of their sugarcane industry. These notes comment the advantages that could be achieved with this type of bioenergy programs and discuss the obstacles that prevent these countries to start using these alternatives, indicating their perspectives and the essential roles of cooperation and integration working as factors to overcome the lack of information and the uncertainties that might still remain. Relying on an appropriate technological support, other countries of the region will be able to use the Brazilian bioenergy model to develop the use of their own resources with advantages for all of those involved.

INTRODUCTION

As sugarcane ethanol has well-proven its sustainability through its environmental differentials and its economic competitiveness, the fact that some countries of Latin America and the Caribbean, with a few exceptions, have not implemented programs aiming at the introduction of this biofuel to their energy matrix still calls expert's attention. Most of these countries are completely dependent on imported fuels, whose supply along the past few years has consumed a high amount of their resources, imposing a heavy burden on the society. However, most of these countries have a secular sugarcane industry with good performance indicators and perfect conditions to offer a national renewable fuel, creating an industry that is able to work synergetically with other relevant goals such as the generation of jobs and the dynamization of productive activities. As an example of the effects, the generation of bioelectricity may be carried out in important levels, in many cases, reducing the use of fuel used in thermal power plants.

Indeed, the production and use of biofuels show a great potential both in Latin America and in the Caribbean, with the possibility of meeting multiple goals, not only energy ones. This potential has been presented in several studies that confirm this region to be one of the most well-favorable to invest in this energy technology. Among the studies that show such potential, it is possible to mention several studies carried out by the Economic Commission of Latin America and the Caribbean, CEPAL, especially in the Central-American sphere (CEPAL, 2004a; CEPAL, 2004b e CEPAL, 2006). Having a broadening character, a review of the advances and the perspectives for bioethanol as an energy vector in the Latin American context were presented by (2007), by the Inter-American Institute for Cooperation on Agriculture (IICA, 2007) and by the Inter-American Development Bank, (BID, 2007).

These notes present an brief review of the two bioethanol programs that are effectively being implemented in Latin America, besides Brazil's, estimate the production potential for each country based on the installed capacity of the sugarcane industry and indicate the evolution in the bioethanol production that has been observe along the past few years. The obstacles that must be considered for the effective and broaden implementation of these programs, which passes through the energy cooperation and integration of the region, are also presented and commented.

TWO EXPERIENCES: COLOMBIA AND COSTA RICA

Aiming at implementing programs for the productions and use of bioethanol, many Latin American countries have been taking actions to introduce bioethanol blends, usually between 5% and 10% in volume, to the gasoline, establishing the legal basis and the regulatory mark, without, however, observing significant changes within today's fuel market scenario. Among the several ongoing initiatives, two countries can be highlighted due to their advances: Colombia and Costa Rica (HORTA NOGUEIRA, 2007).

In 2001, through the promulgation of Bill 693, Colombia started to implement the production and use of ethanol. The main objectives of this Bill are the reduction in the emissions of hydrocarbons and carbon monoxide, the maintenance and the generation of agricultural jobs, the agro-industrial development and the contributions towards the strategic purpose of energy self-sufficiency. In short, the first article of this Bill establishes that "the gasoline used in urban centers that have more than 500 thousand inhabitants must contain compounds such as carbureting alcohol by September 2006". The same Bill defines the oxygenated gasoline with a content of 10% of biofuels (UPME, 2006). In order to meet this purpose, a program was designed and its implementation was preceded by careful planning and information to those who were involved. Today it is fully in motion. As institutional agents that are relevant in this sense, establishing goals and defining chronograms, Unidad de Planificación Minero-Energética, UPME, official organ of energy planning, and Corpodib, a mixed economy venture dealing with innovating projects, must be mentioned.

The first bioethanol fuel Colombian plant started to produce in 2005 with a production of 300 thousand liters a day. Along 2006, five other plants started to produce the same biofuel, all of them located in the Valley of River Cauca, with a combined capacity of 357 million liters a years. Sugarcane crops develop well in this region with harvests all year round, assuring the distilleries a high availability. The Colombian government expects the country to reach an annual production capacity of 1.7 million liters of bioethanol by 2010, the necessary volume to add 10% to the gasoline and attain exportable surplus ranging about 50% out of the total produce (UPME, 2007).

In Costa Rica the first experiences with carbureting bioethanol took place during the 1980s, but they were set aside due to the low cost of oil in 1985 and on. However, with recent scenarios more favorable to biofuels, the government of this country articulated a new program to implement the use of bioethanol. In May, 2003, the executive power published Decree n. 31 087-MAG-MINAE, creating a Technical Commission to "formulate, identify and design strategies aiming at the development of anhydrous ethanol, distilled, and use local raw-material as a substitute of the MTBE of the gasoline". The basic objectives presented by this Decree were: Agro-industrial development (economy reactivation, generation of the aggregated value), environmental improvement (for example, due to the replacement of the MTBE) and from the energy point of view, the diversification of the sources and the reduction in the external dependence of the fuel. Initially, the program aims at adding 7.5% of ethanol to the gasoline used in the country, which will be developed in successive stages for the assimilation of the operational procedures and the gradual expansion of the infra-structure. Experiments using different vehicles were carried out with the fuel blend. As the results were good the commercialization in limited markets began. Considering the addition of 10% of bioethanol to all the gasoline used in the country, the demand of this fuel is estimated to be 110 million liters/year in 2010. The state owned oil company, RECOPE, has played an important role regarding the appropriate introduction of bioethanol to Costa Rica (RECOPE, 2007).

Today, Costa Rica relies on 15 agro-industrial units to process the sugarcane produced by 12 thousand producers, but it manufactures ethanol in only two plants, besides a dehydrating unit that processes the imported product and exports it to the North-American market. It is estimated that 16% of the gasoline commercialized in the country has ethanol (Comisión Nacional de Biocombustibles, 2008).

POTENTIAL AND EVOLUTION OF THE PRODUCTION OF SUGARCANE ETHANOL IN LATIN AMERICA

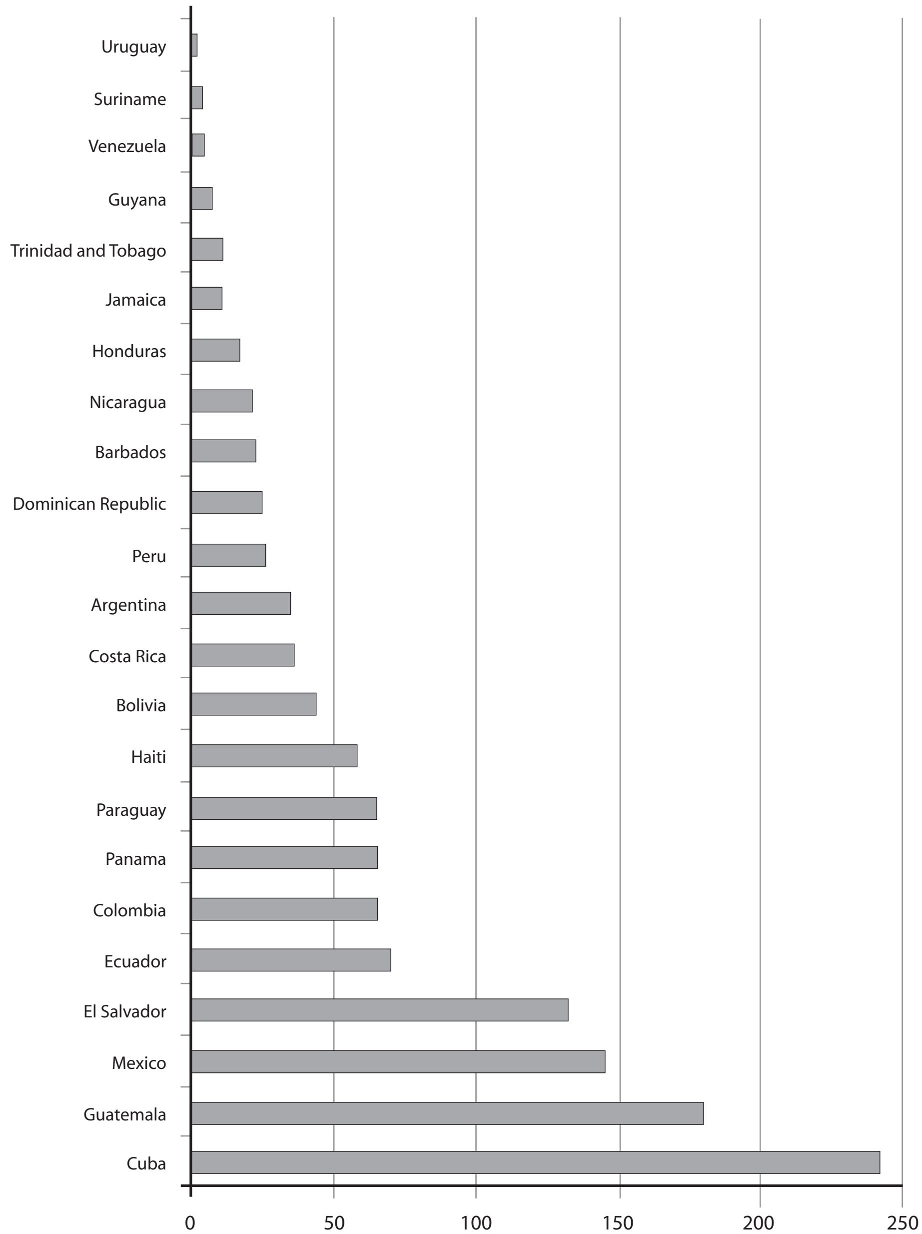
Two scenarios have been analyzed to show the potential of the Latin American countries towards the promotion of a 10% blend of sugarcane ethanol in the gasoline internally consumed, particularly regarding land availability and the size of the local sugarcane industry (CEPAL, 2007): a) production of bioethanol out of the conversion of exhausted molasses, assuming a productivity of 78 liters of bioethanol per ton of produced sugar, and b) the exclusive production of bioethanol, considering an agricultural productivity of 75 tons per hectare and an industrial productivity of 80 liters of bioethanol per ton of sugarcane, corresponding to 6 thousand liters of bioethanol per hectare. For the first case, the fraction of the bioethanol demand that could be met only with that byproduct of sugar manufacture was determined and for the latter, the area of sugarcane demanded was determined as a percentage of the total agricultural area and of the area used for sugarcane crops, according to FAOSTAT (2007). The data regarding the gasoline demand and, therefore, the bioethanol demand, refer to values of 2005, the most recent data available (OLADE, 2006). The results are illustrated by the following figures, where only the countries that have over a thousand hectares of sugarcane crops were included. Brazil has been excluded from this analysis, given that the country already has a huge program for ethanol production and use, including the use of pure bioethanol. This way, there was no meaning in using these indicators.

As it can be observed in these figures, sugarcane bioethanol can be produced according to national needs, without significant impacts. For the Latin American region, aiming at a 10% blend of bioethanol and gasoline, the average demand would be met in 35% through the use of the existing molasses or, alternatively, increasing today's sugarcane cultivated area by 22% for the production of bioethanol, which means about 0.4% of the agricultural land. However, there is a significant diversity among the countries. This way, Cuba, Guatemala, Guyana and Nicaragua present high potential availability for bioethanol production out of molasses, higher than the demand corresponding to a 10% blend in the gasoline.

In another example, in Haiti, Suriname, Uruguay and Venezuela the size of their sugarcane agro-industry does not meet even the 10% demand of ethanol, under the considered scheme. From the land availability point of view, apparently, the situation may be considered almost without restrictions in the Latin American region. The exceptions are Barbados, Jamaica, Trinidad e Tobago, Suriname and Venezuela, which could produce enough ethanol for the 10% blend with less than 1% of their agricultural land.

An important factor that encourages the production of bioethanol in Latin American countries is the re-structuring of the sugar regime carried out by the European Union regarding the Common Agricultural Policy, which will reduce the price guarantees by 36% for these countries within the next years. In response to this situation, countries like Barbados, Belize, Jamaica and Guyana have considered directing their sugar availability to the production of ethanol. About that, Jamaica is the most advanced country, intending to implement the 10% ethanol mandatory blend in gasoline in 2008 (CEPAL, 2007).

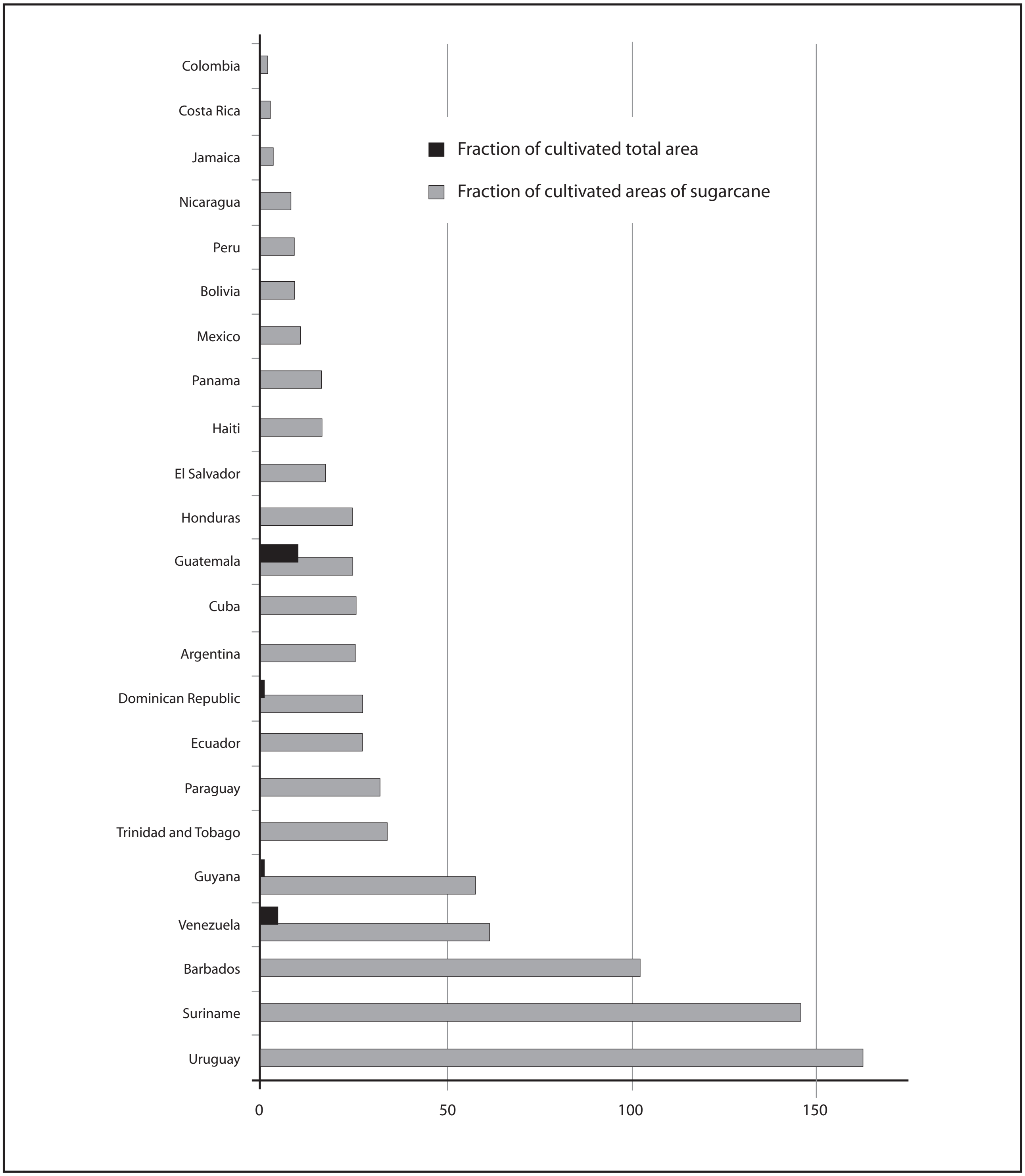
Besides supplying their internal markets, many times with limited sizes, Latin American countries have assessed the possibility of exporting bioethanol, especially to the United States. Some agreements support these initiatives such as the Dominican Republic – Central America Free Trade Agreement, ratified by the American Congress in 2005 and the Caribbean Basin Initiative, CBI, established by the North American Congress in 1983, exempting of importing taxes and other



Source: CEPAL, 2007.

FIGURE 1 Fraction of the bioethanol demand to blend 10% to the gasoline that can be produced out of the residual molasses conversion available in the sugar manufacture.

duties, within the defined conditions, ethanol imported from the beneficiary countries (Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, British Virgin Islands, Costa Rica, Dominican Republic, El Salvador, Granada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Montserrat, Netherlands Antilles, Nicaragua, Panama, Saint Christopher and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago). According to the rules established by the CBI the bioethanol can be exported in the following cases: a) volumes up to 7% of the American market without origin restrictions, i.e., only bioethanol processed in the country is acceptable, b) 132 million of liters of bioethanol as a supplementary quote, which contains at least 35% of local product; and c) a limited



Source: CEPAL, 2007.

FIGURE 2 Fraction of cultivated areas (total and of sugarcane) necessary to produce the bioethanol demanded to blend 10% to the gasoline, assuming the ethanol production straightly from the juice.

value of biofuel since it contains more than 50% of local content.

Responding the growing demand and understanding the new opportunities, ethanol production has been growing in many countries of the region, although the internal market has been ignored most of the times. The following table presents the evolution regarding bioethanol production for the main producing countries of Latin America, except Brazil. It is important to highlight

TABLE 1 Bioethanol production in Latin American countries, from 1999 to 2008 (thousand m^3).

Country	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Colombia	28	25	22	18	15	20	29	269	283	302
Argentina	174	171	168	150	150	167	165	188	195	240
Guatemala	45	55	65	65	65	65	65	80	100	150
Cuba	79	91	106	102	124	134	89	110	121	134
Bolivia	26	31	29	30	46	60	50	80	115	125
Nicaragua	33	27	22	28	29	27	29	29	45	75
Mexico	56	67	62	47	39	35	59	50	60	64
Ecuador	32	38	32	32	50	53	53	44	50	54
Costa Rica	30	30	30	30	30	30	30	40	50	50
Peru	28	28	29	30	30	22	16	16	19	23
Panama	13	11	10	13	13	14	14	15	15	15

* Estimated values for 2008.

Source: F. O. Licht, 2008.

this growth in countries like Colombia, Guatemala and Bolivia; the last two cases associated with the exportation of the biofuel to the North-American and European markets.

It is interesting to compare today's productions, according it was shown in the table, and the values of the potential demand for bioethanol, necessary for the 10% blend of this fuel. In this sense, the Latin-American countries can be grouped into three categories:

a) countries where the production is small in relation to the demand (Mexico, Peru, Panama and Ecuador); the perspective for the introduction of this biofuel need greater effort;
b) countries where the production is close to the demand (Argentina, Colombia and Costa Rica); national programs for bioethanol use are ongoing or could be developed;
c) countries where today's production is lower than the foreseen demand (Guatemala, Bolivia, Cuba and Nicaragua).

Especially the last group, mainly Guatemala and Nicaragua, it is difficult to find arguments that could defend these countries for not investing immediately in programs for the introduction of the bioethanol to the gasoline that is internally consumed. Indeed, it does not matter the several plans, agreements, protocols and attempts regarding legislation adjustments, practically no advances have been registered showing that these countries have made any attempts to use the fuel they produce and export in their vehicles. In fact, besides the reasonability and sustainability of the bioenergy systems at these conditions, there are institutional difficulties and obstacles that will now be briefly discussed.

OBSTACLES TO BE CONSIDERED AND PERSPECTIVES

As it has been seen, some Latin American countries have great conditions to develop the production and the use of bioethanol. In some cases, this production is already taking place, but it has been focused on the external market. Considering the well-known advantages that could be achieved by a greater dissemination of this technology, meeting the domestic demand, the observed inertia is a paradoxical outcome. However, a more detailed analysis lets one notice that a significant obstacle is the lack of information on biofuels that can help the decision making process regarding innovative issues. This lack of information on biofuels added to disinformation and wrong and opportunistic information is often present in several countries.

The questions about the feasibility and opportunity for sugarcane bioethanol have evolved in an interesting way. First, there were doubts whether engines designed to use gasoline could operate with up to 10% of bioethanol without problems, even mentioning risks of phase separation in ethanol/gasoline blends. These doubts, basically planted by oil derivative distributing companies and other parties whose interests lied in preserving the dependence "status quo", fell to the ground one by one, for they did not have technical support and as the fuel markets in developed countries progressively decided to adopt the "Brazilian adding solution", once seen as something exotic and impossible to replicate.

Afterwards, there were questions regarding the production, about the economic and environmental feasibility of bioethanol production, which were progressively challenged by the reality itself. More recently, a new theme was added to the table of questions: the competition between the production of bioenergy and food, the significant scarcity in the region (refer to previous figures) and the fear that in a short run, the introduction of second generation biofuels may become the traditional routes non-economically feasible, which is certainly an incorrect view. So, In order to face this picture of inaccurate concepts and perspectives, it is necessary to provide clear, objective and provable information.

International agencies such as CEPAL and the FAO have made special effort towards giving all kinds of explanations to national authorities, however, in order to overcome this serious disinformation scenario, more powerful measures are necessary, and eventually Brazil can play a relevant role. As examples of the disastrous effects of the lack of basis for competent decisions, it is pertinent to ask what would be the fundamentals and the purposes of countries with a vast experience on the sugarcane industry, completely dependent on fuels imported at prices that are getting higher and higher, ignore them to go towards the production of biofuels through routes that are unlikely to succeed such as ethanol from sweet potato and sorghum, biodiesel from *Jatropha curcas* or castor oil (*Ricinus comunis*), before exploring their great bioenergy potential using conventional technologies and routes.

For Brazil, there are legitimate interests in the healthy expansion of the process of production and use of ethanol in the region, highlighting the formation of the ethanol international market and the business opportunities regarding the supply of equipment and services to the agro-industry. Regarding the last point it is worth to mention the technologies associated to improvements in the varieties of sugarcane, production, use and equipment optimization for sugar and alcohol plants, planting, growing and harvesting and transporting machines, and, in proper time, the "flex-fuel" technology of engine electronic management for the use of bioethanol or gasoline, a possibility that may progressively arise as the ethanol blending programs go further and the availability of this biofuel increases.

The development of production and use of biofuels, particularly sugarcane bioethanol, may represent a rationalization factor for the energy matrixes of the Latin American countries, providing new cooperation and exchange paths, strengthening their economies and promoting long lasting synergies towards a real sustainability.

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15

SUSTAINABLE AGRICULTURAL SYSTEMS AND FAUNAL DIVERSITY:

THE CASE OF ORGANIC SUGARCANE UNDER AGRO-ECOLOGICAL MANAGEMENT

José Roberto Miranda

INTRODUCTION

The presence of wild fauna in agricultural areas has received scant attention in research. In conservation efforts for wild species, research has traditionally focused on the biodiversity of remnants and natural ecosystems (forests, savannas, riparian forests etc.), or research on restoration. Little attention has been paid to the effective role of agro-ecosystems on the maintenance of animal diversity (GLIESSMAN, 2001). The type of management employed in these systems should make a difference in fauna populations and organic farming associated with agro-ecological management should show greater biodiversity (BEECHER *et al.*, 2002).

Populations of plant and animal species in tropical agro-ecosystems vary according to land use and occupation, the temporal and spatial stability of the production systems, nature and spatial division of the natural vegetation remnants and the availability of water resources (SUÁREZ-SEOANE; OSBORNE; BAUDRY, 2002). The evolution of biodiversity in Brazilian tropical agriculture areas is a relatively new dimension and very different from land cultivated in temperate regions (MALCOLM, 1997). The scientific knowledge gleaned from the results of the processes of land use and occupation on fauna richness is still very incipient in our country.

Brazil has one of the largest potentials in the world for intensifying agriculture because of its abundance of solar energy and water, and crops capable of generating large quantities of food and "clean" fuel, such as biodiesel, ethanol and charcoal. Sugarcane fixes more than 50 tons of atmospheric carbon per hectare in its biomass, and can produce ethanol, a renewable fuel, which can serve as a gasoline substitute in addition to reducing the release of carbon into the atmosphere. There are various production systems that can be used in the cultivation of sugarcane, each with different impacts on the physical and biotic environment (KAHINDI, 1997). The most conventional method uses pre-harvest burning, although the use of mechanized harvesters for raw sugarcane is rising. There are organic farming systems that are associated with agro-ecological land management (BACCARO, 1999). Each of these systems offers different environmental conditions and different possibilities for colonization and implantation of wild fauna populations. On the other hand, the use of pesticides can be worrisome in terms of food chain contamination (ALTIERI, 2002). Research on this range of opportunities and limitations for wild animals can help guide initiatives to preserve biodiversity.

With a view to learning more about this environment, the EMBRAPA Satellite Monitoring team monitored the progress of fauna biodiversity and organic production systems on a rural property covering 7,868 hectares from 2001 to 2008, of which approximately 82% is planted with sugarcane, in the Ribeirão Preto region, in the state of São Paulo. The mapping of land use and occupation was conducted in 2003, based on satellite imagery, and after analysis the area was divided into fauna *habitats*. These *habitats* served as the basis for guiding sampling strategies and data collection protocol for fauna and ecological conditions in field surveys (MIRANDA, 2006). To enable comparison, conventional sugarcane cultivation systems on other properties of the region that use pre-harvest burning were prospected.

This innovative research had a two-fold objective: first, to test, adapt and develop a methodology for evaluating biodiversity in delimited areas. Second, it aimed to analyze the richness of terrestrial vertebrate fauna on a property planted with organic sugarcane and in adjacent *habitats* under agro-ecological management. Prospecting in conventional sugarcane farms was also carried out to determine similarities between the fauna populations. In addition to the results of richness and diversity indicators, special emphasis was given to the occurrence of species threatened with extinction in the state of São Paulo, based on the criteria established by the International Union for Conservation of Nature (IUCN), by the Brazilian Institute of the Environment (IBAMA) and according to the list of fauna species threatened with extinction in the state of São Paulo (State Decree n. 42 838, dated February 4, 1998, Secretariat of the Environment of the State of São Paulo. 1998).

MATERIAL AND METHODS

The area under study covers various farms belonging to the São Francisco Mill, all situated in the Sertãozinho region (Figure 1), in the northeastern part of the state of São Paulo (latitude of 21° and 13" South and longitude of 48° and 11" West), totaling 7,868 hectares of farmland and other environments. The area is located in the Mogi-Guaçu River basin, which is part of the Pardo River basin, a tributary of the Paraná River.

Analysis of satellite images from LANDSAT 7 and SPOT 5 enabled the mapping and classification of land use and occupation. Analysis of the land use map yielded ten different types of fauna *habitats*. The ten classifications are as follows:

- *Habitat* 1 – Organic Sugarcane Fields;
- *Habitat* 2 – Exotic Forests;
- *Habitat* 3 – Floodplains with Herbaceous Plants;

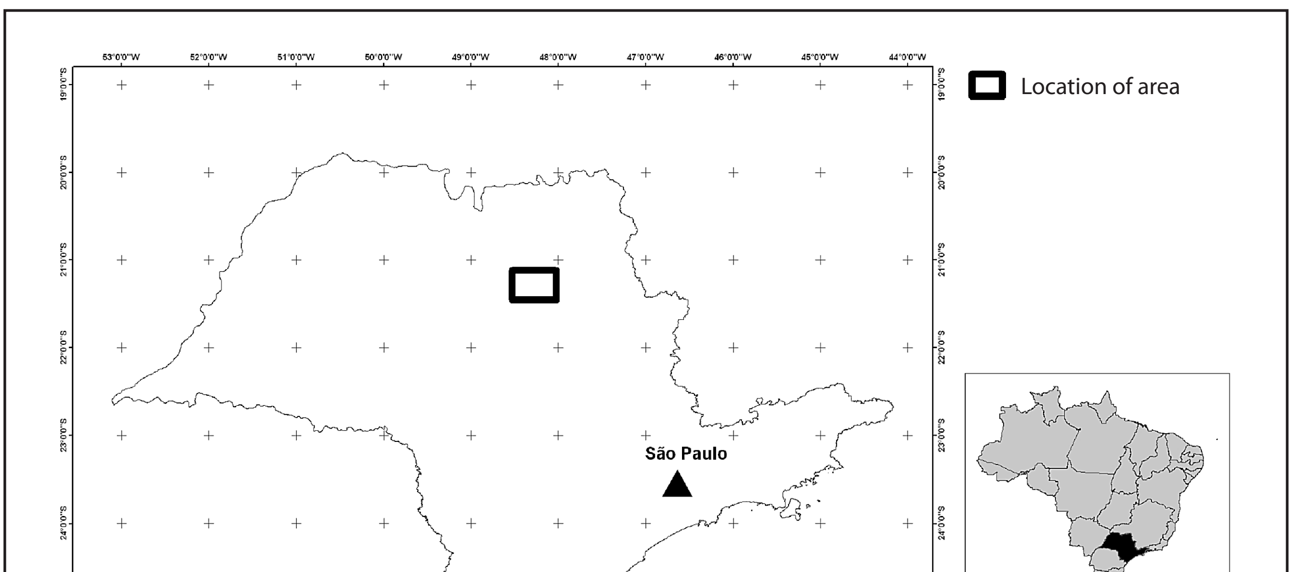

FIGURE 1 Location of the area studied in the Sertãozinho region in SP.

- *Habitat* 4 – Floodplains with Riparian Forests;
- *Habitat* 5 – Restored Native Forests;
- *Habitat* 6 – Mixed Forests Undergoing Regeneration;
- *Habitat* 7 – Native Forests;
- *Habitat* 8 – Drainage Gullies;
- *Habitat* 9 – Forests Undergoing Spontaneous Regeneration;
- *Habitat* 10 – Fields Undergoing Spontaneous Regeneration.

The detection and identification of fauna in the study area involves a series of techniques and practical procedures, including binoculars, camouflaged blinds, traps, nets etc. In addition to direct detection, both visual and audible, presence was also detected through animal signs, including tracks, feces, feathers, nests, dens, fur and regurgitation pellets. Various identification guides and classification systems were used (PETERS, OREJAS MIRANDA, 1970; DUNNING, 1987; EMMONS, 1990; SOUZA, 1998; BECKER, DALPONTE, 1999).

The map of the fauna *habitats* led us to choose the stratified random sampling strategy. This strategy considers the heterogeneous nature of the study area and ensures a judicious comparison of the fauna populations from the different *habitats* (FRONTIER, 1983). A pre-codified survey card was created due to the large number of observations required. The objective and uniform description of ecological conditions in the field ensured the subsequent statistical treatment (DAGET, GODRON, 1982; MIRANDA, 1986, 2003).

The fauna populations and *habitats* were characterized, using indexes that take into consideration the **composition**, defined in terms of specific richness and delineated **structure** for the relative abundance. Four types of richness were established: total, average, cumulative and exclusive, each one presenting its own characteristics (BLONDEL, 1979). To study the structure of the populations various diversity indexes were calculated derived from the function $H' = -\Sigma\, pi \log_2$ by Shannon and Weaver based on the theory of information (MAC ARTHUR, R.; MAC ARTHUR, J. 1961). This index takes into account the number of species in a population according to their relative abundance (MARGALEF, 1982), allowing three diversity types to be discerned (WHITTAKER, 1972). The **alfa ($H'\alpha$)** type, or intra-*habitat* diversity, the **gama ($H'\gamma$)** type, or setorial or macro-cosmic diversity and the **beta ($H'\beta$)** type, representing a Jaccard similarity index, and inter-*habitat* diversity (DAGET; GODRON, 1982).

RESULTS AND DISCUSSION

Countless surveys were conducted between July 2002 and March 2008 in the ten mapped *habitats*, for a total of 1,474 animal ecology surveys distributed in a balanced manner over the 10 mapped *habitats*. A total of 312 terrestrial vertebrate species were detected and identified: 26 amphibians, 17 reptiles, 230 birds and 39 mammals (MIRANDA, J; MIRANDA, E., 2004). Birds were the richest in species and represented approximately 74% of the fauna identified, while mammals represented 12.5%, reptiles 5.5% and amphibians 8%.

Among the most frequently encountered species were the Picazuro Pigeon (*Patagioenas picazuro*), Smooth-billed Ani (*Crotophaga ani*) and the Great Kiskadee (*Pitangus sulphuratus*). The Sayaca Tanager (*Thraupis sayaca*), Southern Lapwing (*Vanellus chilensis*), Southern Caracara (*Caracara plancus*), Southern House Wren (*Troglodytes musculus*), and others were moderately frequent, while the Maned Wolf (*Chrysocyon brachyurus*), Crab-eating Fox (*Cerdocyon thous*), Red Brocket (*Mazama americana*), Toco Toucan (*Ramphastos toco*), Whistling Heron (*Syrigma sibilatrix*), and others were infrequently found. Rare species were responsible for 78.5% of the total number.

Of the 312 terrestrial vertebrate species identified, 35 are present in the catalogue of "Threatened Fauna Species in the State of São Paulo." The Cougar (*Puma concolor*), Ocelot (*Leopardus pardalis*), Jaguarundi (*Herpailurus yagouaroundi*), Maned Wolf (*Chrysocyon brachyurus*), Giant Anteater (*Myrmecophaga tridactyla*), Blue-Fronted Amazon (*Amazona aestiva*), Creamy-bellied Gnatcatcher (*Polioptila lactea*), Cuvier's Dwarf Caiman (*Paleosuchus pal-*

pebrosus) Green Anaconda (*Eunectes murinus*) are examples of some of the species.

The logarithmic curve of the total cumulative richness was obtained from the cumulative allocation of the 312 species detected (y-axis) in the 1,474 animal ecology surveys conducted (x-axis) (Figure 2). After half of the animal ecology surveys had been conducted, 77% of the terrestrial vertebrate species had already been detected. During the final 30% of the surveys, 47 of the 312 species were detected, or in other words, approximately 15% of the total reported.

All the indexes of biological richness (total, average and exclusive), presented a wide variability in the *habitats* (Table 1). The total richness was highest in the Floodplains with Herbaceous Plants, with 150 species. In descending order there were: 137 species in the Restored Native Forest; 127 species in the Native Forest; 126 species in the Floodplains with Riparian Forests; 119 species in the Drainage Gullies; and 92 species in the Spontaneous Regeneration Forests. The Exotic Forest was the poorest *habitat* in terms of biodiversity with 82 species, a number far lower than the 88 found in the Organic Sugarcane Fields.

The average richness varied widely. The highest average gain in species was recorded in the Floodplains with Riparian Forests *habitat*, indicating a large supply of niches for the species, as opposed to the agricultural areas with Organic Sugarcane Fields, where there is greater homogeneity of ecological conditions on offer for the fauna (Table 1).

The exclusive richness showed that all of the *habitats* have original populations or, in other words, the fauna is determined by and sensitive to the ecological conditions offered by each of these environments. The Floodplains with Herbaceous Plants *habitat* had the richest exclusive species populations (26 sp); the others presented much lower figures, around ten species, except for Exotic Forests where only four exclusive species were found (Table 1). This appears to be the least original or differentiated environment in terms of fauna.

The alfa intra-*habitat* diversity index (H'α) values, were relatively close together, but do present a certain variability (Table 2). The complete table, with all the figures obtained for each species, can be found in the Embrapa Series n. 27 (MIRANDA, J.; MIRANDA, E., 2004).

The highest alpha type (H'α) intra-*habitat* diversity indexes were found in populations located in Drainage Gullies and Native Forests. These *habitats* are considered very stable in terms of

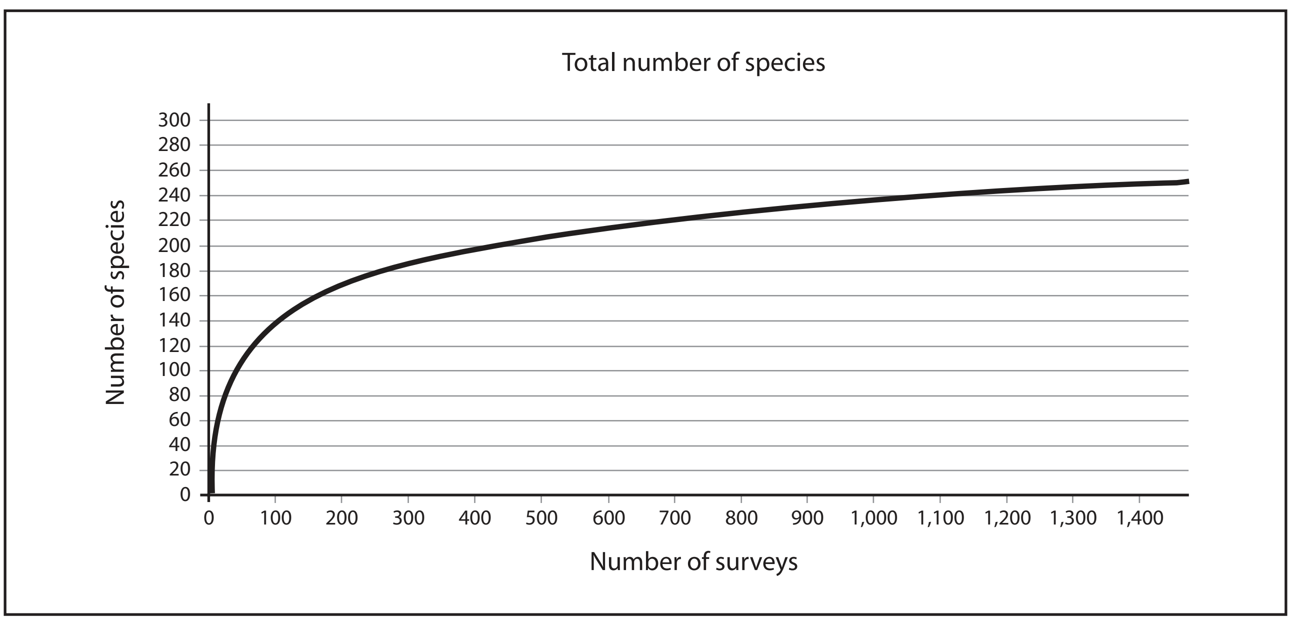

FIGURE 2 Cumulative richness curve for the 312 terrestrial vertebrate species detected in 1,474 animal ecology surveys in the area surrounding the São Francisco Mill-SP.

TABLE 1 Total, average and exclusive richness in the ten *habitats* in the areas surrounding the São Francisco Mill in SP.

Richness	1	2	3	4	5	6	7	8	9	10	Totais	%
Total Richness	88	82	150	126	137	77	127	119	92	87	312	100
Average Richness	0.4829	0.6259	0.857	1.086	0.62	0.7475	0.712	0.759	0.8611	0.7981	–	–
Exclusive Richness	8	4	26	14	15	8	15	10	9	7	116	37

Key:
Habitat 1 – organic sugarcane fields;
Habitat 2 – exotic forests;
Habitat 3 – floodplains with herbaceous plants;
Habitat 4 – floodplains with riparian forests;
Habitat 5 – restored native forests;
Habitat 6 – mixed forests undergoing regeneration;
Habitat 7 – native forests;
Habitat 8 – drainage gullies;
Habitat 9 – forests undergoing spontaneous regeneration;
Habitat 10 – field undergoing spontaneous regeneration.

total richness. However, it is unlikely that new species will be added since the resources provided by these *habitats* are being used practically up to their limits. Consequently, population figures are not expected to vary much over time.

The Floodplains with Riparian Forests, Restored Native Forests and Floodplains with Herbaceous Plants had very high intra-*habitat* diversity indexes, but presented signs of potential for increasing their total richness, especially in the case of the Restored Native Forest areas where a balance between immigration and extinction rates has not been established.

The index amounts for Exotic Forests, Forests Undergoing Spontaneous Recovery, Mixed Forests Undergoing Regeneration, Organic Sugarcane Fields and the Fields Undergoing Spontaneous Regeneration suggest populations with a lower total richness, but with stable population numbers. In other words, the present species are relatively well established in these *habitats*.

Beta type (H'β) fauna similarity indexes were also calculated for the ten *habitats* studied in the area of the São Francisco Mill based on the 1,474 surveys carried out and the occurrence of 312 species. The results are shown in Table 3. The lowest index, 20%, was observed in Organic Sugarcane Fields and Mixed Forests Undergoing Regeneration; the other *habitats* had amounts that ranged from almost 30% to less than 40%. The highest similarities were greater than 40%, with the highest index, 44%, observed between Floodplains with Riparian Forests and Forests Undergoing Spontaneous Regeneration and between Floodplains with Herbaceous Plants and Restored Native Forests, followed by Floodplains with Riparian Forests and Restored Native Forests (42%).

The gamma type (H'γ) sector ecological diversity index calculated for the group of the ten fauna *habitats* of the São Francisco Mill was 6.383, which is considered a very high index. It will rise further due to the arrival of new species colonizing existing *habitats*. This is expected to occur since almost all present *habitats* are growing in terms of natural resources available for wildlife (food, shelter and reproduction), leading to an increase in biodiversity.

A comparative study of two sugarcane production systems conducted 57 prospective surveys of animal ecology in organic crops and detected 88 vertebrate species, compared with 101 surveys of conventional crops that identified 73 species. First of all, a Jaccard similarity index of 0.27 was determined between the two populations. This index shows a difference of specific composition between the two types of sugarcane crops of more than 70%, leading us to believe that the production and farming system of the same agricultural crop can lead to very different populations and biodiversities. Trophic guilds were also established for every situation and the proportions between insectivore and omnivore species were 38% and 21% for conventional sugarcane, while organic farming without burning yielded percentages of 44% and 17% respectively. These amounts are very close. However, when we compare the occurrence

TABLE 2 Examples of intra-*habitat* diversity index values, alfa type (H'α), obtained in areas surrounding the São Francisco Mill in SP.

Species	1	2	3	4	5	6	7	8	9	10
Patagioenas picazuro	-0.165	-0.302	-0.234	-0.242	-0.196	-0.293	-0.173	-0.214	-0.286	-0.237
Crotophaga ani	-0.165	-0.052	-0.259	-0.231	-0.196	-0.080	-0.165	-0.214	-0.213	-0.368
Pitangus sulphuratus	-0.099	-0.331	-0.191	-0.209	-0.217	-0.151	-0.201	-0.165	-0.175	-0.192
Tyrannus melancholicus	-0.042	-0.231	-0.220	-0.112	-0.287	-0.263	-0.104	-0.114	-0.175	-0.138
Coragyps atratus	-0.233	-0.072	-0.227	-0.242	-0.109	-0.100	-0.283	-0.104	-0.286	-0.117
Ammodramus humeralis	-0.345	-0.030	-0.121	-0.158	-0.162	-0.058	-0.180	-0.173	-0.032	-0.192
Thamnophilus doliatus	0.000	-0.072	-0.121	-0.262	-0.069	-0.219	-0.214	-0.073	-0.201	-0.117
Caracara plancus	-0.262	-0.122	-0.078	-0.055	-0.109	-0.058	-0.221	-0.149	-0.161	-0.138
Zenaida auriculata	-0.262	-0.122	-0.183	-0.095	-0.109	-0.080	-0.061	-0.132	-0.147	-0.208
Thraupis sayaca	0.000	-0.090	-0.121	-0.032	-0.236	-0.253	-0.084	-0.073	-0.097	-0.069
Vanellus chilensis	-0.218	-0.122	-0.111	-0.184	-0.130	-0.033	-0.049	-0.187	-0.057	-0.138
Todirostrum cinereum	0.000	-0.106	-0.078	-0.143	-0.202	-0.166	-0.061	-0.061	-0.225	-0.069
Furnarius rufus	0.000	-0.188	-0.111	-0.095	-0.144	0.000	-0.073	-0.149	-0.078	-0.117
Troglodytes musculus	-0.042	-0.221	-0.065	0.000	-0.069	-0.273	-0.084	-0.094	-0.147	-0.040
Columbina talpacoti	-0.145	-0.052	-0.121	-0.076	-0.144	-0.080	-0.104	-0.084	-0.131	-0.069
Tringa flavipes	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.020	0.000	0.000
Tyto Alba	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.020	0.000	0.000
Uropelia campestris	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.032	0.000
Total	**5.126**	**5.542**	**5.728**	**5.732**	**5.729**	**5.356**	**6.011**	**6.063**	**5.507**	**5.122**

Key:
Habitat 1 – organic sugarcane fields;
Habitat 2 – exotic forests;
Habitat 3 – floodplains with herbaceous plants;
Habitat 4 – floodplains with riparian forests;
Habitat 5 – restored native forests;
Habitat 6 – mixed forests undergoing regeneration;
Habitat 7 – native forests;
Habitat 8 – drainage gullies;
Habitat 9 – forests undergoing spontaneous regeneration;
Habitat 10 – field undergoing spontaneous regeneration.

of carnivores in the two farming systems, the index amounts are 17% for raw cane and 5% for conventional cane. While this difference should be further studied, it does point, in principle, to a greater environmental sustainability in raw or organic sugarcane for populations of wild vertebrates.

FINAL CONSIDERATIONS

The mapping of *habitats* by land use and cover allowed us to observe different ecological macro-conditions in the spatial division of fauna populations in the studied area. More stable environmental conditions, in time and space, in the sugarcane areas and adjacent *habitats* are favorable factors for supporting greater biodiversity. The richness and diversity of inventoried and quantified fauna are exceptional for agro-ecosystems considering that there has not been any voluntary introduction of animal species into these properties. A total of 312 terrestrial vertebrate species were detected and identified (26 amphibians, 17 reptiles, 230 birds and 39 mammals) in the animal ecological surveys conducted.

TABLE 3 Fauna similarity index for the 10 *habitats* studied in the areas surrounding the São Francisco Mill in SP.

Habitats	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1.00									
2	0.28	1.00								
3	0.29	0.36	1.00							
4	0.30	0.33	0.38	1.00						
5	0.30	0.37	0.44	0.42	1.00					
6	0.20	0.35	0.25	0.31	0.31	1.00				
7	0.27	0.36	0.31	0.35	0.40	0.38	1.00			
8	0.35	0.40	0.37	0.39	0.39	0.27	0.37	1.00		
9	0.30	0.35	0.30	0.44	0.39	0.34	0.39	0.42	1.00	
10	0.34	0.35	0.35	0.37	0.34	0.33	0.32	0.36	0.40	1.00

Key:
Habitat 1 – organic sugarcane fields;
Habitat 2 – exotic forests;
Habitat 3 – floodplains with herbaceous plants;
Habitat 4 – floodplains with riparian forests;
Habitat 5 – restored native forests;
Habitat 6 – mixed forests undergoing regeneration;
Habitat 7 – native forests;
Habitat 8 – drainage gullies;
Habitat 9 – forests undergoing spontaneous regeneration;
Habitat 10 – field undergoing spontaneous regeneration.

The most frequent and ubiquitous species in the group of *habitats* were the Picazuro Pigeon (*Patagioenas picazuro*), the Smooth-billed Ani (*Crotophaga ani*) and the Great Kiskadee (*Pitangus sulphuratus*). The Sayaca Tanager *(Thraupis sayaca*), the Southern Lapwing (*Vanellus chilensis*), the Southern Caracara (*Caracara plancus*), the Southern House-Wren (*Troglodytes musculus*), among others, was observed with average frequency, while the Maned Wolf (*Chrysocyon brachyurus*), the Crab-eating Fox (*Cerdocyon thous*), the Red Brocket Deer (*Mazama americana*), the Toco Toucan (*Ramphastos toco*), the Whistling Heron (*Syrigma sibilatrix*), among others, were not observed frequently. Rare species accounted for 78.5% of the total number of inventoried fauna. Total fauna richness is probably higher than the findings show, and this should be established in the future with more exhaustive and specific monitoring of some groups of species, such as reptiles, amphibians and bats.

All the quantified rates of biological richness (total, average and exclusive), presented high amounts and some variability among the various existing *habitats*. The accumulated richness curve confirmed that the overall fauna biodiversity identified in the 1,474 surveys conducted over the study's six-year period was satisfactorily inventoried. The alpha type (H'α) intra-*habitat* diversity index amounts obtained were relatively close. The highest amounts were found in populations located in the Drainage Gullies and Native Forests. These *habitats* are considered very stable in terms of total richness. The fauna similarity indexes or beta type (H'β) inter-*habitat* diversity between the ten studied *habitats* in the area ranged from a minimum of 20% for the Organic Sugarcane Fields and Mixed Forests Undergoing Regeneration, to the highest amount of 47% between Floodplains with Riparian Forests and Forests Undergoing Spontaneous Regeneration and between Floodplains with Herbaceous Plants and Restored Native Forests. The first major faunal dichotomy takes place between organic sugarcane fields and the nine other *habitats*. This indicates that organic sugarcane fields exert a selective and special pressure on fauna as an ecologically different *habitat*. Sugarcane fields provide unique ecological conditions since eight species are exclusively found there. The forests, whether native or not, tend to present similarities in the composition of their populations. The gamma type (H'γ) sector ecological diversity index calculated for the group of ten fauna *habitats* of the studied area was 6.383, which is considered an elevated index for an agro-ecosystem.

These initial results point to ongoing biological growth: forests and fields undergoing spontaneous reconstitution, areas being enriched with natural vegetation, vegetalization of paths, important plant chronosequences occurring in floodplain areas, dissemination of plant species by fauna etc. Fauna populations are also growing toward greater stability and better implementation. Various species are reproducing locally and the presence of offspring is frequently observed in the *habitats* as a whole. New species are being added annually to the animal community by means of natural processes; many of them will encounter conditions for permanent implementation. In addition to resident species, there are various species of ducks, sandpipers, swallows etc. that use the areas, including the sugarcane fields, as a place for rest, shelter and even food. The maintenance of organic practices associated with various agro-environmental practices, without the use of agrochemicals or fire, is also fundamental for conserving the high level of biodiversity. Close to 16% of the sugarcane fields are annually being grown (newly planted sugarcane) and are not harvested. They play a special role by providing shelter for fauna during the harvest period.

Despite the imminent expansion of ethanol production systems, the direct influence of the farming system type on the maintenance of fauna biodiversity can make a difference. There are signs that point to a greater stability in the trophic pyramid of organic and raw sugarcane systems, confirmed by the presence of carnivores, such as various species of felines, canidae, birds of prey, snakes etc., indicating that they are *habitats* with a high prey population. This is linked to an important predictability of ecological conditions provided over time in these farming environments. The plant biomass available as forage must be ensuring the food base of the entire vertebrate food chain, playing a significant role in providing food for the species' ecological niche. New scientific studies may uncover how these interactions between fauna biodiversity and agriculture take place. Apparently, the higher environmental sustainability in the raw or organic sugarcane systems is due to the stability of food resources created by the green biomass left on the soil following the harvest periods. Over time, the food chain also increasingly structures itself as a result of the predictability of the repetitive occurrence of this annual food resource, and there is a significant increase in carnivorous vertebrates at the top of the trophic pyramid.

The methodological itinerary used for evaluating the biodiversity of fauna populations and *habitats* has allowed us to meet the objectives of this study. The use of satellite imagery for the mapping and description of *habitats* was fundamental for defining a stratified random sampling strategy appropriate for the heterogeneity of the agro-ecosystems. The use of a protocol with pre-coded cards for animal ecological surveys ensured homogeneity in the collection of condition data and, consequently, its subsequent statistical treatment. The richness and diversity indexes used identified and ecologically defined the populations and their respective *habitats*. The established methodology can be used in other fauna studies within the outlined territory and added to other tools that may be adopted as needed for this type of research.

Wild fauna must be considered an integral part of the production process in agro-ecosystems. Most of the time, it has made a positive contribution in the control of "pest" insects, and played a role in soil nutrient cycles. We are only now beginning to understand positive interactions between fauna and the different agricultural production systems and how they can be enhanced through biodiversity-focused management. The first results from ongoing studies on biodiversity in agricultural areas point to the potential for an increasingly more symbiotic and equally conciliatory relationship between production and conservation. This may become an indicator of environmental sustainability for Brazilian agriculture in its pursuit of new markets. Investment in research of this scientific dimension could become an advantage for Brazilian agricultural products, particularly in the face of international competition for new markets, as well as contributing to public conservation policies and creating a positive image in the minds of consumers.

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16

THE NEED FOR BASIC RESEARCH IN THE SUGARCANE/ETHANOL PRODUCTION CYCLE

Marco Aurélio Pinheiro Lima and *Alexandra Pardo Policastro Natalense*

Brazil does not usually create its own technological agenda. With some exceptions, such as the deep sea oil exploration developed by Petrobras[1] and the Complete Brazilian Space Mission[2], the scientific development of the country is directed to attend the technological demands imposed by other countries, especially the most developed. Identifying a clear and well defined goal is an interesting strategy to guide the scientific and technological development needed to achieve this mission. Actually, this development can produce several results in different areas, which may seem very diverse from the original goal, at a first glance. For instance, several examples could be cited as consequences of the Nasa's space program[3], such as the development of infrared auricular thermometers, solar cells, radial tires improvement, fire sensors etc.

Nowadays, the need for mitigating greenhouse gas emissions, such as CO_2, has become a global challenge. One of the many ways for contributing to this task is to reduce the use of fossil fuels by replacing them for biofuels obtained from renewable sources. In this sense, Brazil was the first country to use fuel ethanol in automobiles un large scale after the National Alcohol Program – Proalcool in 1975, and has also a privileged position in the world's scenario with the recently developed flex fuel engines.

Brazil and the United States are the biggest ethanol producers in the world. Brazilian ethanol, produced from the sugarcane juice, has an 1 to 8 energy balance, while for American ethanol, produced from corn starch, the balance is 1 to 1.3[4]. The raw material is responsible for most of this advantage: the sugarcane juice is already 20% sugar while the corn starch needs to be hydrolysed so that the resulting sugars can be fermented[4].

Sugarcane producing countries lay at latitudes between 36.7 and 31 south from Equator line[5]. Among them, Brazil is the largest producer with 30.2% of the total area dedicated to sugarcane crop in the world, followed by India with 20.6% and China with 6%[6]. These data, among others, show that Brazil has the most favorable conditions to embrace the sugarcane/ethanol cycle as a truly Brazilian technological agenda.

In 2005, the Ethanol Project Report[7], produced by the consortium Nipe – Unicamp/CGEE – MCT showed that Brazil could produce enough ethanol to replace 10% of the gasoline consumed in the world by 2025. To do so, it would be necessary an annual production of 205 billion liters of ethanol. According to the preliminary 2008 National Energy Balance – BEN, Brazilian production in 2007 was 22.557 billion liters of ethanol. This raise in the production can only be reached if investments are made in science and technology of the whole sugarcane/ethanol production cycle, ranging from the choice of the best areas for cropping without displacing food crops or deforesting, to improvements in the cultivation techniques, industrial processes, product distribution etc.

An expressive increase in the ethanol production implies in a substantial increase in the productivity of the planted area. Many factors can influence this increase in the productivity, and one of them (maybe the most expressive), is the possibility of using the whole sugarcane biomass as a raw material for ethanol production, not only the juice. It is estimated that this could result in an increase of about 40% in the production of one determined planted area. An efficient technology for conversion of lignocellulosic material from the bagasse and trash in ethanol needs to be developed, tested and adapted for use in industrial scale.

The three main components of lignocellulose are cellulose, hemicellulose and lignin. Lignin is an aromatic polymer that binds cellulose and hemicellulose together, providing rigidity and resistance to humidity. Cellulose and hemicellulose are composed by chains of sugar molecules that can be hydrolysed to produce monomers. This step represents a great technological challenge, since it is necessary not only to dominate the hydrolysis process, but also to use it in industrial scale.

Some of the sugar monomers (hexoses) can be directly fermented to ethanol by yeast. On the other hand, pentoses (five carbon sugars) can't. This is one of the important scientific challenges in the process. Pentoses (xylose and arabinose) and hexoses (glucose, manose, and galactose) are sugars that compose hemicellulose, among other components. The constituents of lignocellulosic material vary for each vegetable species. For instance, wood from conifer contain about 6% to 7% of pentoses[8], and therefore, it is important to use these sugars in the ethanol production to help in the development of an economically viable process. To do so, it is necessary to develop a genetically modified microorganism, able to efficiently ferment pentoses into ethanol. Another alternative would be to use pentoses in some other kind of process. For example, xylose can be used as a carbon source for bacteria that synthesize polyhidroxyalcanoates, which are natural thermoplastics, used as carbon and energy reserves[9]. There is a great commercial interest on this kind of polyester because they are obtained from renewable sources. The most efficient utilization of pentoses, considering the costs and benefits for the ethanol production chain is a problem that needs to be studied.

The process of converting lignocellulosic biomass into ethanol is far more complex than it seems. In principle, fast growing trees, grass, agricultural and forestry residues and others could be used as low-cost feedstock. However, heterogeneity in these raw material require different process conditions on feedstock preparation, microorganisms and enzymes, which makes the biomass-to-ethanol conversion complex[8]. This complexity is also present when sugarcane bagasse is used. The bagasse that comes out of the last mill in a sugarcane processing plant contains heterogeneous particles with sizes between 1 mm and 25 mm (with an average of 20 mm). This particle sizing depends on the sugarcane preparation and milling processes. The morphologic composition of the bagasse includes external fibers from the stalk and skin which are rigid, contain high levels of lignin, thick cell walls and protect the stalk from mechanical external effects; vascular bundles and other fibrous forms which contribute for the sustentation of the plant and drive foods and elaborated products along the stalk; parenchyma, usually called pith, which has the function of storing the juice[10]. The paper and cellulose industry separates the pith to be used for head and power production and uses the fiber in its production process. The two fractions themselves are more homogeneous than the whole bagasse and look very different from each other, as seen in Figure 1, which shows a sample taken from sugarcane bagasse at Bioethanol Science and Technology Center[11]. These are images from electron scan microscopy made at Centro de Nanociência e Nanotecnologia Cesar Lattes – LME at Brazilian Synchrotron Light Laboratory.

The separation in two fractions (fiber and pith) may or may not represent an advantage for enzymatic hydrolysis and the advantages and/or disadvantages of this procedure must still be studied. The point is that it is necessary to define a physical pretreatment that produces a stable and homogeneous material as feedstock for the hydrolysis process. From this starting point, the results of the scientific research to be done downstream can be reproduced.

Ethanol production from sugarcane bagasse can be done using several different routes. One of them is the enzymatic hydrolysis of lignocellulosic material, which produces sugar monomers. One of the hindrances of this process is that the material

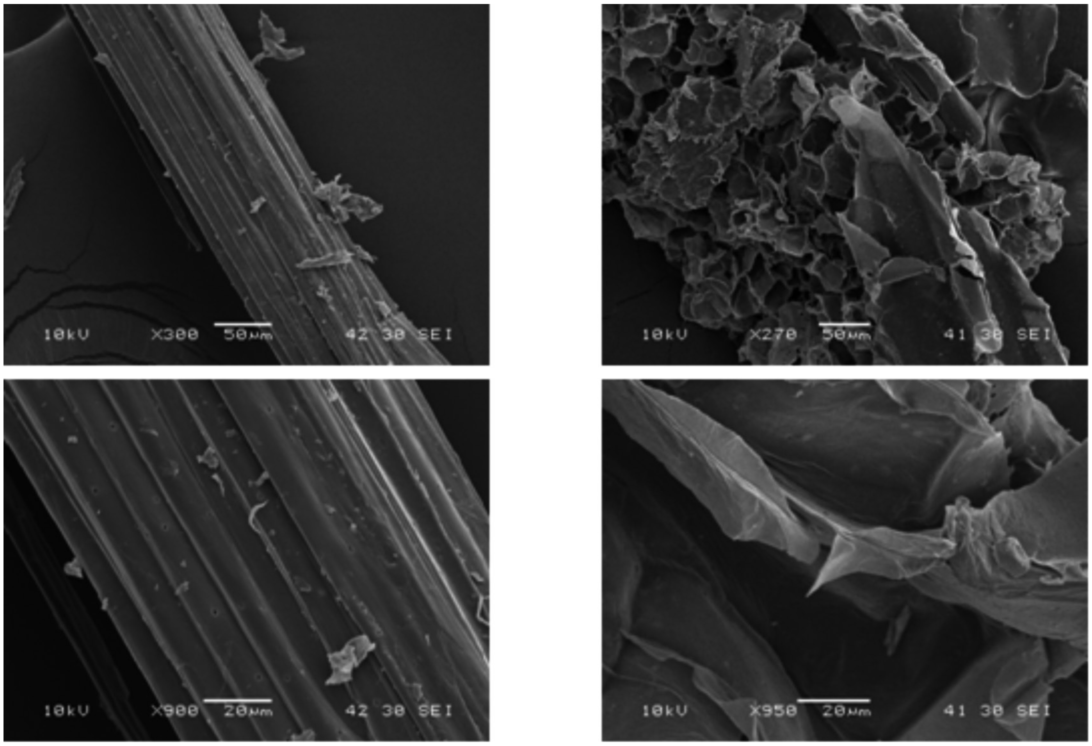

FIGURE 1 Image from electron scan microscope of the two fractions of sugarcane bagasse: left: fiber; right: pith.

is highly crystalline, which requires a pretreatment to expose cellulose, facilitating the action of enzymes. A physical pretreatment as described above could make this task easier since the efficiency of the enzymatic attack is influenced by the material surface available to enzymes. However, lignin is a cellulase inhibitor, and, therefore, there is a need to reduce its percentage in the solid material. There are many different types of pretreatment described in the literature and each one of them have their advantages and disadvantages[12]. The use of one or several pretreatments in association with a better understanding of the structure and composition of the bagasse will determine the success of the chosen method to favor the hydrolysis process. This association should result from scientific research concerning the knowledge of the structure and composition of the material before and after the pretreatment.

Efficient enzymes production at high yields is another scientific challenge to overcome. Cellulases are a group of enzymes that work together to degrade cellulose fibers. Fungi and bacteria that live in contact with cellulosic material can produce cellulases. There are many studies on fungi, since they are aerobic and produce at high rates. There has been many advances on the knowledge about cellulase action, but there is still a long way to go before efficient enzymatic complexes can be developed[13]. This development can be done if the knowledge on the structure and composition of the pretreated material, as mentioned above, is associated with deep understanding on how enzymes act on it.

Historically, the production of Brazilian ethanol started in association with sugar production. The enzymatic route for cellulosic ethanol production could be attached to nowadays sugar mills so that it could use the bagasse as raw material, after the juice extraction for sugar or first generation ethanol production. However, we should keep in mind that alternative routes for cellulosic ethanol production could be more efficient than an attachment to the current technology. One could think about using the whole sugarcane plant in a route that could convert it directly into final products or into feedstock through thermochemical processes such as pyrolysis or gasification. There is a need for a study of the viability of technological routes independently of the existing technologies.

Moreover, the mechanism for breaking the sugar chains of cellulose also need to be studied in much greater detail. For instance, it is known in the literature that low energy electrons generated by the interaction of ionizing radiation with cellules can cause the breaking of DNA molecules[14]. Motivated by this study, the electron molecule scattering scientific community have been working on the interaction of low energy electrons with smaller molecules which are similar to DNA components[15]. This results indicate that electrons could interact with the cellulose chain and cause its breaking down. One of the interesting basic research areas would be the study of this interaction, especially if shape resonances are present, which could cause molecular dissociation through electron capture. This kind of study could bring a new light to the understanding of the cellulose breaking process, which could also help unveiling enzymes cleavage mechanism.

The main goal of all the studies described above is a substantial increase in the ethanol production. However, this increase itself is not enough. Keeping production costs as low as possible is essential. Considering that 70% of Brazilian ethanol production costs are related to agricultural processes, it is important that science can also contribute to minimize them. In this sense, many progress have been made to develop new sugarcane varieties. For example, Instituto Agronômico – IAC, a research institute related to the Agência Paulista de Tecnologia dos Agronegócios from the Secretary of Agriculture of São Paulo State, has been developing regional varieties of sugarcane since 1933 through clone selection[16]. Ridesa – Rede Interuniversitária para Desenvolvimento do Setor Sucroalcooleiro also uses this technique and has been working with clones evaluation related to diseases, plagues and productivity in different production environment[17]. According to Ridesa, it takes around 13 years of research work until a new variety is available for sugarcane producers. CTC – Centro de Tecnologia Canavieira has launched over 60 varieties of sugarcane, all developed through conventional improvement[18]. Although these programs are successful, new varieties could be developed through genetic engineering techniques so that the plant could be available for the producer in a shorter time. Moreover, most of the improvement programs focus on increasing the sugar content in the plant, and this improvement has been slow along the last few decades. This could indicate that basic research on the causes of this slow progress should be associated with alternative strategies for genetic improvement[19]. Recent publications show that photosynthetic activity is modulated by the amount of sugar in the stalk and point out that there is a lack of deeper research on this subject[20, 21].

Sugarcane is a grass originated from Asia. It is one of the most efficient plants in producing carbohydrates from photosynthesis, as has been well known for over 50 years[22]. Nevertheless, studies on sugarcane photosynthesis are scarce in the literature. Some of the studies found by these authors show that the photosynthesis of a young plant is much more efficient than the one of the adult plant[23]. Others show the influence of hydrous stress on the enzymatic activities associated with photosynthesis[24] or the influence of water excess due to flooding in the Everglades (Florida) on photosynthesis, transpiration and others[25]. All these studies are important steps, but the fact is that there are not more profound studies in the literature on the basic operation of sugarcane photosynthesis process, considering its physical, chemical and biochemical aspects.

Other important points to be considered are the farming and harvesting of sugarcane. Nowadays, harvesting mechanization has become needful, since the demand for CO_2 emissions mitigation is increasing every year and burning the field previous to hand cutting is no longer an accepted practice. The adopted mechanized system is the chopped cane harvesting. This system was developed simultaneously in Cuba and in Australia and allows the elimination of burning, by introducing the bulk handling of sugarcane and pneumatic trash removal. However, although this type of mechanization represents a great progress in the sector, it still presents several restrictions such as losses in the transport loading[26] and in the trash removing processes, soil movement resulting in high levels of impurities in the load[27], soil compaction between rows, restriction for use in fields with maximum of 12% slope, incompatibility with no-till farming system etc. The implementation of no-till farming of sugarcane is highly desirable, since it was shown that the system has contributed for the reduction of losses of soil and water in cereals farming[28] and it is expected that the results for sugarcane should be similar. Actually, the minimum tillage application has produced a raise in the average productivity from 89.8 t/ha (conventional farming) to 98.2 t/ha[29]. It is necessary, therefore, to develop a new technology for sugarcane farming to overcome the difficulties faced by the actual mechanization system, which can also contribute to the implementation of no-till farming of sugarcane and for the effective use of precision agriculture.

The use of ethanol as a renewable liquid fuel and as feedstock to chemical industries is of fundamental importance for a more sustainable global scenario. Making people's daily activities more sustainable is a challenge. We recall that along its history, humankind has never been worried with ecosystem's preservation or preservation of the planet as a whole. Damages caused by the industrialization process and by the use of fossil fuels are now evident and grow at a quick rate. Taking sustainable attitudes is fundamentally a change in behavior that begins with education. Besides, it is necessary an in-depth study of the impacts that the development of new technologies can bring to the social and economical progress of the country.

The basic research in the sugarcane/bioethanol cycle still has several obstacles to overcome. It is important to notice the interdisciplinary character of the task, involving problems in the areas of chemistry, biochemistry, physics, mathematical modeling, microbiology, chemical engineering and materials, among others. There is, therefore, the need for human resources in those areas (and related ones), highly qualified, that can interact with each other to collaborate in an efficient and dynamic way in order to attack the problem from different points of view and to formulate creative and solutions for the bottlenecks of the process. Therefore, the commitment of the whole national scientific community in this area is of fundamental importance, so that, joining efforts, we can contribute to maintain the Brazilian leadership in the sustainable production of bioethanol from sugarcane.

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17

THE RELEVANCE LEGAL DISCUSSIONS AND LAW ON ISSUES CONCERNING BIOENERGY

Renata Marcheti

The Society and the Law are mutually and continually influencing each other. Law here ie refered to as a legal statute formally issued by a competent authority, no matter if *strictu sensu*, Law or any other kind of regulation emanated from a Democratic State of Law, enforced, subordinating, systematized in an ordainment capable to govern people´s social life. Society is constantly transformed by Law and, at the same time, the Law is transformed by the Society from which it emanates.

As long as relations between people exist and exactly because of these relations, rises the legal issue of legal rule which, ultimately, we could consider as a socially qualified normative. Accordingly, the Law is a set of disciplines or systems that requires and imposes certain ways of conduct. They are guidelines, conditioning the limitations imposed on social behavior raised from the social behavior itself. To condition here is ment to interfere, to influence, to cause the action in a certain way.

Every time a set of standards is institutionalized or some Law is issued, this Law or this set of rules is intended to orchestrate the life in Society, interfering on people´s behavior. That is the reality in any organized Society or so-called civilized Society, and everyday we have the opportunity to verify this vision embodied.

Examples of Law influencing social life, interfering on Society´s and individual´s behaviors are unlimited. In Brazil, in the Bioenergy area, such examples are not as common, but we could mention the approval of the final guidelines for the Government Auction to buy Reserve of Power, specifically from Small Hydroelectric Centrals (PCH) and from private small ventures generating energy from biomass and wind sources, approved by the Ministry of Mines and Energy (MME) of Brazil.

The Ordinance Act n. 407, published in the Official Journal of the Union on 05/04/2010, considered the guidelines of energy reserve auctions held in 2008 and 2009, improving the model quite a bit, so it could correspond to the provisions of article 2 of Ordinance Act n. 55/MME of 2010. From now on, in the government auctions, Reserve Power Contracts of Energy (CER) generated from wind sources and from PCHs will be negotiated, supplying from September 1st, of 2013 on, and also Reserve Power Contracts of Energy for three new products, generated from biomass, with initial supplying hired respectively for 2011, 2012 and 2013, in the months as declared by the entrepreneur in the Technical Project sent and approved through Habilitation Process of Energy Supply, because the regulation did consider the specificities of this type of energy generation, like the harvest period. These guidelines provide a series of complimentary “commands” that will rule the energy production from these sources, from now on and for many coming years.

For instance, the above mentioned Ordinance Acts extend the deadline for registration and filing projects to supply Reserve Energy in 2010, defines its process and procedures, and extend to enterprises generating energy from biomass and PCHs, instruments that were provided only for wind sources.

On February 4th, the MME published another Ordinance Act, establishing two auctions to purchase power from new venture mills, called “Leilões A-5 de Energia Nova”.

There is no doubt that such regulations can be considered an important signal for the ethanol or sugarcane energy industry, demonstrating that the Government considered bioelectricity´s relevance, which includes all kinds of biomass but whose most important raw material in Brazil, is the cane sugar waste,primarily bagasse, tops and leaves.

Bioelectricity in 2009, even with the world financial crisis, outperformed the other energy sources, as far as its system´s capacity is concerned. With these regulations defined, there will be more regularity in the buying of bioelectricity in specific auctions and undoubtedly this situation will improve certain aspects of the sector as for e.g. the difficulty of connection of these sources to the system, and certainly will lead the development of differentiated funding lines for these renewable and higher quality energy sources. I´m certain it configures an important step forward for the ethanol industry, and will determine improvements on production technologies, new neuralgic connections linking those sources to the national energy system, and why not (?), a new *modus operandi* of this industry.

It is the Law interfering, influencing, delineating, and determining, that a particular industry goes in a particular way. It is the Law ruling Society’s life, as in the ethanol industry.

And this happens not only in Brazil. On February 1st, 2009, President Obama passed the *American Recovery and Reinvestment Act of 2009.* The referred legal note is about an economic stimulus package that contains numerous provisions related to biomass and other renewable energy projects. This Act provides real incentives to investors of the segment. And these “incentives” will lead investors lives and biomass project developers in the USA until far ahead the year of 2013. The regulation removed a significant uncertainty over long term biomass projects, for the investors. Thus, we see another clear example of Law interfering in social life and leveraging an entire segment within the territory it has effectiveness. Similarly, in Europe, a change in the legal position of the *European Environmental Commision* alarmed many environment sector stakeholders and many representatives of various entities such as FERN, Finish Association for Nature Conservation, Forest Monitor, The Woodland League, Friends of the Earth Europe etc... that sent a letter to the General Director of the Environment European Commission of the European Community declaring they were alarmed with the “change in the Commission’s position in no longer consider the criteria for the production of solid biomass legally Biding,”, i.e. legally due. According to those entities:

> The need for binding sustainability criteria for biomass used in heat and electricity production came out clearly in the public consultation in July – September 2008, with a large majority of stakeholders advocating for legally binding criteria. By adopting legally binding sustainability criteria for bio-fuels and bio-liquids and not requesting legally binding criteria for solid biomass, the European Commission will create perverse incentives as well as unfair competition between different biomass sources.

This example also demonstrates how the Law can intervene directly in social life, and negatively in some cases, if it is not well “shaped”, thought through, or if the legal provisions are not maturely “born” or discussed in great detail, flaw less, free of gaps, and ment not to create injustices.

In contrast to the conditioning of social reality by Law, this same social reality determines the Law, and it´s precisely the behavior of the people who ultimately leads to the creation of new rules, new Law, new rights.

When we establish a Law into Society and show that such Society must follow that Law, we provide the path, we indicate the expected behavior from people, from that Society, and at that particular time. When there is social development, the establishment of new technologies, new discussions, new trends, new forms of relationship within the Society and a new social organization, this new reality requires to be disciplined, to be regulated, to be tutored and tailored, under penalty of not being covered up or orchestrated by a single command, raising chaos and conflict. Just as new musicians, when they begin to play in an old orchestra, they need to amalgamate to the team already pre-set and to be governed by the same conductor who rules it all; the new social factors also need to be ruled by the same spirit of Law that governs that Society. It's the new social reality demanding a "new" Law, or new area of Law, or a new regulation by the Law.

Today, companies around the world are implementing energy efficiency programs. They are viciously fighting to reduce costs and to increase competitiveness. We live in a time when companies seek far more efficient management of the entire production cost, struggle for new forms to produce more using less raw material, less energy and less water. Germany, Japan, Korea, China, USA and other countries have set as a strategic priority the efficient use of energy. This political command forces companies to develop more sustainable ways of production, not only for the economic benefits that efficiency brings, but also for environmental reasons. The search for efficiency, however, goes through the development of technological knowledge and management skills.

These technological developments and new management ways require regulation and "call" the Law. Since the beginning of the researches, the Law is necessary and "called to act". The funding of research projects, for example, forces the Law to reinvent itself. To raise millions of dollars in funding for bio-energy projects is a complex matter and presents many challenges. One is the design of the financing operation "debt" and "equity" that everyday acquires new facets. From the need of special contracts, we see legal institutions rising all the time. Some examples are the contracts for insurance to cover adverse events in research, contracts for private equity, institutional and individual, contracts of vendor etc.

Whenever there is social evolution, the requirement of its social discipline comes along, which is given by Law only, in a non-subjective way, imposed, and previewing penalties in the case of non binding of the Law.

We can mention as another example of Society evolution determining "new" Law, the issue of sugarcane straw burning.

The use of fire in agriculture is millennial. The burning to remove forests and fields, seeking the establishment of pastures, crops, building of towns and cities has been practiced by explorers and settlers since the old ages. In colonial Brazil the fires were intensively used to prepare areas for plantation of a variety of crops and pastures, including the plantation of sugarcane. Gilberto Freire has said that "the sugarcane plantation destroyed all that thick bush in the most crude way, by the burning. ... The culture of sugarcane (…) valued the plantation and the forest became despicable."[1] For centuries, to plant the sugarcane, the forest was first chopped down or burned up. And at some point we suffered the absence of these forests as firewood in the production process of sugar, or to build the mills. Nowadays we suffer it´s environmental consequences.

Burning made possible to produce sugarcane and, at the same time, put it at risk, because the burning of forests removed firewood and the production of sugar suffered. The reckless use of fire for "deforestation" of farmlands, pastures, housing etc, causes effects that are felt today, mostly because this practice remains still widespread. And yet, we continue the burning of sugarcane itself, in order to facilitate cutting.

In the 1970s we had the launch of "Proálcool" (1975). The government subsidized the cultivation of sugarcane, lending money at negative interest rates and with gracious periods for payments – that were extremely long. The sugarcane crop has advanced greatly and, with it, has grown the practice of burning down forests for the "cleansing" of the land and the burning the sugarcane plantation for cutting. The intensive burning sparked off social movements and NGO groups opposed to the interests of sugarcane industry, in favor of the environment and quality of the air we breathe. This social situation moved people, groups and institutions, especially the State Judges and Prosecutors, who were forced to take a stand.

Numerous studies have been carried out to determine, and in most cases proved, that sugarcane burning causes injury to the environment and to the population.

In total dissonance with the movement for the eradication of sugarcane burnt, it began to spring movements in which workers demanded their rights in the field. The workers of sugarcane industry did not want the end of burning. Rather, there

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[1] FREIRE, Gilberto. **Nordeste**. Rio de Janeiro, 1985.

was demanding for justice in their payment for the manual harvesting of sugarcane, better working conditions and maintenance of their jobs. There are numerous reports of disagreements between workers and industries precisely on the basis of this demand for cane cutters. In 1986 there was an outbreak of strikes, which began in the city of Leme, within the State of São Paulo, and spread to other sugarcane areas of the country. It was not the first time. It was the third major strike held by workers, the first being the infamous "Guariba strike of 1984". In all of them workers required the maintenance of their jobs, they fought against unemployment and demanded greater fairness in their remuneration system.

Industrialists, in turn, wanted to increase productivity, wanted the subordination of workers and the work of the system already established. The end of the strike in 1986 was achieved only when they all came to an agreement for a significant change in the methodology of cutters´ payments and in the supervision system to which the workers in production were submitted. That is, the strike only ended with the promise of maintenance of working relationship and better remuneration and control. It was the Society demanding regulation accordingly.

The environmental groups, on the other hand, went in the opposite way to all that.

In Ribeirão Preto, from l988, Ecological and Cultural Association "Pau Brazil" was created, becoming the most resilient entity against the burning of sugarcane; with the campaign slogan "Enough of Burning! We want to Breathe" they were able to collect over 50,000 signatures on a document against the fires, reported in the media and subsequently sent to the Governor of São Paulo. The end of sugarcane burning, as we all know, means the end of sugarcane manual cutters work.

How come, two areas of Law specifically call for such contradictory attitudes from the same business? Despite this, and even disregarding the collective labor agreements signed for the maintenance of the sugarcane cutters jobs, the Governor of the State of São Paulo, on August 30th 1988, issued Decree n. 28 848, prohibiting any form of use of fire for cleaning and preparing the ground or crops, including burning as a preparation for the harvesting of sugarcane.

This was the first piece of legislation that dealt specifically with the subject of sugarcane burning, a shining example of Society pressuring government to "make Law" or, in other words, an example of Society "making Law", since the rule of Law is always produced by people´s representatives.

The new rule, however, elaborated because of social pressures from NGOs and other institutions, created, within Society, problems of a different nature. For example, mechanization led to the release of a great number of workers that had no qualification for other kind of jobs and thus became unemployed resulting, nearby to their old work places, a substantial increase in crime, marginalization and social poverty. We saw and suffered because the labor legislation did not follow the evolution of environmental legislation. The environment was being protected but nothing was created in terms of protective legislation for the labor force released by the mechanization of sugarcane cutting, which was forced by the prohibition to burn the cane. Likewise, no efficient public policy was put in place, towards retraining of the unemployed workforce the mechanical cutting of raw and unburned sugarcane generated.

Again we have the Society and its new reality requiring do be disciplined, ruled, organized, under the risk of not being "covered up" by a one way legal command. The prohibition of sugarcane burning had social gaps because it didn´t take care of the hole problem, looking at it from only one particular angle. The legislation proved to be inadequate and it created problems instead of solving them, not only economic ones for the companies that were unable to mechanize their sugarcane harvest, but several other social problems, of different nature. That situation forced the government to review the rule and it was again allowed the use of fire under certain conditions. After only twenty days, under pressure from the business sector and the people, the State Government of São Paulo edited a new Decree (Decree n. 28 895/88) that, attending the political circumstances of the moment, allowed the burning of sugarcane fields beyond a radius of two kilometers from town limits.

In 1991, with broad popular participation, a referendum took place which resulted in 95% of the population voting against the burning of sugarcane fields. Numerous Lawsuits against sugarcane burning and sugar and ethanol industry have also become reality. Even today there are still court cases discussing the matter. An example is the decision in the Regimental Appeal within the Special Appeal n. 2008/0053216-3, summarized by Minister Mauro Campbell Marques, ruled within the Second Chamber of Superior Court of Justice and published in the Official Paper on 10/09/2009, which specifically says:

> First, within this Superior Court, the understanding that the burning of sugarcane causes damage to the environment was pacified, and that is why its implementation depends on the approval from the competent environmental agencies, becoming perfectly possible, therefore, the trial of this Law suit based on art. 557 of the CPC. As example, see REsp 439 456/SP, Rel Min João Otávio de Noronha, Second Chamber, DJU 3/26/2007.

This case is still ongoing today. All this and the many studies showing the harmful effects of burning on agricultural sustainability and its impacts on flora, fauna, and also the negative social impacts and the social pressure on the public spheres forced the change of environmental legislation that forces the ethanol sector to face, since long ago, a big challenge: to enforce the Law and to continue generating employment, income and development.

At the federal level, Decree n. 2 661, issued on July 8th 1998 established, among other things, the gradual elimination of sugarcane burning fields where the mechanization harvest is possible, and such reduction shall be at least 25% of the mechanizable area, each five years. So it is expected that in 2018, 100% of fires in mechanizable areas of the country would be eliminated.

In the State of São Paulo the discussions concerning the use of fire to harvest the sugarcane resulted in Law n. 10 547/00, which established "a plan of fire" in the State.

Also, the Decree n. 48 869/01 regulates the dispositions of that State Law and treats certain aspects of the fire use in the sugarcane industry, as well as other existing statutes. This legislation makes it impossible manual harvesting because the non burned cane straw is an obstacle to the human manual labor. Again we see the Law determining the social and technological advancement in the same way that the social and technological developments determined the Law itself: it created an irreversible process of mechanization of sugarcane harvesting where it´s possible, or harvesting of green cane, removing large number of workers in the industry, perhaps increasing the exodus to the cities and worsening the situation of that labor force released from the fields.

It is inevitable to recognize that the Law n. 10 547/00, and the Decree that regulated it (Decree n. 48 869/01), transformed the sugarcane agriculture and the use of fire in the State of São Paulo. It is now predicting the elimination of fire to burn the sugarcane before harvest, which should be completed by 2020, already gradually occurring. But what about the right to work of the sugarcane cutters? How is that?This guideline should necessarily be accompanied by policies for recycling and using human labor force released from sugarcane industry that, without a former occupation, will swell the cities around the sugarcane fields, starting to live on inhuman conditions, disorderly, dedicating to informal services and marginal activities.

We all know that in the sugarcane industry, the dominant trend was the use of large numbers of temporary human labor force.

Studies have shown that mechanization will decrease by 53% in total the human labor force used in the cultivation of sugarcane, since the productivity of a machine to harvest sugarcane is 100 times greater than the productivity of human.

A book organized by BNDES and the Management and Strategic Studies Centre, a social organization supervised by the Ministry of Science and Technology of Brazil, entitled Bio-ethanol from sugarcane – energy for sustainable development[2], we can read as follows:

> The important relationship between bio-ethanol production from sugarcane and the demand for labour is a central issue on bio-energy in Brazil and certainly crucial to social viability.

[2] **Bioetanol de cana-de-açúcar:** energia para o desenvolvimento sustentável. Organização BNDES e CGEE. Rio de Janeiro: BNDES, 2008.

> Sugarcane agribusiness is a major generator of jobs: based on the Social Information Annual Report (Rais) of Labor and Employment Ministry of Brazil and the National Survey through Domestic Sampling (PNAD), held periodically by IBGE, it is estimated that in 2005 there were 982,000 workers directly and formally involved with the production of sugar and ethanol, [Moraes (2005)]. Accordingly to a study based on the Matriz Insumo-Produto of Braziilian industry, in 1997, for each direct job in this industry, there werea further 1.43 indirect employment and 2.75 induced jobs [Guilhoto (2001)], which allows to estimate for 2005 a total of 4.1 million people in some way dependent on the sugarcane agribusiness activity, if these number relations have been maintained. These jobs are distributed widely in the Brazilian territory and cover a range of skills and training, but for the most part, are jobs with low qualification.
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> With the evolution of the technologies employed, we see a slower growth of staff requirements, followed by an increase of training required and increase of work quality. This dynamic has motivated many studies within the framework of the rural economy and sociology, which provides a comprehensive view of the ongoing processes and their implications.

The generation of employment and income in the production of bioethanol, the recent social evolution in the area of labor relations to meet the necessity for better prepared workers and all this associated with the expansion of mechanized harvesting of sugarcane are therefore topics on the agenda, as are the working conditions of workers of bioethanol production from sugarcane. This relationship between production and demand for workers will determine the viability of our social model.

And we cannot take the risk that Labor Law goes against or conflicts with the Environmental Law.

Besides the social impact caused by mechanization, it is important to bear in mind that mechanization, or green cane harvesting, is only feasible in areas with no steep slopes, and the machines work with a maximum slope of 12% of inclination. This undermines the mechanization, considering only the state of São Paulo, in approximately 45% of the sugarcane planted area. And its cost is high, making it infeasible for the small producer. And yet, mechanization also causes damage to the soil, gradually decreasing its productivity, for the compaction it causes. The weight of the cane harvester reduces the life of the sugarcane plantation.

We cannot deny that agricultural mechanization brought positive contributions to agriculture, with gains in harvesting productivity, less crops´ losses etc. According to studies by CGEE[3], mechanization is a growing trend and more than 400 harvesters are sold each year, each performing the work 80-100 cane cutters. During the period 2000-2005, compared to a 28.8% increase in cane production, expansion in the number of jobs was 18%. The higher productivity is a proven fact and the most positive aspects of mechanization. But it also brought negative contributions that can not be ignored. We already mentioned the social issue but we must also mention the soil compaction and increased emissions of pollutants by the use of fossil fuel.

The traffic of heavy machinery imposes burdens on the sustainability of sugarcane´s cultivation since increases its cost, both in production and in the conservation of soil. The weight of the equipment and the intensity of land use change the physical properties of soil with the increased of density and decreased of the water and fertilizer penetration. This, in its turn, requires additional expenditures or investments in machinery, operators of machinery and fuel for soil preparation (recomposing of the soil) for the next crops, since the soil needs to be treated for the new harvest. As for emissions, it is certain that the use of fossil fuels, particularly diesel, during the preparation of the land, has becoming more intense without burning. This is precisely why, after harvest, it is necessary to plough the soil and return it to the ideal planting density which requires the use of machinery powered by fossil fuels. And the burning of fossil fuels undoubtedly generates environmental pollution.

Despite the negative aspects, however, if the legislation now in force, in the State of São Paulo,

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[3] CGEE – Centro de Gestão de Estudos Estratégicos. **Estudo prospectivo de solo, clima e impacto ambiental para o cultivo da cana-de-açúcar e análise técnica/econômica para o uso do etanol combustível – Etanol fase** 3. Campinas: Nipe/Unicamp e CGEE, 2007.

prevails, this activity will be impracticable in many areas, whether for social, economic or technical reasons. Thus, inevitable to watch, in a short period of time, a new law being introduced to treat and balance all these issues. This will happen because the legislation we have so far does not "cover" all social, economic and technical aspects.

In economic terms, our Law cannot, for example, prevent tax evasion. The evasion is bad for all those who are involved in the production chain. Everyone loses with the unfair competition. And the States and the Union also loose as there will be less revenues in government coffers from taxes. With evasion, the Government invests less and there is a loss to Society in general. It would be desirable to have a more repressive legislation, more effective, to avoid the practice of tax evasion within the production chain of bioethanol, as it is visceral element to the national growth in the world stage.

But does the law need to be like that for ever? Could Society, when creating its own rules, do it in a more integral way, in order to address and cover all the social issues that currently comes up? Will the legislation developed from a social reality always fail and will there be always gaps or conflict with legislation of other areas of Law? Will the Law require to be amended continuously to cover other aspects of the same social reality that was not covered in the first place?

If these Laws have gaps, such gaps must be addressed quickly with the establishment of new rules, new guidelines dedicated to these social facts, to ensure that Society follows its course in peace. Could not it be possible that such legislation arises without such deficiencies, and without such conflicts?

After its establishment, the guidelines shape life in Society, in a cogently way. The rules laid down as rules of Law dictate how people should behave, and constitutes an expression of a scientific-legal nature, with a rather peculiar way of seeing reality. Such rules are the pathway to determining the solution of conflicts. Therefore, we can say without fear of making mistakes, that the Law is an adjustment mechanism of human relationships and seeks to achieve and ensure concrete social goals, being one of such goals, without doubt, to preserve peace and order in Society. It is important to bear in mind, however, that such guidelines or adjustment mechanism cannot be divorced from the social reality that aims to regulate, otherwise there is a risk of not being "recognized" or respected and it cannot be produced to "firefight" situations when it fails yo address, in a "holistic" way, the social issues it aims.

This adjustment mechanism of human relationships does not exist in isolation from other phenomena. For example, Law and Sociology – as the study of social phenomena – have a close relationship since the Law itself is a social fact, resulting from the impact of various social factors (religious, moral, demographic, scientific etc.). Similarly, Law and History go together, being a cause and consequence of each other. Understanding the human past is of great importance to the Law and justice, for there is the embryo of Law as a historical phenomenon – it has its own story linked to other facts and historical events. Law has also a strict affinity to Economics as a science, which aims to achieve and use material conditions, artificial or not, to meet the needs of human welfare. The same is true for other areas of knowledge and other phenomena of everyday life. We can illustrate this by mentioning measures to regulate the market, and business requirements that are established in compliance to policies and rules, especially imposed by U.S. and E.U., in order to "control the sale of" bio-fuels, to meet the standards recently established.

According to the Theory of Minimum Ethical of the German iuris-philosopher Georg Jellinek, Law is a minimum set of moral rules binding on the Society's survival, since not every individual is willing to accept all the moral precepts basic to social stability, spontaneously. Thus the Law as a cogent element in Society, the tool we have to ensure compliance with this minimum ethical required by individuals for the survival of Society.

But how is the Law created as a behavior standard and social organization rule? In democratic regimes, as is the case of Brazil, the Law is drafted and dictated by the representatives of the people within the Legislative Power that, after the discussions enrolled and pacified the disagreements between those representatives of different political forces, dictate and enforce rules of Law. Those are already born as the ordering command, the bilateral standard for social relations, as the common good, positively valued or positively brought and imposed on the Society. And this is exactly where the danger lies. To address very complex issues in a simplistic way, or based only in a political approach, just to "appease social niches", taken by social and economic lobbies, doing so divorced from the technical, organizational research etc., creates rules that do not subsist in time, full of gaps and inconsistencies and, in short, that will need to be amended, altered, otherwise they will not serve.

The proposal is precisely to produce a Law consonant with the technology and the technical research. To advance legally concomitantly with the scientific advancement of the segments, avoiding a Law that "runs behind the social fact" in areas as relevant as the area of Bioenergy.

What we propose is a discussion that involves everyone, as to expedite new projects and new technologies but also streamlining modern legislation, comprehensive, covering as many aspects of daily life as possible. That would be only possible if the Law and technology were born together, grew up together and matured together.

It is true that the word "Law" can have several meanings, which must be carefully stated. It may mean, therefore, both the legal system, i.e., the system of norms or rules of Law which draws men to certain forms of behavior, giving them opportunities to act, as a kind of science that studies its behavior or as the decisions from Court. Many misunderstandings arise from not making a clear distinction between one meaning and the other. But in any sense, the fact is that without the Law there is no Society and without Society would not Law. The Law and Society do not depart, they are inextricably linked.

If the Law is a social product and intrinsically linked to the Society, how does Society influences the Law? The answer is: through the common behavior, which belong to the sphere of informal rules, not cogent, not assertive. Common behavior is the expression of personal and social culture and is configured within the bosom of the Society itself, through repeated attitudes, but informal. From the moment it is turned into a legal rule, or into Law, no longer belong to an informal level, losing the pure cultural characteristic and becoming socially and legally binding. They will now be part of Society as a positive rule, valued, in the category of what is essentially legal. Thus, any movement that exists within Society and that has wide representation, has direct or indirect influence on a legal status.

So it is, precisely because the Society influences the Law and the Law affects Society. And that is precisely why we shall not aim to apply a particular Law relevant to a certain social environment to a different Society from which that Law was created. For instance, we may compare the French Law – or others – to Brazilian Law, but we can not apply French Law to Brazilian Society, or change the French Law into a Brazilian Law without the necessary adaptations, since each country has a specific Society, specific movements and the Law emanating from that Society shall follow that Society. Try to transfer to Brazil a legal system that is bid and concerns to another Society corresponds to an attempt to transplant to the Brazilian soil, values, characteristics, culture, movements and common senses that do not belong there. Transplanting values that do not reflect our reality means taking the chance of imposing to the national Society values that are not appropriate to us.

Studies, development, discussions and advancements in Bioenergy in our country are already social reality, particularly regarding bioethanol. There are countless examples demonstrating that in this subject there are indeed relevant social facts and it is in full a swing.

The ongoing research, the Institutions nowadays dedicated to the subject, whether governmental or private, the financial figures involved in the development of this segment, the names of researchers, administrators, businessmen, politicians etc. that are involved in Bioenergy and the relevance of the subject to the national and international scenarios show clearly that the sector represents, not only to Brazil, but also to the world, a strategic opportunity to meet increasingly global demand for clean renewable energy. That's social development. Internationally, countries have set ambitious goals to access biofuels, reducing their dependency on imported fossil fuels and thus meet the requirements of Kyoto Protocol. Governments today already have official agencies that are dedicated specifically to this subject; international institutions have created sectors intended to deal exclusively with Bioenergy and its impact in the world today. In Brazil, it is still the National Agency of Petroleum, Natural Gas and Bio-energy who regulates the bioenergy industry, but when we read on their electronic site[4] about their publications, we see the following:

> The National Agency of Petroleum, Natural Gas and Biofuels has as a central point of its performance to accomplish the task of regulating the oil and natural gas industry with as much transparency as possible. In this sense, the ANP promotes, encourages and monitors various studies and analysis on oil and natural gas activities in Brazil. Many of these studies were transformed into books, articles, speeches and other publications – that are accessible to the population...

And worse, when they mention the segments of ANP, only once of the biofuels are mentioned:

> Fuel prices are based on free market in the country since January 2002. The ANP accompany, through a weekly research, the common gasoline, ethanol, hydrated fuel, diesel oil, non-aditivated NGV (NGV) and gas liquid petroleum (GLP) prices charged by retailers and resellers of 555 municipalities of all States.

We are looking at a social development of the sector, but how are we in terms of regulation? How is the Law in relation to biofuels, a clear, relevant and irreversible social development? The answer is simple: We are staring at the opportunity to "make Law", or to create a new legal framework, that provides the Society the guidelines required for the progress of this branch of science.

This "new" field of Law, still embryonic in the national scene, is imperative and we must dedicate ourselves to consider it, to discuss it, to manage it and to create and adapt it to our social reality and the concomitant technological research in the segment.

And it will inevitable to do so, unless we take the chance to run across conflictive situations without the corresponding rules – like the control of the sugarcane burning issue.

Society is boiling over the issue Bioenergy. Routinely, there are many congresses related to Bioenergy, Biothech fairs, workshops, surveys, studies, seminars, technological advances and innovations in the field of Bioenergy. For example, the Bioenergy Workshop on Integrated Sustainability Assessment for Ethanol Context, of the School of Engineering of São Carlos (EESC), University of São Paulo, which aims to stimulate discussion and debate on the feasibility of systemic tools for integrated assessment of sustainability within the context of ethanol production from sugarcane. Protocols are signed for Bioenergy, such as the Environmental Protocol of the Sugar-energy Sector, signed in 2007 between the Government of the State of São Paulo and the *União da Indústria de Cana-de-Açúcar* (UNICA). The Inter-American Development Bank (IDB), that so far has devoted only 30% of its loans to the energy area and to projects of renewable energy, has announced that in the next three years, this percentage will increase to 80%. According to the IDB, improvements in the regulatory process and the lower cost in equipment boosted and will continue to boost demand for investment in renewable energy projects in Latin America and the Caribbean. "Several countries in the region wish to diversify its energy sources and are changing its regulatory framework to attract more investments in clean energy," said Hans Schulz, General Manager of the Department of Structured and Corporate Finance at the IDB[5]. It may already be considered a *cliche* phrase, so repeated it is, but the fact remains: research development and acquisition of renewable sources of energy are the priority of the twenty-first century. On March 30, 2010, at the International Forum for Strategic Studies in Agricultural Development and Respect to Climate (FEED 2010), an event sponsored by the Confederação da Agricultura e Pecuária do Brasil (CNA), which aims to discuss the relationship between climate change and agricultural activity, the economist and former Finance Minister Antonio Delfim Netto, told the audience

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[4] Available at: <http://www.anp.gov.br/?pg=15557&m=&t1=&t2=&t3=&t4=&ar=&ps=&cachebust=1273026201826>.

[5] J. Santos – Agência Ambiente Energia – Available at: <http://www.eventobioenergia.com.br/congresso/br/noticia32.php>.

that the energy agenda is already focused on energy research and development of clean energy sources. “Man does not want to go back to the Stone Age. Any solution on energy has to include an appropriate level of growth” warned the economist. Delfim Netto said that relatively to energy self sufficiency, the U.S. president, Barack Obama, has given clear signs that it will invest in clean energy sources and alternatives, prioritizing biofuels. “The energy revolution is already happening in the labs. Energy is the program for the XXI century,” he said. Brazil has large advantages within this challenge because it already uses renewable arrays to generate 45% of the energy it consumes. “Moreover, in Brazil, there is no conflict in the use of land for food production and renewable energy sources” he affirmed[6]. Even the ISO – International Organization for Standardization – has created a Joint Technical Committee, called the Energy Efficiency and Renewable Energy Sources – Common Terminology, whose goal is to promote standardization in the field of energy efficiency and renewable energy sources in which 20 countries participate directly and have another 20 countries as observers[7]. The initiatives related to Bioenergy are there to be seen and are a striking reality.

We know that the US has the goal of reducing fossil fuel consumption by 20% until 2017 which directly impacts the demand for ethanol. If the goal is achieved, it will mean 132 billion gallons per year of additional demand, more than three times the current world production of ethanol.

In Brazil, 45% of the energy matrix is clean renewable energy. This is a highlight in the world stage, as the developed countries consume only 6% of clean energy, yet using, on a large scale, highly polluting energy sources like oil, gas and coal.

In addition of being already a showcase to the world because of our current position in relation to the energy matrix, we have a huge competitive advantage in the bigger evolution, still necessary, of quality energy used. We have abundant and quality land available for agricultural production, a relatively low price of properties, lots of water and sun. And we have a good advantage and production on scientific and technological development for the production of ethanol. Yes we can become a powerhouse in the production of ethanol and we must not lose this opportunity.

However, we must improve a lot in the Law field, against the negative aspects that this evolution entails.

We´ll have with the expansion of ethanol production, a large increase in national wealth that will permit us to quickly solve our social problems. President Lula and government officials do not get tire affirming that ethanol production is an important factor in achieving the goals of his Growth Acceleration Program. The positive effects are numerous (...). We will see an increase in exports with an increase of primary surplus, greater preservation of the environment through the replacement of non-renewable and polluting energy by renewable and clean energy; this sector of the economy will grow and generate new work positions etc, but we should have a strong legislation and comprehensive enough to avoid side effects such as the possibility that ethanol replaces food production, impairs biodiversity, worsen the problems of hunger and environmental degradation. We have availability of land to plant sugarcane for ethanol production, but the logic of the capitalist system may, if not limited by Law, bring effective risks that in certain regions, the cane could replace food production if it becomes a more profitable crop. Suani Teixeira, Vice Secretary of the Secretariat of Environment of the State of São Paulo, interviewed on 26/07/2006 stated:

> The cane sugar already stealtraditional fields of grain in São Paulo. In the red soil of the southwestern part of the state, where such crops as beans predominated, sugarcane production advances and changes the local landscape. [...] Data from the Agricultural Economics Institute (IEA), linked to the State Secretariat of Agriculture, indicate that the region has 7,000 new hectares planted with sugarcane, totaling 20,800 hectares this year. In Taquarituba were planted this year 2,000 hectares with sugar-

[6] Available at: <http://www.envolverde.com.br/materia.php?cod=72163&edt=7>.

[7] Available at: <http://www.iso.org/iso/standards_development/technical_committees/list_of_iso_technical_committees/iso_technical_committee_participation.htm?commid=585141>.

cane [...] In Avare, sugarcane occupies 7,400 hectares, planted to meet the demand of mills in Lençóis Paulista and Barra Bonita[8].

A democratic government must act to control the logic of the capitalist system and intervene. We must ensure a balanced development, in the interests of social and environmental preservation. This can only be done with regulation, to establish a "new Law" that deals with all the elements necessary to avoid such disastrous consequences. If the authorities fail to curb the market logic and its goal of maximum profit, certainly food production and the environment will suffer. And yet we do not have even outlined any legislation providing for some kind of regulation accordingly. There are tons of zoning Laws for urban growth, industrial and environmental development. But there is no news of a legal instrument regulating the planning of soil use and environmental management that addresses the demarcation of areas for planting food/cane. We need rules assigning uses and activities compatible with the capabilities and constraints of each region of the country, aiming at the sustainable use of natural resources and the balance of existing ecosystems. And these rules can not be dissociated from the technological, scientific and economical production of ethanol study. They must be based on careful analysis and integrate region, technology, Society, location etc., considering the impacts of human actions and the capacity of the environment in question. Again, the social reality and the risks to Society, "call the Law", or better call for a good framework of Law.

Another issue that requires immediate government action is the advancement of foreign capital in buying land in the country to produce ethanol. Multinationals are constantly buying sugar/ethanol mills and large portions of land. George Soros became a partner of Adecoagro with industries in Minas Gerais and Mato Grosso do Sul. In the web page of the company[9] we read:

"La caña de azúcar es uno de los cultivos más eficientes para la producción de energías renovables en forma de etanol y cogeneración de electricidad. **Adecoagro** *cuenta con* **Usina Monte Alegre**, *planta industrial ubicada en el estado brasilero de Minas Gerais, (...). En la región se cultivan 14.000 hectáreas de caña de azúcar, que aseguran el abastecimiento de la empresa, (...). Uno de los principales proyectos de inversión de* **Adecoagro** *constituye la construcción de nuevas plantas destinadas a la producción de azúcar y etanol en Brasil, en el estado de Mato Grosso do Sul. Las localidades seleccionadas para desarrollar nuestros proyectos poseen condiciones de clima y suelos ideales para la producción de caña de azúcar, permitiendo obtener altos rendimientos. Siguiendo este objetivo en Agosto de 2008 inauguramos un nuevo Ingenio Azucarero, Angélica, ubicado en la zona de Angélica, Mato Grosso do Sul. Esta moderna planta alcanzará su capacidad máxima de molienda en el 2010 con aproximadamente 4 millones de toneladas de caña de azúcar, cosechadas en 55.000 hectáreas, produciendo etanol hidratado, etanol anhidro, azúcar VHP y vendiendo energía a la red local. Adicionalmente, ya contamos con dos emplazamientos próximos a Angélica, en la localidad de Ivinhema, con capacidad para desarrollar otros dos proyectos industriales, permitiéndonos generar enormes eficiencias productivas debido a las economías de escala existentes. El primero de ellos, Ivinhema, se prevé que se comenzara a construir en el 2012, y el segundo, Amandina, en el 2013. Esperamos desarrollar una capacidad de procesamiento de unas 11 millones de toneladas de caña de azúcar por año durante los próximos 5 años (...).*

The company Infinity Bio-Energy has made eight (8) acquisitions in Brazil (Usinavi, Alcana, Cridasa, Disa, Paradise, Ibiralcool, Montasa and Laranjal). It has 14.5 million tons of sugarcane crushing capacity considering new investments

[8] RODRIGUES, D.; ORTIZ, L. **Em direção à sustentabilidade da produção de etanol de cana-de-açúcar no Brasil.** Available at: <http://www.bothends.org/project/project_info.php?id=41&scr=st>.

[9] Available at: <http://www.adecoagro.com/index.php?seccion_generica_id=194>.

in industrial facilities and plantations[10]. Cargill acquired participation in the Itapagipe Plant, MG and controls of Cevasa Plant in São Paulo. According to an article published in EXAME magazine[11], entitled "The Moment of Truth for Ethanol", "we see the growth of foreign groups which already holds 25% of the stock capital of the sector of ethanol from sugarcane, and oil companies are beginning to invest in renewable fuel." Louis Dreyfus Bioenergy and Louis Dreyfus SEV already have shares in companies from Mato Grosso, São Paulo, Minas Gerais, Rio Grande do Norte and Pernambuco. The group Pacific Ethanol is already researching to expand in Brazil. The Australian Robert Newel bought 11,350 hectares of land in the County of Rosario, Bahia[12]. The Calpers Pension Fund has acquired properties in California and Santa Catarina. Numerous other examples could be mentioned. Powerful multinationals are buying lands and mills to produce ethanol in Brazil. It is essential to introduce clear legal measure in order to balance the foreign invasion of this sector in Brazil.

Another important issue to be addressed is the genetic manipulation of sugarcane. This practice is already old and ensures resistance to pests. Before, it was done with the replacement of species adapted for cycles of 10-15 years. The use of GMOs can reduce these timespan. There are already several pleas to research on transgenic sugarcane pending before the National Technical Commission on Biosafety. However, the regulation on the subject is negligible.

Brazil shall not lose the train of history and fail to occupy the place it deserves as the leading supplier of renewable energy in the world, but we can not accept development at any price. We must protect the interests of the country and the people, fighting the negative effects that ethanol production on a large scale may cause. For this we have to "make Law", build an effective legislative framework, absolutely necessary to an effectively sustainable development. In the same way that Brazil needs to invest in technological research to avoid losing its competitive advantage of ethanol from sugarcane, and the production of cellulosic ethanol, we must invest in research and construction of legal mechanisms that allow us to guarantee the national interests in preserving and develop the environmental. Only the Law can create an obligation to curb the hunger and determine the respect for sustainability from the capitalist system, necessary for the development of humanity, but that has a tendency to destabilize a lot in the pursue of easier and greater profit.

The sustainability of any system or process requires a lot of responsibility, austerity, fairness in dealing with various factors involved in this system or process. It is not, and will not, be different with Bioenergy particularly that derived from cane sugar.

We need Society to make good use of this time of intense economic, technical and social study and debate, to analyze the legal standards and the need of legal criteria for sustainable production systems, not only of ethanol but also of its raw material – sugarcane, as well as criteria for international trade of the ethanol produced in Brazil; as well as criteria for monitoring sustainability, aiming to minimize negative impacts, in both Society and the environment; and ensuring the adoption of those principles by all actors, national and international, of the sugar industry, as indeed, the whole Bioenergy industry.

There are as priority actions in the legal area as in the ones regarding research and technological development of the Bioenergy sector. For example, the review of existing provisions and rules on mechanical harvesting and end of burning of fields of sugarcane comes to mind. The end of burning and the mechanization are actions desired by all, but from the social point of view, the total mechanization of the harvest unaccompanied by other social actions would be a disaster, replacing and throwing into marginality a large contingent of non qualified workforce. It is necessary to establish obligations to the various players in the system to force them to train and relocate some of these workers, and improve the process of agrarian reform, establishing some other part of them.

Likewise, the format of the licensing of new mills and distilleries deserves to be reviewed. We

[10] Available at: <http://www.infinitybio.com.br/infinity/web/index_pti.htm>.

[11] March 2010.

[12] Available at: <http://www.cofeci.gov.br/paginternas/destaques.php?nDestaque=335>.

have already a huge environmental liability and considering the history of disrespect to the Brazilian Forest Code, States should legislate to condition new licensing processes for new distilleries and mills, to the presentation of a registration of legal reserves and the properties in permanent protection areas of the land involved in the undertaking of sugarcane production.

We still have the issue on regulating the price and the stocks of ethanol. Fluctuations in the value of fuels are natural, and expected in a scenario like ours, especially when there is adverse weather conditions prior to production. Similarly a lower supply of the product is understandable and can result from this scenario. Despite this, when that price volatility is the result of lack of product on the market due to exports to foreign markets, or because the raw material is being diverted to the production of more profitable asset, this translates into an affront to consumers who believed in that the productive sector. Greed can not be the motive of financial conduct which is harmful to domestic consumers and the national Society. And the way to determine the balance that the capitalist model course fails to deliver is creating legal obstacles, both related to the price and to the buffer stocks needed. “Agência Brasil”[13], in January 23rd of 2010, reported an excellent cote from the Minister of Agriculture, Reinhold Stephanes:

> There must be compromises. The domestic market is the one that maintains the ethanol industry, and there’s a consumer to whom we owe allegiance. When the price rises above the appropriate level that it is not quite right with the customer. Of course in this case there was an abnormal phenomenon which was the heavy rainfall in the period, but either way, one should plan to avoid this in the future.

The regulation provides another point of legal deficiency that needs to be quickly corrected: the position and legal status of regulatory agencies – ANEEL and ANP. Oddly, when it comes to ethanol, this product can not be regulated by ANEEL for obvious reasons. But neither the ANP has provided exemplary service to regulate the biofuel sector. Due to the huge new developments in the oil sector in Brazil, and also looking at the considerable importance of Brazilian ethanol, not only domestically but also internationally, isn´t time to leave the National Petroleum Agency to deal exclusively with fossil fuels?

We should also pay “legal” attention to aspects of the international market for biofuels.

Ethanol from Brazil suffers a competitive disadvantage in the European Union because of the tariffs imposed on the product, even if proven that our ethanol comes from sustainable sources, and with a much lower cost than ethanol corn based, and with considerable environmental advantages.

In an interview with the BBC Brazil[14], published on September 11th of 2007, the Trade Minister of Sweden, Sten Tolgfors, advocated “the creation of an international market for biofuels to stop global warming” and also defended a zero tariff to ethanol. “We must eliminate all tariff barriers imposed on ethanol,” he said, and subsequently added:

> The value of the tariff imposed by the EU to ethanol is currently up to 55% depending on the product price. At the same time, the European rate for oil is only 5% (...). Simply makes no sense to impose high taxes on renewable fuels like ethanol, and not to fuels that cause climate change; Especially at a time in which we are trying to expand the use of ethanol. (...) We, the European Union countries, must be prepared to eliminate trade barriers that do not match the ideals of the World Trade Organization.

It is true that in international affairs, you can not promote a Law that enforces everyone to abide by it, as in the case of domestic Law. No country can impose anything to the other. And yet, as a member country of the E.U., Sweden can not take unilateral decisions in terms of changing or abolishing tariffs imposed by the bloc, as no other country of the same group can. But it is always through International Laws, as in this case – that

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13 Available at: <http://www.correiobraziliense.com.br/app/noticia182/2010/01/23/brasil,i=168610/BRASIL+DEVE+FORMAR+ESTOQUE+REGULADOR+DE+ETANOL+DIZ+STEPHANES.shtml>.

14 Available at: <http://ethanolbrasil.blogspot.com/2007/09/para-ministro-tarifas-prejudicam-etanol.html>.

we could create an international market for biofuels and thus to ameliorate the climate change threat, promote development and reduce poverty. In relation to the tariffs imposed on international trade to Brazilian ethanol, since little has been done so far, they still persist. Proof that nothing changed was published in the article by O Globo, on April 19th, 2010, entitled "Producers complain to the WTO on ethanol tariffs.:

> *Os produtores de etanol aproveitaram a visita ao país do diretor-geral da Organização Mundial do Comércio (OMC), Pascal Lamy, para reivindicar a redução das tarifas sobre a comercialização do produto nos mercados americano e europeu. Lamy ouviu as queixas dos produtores, representados pela União da Indústria de Cana-de-Açúcar (Unica), mas deixou claro que as negociações dependem do que o Brasil oferecerá em troca para outros países. Em visita à Usina São Martinho, em Pradópolis (SP), Lamy afirmou que a produção brasileira de etanol é "um bom exemplo do que os países emergentes podem fazer". Mas se esquivou de tomar qualquer posição em relação ao pedido do Brasil de transformar o etanol numa commodity ambiental.*

Only through international agreements, perhaps in a new Doha round, we may see the liberalization of international trade, particularly for developing countries.

There are many "legal green fields" in which we have to work, as there are many Laws that displease rather than please in this area. It's time to pay attention to the legal issues involved in Bioenergy, in particular ethanol.

We are ahead, but to keep ahead in such a privileged position in the world of ethanol, we need to, as I said, "do it right". We have good natural resources to win the battle for the new global energy cycle. We also have an excellent research base with many researcher scientists that, since the 1920s have been studying and developing the technology to produce clean, renewable energy. But we are late in the legal regulatory field in many important aspects. We are in the spotlight, especially if we compare our legislation with that of developed countries. At least in relation to ethanol production, when Laws have been enacted, often fail to reflect the technological and social reality, bringing other problems which, in turn, require legislative reform.

It is time for us, Law professionals, to leave aside formalities, to approach the technological areas, to engage in social issues and to create or develop a fertile and perennial legislative field, in accordance to the social and political reality, that especially serves the evolution of the system as a whole.

The Bioenergy Law(s), as in all areas of human existence, is of fundamental importance, both for channeling science and for technological and social development. There isn´t, as said, development without the Law and the Law often must shape this advancement to avoid conflicts and preserve values such as environment, employment relationships, social organization, productivity, profitability and so forth. The rule, the limit, the definition of what is right and what is wrong, of what is possible and what should be avoided, only the Law can provide; only the Law can provide the necessary guidance to the Society. Just as a child needs to be tutored to grow healthy, a country, to be a great country, must be well oriented by its Laws. And in the area of Bioenergy, our regulation is still embryonic and requires competent people to help Brazil to create a mature Law, not based or dedicated to protecting the interests of segments or groups, but dedicated to protecting the country as a whole, its people, its land, its wealth, its Society, its values, its environment etc. The world is watching us. And the world can be cruel. If we are not well prepared for the locomotive of progress that is ahead of us, we will either lose the train or it will pass us. Even if our scientists are brilliant and even if our technology was ahead of times, (or still is), even is our leaders try to show us to the world as "a big country of well grown people", if our social relations, in the field of Bioenergy, are not based on mature, integral regulations, that go hand in hand with all this progress, we will not be as big as we want to, nor as important as we could be in the international scene. And only the old good "new" Law will be able to establish such fair and progressive Society. I'm willing to get involved and to help in the creation of this new Law. What about you?

Part 2

SUSTAINABILITY OF BIOFUELS PRODUCTION AND CONSUMPTION

Arnaldo Walter and
Manoel Regis Lima Verde Leal
(organizers)

1

INTRODUCTION

Arnaldo Walter and *Manoel Regis Lima Verde Leal*

The sustainability of biofuels[1] has been the focal point in the recent debate regarding its feasibility for displacing fossil fuels. The main reasons for using biofuels in large-scale include the potential reduction of greenhouse gas – GHG – emissions and the potential socio-economic benefits to rural population[2], including jobs creation, raising income and, in some cases, access to energy services[3].

Recently, doubts have been raised about the rationale of producing and using biofuels. The most common questions raised at the international level have been regarding the effective contributions of biofuels in avoiding GHG emissions, the impacts due to land use change – LUC[4], and on food supply. It's impossible to do an ultimate evaluation on this issue, but there are still a combination of serious concerns, lack of information and also defence of specific interests[5].

However, two aspects should be taken into account. First, biofuels have been produced in very heterogeneous conditions, with regard to raw materials (e.g., different results on GHG emissions, different productivities, required land, alternative uses etc.) and the production in itself (e.g., depending on soil and weather conditions and even producer's behaviour). Thus, any generalization would be risky, as good and bad examples can be easily found. Second, there is a great expectation due to the drivers indicated above.

Biofuels would be accepted as a sustainable energy option if the three following conditions are fulfilled:

1) their contribution to the reduction of GHG emissions needs to be significant, and the costs of avoided emissions should be relatively low;
2) local and regional environmental impacts should be significantly reduced[6];
3) social segments directly involved with the production should get real benefits.

It is not reasonable to consider that the concerns regarding the sustainability of biofuels would be just transitory. Quite the opposite, it is clear that consumers' behaviour has been more and more impacted by environmental and socio issues, and this would not be different with energy. Brazil, as a country with large potential for biofuels production, and with comparative advantages and low production costs, would be in a much better position in the international market if the sustain-

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[1] Taking into account their full life cycle.

[2] Other important reason is the enhancement of the energy security supply; for some analysts, this is in fact the main driving force for biofuels.

[3] In less developed regions the production of biofuels could make possible, for instance, local production of electricity, water pumping, mechanization in the agriculture and the transport.

[4] This question is further analyzed in more details. The impacts of land use change can be either direct or indirect, and can be on GHG emissions, on food supply or over biodiversity.

[5] For instance, the oil and the food industries have reasons to be against large-scale production and consumption of biofuels, because the impacts on gasoline and diesel markets and on prices of the raw materials, respectively.

[6] This means, the impacts where the production takes place or close to there.

ability of its production is widely recognized. Even more, if Brazil implement ambitious targets and improves the sustainability of its production, the country could further reinforce its leadership in the biofuels market.

This chapter is about sustainability of biofuels, in general. However, as the publication is about ethanol production in Brazil, specific aspects of this fuel, and about the Brazilian case, are also highlighted.

The follow section is about the different point of views on sustainability of biofuels. International and national initiatives aiming at assuring the sustainability of biofuels, including principles, criteria and policies, are also discussed. This follows by some thoughts about the knowledge available and the required actions.

VISIONS ABOUT SUSTAINABILITY OF BIOFUELS

The meaning of sustainability is wide and its definition is not simple; the term has been applied to almost all natural systems and human activities. There are different views regarding sustainability as the concept is normative[7] and definitions are related to values, believes and choices. In particular, there is no consensus about the basic principles of sustainability of biofuels (RSB, 2008).

It's widely accepted that sustainability has three dimensions, i.e., any productive activity is sustainable if and only if it is (economically) feasible, socially desirable and environmentally correct[8] (UNITED NATIONS, 2005). In respect to biofuels, the economic feasibility depends both on the competitiveness with fossil fuels (i.e., gasoline and diesel) and on the cost of avoided emissions. In other words, in mid – to long-run biofuels should be feasible when compared to traditional fuels, without subsidies, and the costs of avoided emissions (e.g., in $/tCO_2$) should be moderated regarding other mitigation options. Among all biofuels currently produced, only ethanol from sugarcane, mostly produced in Brazil, is feasible with gasoline as long as oil prices are higher than 45 to 50 US$/barrel[9]. As the balance of GHG emissions of the sugarcane ethanol is the best among all current biofuels, the costs of avoided emissions are also the lowest (IEA, 2004). This fact is internationally recognized and, as consequence, there is no doubt about the economic dimension of the sustainability of the Brazilian sugarcane ethanol. This is not the case of ethanol from corn and wheat, and even biodiesel.

As for the social dimension of biofuel sustainability, what is desired is that their production could enhance life conditions of the workers and the people directly involved (e.g., RSB, 2008). The aspects considered most important are jobs creation, working conditions, the compliance with worker's rights and the avoidance of land tenure problems. In this case, it has been considered that the basic principle is the enforcement of the conventions of the International Labour Organization – ILO –, as well of Human Rights Convention.

A second aspect concerns the potential risk that biofuels production could negatively impact food supply due to the land competition and higher demand of agricultural products traditionally consumed as food or feed. These concerns is one of the main reasons for the development of technological routes known as second generation biofuels, based on cellulosic biomass; cellulosic biomass can be produced in low quality land and does not necessarily competes with land for food production. In 2007/2008, the growth of biofuels production was blamed for the raise of food prices. Despite the fact food prices have declined since 2009, and even with the continuous growth of biofuels production[10], there remain still concerns with this issue.

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[7] Normative is a concept defined by social groups and that is related to values perception.

[8] The so-called three pillars of sustainability.

[9] Supposing that ethanol producing costs are between 590.00 and 660.00 R$/m^3, that the equivalence ratio is 1 litre of ethanol = 0.85 litre of gasoline, exchange ratio 1 US$ = 2.20 R$, and that the cost of the barrel of gasoline is 12% higher that the price of oil.

[10] For instance, in March 2009 an official of International Energy Agency stated that one the challenges in the energy market is the potential competition for biomass, for biofuels and food production. See PFLÜGER, A. Potential Role of Biofuels in Future Markets. In: Biofuels Markets – Congress and Exhibition. Available at: <www.iea.org>.

The environmental dimension of sustainability is much wider as there are many aspects that could be taken into account. The most frequent concerns are not the potential impacts at the end-use stage, as it is recognized that disadvantages "vis-à-vis" fossil fuels will be few. For instance, in the case of ethanol the emissions of aldehides could be higher than with the gasoline and the emissions of nitrous oxide could be higher with the use of biodiesel.

Conversely, there are more concerns regarding the impacts along the production chain of biofuels. The most frequent argument is that biofuels production could cause deforestation, directly or indirectly. In fact, the growth of biodiesel production from palm in Malaysia and Indonesia have caused deforestation in rain forests (direct impacts) (FRIENDS OF EARTH, 2005; WWF, 2002) and the same hypothesis has been presented regarding the indirect impacts of sugarcane expansion in Brazil, that has been correlated with deforestation in Cerrado and in Amazon forest.

With regard to biofuels production, two papers published in Science early 2008 have heated-up the debate on direct and indirect impacts of LUC. FARGIONE *et al.* (2008) analysed the direct impacts over GHG emissions due to the expansion of agricultural crops in biomes with significant carbon stock. As for Brazil, the authors have considered sugarcane cropping in areas previously occupied with woody Cerrado and soybeans production (for biodiesel) both in the Cerrado and in the Amazon Forest. They concluded that the GHG emissions due to land use change would cause significant impact, and that it would be necessary to produce biofuels during tens or even hundreds of years in order to balance the up-front emissions[11].

SEARCHINGER *et al.* (2008) addressed the same issue considering also the indirect effects of the expansion of corn production in US; the hypothesis is that due to larger ethanol production from corn, the production of other agricultural goods (or even corn, for food or feed) would be displaced from US to other countries, potentially causing deforestation.

In the case of ethanol production from sugarcane in Brazil, the authors conclude that four years of ethanol consumption would be necessary to equal the up-front emissions due to LUC if sugarcane was to be planted in pasturelands, or 45 years in case the expansion of sugarcane would induce deforestation of the Amazon Forest[12].

Regarding the aspects mentioned above, the basic principles of sustainability are that the biomass production does not jeopardize sensible biomes and those that should be preserved (RSB, 2008), and that the biomass production does not occur in forest areas, wetlands, and regions with high biodiversity (EUROPEAN PARLIAMENT, 2008)[13].

On the other hand, so far the main principle driving the sustainability of biofuels is the required reduction of GHG emissions considering fossil fuels displaced. Minimum amounts have been set considering the full life cycle of biofuels and fossil fuels. It is almost consensual that the GHG emissions on direct impacts of land use change should be taken into account but the same is not true regarding the indirect impacts[14]. For instance, in

[11] In the case of sugarcane cropping in the Cerrado region, 17 years would be necessary to balance the up-front emissions. In the case of biodiesel production from soybeans, 37 to 319 years would be necessary to balance the up-front GHG emissions (respectively, considering soybeans displacing Cerrado or Amazon forest).

[12] On indirect impacts, the hypothesis is that cattle heard would be displaced to the Amazon and this would be the immediate cause of deforestation. The deforestation would be indirectly caused by sugarcane expansion, as it would happen in pasturelands, even far from Amazon. It is true that most of the areas recently cleared in the Cerrado and in the Amazon region are immediately occupied by extensive cattle ranch and that sugarcane expansion has mostly occurred in pasturelands. However, there is no evidence of the indirect effects of sugarcane expansion as considered by SEARCHINGER *et al.* (2008). In fact, in recent years sugarcane expansion has occurred simultaneously to the intensification of cattle heard in Southeast Brazil. It has also been observed that cattle heard have entered in deforested areas of the Cerrado and the Amazon, due to enlargement of the activity and also due to the low land prices.

[13] The Directives of European Commission, approved in December 2008 and published in May 2009, define areas in which biomass production should not occur – the so-called "no-go areas".

[14] In the case the Directives of the European Union, the GHG emissions due to indirect impacts of land use change won't

the case of the Directives of European Union[15], the avoided GHG emissions of biofuels use in 2010 should be 35% regarding the life cycle of gasoline or diesel, and this level will be raised to 50% in 2017 (60% in the case of new production plants). In the early years indirect impacts of LUC won't be considered, but the society is pushing for a review in the short-term (i.e., indirect impacts of LUC could be considered in 2011).

The state of California, in US, has adopted a strategy based on a minimum level of reduction of GHG emissions (10%) in the transportation sector by 2020. This reduction should be proved by those who produce, import or commercialise fuels. Contrary to European Union, both direct and indirect impacts of land use change should be considered along the evaluation of GHG emissions in the biofuels life cycle.

The decision has been criticized because the hypothesis considered for evaluating the impacts of land use change in case of biofuels or the fact that the impacts of land use change have not been considered in case of oil products[16]. In the case of ethanol produced from sugarcane in Brazil, the direct emissions in the production chain were estimated as 27 gCO_2eq/MJ, while the emissions due to land use change were estimated as 46 gCO_2eq/MJ, totalling 73 gCO_2eq/MJ. Thus, without changes on the efficiency of the ethanol engines, the avoided emissions regarding gasoline life cycle (estimated as 96gCO_2eq/MJ, in case of California) would be low.

Other environmental aspects that have caused concern is that biofuels production could not negatively impact water resources, air quality and the soil. The associated criteria are that the use of fertilizers and agro-toxics should be minimized, to no contamination of water bodies, minimization of residues production and proper disposition, and use of agriculture techniques that would avoid erosion etc.

INITIATIVES AIMING AT SUSTAINABILITY OF BIOFUELS

International initiatives

This section describes the sustainability principles and criteria currently considered abroad regarding biofuels. The cases highlight are considered to be the most relevant.

Directives of European Union

The sustainability criteria for biofuels at the European Union (EU) was set by the European Parliament in December 2008. The correspondent law was published early 2009. In respect to renewable energy sources, the Directive sets targets for the transport sector and sustainability criteria for biofuels. In the transport sector, the energy suppliers must reduce GHG emissions by 6% in the period 2011 to 2017[17] and present reports about GHG emissions along the life cycle of all energy sources, starting in 2011.

Fuel suppliers should provide an adequate standard of independent auditing that must be verifiable, reliable and fraud-resistant.

The overall target was set at 20% share of renewable energy sources in energy consumption by 2020 in all Member States, and a 10% binding minimum target for biofuels in transport (energy basis). In the accountability process on avoided emissions, the contribution of biofuels produced from lignocellulosic materials will be weighted twice. The GHG saving regarding full life-cycle of fossil fuels must be at least 35% in 2010 and this target will be 60% in 2017 (50% will be the minimum for existing producing units at that year). As previously mentioned, the emissions due to direct impacts of land use change must be considered, but not those caused by indirect

be considered because the scientific knowledge is not solid enough to support such decision. Other argument is that indirect impacts of land use change cannot be attributed to the producers of biofuels.

[15] Renewable Energy Directive, that includes a Fuel Quality Directive.

[16] Brazilian producers of ethanol, represented by UNICA, have presented documents showing that the evaluation done by CARB – California Air Resources Board, had mistakes both regarding direct emissions and emissions due to land use change.

[17] In respect to "emissões de combustíveis fósseis" in 2010.

impacts[18]. However, during 2010 the European Commission will propose procedures that could lead to take into account the indirect impacts as well (HODSON, 2009).

The UE Directive also focus on saving biodiversity and on the preservation of most sensible feedstock as biofuels produced in areas previously occupied by undisturbed forests, wetlands, area designated for nature protection could not be considered regarding the targets[19]. In addition, social aspects of biofuels production should be reported periodically (every two years) by each Member State[20]; the references being the conventions of the International Labour Organization – ILO, but there are concerns regarding the legality vis-à-vis Word Trade Organization – WTO procedures (DE DOMINICIS, 2009).

California State Government

The initiative of the state of California is known as Low Fuel Carbon Standard – LFCS and aims at reducing 10% of GHG emissions in 2020, regarding 1990. Besides the reduction of GHG emissions, the initiative also aims at reducing oil dependency, and at creating a market for clean-energy technologies in the transport sector. Emission standards have been proposed for fossil fuels (i.e., gasoline and diesel) and the energy that can displace them (CARB, 2009).

Considering the timetable for the period 2011 to 2020, more ambitious targets were defined for the last five years, and this is explained by the fact that more alternatives would be available by the end of the decade (e.g., hybrid vehicles, electric vehicles, fuel cell vehicles, second-generation biofuels etc.). Thus, biofuels are only one the options considered for the reduction of GHG emissions. For the purpose of estimating emission reductions, the reference fuel in 2020 would be reformulated gasoline blended with 10% ethanol from corn (volume basis) and mineral diesel with low-sulphur content.

During the period 2011 to 2020, the agents responsible for the energy supply in the transport sector will report of results. If an agent has surpassed its targets, the commercialisation of credits will be possible.

Currently, the aim of the LFCS concerns reduction of GHG emissions. The Air Resources Board – ARB in California, has accepted a compromise that a wide set of sustainability criteria for biofuels will be proposed until 2013. Thus, other sustainability aspects will be considered. In a first moment, the environment assessment that will be conducted by ARB will take into account the impacts of LFCS over water resources and biologic resources, soils, and disposal of wastes etc. (CARB, 2009).

Renewable Transport Fuels Obligation

In United Kingdom, the Renewable Transport Fuel Obligation – RTFO – which came into force in April 2008, is a requirement on transport fuel suppliers to ensure that 5%, by 2010, of all-road vehicle fuels are from sustainable renewable sources (biofuels among them). It is predicted that RTFO will be implemented by a certification scheme controlled by the Renewable Fuels Agency – RFA. Fuel suppliers will be obliged to include the required percentage of biofuels (e.g., biodiesel and biogas, besides bioethanol) in their fuel mix or pay a penalty; certifications could be sold in the market. The focus point of RTFO is on reduction of GHG emissions[21].

RFA requires biofuel suppliers to submit annual, independently verified reports on both the net GHG savings and the sustainability of the biofu-

[18] The decision was based on the fact that currently the scientific knowledge is not enough to support decisions regarding indirect impacts of land use change. One of the main concerns is that complains could be presented to the World Trade Organization – WTO.

[19] According to the Directive, the commercialization and consumption of such biofuels is not forbidden, but they cannot be considered in the accountability that each Member State should present to prove that the targets have been reached.

[20] Member States will be responsible for the information presented. Each MS should be sure that all economic agents are supported by independent auditing systems.

[21] In UK, the transport sector is responsible for 25% of total GHG emissions (DEPARTMENT OF TRANSPORTS, 2008a).

els they supply (DEPARTMENT OF TRANSPORT, 2008b). In the first stage, a report on carbon and sustainability is obligatory, but without consequences if poor performance is reported. By April 2010 it is predicted that biofuels will be rewarded according to the amount of carbon savings, and by April 2011 only biofuels that meet all sustainability standards will be rewarded.

Regarding GHG emissions, the methodology recommended is based on a well-to-wheel procedure including all significant sources of GHG. The required reduction of GHG emissions is 50% "vis-à-vis" the displaced fossil fuel. The recommendation will also include, when possible, the effects on overall GHG savings of previous land use change.

According to environmental and social principles, it is recommended that biomass production will not cause impacts such as those listed bellow (DEPARTMENT OF TRANSPORT, 2008b):

- destruction or damage of above or below ground carbon stocks;
- destruction to high diversity areas;
- soil degradation;
- contamination or depletion of water resources;
- lead to air pollution;
- adversely affect workers rights and working relationships;
- adversely affect existing land rights and community relationships.

It is worth mentioning that the UK Government recognises that some principles would be difficult to monitor at the fuel supplier level. Land use change arising as indirect result of biomass production and impact of biofuels on commodity prices is explicitly mentioned as an example (DEPARTMENT OF TRANSPORT, 2008a). Overall, the recommendation is that all principles should be monitored ex-post and the RFA report annually the potential effects to the Parliament.

Roundtable on Sustainable Biofuels

The Roundtable on Sustainable Biofuels is an initiative coordinated by the École Polytechnique Fédérale de Lausanne – EPFL, based in Lausanne, Switzerland. In August 2008 launched the so-called "Version Zero" of Global Principles and Criteria for Sustainable Biofuels Production[22], developed with participation of a considerable number of stakeholders of different countries. "Version Zero" was evaluated in a public consultation process and the so-called "Version One" should be released by mid 2010 (RSB, 2008).

Sustainability principles and criteria were proposed and discussed, but so far indicators have not been considered in details. Twelve relevant aspects should be considered in order to assure sustainable biofuels production is a broad sense. These aspects are the following (EPFL, 2008):

- All applicable laws of the country in which production of biofuels occur, as well as all international treaties relevant to biofuels' production to which the producer country is a party, should be followed.
- For biofuels projects, all relevant stakeholders should be involved along the main steps of the decision process.
- Significant reduction of GHG emissions should be reached through biofuels use, also considering direct and indirect land use change.
- Biofuel production shall not cause violation of human rights or labour rights (include child and slave labour); working conditions should be decent.
- Biofuel production shall contribute to the social and economic development of local, rural and indigenous peoples and communities.
- Biofuel production shall not impact food security.
- Biofuel production shall avoid negative impacts on biodiversity, ecosystems, and areas of high conservation value.
- Biofuel production shall promote practices that seek to improve soil health and minimize degradation.
- Biofuel production shall optimise surface and groundwater resource use, including

[22] Available at: <http://EnergyCenter.epfl.ch/Biofuels>.

minimizing contamination or depletion of these resources.

- The supply chain of biofuel production and use should not cause significant air pollution.
- Biofuels shall be produced in the most cost-effective way.
- Biofuel production shall not violate land rights.

Global Bioenergy Partnership

The Global Bioenergy Partnership – GBEP – was created in 2006, following a decision taken during the meeting of G8 + 5[23] in 2005 with the purpose of fostering biomass and biofuels consumption mainly in developing countries. During the meeting of the G8 + 5 group in 2008 it was decided to enhance GBEP's action and it was asked the development of bench marks and indicators relative to the best practices of production and consumption of biofuels (GBEP, 2009).

The action plan of GBEP in short-term includes the following actions (GBEP, 2009):

- The promotion of sustainable bioenergy, including the support to the implementation of projects. This working group is led by Unit Kingdom and aims at the development of criteria and indicators, as well as examples, of best practices on biofuels sustainability. The group also aims at evaluating impacts of biofuels on food supply, taking into account specific aspects of each production process and of each producer country.
- The harmonization of methodologies of evaluation of GHG emissions considering the production of biofuels and solid biomass. This working group is headed by United States and final results will be presented in early 2010.
- The promotion of bioenergy, including the dissemination of information.

In its preliminary version, the sustainability criteria defined by GBEP's working group were classified in four categories: environmental, social, economic, and related to the security of supply. The most important environmental aspects are related to GHG emissions, to the capacity of production of land and ecosystems, to land use change (including indirect impacts), air quality, availability and quality of water resources, and to biological diversity.

The relevant social aspects include security of food supply, access to land, access to water resources and to natural resources, working conditions, rural and social development, access to energy services, human health and security.

Finally, the relevant economic aspects include the availability and the efficient use of resources (e.g., soil, water, capital, working force, energy etc.), the economic development, the economic feasibility and the access to capital and to technological capacity (GBEP, 2009).

Cramer Report

In 2006/2007 the so-called Cramer Commission[24] set the Dutch sustainability principles defined by the project group "Sustainable Production of Biomass" (CRAMER *et al.*, 2007). In the final report, principles, criteria and indicators were defined for the main issues concerned to the environmental and social sustainability of biomass production (including biofuels).

Six areas of concern were highlighted by the Cramer Commission. The principles concerned to these priorities are listed bellow:

- GHG emissions – the use of biofuels should imply reductions of GHG emissions. The comparison should be done regarding the average use of fossil fuels, considering the life cycle of fossil and biofuels (i.e., well-to-wheel basis) and in case of biofuels reduction should be at least 30%. Carbon

[23] The eight most important countries from an economic point of view (USA, Germany, Japan, United Kingdom, France, Canada, Italy and Russia); and the five most important developing countries also from an economic point of view (China, India, Brazil, Mexico and South Africa).

[24] Headed by Jacqueline Cramer, Ministry of Environment of The Netherlands.

emissions due to land use change[25] should also be taken into account.

- Impacts over food supply – the production of biomass for energy must not endanger the food supply and other local biomass applications. The analysis should be developed considering possible changes of land use in the region of biomass production.
- Biodiversity – Biomass production must not affect protected or vulnerable biodiversity. The basic criteria are that violation of national laws and regulations are unacceptable.
- Local environmental effects – Principles include (a) soil and soil quality, that must be retained or even improved, (b) ground and surface water supply, that must not be depleted, and water quality, that must be at least maintained, and (c) air quality, that must not be depleted. The basic criteria are that national laws and regulations should be enforced.
- Local economic effects – The production of biomass must contribute towards local prosperity.
- Social well-being – The production of biomass must contribute towards the social well-being of the employees and the local population.

National Initiatives

The text to follow presents some initiatives at national level that aim at enhancing biofuels sustainability at their production and use.

Agro-ecologic Zoning (at national level)

Embrapa is the Brazilian Research Centre for Agriculture, linked to the Ministry of Agriculture (MAPA), and assumed the coordination of the Agro-ecologic zoning for sugarcane at national level. The Zoning has been developed by a multidisciplinary group of state institutes/universities, government organizations and private consultants. The results of the Zoning should be used as guidelines for licensing and credits concession with public funds. Among the targets are the minimization of risks due to the expansion of sugarcane in sensible areas and also avoidance of pressures on food supply.

The following aspects have been considered in order to define adequate areas: a) soil and weather adequacy; b) topography[26]; c) water availability and water requirements[27]; d) that sugarcane cannot be planted in areas with sensible ecosystems[28]; and e) areas where other crops have been produced.

The study was finished in mid 2008 but it was released only about one year after due to political disagreements as some areas currently with sugarcane production were considered inadequate. The results of the Agro-Ecologic Zoning show that 65 Mha are considered suitable for sugarcane cropping of which 37 Mha are currently pasturelands. About 30% of the total area is considered of very large potential for sugarcane production. The most suitable areas are concentrated in the regions where the bulk of the production already occurs (e.g., São Paulo, Paraná, Minas, Mato Grosso Sul and Goiás).

Certification by INMETRO

INMETRO is the National Institute of Metrology, Standardization and Industrial Quality that belongs to the Ministry of Development, Industry and Foreign Trade[29]. In 2007/2008 the Institute decided to conduct the so-called Brazilian Program of Biofuels Certification. According to its premises,

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[25] Both considering above ground carbon sinks (vegetation) and underground carbon sinks (soil). In addition, as principles, (1) the installation of new biomass production units must not take place in areas in which the loss of above ground carbon storage cannot be recovered within a period of ten years of biomass production, and (2) the installation of new biomass production units must not take place in areas with a great risk of significant carbon losses from the soil, such as certain grasslands, peat areas, mangroves and wet areas.

[26] Maximum declivity 12% is due to the consideration of current technology for mechanization. It is possible to take into account 18% as the maximum, which would enlarge the area. However, the required technology is not yet available.

[27] A minimum level of irrigation has been considered (e.g., the so-called salvation irrigation).

[28] For instance, Amazon and Pantanal were fully excluded as adequate areas.

[29] More information is available at: <www.inmetro.gov.br>.

certification would not be compulsory and the criteria should be in-line with strategies aiming at foster biofuels exports and at reduction of trade non-technical barriers. A first version of the proposal was submitted to public consultation in mid 2008 and a final decision by the Brazilian government was expected during the first semester of 2009, but it has not happened yet at the time of writing.

INMETRO has a similar program aiming at certifying forest management (CERFLOR), which is internationally recognised; INMETRO evaluates that this experience is a good start-point for the program with focus on biofuels. Ethanol certification was defined as the main priority. According to the proposal, an ethanol producer could only start the certification process if the following conditions are fulfilled (INMETRO, 2008):

- Sugarcane production should be in accordance with the Agro-Ecologic Zoning.
- All environmental licences are required.
- Evidences of water recycling are required.
- Electricity should be generated on-site, from sugarcane residual biomass.
- Evidences of trash deposition over the soil are required.

Agro-ecologic Zoning in São Paulo

The Agro-ecologic Zoning in São Paulo has been effective since October 2008. The information provided by this study has been considered by the Environment Secretary along the licensing process of new mills. The zoning was defined taken into account the following aspects: a) soil and weather constraints; b) topography; c) water availability at the surface and risks to water shields; d) the existence of protected areas; e) areas that should be preserved considering conservation of biodiversity; and f) air quality.

The cultivated land in São Paulo was estimated in 2006 as 7.9 Mha, being at that time 4.3 Mha were already cultivated with sugarcane.

Agro-environmental Protocol (State of São Paulo)

The Agro-environmental Protocol was established in the state of São Paulo in 2008, signed by the state Government and the sugarcane sector. In São Paulo, 151 out of almost 190 ethanol mills have adhered the Protocol; the number of sugarcane suppliers that have adhered to the Protocol is estimated as 13,000 (LUCON, 2008). The Protocol is a voluntary scheme aimed at promoting best practices beyond business-as-usual. One the future target is issuing a Certificate of Conformity. Ten directives were defined as guidelines, as presented bellow (SÃO PAULO, 2008a):

- Anticipation of the due-date for phasing-out of sugarcane burning previous to harvest in areas with declivity lower than 12% (from 2021 to 2014)[30].
- Anticipation of the due-date for phasing-out of sugarcane burning previous to harvest in areas with declivity higher than 12% (from 2031 to 2017).
- In areas of sugarcane expansion burning should not be a practice.
- All by-products of sugarcane cannot be burned without a control system.
- Protection of the riparian forest of sugarcane planted areas[31].
- Recovery of natural vegetation in order to protect water springs of sugarcane farms.
- Implementation of a technical plan of soil conservation, including erosion control and contention of water runoffs.
- Implementation of a technical plan aiming water resources conservation, including reuse action and a water quality program.
- Adoption of good practices for agrochemicals packaging waste.
- Adoption of good practices aiming at minimizing air pollution and optimise recycle of solid wastes.

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[30] It is defined by law that the due date for phasing-out of sugarcane burning before harvest is 2021 in areas with declivity lower than 12% and 2031 as the due date for areas with declivity higher than 12%. Through a voluntary agreement, the intention is to anticipate such due dates.

[31] The existing law already defines protection of riparian forest as an obligation, but there are areas in state of São Paulo where the enforcement is weak.

CONSIDERATIONS REGARDING THE CURRENT STAGE AND THE NEAR-TERM

The previous text gives an overview of a reasonable number of initiatives and also makes clear the different point of views regarding the subject. Sustainability, in general, and sustainability of biofuels, in particular, is a relatively new theme and disagreements regarding its importance, priority aspects, and how to use the results in a constructive way are natural.

On the other hand, it has been observed that in past few years the resistance of some social sectors has declined. In fact, it is impossible to overlook the importance of sustainability and not to be part of the debate as it is the main driving force of biofuels and also due to the significance of the priority aspects.

Obviously the real target of the whole process should be the improvement of the production systems and better results of biofuels production and consumption. However, as there are many different interests and the state-of-art of knowledge is not that advanced, it has been possible to distort information and to define rules with particular purposes.

A very important aspect is that this process could not resume in a single certification process, satisfying those who are not exactly concerned with real social, economic and environmental benefits. It would be disastrous to have a certification process with all known distortions of those of existing certification processes.

The development of biofuels should allow the inclusion of the most marginalized social sectors that have had few job opportunities, few opportunities for improving life, and for having access to energy services. The sustainability of biofuels production chain is essential but cannot be an excuse for setting trade barriers for less developed countries. In this sense, it is necessary to assure technology transfer, building capacity, financial support and less constrains on trade in order to make biofuels a real option.

But it is also necessary to have in mind that biofuels are not a panacea for solving energy supply and GHG emissions problems. Firstly because it is not possible to conceive a sustainable scenario, in long-term, based on the current transport system. Secondly, because as an alternative to reduce GHG emissions, there are other most cost-effective options with the required technology already available (e.g., the improvement of end-use efficiencies).

On the other hand, it is important to recognise that many of problems imputed to biofuels have been historically observed in the agriculture e.g., soil degradation, large-scale use of fertilizers and agro-toxics, changes on carbon stocks and land tenure problems. The production of biofuels is and will be marginal with regard to agriculture and thus cannot be blamed for the main problem. In fact, biofuels production could help to modernize agricultural practices and disseminating best techniques.

It is worth to mention that the controversy surrounding sustainability of biofuels is also motivated by lack of understanding, expeculative behaviour and incorrect generalisation of few results. Sustainability is clearly a multidisciplinary issue and is very close to people's day-by-day, and this has both positive and negative aspects; the debate can be wide and democratic, but also moved by interest and based on non-accurate information. Clearly, there is a lot to be done by basic science, technology and dissemination of knowledge. An adequate data basis is required for each region, and models should be developed or adjusted to each specific case.

Brazil has long tradition on ethanol production, a huge potential for biofuels production and adequate conditions – including human and materials resources – for contributing with scientific and technology development. It is clear that Brazil has a very important role because is one of the few developing countries that can influence the biofuels debate and set positive bench marks on sustainability. The country is able to cooperate on disseminating biofuels production to other developing countries, as it has the technology, qualified people and reasonable investment capacity. Brazil is currently able to produce biofuels in large-scale, and at low costs and fulfilling the most relevant sustainability principles.

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2

THE IMPACT OF ETHANOL USE ON AIR QUALITY IN MAJOR CITIES

Alfred Szwarc

INTRODUCTION

Air pollution has been a serious problem for industrialized countries for various decades, and more recently it has affected many developing countries. The damaging effects of atmospheric pollution on human health, ecosystems and the economy are well known and are described in hundreds of scientific studies. While there are various important sources of atmospheric pollutants[1], the principal cause of air pollution in a large percentage of urban agglomerations is the intensive consumption of fossil fuels for passengers and cargo transportation.

Growing fleets of automobiles, pickups, vans, trucks, buses and motorcycles are usually the principal sources of pollutant emissions in these regions. A complex association of factors related to the vehicles (their age and state of maintenance, engine characteristics, fuel quality and characteristics and so on) and also to their use (profile, the intensity and traffic flow, road characteristics, average mileage and so on) are all factors that determine pollutant emission and, as a consequence, the impact on air quality.

It is quite common to have high concentrations of pollutants generated by vehicle use in urban areas, in particular in central regions and those neighboring heavy traffic thoroughfares. As these also tend to be places with high demographic density, the population is exposed to the risks and negative impacts of this pollution. This situation is of itself worrying, but it is frequently aggravated by conditions that are not favorable to pollutant dispersion, caused by meteorological and topographical effects and by the influence of urban constructions on local ventilation.

Pollutants that are frequently associated with transportation activities are carbon monoxide (CO), volatile organic compounds (VOC)[2], nitrous oxides (NOx), sulfur oxides (SOx), particulate matter (PM), tropospheric ozone (O_3 – coming from reactions in the atmosphere that involve mainly VOC and NOx in the presence of solar energy)[3] and heavy metals such as lead, nickel, cadmium and manganese.

While intensification of the greenhouse effect is not considered to be an urban problem, the vehicle fleet circulating in urban regions makes a significant contribution to the occurrence of this global phenomenon. The main greenhouse gases (GHG) generated by vehicles use are carbon dioxide (CO_2)[4], methane (CH_4), nitrous oxide (N_2O), CO and O_3. Based on various existing studies (INTERNATIONAL ENERGY AGENCY, 2005, and others) it can be said that the contribution of road

[1] Factories, electricity generation, commerce, civil construction, services, air and water transportation, burning of waste, pollutants carried from other regions etc.

[2] The VOCs are also frequently called hydrocarbons (HC).

[3] Also known as photochemical reactions; in addition to tropospheric ozone (which is generated in the lower atmosphere, unlike the "ozone layer" which occurs naturally in the upper atmosphere and acts as a shield against ultraviolet radiation) they also generate other pollutants such as aldehydes, organic acids etc.

[4] CO_2 is considered to be the principal GHG.

transportation to the global emission of CO_2 is between 20% and 25%, and that vehicles are the world's most rapidly growing source of CO_2.

Despite important progress made in recent decades to improve air quality, achieving and maintain good standards of clean air is still an enormous challenge, above all in the major cities. This is because of the very rapid growth in the vehicle fleet and in vehicle use. In Brazil the number of new vehicles licensed in the period January through May of 2008 was 30.3% greater than in the same period of 2007. In absolute numbers this means adding 883,600 vehicles to the existing fleet (CARTA DA ANFAVEA, June 2008). According to updated estimates, the fleet stands at around 27 million units (data from ANFAVEA adjusted to May of 2008). Although data on the Brazilian vehicle fleet is imprecise, and varies considerably from source to source, it is possible to identify 11 metropolitan regions where, given the size of the fleet (www2.cidades.gov.br/renaest), fuel consumption and economic activity (www.ibge.gov.br, www.anp.gov.br), vehicular emissions have an impact on air quality. These regions are: São Paulo, Belo Horizonte, Rio de Janeiro, Curitiba, Brasília, Porto Alegre, Campinas, Goiânia, Salvador, Fortaleza and Recife. Of these, the São Paulo Metropolitan Region (RMSP) is the one with the greatest amount of information available about air quality, and which has been most studied. For these reasons, the RMSP will be taken as reference in this paper.

STRATEGIES TO CONTROL VEHICULAR POLLUTION

Various strategies have been used for the prevention and control of vehicular air pollution, since this came to be seen as a matter for concern in the 1950s. Amongst the ones that have given positive results, particularly when used in an integrated manner, we can highlight the following:

- Setting emission limits for new vehicles and engines. This stimulates the development of technologies that can significantly reduce pollutant emissions. In Brazil this strategy is based on two programs that are regulated by the National Environmental Council (Conselho Nacional do Meio Ambiente): PROCONVE (the Motor Vehicle Air Pollution Control Program, Programa de Controle da Poluição do Ar por Veículos Automotores, in effect since 1986) and the PROMOT (Motorcycles and Similar Vehicles Air pollution Control Program, Programa de Controle da Poluição do Ar por Motociclos e Veículos Similares, in effect since 2002).
- Changing the characteristics of fuels, thereby reducing their pollutant potential and making possible the use of advanced systems of pollution control which could otherwise not be used. Reducing the level of sulfur, for example, in addition to reducing SOx emissions, makes it possible to equip vehicles with latest-generation catalytic converters that are very sensitive to the presence of sulfur in the fuel. These allow for control of other emissions with great efficiency[5].
- Periodic inspection of emissions of the fleet in circulation, to check the state of vehicle maintenance to ensure that pollutant emission is in line with defined standards. Currently there are only two programs operating in Brazil aimed at conducting periodic vehicle emission checks: in Rio de Janeiro State, since 1997; and in São Paulo City, since May of 2008.
- Encouraging the use of low-emission public transportation.
- Traffic engineering measures to improve traffic flow. In addition to saving fuel, this avoids increasing pollutant emissions.
- Planning of urban land use and transportation systems to promote more rational use of means of transportation.

Using better quality fuels, with a lower potential to pollute, is a strategy that has a virtually

[5] The presence of sulfur in the fuel is not desirable, because it results in the formation of SOx and contaminates the catalytic converters used for emission control; this can significantly reduce their operational efficiency or even stop them functioning.

immediate impact on air quality because it yields benefits as soon as the fuel is placed on the market. Additionally, it is fundamental in defining the technologies that are applied to vehicle propulsion systems, to define the characteristics of pollutant emissions.

Ethanol is a product that fits this profile perfectly, and Brazil has been the world's great laboratory and an example of large-scale efficiency in ethanol use. Ethanol started being added to gasoline and achieved national scale and strategic importance as of 1977 under the National Ethanol Program (Programa Nacional do Álcool). Current legislation determines that ethanol shall be mixed in gasoline in the range of 20% to 25%, a mixture that is called Type C Gasoline by the National Agency of Petroleum, Natural Gas and Biofuels (ANP – Agência Nacional de Petróleo, Gás Natural e Biocombustíveis). With the exception of aviation fuel, all gasoline sold in Brazil contains ethanol. Moreover, ethanol has since 1979 been used as a stand-alone fuel in vehicles equipped with ethanol engines, and Brazil has to date built more than five million such vehicles. March of 2003 saw the introduction of flex fuel vehicles that can run just on ethanol, just on type C gasoline or on any mixture of the two, and these have rapidly become first choice for consumers. In March of 2008 they accounted for 87.6% of all new vehicles sold, and there were approximately 5.5 million flex fuel vehicles in the national fleet (CARTA DA ANFAVEA, January to June 2008).

ETHANOL

Ethanol is a low toxicity fuel and unlike gasoline it contains oxygen in its chemical composition. This contributes to more complete combustion in the engine, and in turn to lower emission of pollutants. In Brazil, ethanol is produced exclusively from sugarcane. Given the progress made in the area of biotechnology, it is probable that within a decade it will be possible to produce ethanol in commercial scale and at competitive costs from materials that contain cellulose and hemicellulose, for example sugarcane bagasse and straw. This will allow for a substantial increase in productivity.

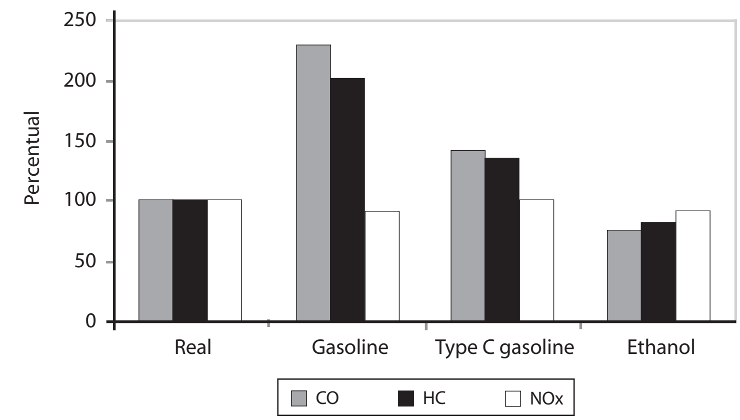
Two kinds of ethanol are used as fuel in internal combustion engines: hydrous and anhydrous. Hydrous ethanol contains roughly 95% ethanol by volume; the remainder being water. This is appropriate for use in motors with spark plug engines (Otto Cycle) and, if mixed with appropriate additives or used in a two-fuel system, it can also be used in compression ignition engines (Diesel Cycle). Production of anhydrous ethanol requires an additional stage of dehydration, following distillation, and the final product contains 0.4% of water by volume. Dehydration is used so that the ethanol forms a homogeneous mixture with the gasoline, without the risk of phase separation in the fuel storage tank or indeed in the vehicle fuel tank[6].

USE OF ETHANOL AND THE VEHICULAR EMISSION OF POLLUTANTS

While the National Ethanol Program was not conceived with the purpose of reducing automotive vehicle pollution, the mixture of ethanol in gasoline and the direct consumption of ethanol have allowed for a significant reduction in pollutant emission, so contributing to important environmental benefits. This fact was particularly important in the 1980s and 1990s, when Brazil registered high levels of environmental pollution in its principal urban regions. At that time PROCONVE was just getting under way and PROMOT, the equivalent program for motorcycles, did not exist.

It is appropriate to mention the results of a study (CONFEDERAÇÃO NACIONAL DA INDÚSTRIA, 1989) that evaluated the environmental importance of ethanol in the RMSP. The study estimated pollutant emission by vehicles in different scenarios of fuel and usage: with ethanol, Type C gasoline and ethanol-free gasoline. The study took as its reference the current situation of

[6] Characteristic that favors the formation of tropospheric ozone and other pollutants.
Given that ethanol is infinitely miscible with water, the greater its presence in the mixture then the greater is the tolerance to the presence of water and the lower the risk of phase separation. It is this situation that makes it possible to mix hydrous ethanol with Type C gasoline in flex fuel vehicles.



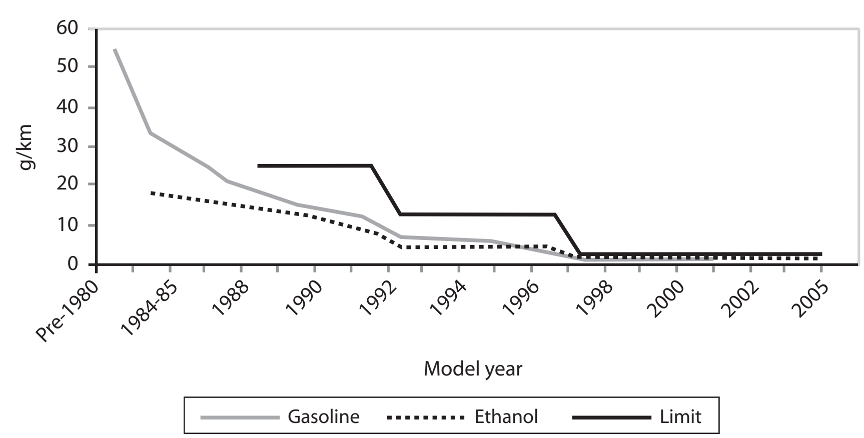
Source: CNI, 1989.

FIGURE 1 Scenarios for emission in the RMSP.

the light vehicle fleet at that time, comprising 76% of vehicles powered by Type C gasoline and 24% powered purely by ethanol (Figure 1). The results showed that if the fleet were powered exclusively by pure gasoline, there would be an increase of 130% in CO emissions, of 100% in hydrocarbons and a reduction of 10% in the emission of NOx in relation to the reference scenario. In the case of using just Type C gasoline, there would be an increase of 40% in the emission of CO and 37% for HC, with no change in the emission of NOx. Finally, in the scenario of using just ethanol, there would be a reduction of 23% in CO, 20% in HC and 10% in NOx.

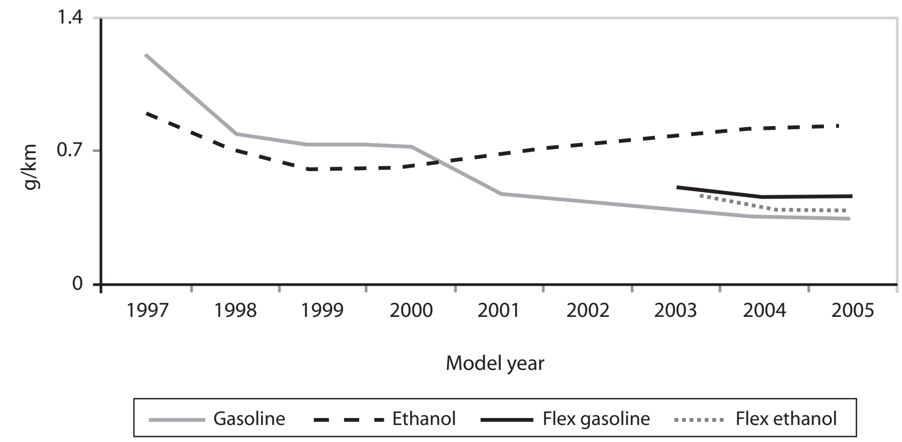
The study demonstrated the environmental importance of using ethanol, be it mixed with gasoline or not, and showed the correctness of the option for large-scale use of ethanol. We can deduce from this study that the high levels of atmospheric pollution in the RMSP at that time, particularly CO, would have been even more critical were it not for the use of ethanol.

While it is true that the reduction in emissions of CO, HC and NOx did not happen solely because of the use of ethanol, and was due rather to the combination of more advanced technologies and the use of cleaner fuels, the fact is that ethanol made an important contribution. This can be seen



Source: CETESB.

FIGURE 2 Average emission of CO for new vehicles.



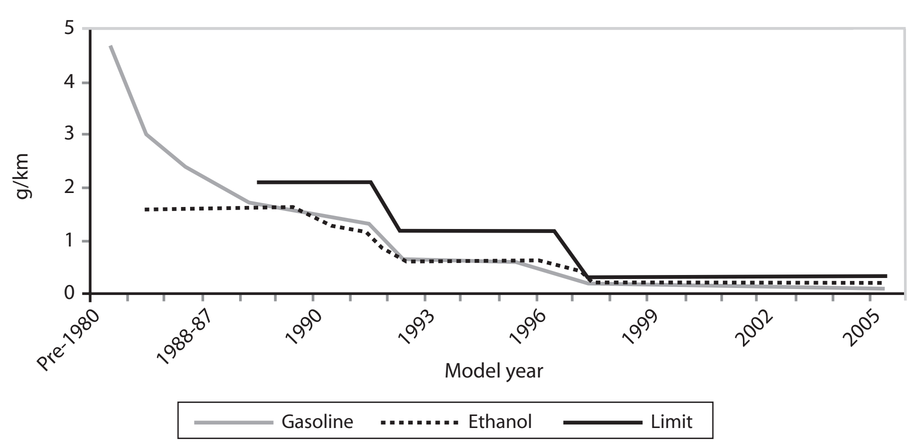
Source: CETESB.

FIGURE 2A Average emission of CO – detail for 1997/2005.

in Figures 2 through 4, which show the variation in emissions of these pollutants since 2005. The graphs show the average levels of emissions of new vehicles powered by pure gasoline (only for pre-1980 vehicles), reference Type C gasoline (78% gasoline and 22% anhydrous ethanol) and hydrous ethanol (CETESB, 2005). Figure 2A also shows data for emissions by flex fuel vehicles.

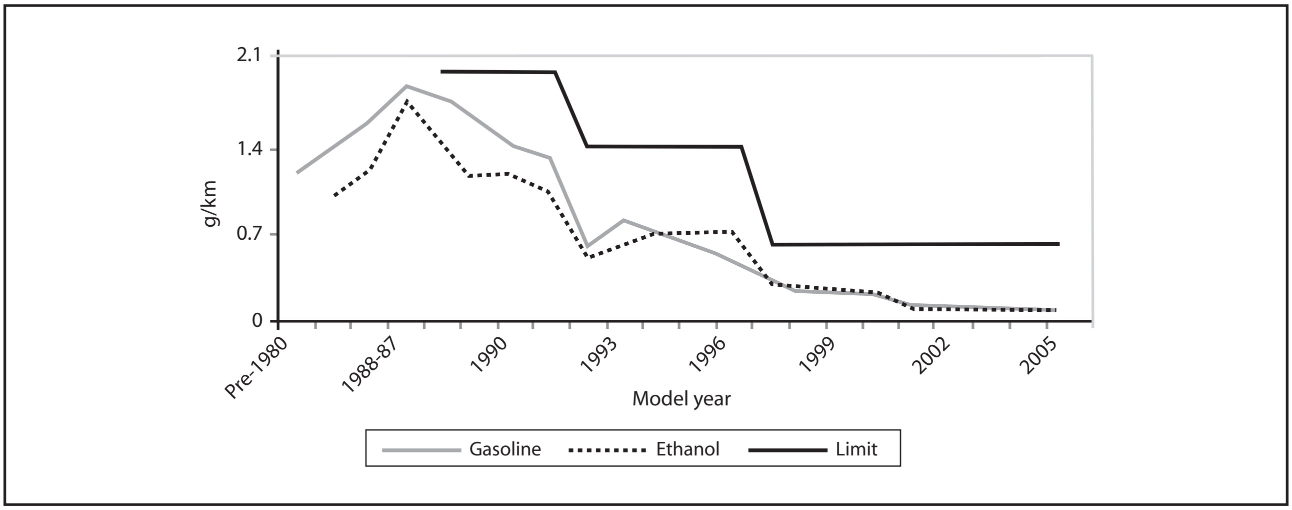
As we can see, the use of ethanol allowed for significant reductions in emissions for ethanol-powered vehicles when compared with their gasoline-powered equivalents, in particular until the middle of the 1990s. In these cases ethanol contributed to the full achievement of the legal limits for emission controls as defined under PROCONVE.

Given the need to meet ever stricter emission limits from 1986 onwards, gasoline-powered vehicles started to be equipped with more advanced emission control systems, in particular from 1997 onwards when catalytic converters became standard. As a consequence, there was a substantial reduction in pollutant emission, which fell practically to the levels seen in ethanol-powered vehicles. For



Source: CETESB.

FIGURE 3 Average emission of HC for new vehicles.



Source: CETESB.

FIGURE 4 Average emission of NOx for new vehicles.

various factors, but principally the relatively low price of gasoline, the automobile industry at this time lost interest in ethanol-powered vehicles. This led to a reduction in investments for their technological development and only limited progress was made in their environmental performance. The effect of this situation can best be seen in Figure 2A. In the case of flex fuel vehicles, the use of a mixture of Type C gasoline and hydrous ethanol produces benefits that lie between those seen with each of these fuels separately. However, the variations observed represent only a marginal difference if we take into account the scale in which this is happening.

It is important to note that while the emission of HC is quantitatively equivalent for Type C gasoline and ethanol (Figure 2) the emission that results from the exclusive use of ethanol is less toxic and is less photochemically reactive[7]. These factors must be taken into account in any analysis of the question.

With respect to the emission of NOx, it should be noted that the use of ethanol was advantageous most of the time.

Another important benefit of ethanol was the elimination of the use of lead-based additives, which are shunned because of their high toxicity. Additives such as tetra-ethyl lead were widely used in Brazil to raise the octane rating[8] of gasoline. The fact that ethanol has a very high octane rating[9] means that when it is added to gasoline in large proportions it renders these additives unnecessary, and their use was banned in 1990. This fact led to Brazil being the first country in the world to completely eliminate these gasoline additives and produced relevant environmental gains. The measure rapidly reduced by 75% the concentration of toxic lead compounds in the atmosphere in the São Paulo Metropolitan Region (RMSP) and made possible the use of catalytic converters[10], which constitute a very efficient technology to control pollutant emissions.

The use of high levels of ethanol in gasoline made it unnecessary to carry out expensive modifications to refinery processes in Brazil to increase the octane rating of gasoline, which could raise the level of aromatic hydrocarbons in the fuel. These hydrocarbons – benzene, toluene, xylene and

[7] Parameter of the quality of gasoline that indicates its resistance to pre-ignition.

[8] 109 to 115 octane by the RON (Research Octane Number) method.

[9] Lead-based additives contaminate the catalytic converters and thus stop them working.

[10] Assuming an average level of sulfur in ethanol of 3 ppm and in gasoline of 300 ppm.

others – are toxic and have high photochemical reactivity, which is why their concentration is being significantly reduced in gasoline used in more developed countries.

As for SOx emissions, the use of ethanol makes a decisive contribution to reducing air pollution. In gasoline-powered vehicles, SOx emission is reduced by between 20% and 30% depending on the amount of ethanol used in the fuel. Where the fuel used is just ethanol, then the emission of SOx is 100 times less than that of gasoline[11]. In flex fuel vehicles, the greater the use of ethanol, then the greater the reduction in SOx.

A similar argument can be made for the various organic compounds in gasoline that demonstrate higher levels of photochemical reactivity and are significantly toxic, for example benzene and 1,3-butadiene. As ethanol contains just two carbons, the emission of particulate matter is virtually zero. This is an important quality, because the fine particles emitted mainly by diesel vehicles are currently considered to be the most aggressive form of pollution for human health.

Aldehydes

Emission of aldehydes (R-CHO) deserves separate analysis, because it is a subject that is frequently misunderstood. While it is true that burning ethanol produces aldehydes, this is also true for other automotive fuels such as pure gasoline, diesel oil and natural gas, although this fact is not widely known. A first point to be cleared up is that fossil fuels preferentially produce aldehydes that have a high degree of toxicity and high photochemical reactivity in the atmosphere, for example formaldehyde, while burning ethanol produces mainly acetaldehyde, which is a less toxic product with lower environmental impact (Table 1).

In any case, the emission of aldehydes has been greatly reduced over the years thanks to the progress made in automotive technology. In the case of ethanol-powered vehicles, the average observed in 1992, of 0.035 g/km, is lower than the level registered at the end of the 1970s for vehicles powered by pure gasoline (0.05 g/km), while in 2003 vehicles powered by ethanol and Type C gasoline registered respectively average emissions of 0.02 g/km and 0.004 g/km. In 2006, flex fuel vehicles had average emissions of 0.014 g/km using just ethanol and 0.003 g/km using Type C gasoline (CETESB, 2005). These values are significantly lower than the current and future limits for aldehyde emissions[12]. Moreover, various studies conducted by CETESB have shown that the large-scale use of ethanol does not result in the presence of concentrations of aldehydes in the environment that can pose a significant risk for the population.

TABLE 1 Characteristics of aldehydes.

Parameter	Formaldehyde	Acetaldehyde
Maximum incremental photochemical reactivity (g O_3/g substance)*	6.2	3.8
Limit for occupational exposure** (ppm)	2	100

Source: BRANDBERG, A., 1991* and U. S. Occupational safety and health administration**.

With respect to aldehydes emitted by other fuels, it is worthwhile mentioning two studies. The first study (ABRANTES, 2003) deals with the belief that the use of ethanol is the main cause of this kind of emission. This study was carried out with light commercial diesel vehicles, and showed that the emission of aldehydes varied between 0.022 g/km and 0.16 g/km. In other words, taking the 2003 emission data as a base, we can say that the diesel vehicles tested demonstrated aldehyde emissions that can be up to eight times greater than those of an ethanol-powered vehicle or up to 40 times greater than those of a vehicle powered with Type C gasoline.

The second study (CORREA, 2003) was carried out by the Rio de Janeiro State University

[11] Particles with diameter less than 2.5 micron.

[12] Currently the limit for aldehydes (counting acetaldehyde and formaldehyde) must be below 0.03 g/km, falling in 2009 to 0.02 g/km.

and showed a direct and very close relationship between the growth trend of the fleet converted to using natural gas in the city of Rio de Janeiro and the increase in the environmental concentration of formaldehyde.

CONSIDERATIONS ABOUT AIR POLLUTION IN THE SÃO PAULO METROPOLITAN REGION

Based on CETESB data (Daily Air Quality Bulletins) it is possible to deduce that primary standards for air quality are sometimes exceeded in the RMSP, particularly in terms of PM and O_3. This happens despite the reduction in pollutant emissions that has resulted from the use of ethanol and is due, essentially, to the "emissions generated by the fleets of light and heavy vehicles that circulates in the region, together with emissions from fixed sources such as factories." (RELATÓRIO DE QUALIDADE DO AR NO ESTADO DE SÃO PAULO, 2007).

In fact, the vehicle fleet registered in the RMSP is very large. According to data from DETRAN-SP, in January of 2008 the fleet of vehicles registered in the RMSP comprised 8,467,203, distributed as follows:

- gasoline vehicles: 5,161,751
- ethanol vehicles: 969,425
- flex fuel vehicles: 854,052
- diesel vehicles: 457,610
- motorcycles: 1,024,365

According to estimates by SINDIPEÇAS (ESTUDO DA FROTA CIRCULANTE, 2006), the fleet has an average age close to 10 years, while the two-wheel fleet has an average age of close to five years. While in general the fleet cannot be considered old, the fact is that the standard of vehicle maintenance is frequently below that which would be desirable, resulting in increased emissions.

In terms of absolute numbers the principal group is gasoline-powered vehicles, followed by motorcycles. In the case of two-wheel vehicles the pollutant emission is substantial, and in many cases it is higher than that of new automobiles and light commercial vehicles, given that the requirements for emission control defined in PROMOT are relatively recent and less severe than those pertaining under PROCONVE. While in purely numerical terms the fleet of ethanol-powered vehicles is of the same order of magnitude as that of the flex fuel fleet, the latter is significantly newer and demonstrates a considerably lower level of emissions.

In cases where air quality standards are exceeded for PM, the emission sources are mainly diesel vehicles, stationary sources, fugitive dust and secondary aerosols (above all sulfates and nitrates) that are formed in the atmosphere from emissions of SOx and NOx. In cases where air quality standards are exceeded for O_3, it is more difficult to clearly identify the main culprits for the formation of this substance, given that it is a secondary pollutant formed mainly by photochemical reactions of VOC and NOx, and the mechanisms for its formation in the RMSP are not well known.

However, based on data for the inventory of air pollution sources in the RMSP (RELATÓRIO DE QUALIDADE DO AR NO ESTADO DE SÃO PAULO, 2007) it is believed that the main contributions to the formation of O_3 come from diesel vehicles (given their high level of emission of NOx), from light vehicles (principally those powered by Type C gasoline), from motorcycles and from fuel losses through evaporation, given its contribution to emission of VOC.

SOCIAL COSTS OF AIR POLLUTION

One question of fundamental importance in the current discussion is the impact of vehicular emissions on public health and the resultant social costs. Innumerable studies have shown that there is a direct relationship between air pollution, the impact on health and premature death. One example is the relationship between asthma and air pollution in proximity to traffic thoroughfares. There is extensive literature on this subject. It identifies SOx, PM and ozone, pollutants associated above all with fossil fuels, as being the principal triggers for asthma crises (ENVIRONMENTAL DEFENSE). A study carried out in Europe showed that the social costs of PM air pollution could be as high as € 190 billion per year, taking into account premature deaths and associated illnesses. The study emphasized the contribution to the problem of diesel-powered vehicles, which are responsible for around one third of the emissions of fine PM in the region (ORGANIZAÇÃO MUNDIAL DA SAÚDE, 2005). A study conducted in Canada (VICTORIA TRANSPORT POLICY INSTITUTE, 2002) estimated that the average environmental cost of vehicles powered by pure gasoline and diesel oil was in the range of 0.6 cents and 5 cents of a dollar per kilometer.

In São Paulo, estimates by the Air Pollution Laboratory of the School of Medicine of the University of São Paulo (SALDIVA *et al.*, 2008) indicated that in 2005 the cost associated with atmospheric pollution (cardiovascular diseases, chronic bronchitis, emphysema, asthma and lung cancer) was of the order of US$450 million.

Another study (MAC KNIGHT, 2006) estimated that the cost due to the pollution of urban diesel-powered buses in the RMSP was R$ 532 million in 2005.

RESEARCH SUGGESTIONS

The information presented indicates that the use of ethanol makes possible a reduction in the emission of pollutants by automotive vehicles. While positive, this fact is not sufficient to avoid the occurrence of air quality standards being exceeded in the RMSP. We can assume, however, that without the presence of ethanol the environmental conditions would be even more critical in the RMSP, with even higher social costs than those currently experienced.

Given that air quality standards for ozone have been exceeded quite frequently, and that the mechanisms for its formation in the RMSP atmosphere are little known, it is recommended that a research program be established to investigate the matter, seeking to evaluate the role of the use of ethanol in this process. This is an important subject, given that the use of ethanol is expanding and that it is important to know if its use could result in a reduction in the formation of ozone and other photochemical pollutants. Studies to this end would also be of use for other urban regions in Brazil. Given that this is a complex matter and one that has been little developed in Brazil, it is recommended that this study be carried out in conjunction with North American universities (University of California – Riverside, California Institute of Technology etc.) that have proven experience in developing this kind of study.

Another subject that merits investigation is the effect of fuel evaporation emissions on the formation of ozone. The control of evaporative emissions currently targets just vehicles, and there is no control for fuel stocks and fuel transfer operations. Estimates of evaporative emissions are of limited reliability, and need to be improved. It is additionally necessary to know the effective pollutant impact of evaporative emissions and the efficiency of possible control measures. In this context it is necessary to study the emissions resulting from the evaporation of ethanol (pure and when mixed with gasoline) as well as from hydrocarbons produced by the fossil fuels currently in use, and from engine lubricants. Studies in this sense could be extremely useful for guiding the establishment of policies and regulations designed to control evaporative emissions.

A third subject associated with the use of ethanol which appears interesting, although it has not been covered in this paper, is the possibility of substituting ethanol for diesel in public transportation and in other urban transportation applications. Technological options exist that make this use possible, and allow – among other advantages – for significant reductions in PM, SOx, CO, VOC and NOx (the last two participate actively in the formation of ozone). To this end, it would be opportune to analyze the feasibility of these technologies and their environmental impact, in particular in the central regions of cities and along transport corridors used by urban buses.

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3

CLIMATE CHANGE AND SUGARCANE IN THE STATE OF SÃO PAULO

Jurandir Zullo Junior, Hilton Silveira Pinto, Eduardo Delgado Assad, Fábio Ricardo Marin and *Giampaolo Queiroz Pellegrino*

Agribusiness accounted for 23% of Brazilian Gross Domestic Product (GDP) in 2007, being around 49.7 billion dollars the surplus of the sector's trade balance. Jobs related to agribusiness were approximately 37% of total national jobs. Brazil is the world's largest producer of sugar, alcohol, coffee, and orange juice; the second in soybeans, beef and chicken; the third in fruit and corn and the fourth in pork. It is the first exporter of sugar, alcohol, coffee and soybeans. Brazil was a global leadership of beef and chicken in 2003. Brazil sells 82% of orange juice, 29% of sugar, 28% of coffee beans, 44% of coffee, 38% of soybeans and 23% of tobacco consumed on the planet. It occupies the first place in the world of tanned leather and leather footwear. It is possible to conclude therefore from the above data that the agribusiness is a fundamental component of the country and various regions of the world.

The climate is one of the major determinants of agricultural production due to: a) natural variability of the various systems prevailing in the country; b) insufficient knowledge about their behavior and c) difficulty in forecasting. The drought that affected Rio Grande do Sul in January and February 2005, for example, had a negative impact throughout the economy of the state and not just in agriculture. The state government estimated a total loss of 300 million dollars in the budget of the year. According to IBGE – Brazilian Institute of Geography and Statistics, Rio Grande do Sul was the only state that accumulated a fall in industrial production in the first two months of 2005, a decrease of 1.6% compared to a 5.2% increase in the national average (BUENO, 2005). The most severe frost of July 18, 1975 decreased by 20% the budget of the state of Paraná, with estimated losses of 1 billion dollars and 500 million coffee trees.

Until the early 1990's, Brazilian agriculture recorded high loss rates that drastically limited their development, since they were making the sector economically unviable. According GÖEPEFERT *et al*. (1993), the 1992/93 harvest losses were about 30% for rice and 21% for beans in São Paulo; 37% for corn and 29% for soybeans in Bahia; and 81% for cotton and 32% for irrigated soybeans in the Northeast. According to ROSSETTI (2001), approximately 90% of the losses recorded in Brazilian agriculture until the early 1990's were caused by two main climate factors: a) dry spells during the critical phase (in 60% of all cases) and b) excessive rain at harvest (in 30% of all cases). These losses were related to a poor knowledge of rainfall distribution that led the farmers to plant after the first rainfalls of spring.

Based on these high loss rates of domestic agriculture, the Ministry of Agriculture – MAPA started in 1995 an official program of agricultural zoning in order to reduce climate risks associated with dry spells during the critical phases of crops and excessive rains at harvest. The practical tools used to achieve these goals have been planting calendars based on meteorological data and parameters for the main crops of the country, considering periods of planting having ten-days length, three different soil types, two or three types of cultivars and each of the municipalities of the regions potentially suitable for plantations.

The planting calendars have to be updated annually to include new crops, cultivars and climate data, and improving the methods used in zoning, being 80% the minimum probability of crops achieving economic productivity. Climate oscillations, such as those attributed to phenomena such as El Niño and La Niña began to be normally considered in the annual updates of the Zoning. This program is thus based on the integration of crop growth models, climate and soil databases, decision analysis techniques, and geo-processing tools (CUNHA, 2001). More details of the methodology normally used in Agricultural Zoning can be found in ASSAD *et al*. (2008b, 2008c) and CARAMORI *et al*. (2006).

The annual update and the continuous operation of the Program since 1995 are two aspects favorable to the improvement of Agricultural Zoning that is used as the basis of the official programs of agricultural finance and rural insurance from the federal government, that is, it is used in practice as a public policy. This provides a continuous, comprehensive and detailed monitoring of the information available in the Agricultural Zoning, by the financial institutions, government and farmers, corresponding to a practical verification of program performance. Another aspect that should be highlighted in the current Agricultural Zoning Program is the existence of a scientific community specialized in agro-meteorology, mathematical modeling and GIS, with experience in transforming scientific research in public policy, based on similar programs in Brazil since the 1970's.

Reliance in good performance of the methodology and in results available in the Agricultural Zoning are fundamental for assessing the impacts of climate change on agriculture made since the release of the third IPCC report in 2001 (IPCC, 2001a and 2001b). The fourth report, released in 2007 (IPCC, 2007), has heightened the interest of the World, including several governments and governmental organizations, by the theme of climate change. It is emphasized that this issue has been receiving special attention after the hurricane season in North America and the heat wave in Europe in 2005.

The significance of climate to agriculture, as mentioned above, makes it one of human activities potentially more vulnerable to changes described in the IPCC reports. According to SEGUIN (2007), climate change is not the only factor that will affect the European economy in coming decades, but have a very significant impact on crop productivity and geographical distribution of potential agricultural areas. According to BATTISTI and NAYLOR (2009), the increase in temperatures will seriously affect agriculture in tropical and subtropical regions, and, if nothing is done, at least half of the world population will face a drastic shortage of food until the end of the century.

ASSAD *et al*. (2004) and PINTO *et al*. (2001 and 2002) assessed the impact of climate change described in the third IPCC report, in the agro-climatic zoning of arabica coffee, in four Brazilian states: São Paulo, Minas Gerais, Parana and Goias. They concluded that increases of 1 °C, 3 °C and 5.8 °C in mean temperature may lead to reduction in areas with low climate risk and their changeover to higher altitude areas, considering the commercial varieties currently used and no adaptation or genetic modification. According to ZULLO Jr. *et al*. (2006), the low climate risk areas for Arabica coffee in São Paulo can decrease from 78.7% of total surface (current situation) to 58.9% (increase of 1 °C), 30.3% (increase of 3 °C) and 3.3% (increase of 5.8 °C). For corn, the estimated average decrease of areas with low climatic risk for planting between October and December in loam soils, was 1% (an increase of 1 °C), 33% (increase of 3 °C) and 84% (increase of 5.8 °C).

Replacement by crops or species more tolerant to drought and heat can be a way of adapting agriculture to climate change. PINTO *et al*. (2007), for example, pointed out that the loss of current areas of low climate risk for Arabica coffee in the southeast region of Brazil may be compensated by new areas of low climatic risk for another kind of coffee more tolerant to high temperatures and that is cultivated in the state of Espírito Santo: the Robusta coffee. Similarly, the current areas of high climatic risk due to low temperatures and high risk of frosts may be benefiting from the rise in global temperature. Such potential areas correspond to the states of Rio Grande do Sul, Santa Catarina and the southern Parana, Brazil, Uruguay and northern Argentina.

WREGE *et al.* (2007) found that rising temperatures could reduce the current areas of low climate risk for the production of temperate fruits in the state of Rio Grande do Sul due to the reduction in the number of chilling hours that are required for their development. ASSAD *et al.* (2008d, 2006 and 2005) concluded that the size of areas with low climatic risk in the Agricultural Zoning for soybean, bean, corn and upland rice decreases when average temperature and precipitation increase, for plantings in November. Other studies show similar assessments on the impact of climate change on domestic agriculture, such as those of PINTO *et al.* (2008 and 2005), NOBLE *et al.* (2005), ASSAD *et al.* (2007b and 2007c) and ZULLO JR. *et al.* (2008).

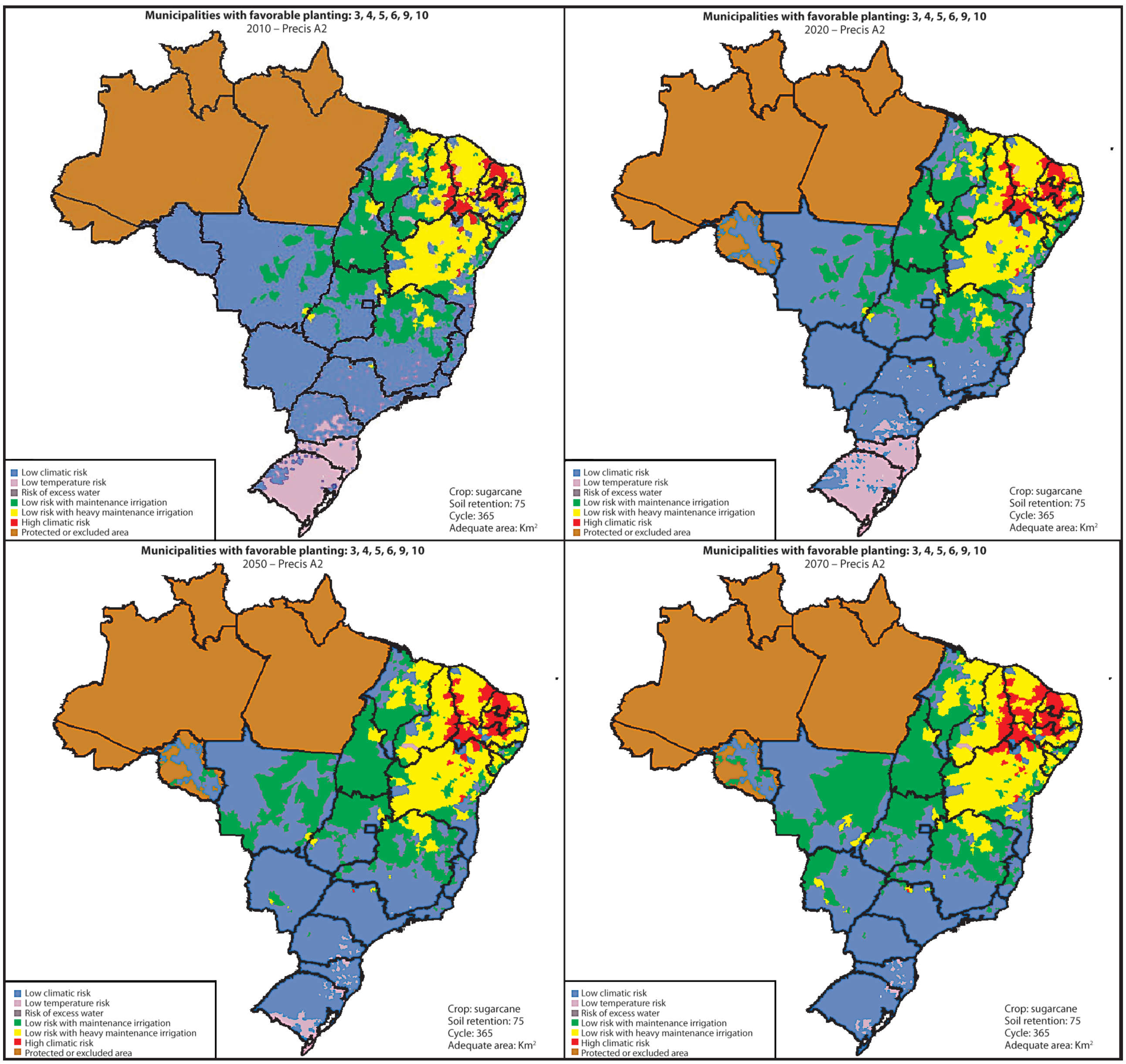
In general, all these studies have found a great vulnerability of Brazilian agriculture, linked to climate changes described in the third and fourth IPCC reports, provided that adaptation and mitigation are not well developed and made effective in the coming years. Despite this increasing vulnerability, agriculture has significant capacity to adapt to new climatic conditions, considering: a) the limits of biological tolerance; b) the existent technological challenges; c) the available natural resources; and d) the time available to apply appropriate solutions. ASSAD *et al.* (2007a) highlighted the following items necessary for the adaptability of the main crops in Brazil: a) heat tolerance throughout the country; b) drought tolerance to the South and Northeast; and c) soil management to increase the capacity of water conservation. The biodiversity of the *Cerrado* and the Amazon regions can contain genes that may be used to adapt the existing crops to environmental stresses. The diversity of environmental conditions in Brazil can be a great advantage in adapting agriculture to new climatic conditions.

Another feature of the studies cited above is that, in general, they used climate change scenarios in the order of 1 °C and 5.8 degrees on the values of temperature and 0% to 15% for total rainfall in all evaluated regions. There is considerable interest on climate change and a huge amount of studies have (and are) been carried out which are throwing light into this area and are making considerable contributions to our understanding of the potential implications, as described by VALVERDE and MARENGO (2007), and ASSAD *et al.* (2008). This study includes the results of nine crops (cotton, rice, coffee, sugar, beans, sunflower, cassava, maize and soybean); it uses two emission scenarios of greenhouse gases (A2 – high emission and B2 – low emission), four different periods of time (currently, 2020, 2050 and 2070); and spatial resolution of 50km in all states of the country, excluding the Amazon region.

The results for all crops, except for sugarcane and cassava, confirm those obtained in previous studies. The soybean crop is the most affected, with losses up to 40% in 2070, with an estimated loss worth UD$ 3.8 billion/ year in the worst scenario. Arabica coffee could lose up to 33% in the low climate risk area in São Paulo and Minas Gerais, although there is an increase in productivity in the south of the country. Corn, upland rice, beans, cotton and sunflower will also experiment a significant reduction in the low climate risk areas in the Northeast region, with significant loss of production. CASSAVA may have an overall gain in the low climate risk area, but may register losses in the Northeast region. The losses in grain crops could be about US$ 3.7 billion in 2020 and about US$ 7 billion in 2070. Such changes have the potential to change the geography of agricultural production in Brazil, if no measures for mitigation and adaptation to climate change is taken.

Sugarcane, however, showed different results from the crops assessed. Its development is directly influenced by changes in weather conditions observed during the length cycle that takes one year to 18 months. The best performance of current sugarcane varieties is observed when there is a hot and humid season, with intense solar radiation during the growth phase, followed by a dry period in the early stages of maturation and harvest. This corresponds, in practice, to regions with water deficit between 10 mm and 180 mm. Irrigation is needed to ensure the re-growth where the annual water deficit is between 180 mm and 400 mm. Over this value, irrigation would have to be increased significantly. The maximum rates of growth and biomass accumulation are obtained when the air temperature is between 22 °C and 30 °C and no growth above 38 °C, being restricted due to the risk posed by frost greater than 20%, below to 19 °C). The diversity of climatic conditions in Brazil allow to have two harvests per year: from May to December, in the Central-south region, and from September to April, in the North and Northeast regions.

Thus, based on these parameters, it is observed that, as shown in Figures 1 and 2, the sugarcane can be doubled its area in the coming decades, from a potential value of six million hectares for approximately 17 million hectares in 2020, in a scenario of low emission of greenhouse gases (B2), and 16 million ha for the high emission scenario (A2). Thus, the value of production, which was estimated at 17 billion dollars in 2006, could reach 29 billion dollars in 2020, in the B2 scenario. In scenario A2 (high emission of greenhouse gases), the potential area could reach 16 million hectares.

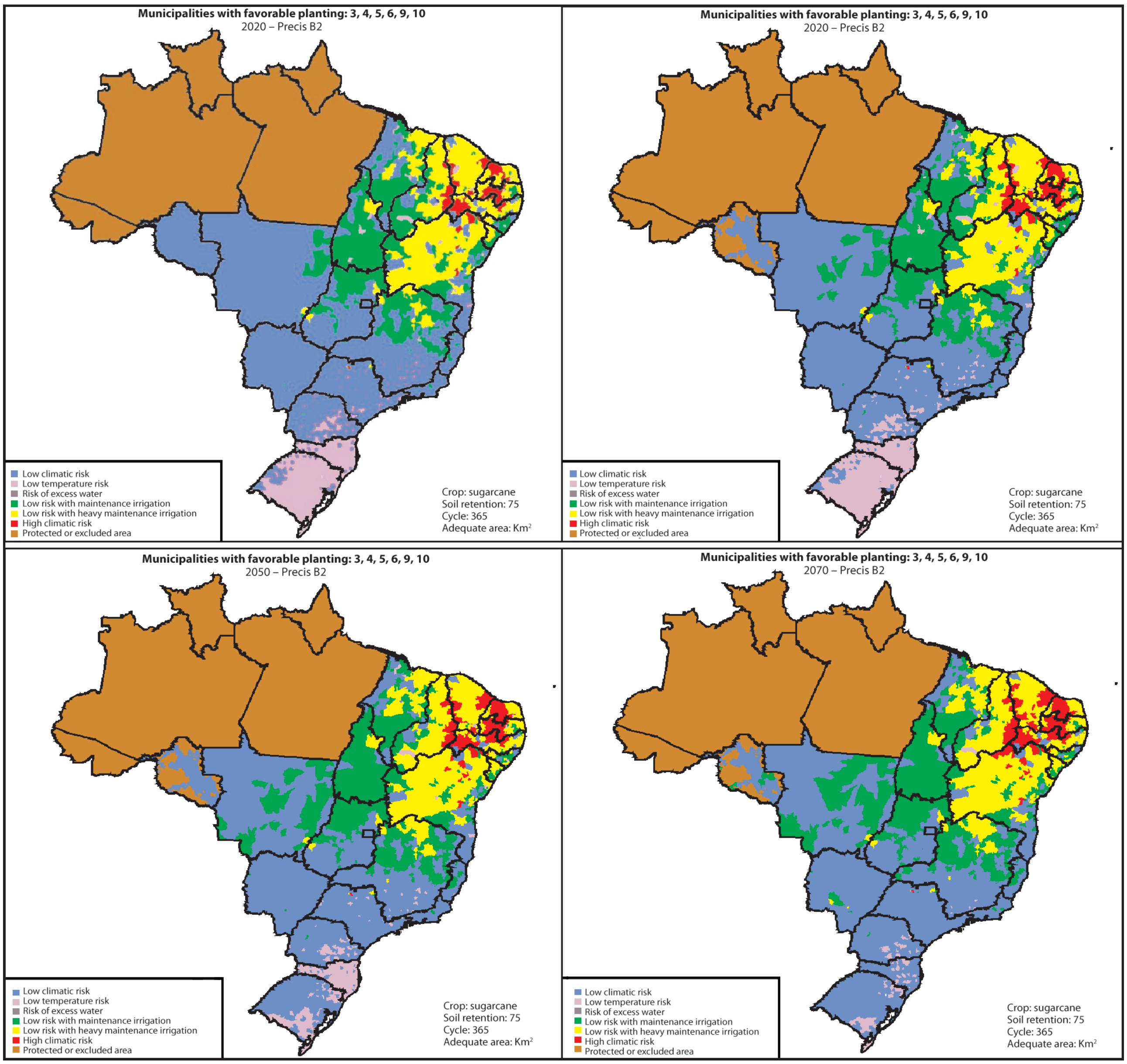


Source: ASSAD *et al.* (2008a).

FIGURE 1 Areas with low climatic risk (blue), risk of low temperatures (pink), low risk with irrigation (green and yellow) and high climatic risk (red) to the development of sugarcane, considering a high emission of greenhouse gases for four periods: current climate conditions (top left), 2020 (top right), 2050 (bottom left) and 2070 (bottom right).

Areas located at high latitudes in the Southern region of Brazil, which currently have high risk of frost that could affect crop – growing, may turn into areas with potential production, especially from 2050. Areas in the Midwest region, that currently have high production potential, could become increasingly dependent on irrigation of 50mm or so, during the driest period of the year. The continued increase in temperatures will result in greater use of irrigated crops. According to MARIN *et al*. (2007), a temperature increase of about 4 °C will lead to water restriction in 80% of the State of São Paulo, including in regions where there sufficient rainfall during the dry season for crops to mature.

The possibility of increasing suitable areas for sugarcane production, even with changes in current climate conditions, shows that in addition to mitigating emissions of greenhouse gases by replacing fossil fuels, sugarcane has a much greater



Source: ASSAD *et al.* (2008a).

FIGURE 2 Areas with low climatic risk (blue), risk of low temperatures (pink), low risk with irrigation (green and yellow) and high climatic risk (red) to the development of sugarcane, considering a low emission of greenhouse gases for four periods: current climate conditions (top left), 2020 (top right), 2050 (bottom left) and 2070 (bottom right).

capacity to adapt to climate change described in the IPCC reports, that the other eight cultures assessed by ASSAD *et al*. (2008a), considering current varieties and planting techniques. This increases interest for the use of sugarcane as a primary energy source in Brazil and beyond to expand further cane plantation areas, particularly if no measure of adaptation is developed for other major crops of the country.

This expansion, however, should be properly planned, considering the possible impacts associated with the environment, energy sector, food security and nutrition, national economy, demographic dynamics, culture and human health. A poorly planned expansion can have disastrous consequences and cause negative many impacts. The degraded pasture land area in Brazil is estimated at approximately 100 million hectares and can be used for sugarcane expansion avoiding food production areas or environmental preservation areas.

Various factors need to be considered: a) sugarcane expansion implications; b) production methods of cane main products (sugar and alcohol); and c) impacts directly associated with sugarcane performance (i.e. environmental, food security and nutrition, population dynamics and human health). Brazil should take this great opportunity for business and developmen, but should consider all the economic, social and environmental impacts based on strict technical and scientific criteria.

Adaptation to climate change is complex, and the sugar and alcohol sector needs to confront this challenge that requires coordinated and cooperation by experts in various subject areas such as climate, environment, GIS, population dynamics, food security and nutrition, health, science communication, public policy and scientific and technological development. The long historical experience of State of São Paulo in the development of sugar and alcohol industry, puts the state in a strong position to face the future development of sugarcane.

It is emphasized that the main objective of the scenarios of impacts cited in this paper, is avoid that a strategic sector for Brazil, such as agribusiness, do have information about all possible adverse effects caused by the climate changes and the effects on the major crops in the country. Despite the current usefulness of these scenarios, it is clear that considerable more research is needed to better understand these potential problems. These scenarios are just a starting point for the establishment of public policies aimed at adaptation Brazilian agriculture to climate change.

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4

CARBON STOCK IN SOIL AND GREENHOUSE GAS FLOWS IN THE SUGARCANE AGRO-SYSTEM

Carlos Clemente Cerri, Brigitte J. Feigl, Marcelo Valadares Galdos, Martial Bernoux and *Carlos Eduardo Pellegrino Cerri*

INTRODUCTION

Brazil is the world's largest sugarcane producer (FAOSTAT, 2007), with an area of approximately 7 million hectares, and a production of 550 million tons (2006/2007 harvest season), which represents a 13% increase in planted area and 16% over the previous harvest season (UNICA, 2008). From these 7 million hectares, 3.7 are located in the São Paulo state, representing 52.8% of the country's area, and 58% of the domestic production (CONAB, 2008). Estimates from Ministério da Agricultura, Abastecimento e Pecuária (MAPA, 2007) indicate a significant increase in the cultivated area for the next 10 years, to about 10.3 million hectares, as a result of potential demand from several countries interested in using ethanol as fuel, either to comply with the Kyoto Protocol, (mostly environmental considerations) or geopolitical and security of supply issues (MACEDO *et al.*, 2008).

In the sugarcane production system, burning tops and leaves before harvesting has been a common practice, to make stalks cutting, loading and transportation operations easier. The burning process produces the emission of gases like CO_2, CH_4, and N_2O, responsible for the greenhouse effect. Such practice also releases soot, which causes inconveniences as well as health hazards to neighboring populations (CANÇADO *et al.*, 2006).

Public policy banning sugarcane burning, together with the development of more efficient harvesting machinery, has favored harvesting of "raw" sugarcane (that is, unburned sugarcane), leaving the trash on the ground. In the São Paulo state, where more than half of the Brazilian sugarcane is produced, mills and distilleries are required by law (Decree n. 10 547, of May 2nd, 2000, complemented by Decree n. 11 241, of September 19th, 2002) to progressively phase out sugarcane burning. There are projections that 80% of the planted area in the Center-South region of Brazil – where most of the production is located – will be harvested unburned by 2014 (MACEDO, 2004). Brazil has accumulated considerable know-how in sugarcane handling that adopts trash burning; however, as it is relatively recent, there is still little information on the effect of handling unburned cane on the soil characteristics and other environmental impacts (GALDOS, 2007).

Recent studies have pointed out that leaving the trash on the soil will alter its physical, chemical, and biological properties. Various authors have studied the effect of the trash in the nitrogen dynamics in the sugarcane agro-system, focusing on issues such as immobilizing soil nitrogen by the microbiota after the addition of high C>N ratio residues, and making nitrogen available from the trash for absorption by the plant (BASANTA *et al.*, 2004; GAVA *et al.*, 2005). Significant effects of leaving the trash on the soil's physical factors, such as spatial variability of temperature and moisture (DOURADO-NETO *et al.*, 1999), soil density (TOMINAGA *et al.*, 2002), aggregate stability, and infiltration speed (CEDDIA, 1999; GRAHAM *et al.* 2002), in addition to the reduction of gas emissions, if compared to the traditional harvest system (ANDREAE, 2001) have been reported. If most of this trash is progressively mineralized over the year, part of it is capable of remaining longer in the system, resulting in a higher organic matter (OM) content in the soil. Various experiments have shown correlation between leaving the sugarcane trash and the increase in the soil total carbon content, influenced by variables such as time the unburned cane system was adopted, soil texture, and extent to which the soil was ploughed upon reforming the sugarcane plantation (GRAHAM *et al.*, 2002, CANELLAS *et al.*, 2003, ROBERTSON, 2003, CERRI *et al.*, 2004).

As for the organic matter (OM) content, it is known that tropical climate soils have an average of 1-2% in the first 20 cm of depth, which can be divided into fragile and persistent compartments. In the fragile fraction, most of the elements essential for plant development are found, part of N, P, and C present in the soil, and all the microbial population. The persistent fraction – the more advanced decomposition stage, in turn represents between 70% and 90% of the total soluble OM, contributing with about 98% of the organic form C, and 50% to 97% of the humic substances.

As a renewable source of energy, sugarcane has one the highest yields, in terms of efficiency and flexibility, producing solid, liquid, and gaseous fuels (RIPOLI *et al.*, 2000). It offers opportunities for mitigating global warming by replacing fossil fuels, without requiring excessive subsidies or the development of expensive infrastructures. Additionally, the wide application of conservationist agricultural practices may further increase the environmental offset of ethanol relative to fossil fuels. However, the quantification of this effect, which has been done in a sporadic and haphazard manner, has is of a strategic relevance for Brazil. A synthesis of the key information available on the matter will be presented next.

MITIGATION OF GLOBAL WARMING: QUANTIFICATION OF PARAMETERS IN THE SOIL-PLANT-ATMOSPHERE INTERACTION

A survey of the contribution of vegetal biomass, carbon stock in the soil, and greenhouse effect gases (GHG) emissions was carried out on two sugarcane plantations in the Ribeirão Preto area, São Paulo state. The region has a tropical climate, with average yearly temperature of 22.9 °C, and average rainfall of 1560 mm yearly, concentrated in summertime.

Situation 1: The clayous soil (70-80% clay) of the areas surveyed was classified as Red Dystrophic Latosol (EMBRAPA, 2006), Orthic Ferrasol (FAO, 2006) or Typical Haplugow (SOIL SURVEY STAFF, 1999). On the surface (0-10 cm), the pH $CaCl_2$ pH is 4.7, cation exchange capacity is 9 cmol (+)/kg^{-1}, and the exchanges complex bases saturation ratio is around 30%. For 50 years, until 1995, harvest was done in the traditional way, preceded by burning. From 1995 on, the area was divided into 12 parts: six of them were maintained under the same handling (burning), while the other six parts had mechanized harvesting, and the unburned tops and leaves and tips left on the soil surface (unburned cane treatment – Figure 1). Each part was randomly assigned to either type of handling. The field was fertilized with NPK, formulation 25-125-125 kg/ha every six years on the occasion the sugarcane field was reformed, and with 85-50-100 kg/ha at every resprout, i.e. every year, since the cultivation cycle lasts 12 months. The variety of sugarcane planted was the SP 80-185, with regular spacing of 1.50 m between rows.

Situation 2: The sandy soil (10-15% clay) of the parts studied was classified as Sand-Quartz Neosol (EMBRAPA, 2006), Arenosol (FAO, 2006), or Quartzipsamment (SOIL SURVEY STAFF, 1999). The variety of sugarcane planted was the RB 7851-48, with regular spacing of 1.50 m between rows. The survey was organized as in Situation 1.

Contribution of vegetal biomass in the soil

Quantification of the vegetal biomass contribution in the soil was done collecting material deposited within a known area (Figure 2), randomly distributed in the planting midline.

In parts where sugarcane was burned before harvesting, there was no contribution of vegetal biomass in the soil. Conversely, in the unburned

FIGURE 1 Soil surface in sugarcane areas harvested with and without trash burning.

cane harvest, the average vegetal biomass production in the 1996-2000 period was 13.9 t/ha in Situation 1, and 12.9 t/ha in Situation 2 (Table 1).

CAMPOS (2003), in an agronomic study of Situation 1, assessed the effect of different sugarcane varieties in the vegetal biomass annual production on the occasion of the harvest: the most commonly used variety for producing sugar (SP 80-1816) and three other selected varieties, according to their vegetal biomass production capacities: RB 82-5335 (high production), RB 83-5486 (average production), and RB 85-5453 (low production). No significant difference was observed between the parts harvested without burning, where the varieties were maintained for four years. The quantity of residual trash after three years (before the fourth harvest) had little variation, from 6.5 t DM/ha to 7.5 t DM/ha, which corresponds to a stock of 2.3 to 2.7 t C/ha. The trash stocks, before harvest in Situation 1, are shown on Table 2.

Regarding Situation 2, only one collection was made in 1999 before the harvest. The remaining

TABLE 1 Culture productivity and annual leftover of vegetal biomass during harvest in the two situations studied, in t/ha.

Year	Situation 1			Situation 2		
	Productivity	Leftover	%	Productivity	Leftover	%
1996	104	15.7	15.1	132	10.5	8.0
1997	114	12.8	11.2	96	16.8	17.5
1998	99	11.3	11.4	68	11.4	16.8
1999	82	14.5	17.7	43	–	–
2000	78	15.2	19.5	–	–	–
Avg.	95.4 ± 13.5	13.9 ± 1.6	15.0 ± 3.3	84.8 ± 33.1	12.9 ± 2.8	14.1 ± 4.3

* yields and leftovers were determined by Copersucar (Sugarcane project final report of the 1999/2000 harvest season RT #961, 2000).

FIGURE 2 Trash left on the soil surface under sugarcane harvested without burning.

trash contained 3.58 ± 0.39 t DM/ha (i.e. around 1.35 t C/ha and C/N ratio = 65), and represented 12.5% of the accrued entries since 1996.

Based on the quantities of vegetal biomass deposited after the harvest (Table 1) and residual before harvest (Table 2), it is possible to study the yearly material decay dynamics, and calculate the average decay rate. The simple hypothesis of an exponential type decay occurring may be made over one year, the quantity of vegetal biomass on a certain date t is obtained by the formula $Q(t) = Qo\ e^{-kt}$, considering that on a first moment the decay speed is the same every year, the data available allows us to write the following equations:

For the 2000 harvest season:

$$5.59 = 14.5^{e-k} + 11.3^{e-2k} + 12.8^{e-3k} + 15.7^{e-4k}.$$

For the 1999 harvest season:

$$4.46 = 11.3^{e-k} + 12.8^{e-2k} + 15.7^{e-3k}.$$

For the 1998 harvest season:

$$5.97 = 12.8^{e-k} + 15.7^{e-2k}.$$

The mathematical solutions of the equations are, respectively, k = 1.23635/year, k = 1.2814/year, and k = 1.1039/year. These values calculated for k vary due to errors associated to the measurement of vegetal biomasses weight, and the spatial variability of deposits. Decay speed depends on biologic activity, which is strongly dependent on temperature and moisture conditions. Such conditions may vary from one year to another. For this first approximation, a weighted average decay factor of k_{avg} for the period 1998-2000 of 1.222/year or yet 0.0034/day may be considered. This decay coefficient corresponds to one average half-life (half-life = ln2/k) of 0.567 per year, or 207 days. Integrating the yearly average decay equations it is possible to calculate the average stock of vegetal biomass (ASVB) present in the soil for each year, therefore being, in the first year, ASVB = 8 t DM, and in the fifth year, 11.3 t DM, with an average of 10.4 t DM (about 4.6 t C) for the five-year period after planting the sugarcane.

Measurements were likewise taken over the 1999/2000 period between two successive harvest seasons (Figure 3). Simplifying the decay model, reducing it to one sole global equation, it is possible to calculate a decay coefficient of 0.0027/day and an average half-life around 257 days for the referring period corresponding to an EML around 9 t DM.

These results show that, after harvesting without burning, an important stock of C, to the tune of tons per hectare, is formed on the soil. This behavior is quite fragile, and may be significantly

TABLE 2 C stocks and C/N ratios in the vegetal biomass in Situation 1, after one year of decay, before the harvest.

Period Year	Dry matter intake t DM/ha	Carbon stock t C/ha	C/N ratio	Accrued intakes since 1996 %
1998	5.97 ± 1.55	2.55	N/A	20.9
1999	4.46 ± 0.70	1.61	51	11.2
2000	5.59 ± 2.36	2.36	N/A	10.3

reduced, for instance, by an accidental fire. Likewise, it is not known what will happen after the sugarcane field reform process, performed every 5-7 years, when the soil is plowed and graded usually for planting sugarcane.

Carbon stock in the soil

The soil samples were collected in March 1999, at the end of the rainy summer, one week before the fourth harvest. In each experimental part, six mini-trenches (three of them on central lines, and three on the interlines) samples were taken at 0-5, 5-10, and 10-20 cm depth. Samples were dried and sieved to 2 mm. Standard-size samples were taken to quantify the C content using a dry method, with an auto-analyzer Leco CN-2000, and to determine soil density by means of cylinders (Figure 4), necessary for calculating carbon stock.

The quantity of vegetal biomass accumulated and returned in Situation 1 from the three previous harvests is 39.8 t DM/ha, which represents around 17 t C/ha. Differences in C stock between burned and unburned cane (ΔC) are significant only for the 0-5 cm layer. The increase in stocked ΔC in unburned cane in the 0-20 cm layer represents 38% of the C returned by the vegetal biomass. Around half of it is in the 0-5 cm layer, where the increase in C represents 18.5% of the C returned by the vegetal biomass. This value is higher than the C stock present in the residual material (1.61 t C/ha), which represents 9.5% of the C returned as

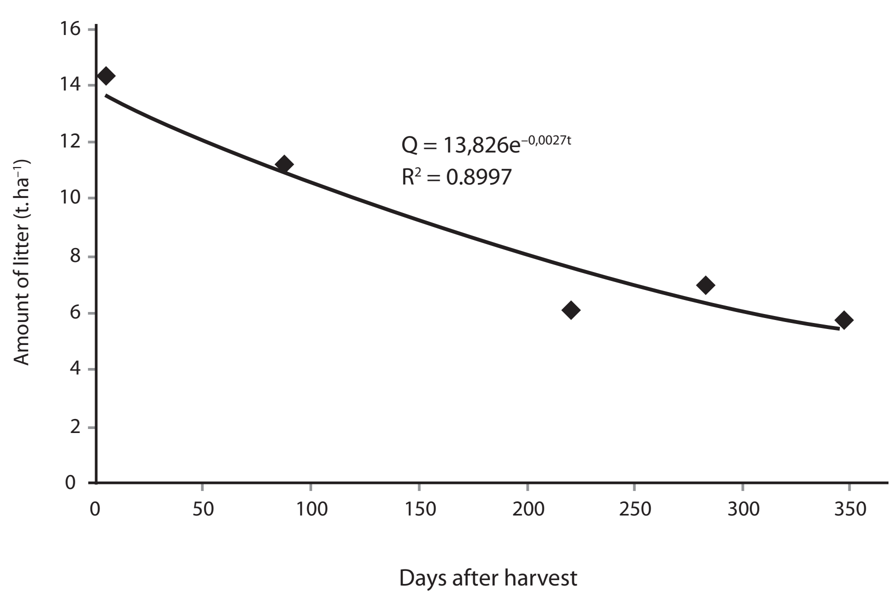

FIGURE 3 Variation in the vegetal biomass quantity during a culture cycle (1999-2000) in Situation 1.

FIGURE 4 Illustration of soil samples collection for analyzing carbon content and determining soil density (cylinders).

TABLE 3 Carbon stocks in the soil in Situations 1 and 2 after 4 years' cultivation in the burned and unburned cane systems.

Layer	Carbon stock (t C/ha)					
	Situation 1			Situation 2		
cm	Burned cane	Unburned cane	ΔC	Burned cane	Unburned cane	ΔC
0-5	11.72	14.87	3.15	4.84	7.68	2.84
5-10	12.43	14.41	1.98	5.35	5.92	0.57
10-20	24.80	26.17	1.37	10.80	12.26	1.46
0-10	24.15	29.28	5.13	10.19	13.60	3.41
0-20	48.95	55.45	6.50	20.99	25.86	4.87

vegetal biomass. For Situation 2, sandy, the excess C stoked in unburned cane in the soil (0-20 cm), and the stocks in the vegetal biomass represent respectively 29.5% and 8.2% of the C introduced into the system (FELLER, 2001).

In Situation 1, the unburned cane system stores 6.5 t C more than the burned cane system in the 0-20 cm layer, which represents a stocking rate of 1,625 kg C/ha/year for the first four years. It is interesting to note that for the sandy soil in Situation 2, the increase (ΔC = 4.87 t C/ha) is of the same magnitude as in the clayous soil, even the initial stocks in the soil being quite different.

Other results for the 0-20 cm layer, obtained in the same region of Brazil in studies of commercial parts, for burned and unburned cane, were

TABLE 4 Yearly stocking rates observed in the 0-20 cm layer of the soil under commercial sugarcane planting in the Center-West region of the São Paulo state.

Part	Brazilian soils classification	Clay	Carbon stock (burned cane)	Carbon stock (unburned cane)	Time unburned cane	Yearly accumulation rate
		%	t C/ha		years	t C/ha.year
Usina São Martinho (Pradópolis, SP)						
A	Dis. Red Latosol	70-80	42.11	43.61	3	0.50
B	Dis. Red Latosol	70-80	42.11	40.98	5	–0.23
Usina Santa Luiza (Matão, SP)						
C	Chromic Claysol	18-25	23.88	28.93	4	1.26
D	Red Yellow Latosol	32-36	40.01	43.91	12	0.33

described by FELLER (2001), and are summarized on Table 4.

FELLER (2001) shows that, at the time of implementing the burned and unburned cane alternatives in part B, it was likely that there were initial differences that influenced the results. Furthermore, referring to part D, there was a reform revolving the soil, and probably the residues were buried. From these results, it is possible to notice that for the 3-5 periods, the increases in C stock in the soil go from 0.5 to 1.6 t C/ha/year, but they are strongly mitigated on the mid term with the start of sugar field reform, and/or may have a tendency to reach balance.

Few results were published comparing the harvest systems with burned and unburned cane. GRAHAM *et al*. (2002) studied, in South Africa, the impact of trash management with burned and unburned cane, left on site or removed, and of fertilization on the soluble OM in a long term study (59 years). The C stock in the 0-30 layer of the fertilized system with unburned cane was 137.7 t C/ha. Though in the same system with burned cane the result measured was 132.6 t C/ha, the difference was not meaningful. On the other hand, significant differences were reported for the superficial 0-10 cm layer, however the figures are not provided in the paper. Whatever are the differences in stock, they translate into a very low annual growth, not surpassing 0.09 t C/ha.year.

In Australia (tropical climate, average yearly rainfall – 4,300 mm, 15-20 t DM residues per year, NOBLE *et al*. (2003) noticed an increase of 4.8 t C/ha in the 0-10 cm layer, after seven years of unburned cane handling, i.e., an average sticking rate of 0.69 t C/ha/year. Also in Australia, THORBURN *et al*. (2000) studied five different situations with burned and unburned cane, over a period of 3 to 18 years. In all five situations, C stocks for unburned cane were statistically higher than burned cane only in the 0-5 cm layer. They found a maximum increase of the C content of 0.24% for the 0-10 cm layer of a clayous soil, after seven years of unburned cane culture. Considering an arbitrary density of 1.2 g/cm^3, this increase corresponds to a yearly increase rate of about 0.4 t C/ha.year.

Greenhouse Effect Gases – GEG

Greenhouse effect gases (CH_4 and N_2O) flows were measured in a vegetal biomass/soil/atmosphere in incubation chambers built from a circular base having 29 cm diameter attached to the ground, and a lid with an orifice that allowed collecting the accumulated gases. Six chambers were used in each burned and unburned cane handling. Gas samples were taken with 20 ml syringes 0, 5, 10, and 20 minutes after the lid was closed, which allowed following changes in GHG concentration and the calculation of the flows in the soil-trash-atmosphere system (Figure 5).

Samples were taken three times a day, at 7 AM, 12 noon, and 5 PM. Next, the syringes were

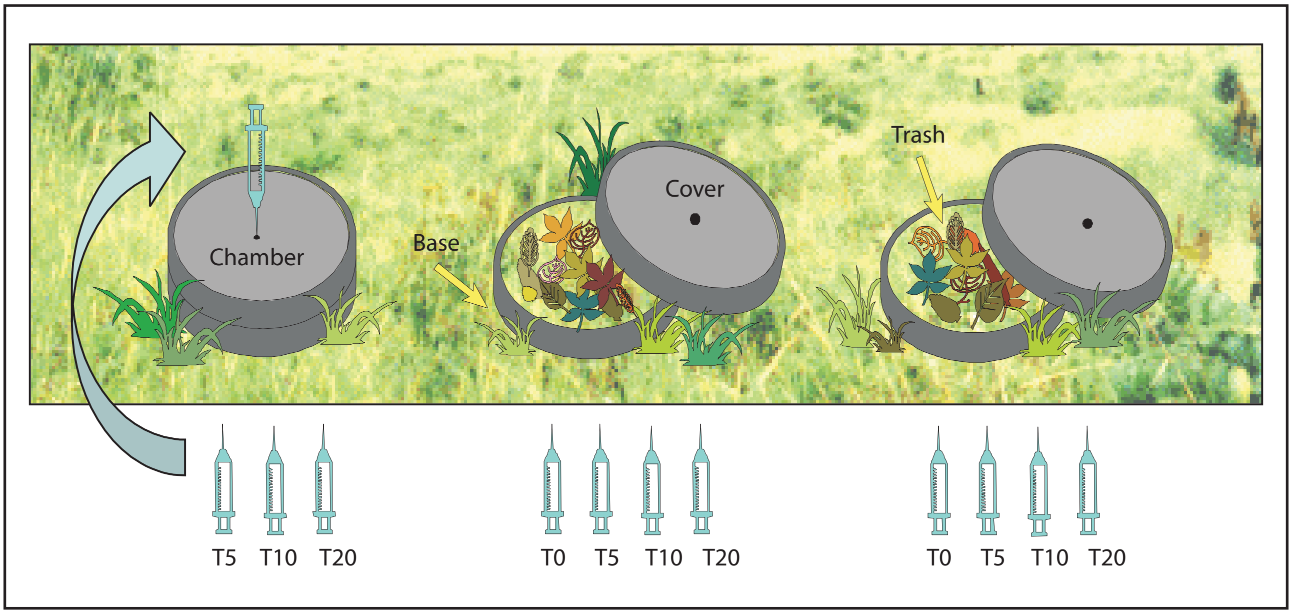

FIGURE 5 System used for collectting sample of gas emission.

taken to the laboratory to measure CH_4 and N_2O concentration, using a Shimadzu, CR501 chromatograph (Figure 6).

Yearly CH_4 flow from soils

Methane flows may be positive (produced by soils) or negative (consumed by soils) as a function of the bacterial community present, expressed according to the environmental conditions. The results from measurements taken in the burned and unburned cane handling systems in Situation 1, over the agricultural year 1999/2000, are summarized in Figure 7.

The burned cane handling presents constant methanotrophy (oxidation of CH_4 by the soil microbial community) throughout the year, at rates between -4.9 and -48.8 g CH_4/ha/day, with an average value of -16.9 g CH_4/ha.day. This average value corresponds to a yearly consumption of 6.17 kg CH_4/ha in the burned cane system. In the unburned cane handling, variation amplitude is higher, with results indicating methanotrophy of up to -24.6 g CH_4/ha.day to methanogenesis (CH_4 generation by the microbial community in the soil) of 10.1 g CH_4/ha/day. However, the methanotrophy process prevails, with an average oxidation of 8 g CH_4/ha/day, which corresponds to an annual total

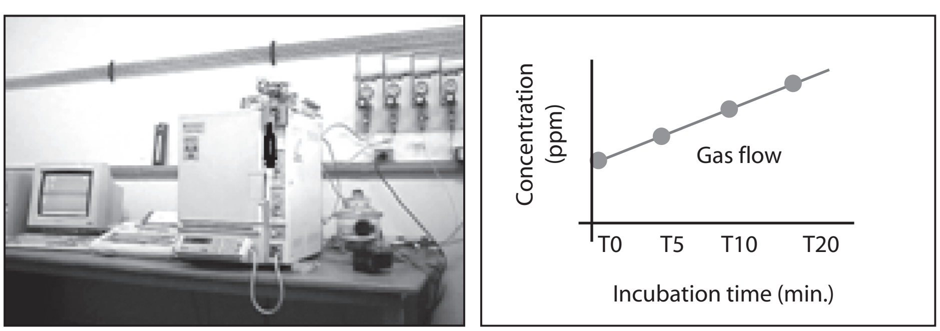

FIGURE 6 Gaseous phase chromatograph and gas flow schematics.

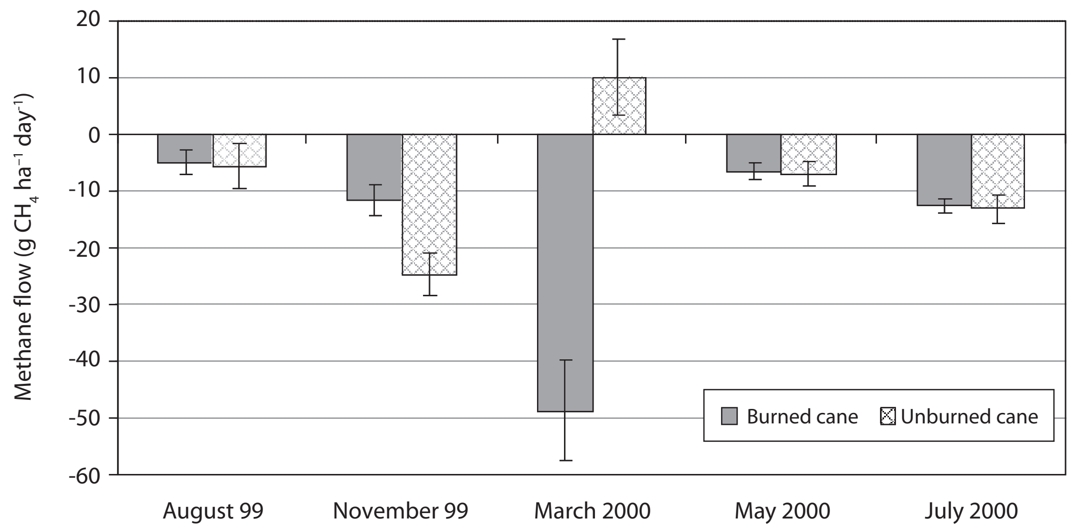

FIGURE 7 Methane flow in burned and unburned cane systems. Bars represent the standard error (standard deviation divided by the number of observations).

of 2.92 kg CH4/ha. In a measurement taken one week after the August 2000 harvest, the burned cane system presented an oxidation rate of 21.6 g CH_4/ha/day, while the unburned cane system was emitting 38.4 g CH_4/ha/day.

SCHWEIZER (2000) measured during three months of a rainy summer (November through January) the GHG flows in sugarcane fields located in Piracicaba (São Paulo state), 200 km south of Situation 1. The author calculated average oxidation rates of 3.9, 0.1, and 1.1 g CH_4/ha/day in each burned cane harvested field after, respectively, 28, 66, and 21 years.

Yearly N_2O flow from soils

Complex interactions between soil properties, climatic factors, and agricultural practices determine the nitrous oxide emission rate during the nitrification, and mostly denitrification processes, resulting in a wide spatial and timely variability (GRANLI, 1994).

For the burned cane system, average flows vary from -0.3 to 22.6 g N_2O/ha/day, and present an average yearly value of 11 g N_2O/ha.day. In the unburned cane system, flows present wider variations, with extremes from –6.8 and 23 g N_2O/ha/day, and an annual average of 15.7 g N_2O/ha/day. Negative N_2O flows are unusual; however, other authors have already observed this phenomenon (BOWDEN *et al.*, 1991; YAMULKI *et al.*, 1995). During one year, the burned and unburned cane systems emitted, in average, 4 kg N_2O/ha and 5.7 kg N_2O/ha, respectively (Figure 8).

SCHWEIZER (2000) also measured N_2O flows, and attributed average values of 7, 3, 10, and 7.7 g N_2O/ha/day, for each area harvested with burned cane for 28, 66, and 21 years, respectively. Few results were published considering N_2O flows in the unburned cane system. DALAL *et al.* (2003) quote from the works of WEIER (2000), reporting average emission values of 21 g N_2O/ha/day for unburned cane, and 17.8 g N_2O/ha/day for burned cane.

It is necessary to study in more detail N_20 emissions in burned and unburned cane systems, mostly at the time of applying fertilizers, burning the vegetal biomass, and reforming the sugarcane fields.

CH_4 and N_2O flow during vegetal biomass burning

Every combustion of organic residues comprises emissions of methane and nitrous oxide.

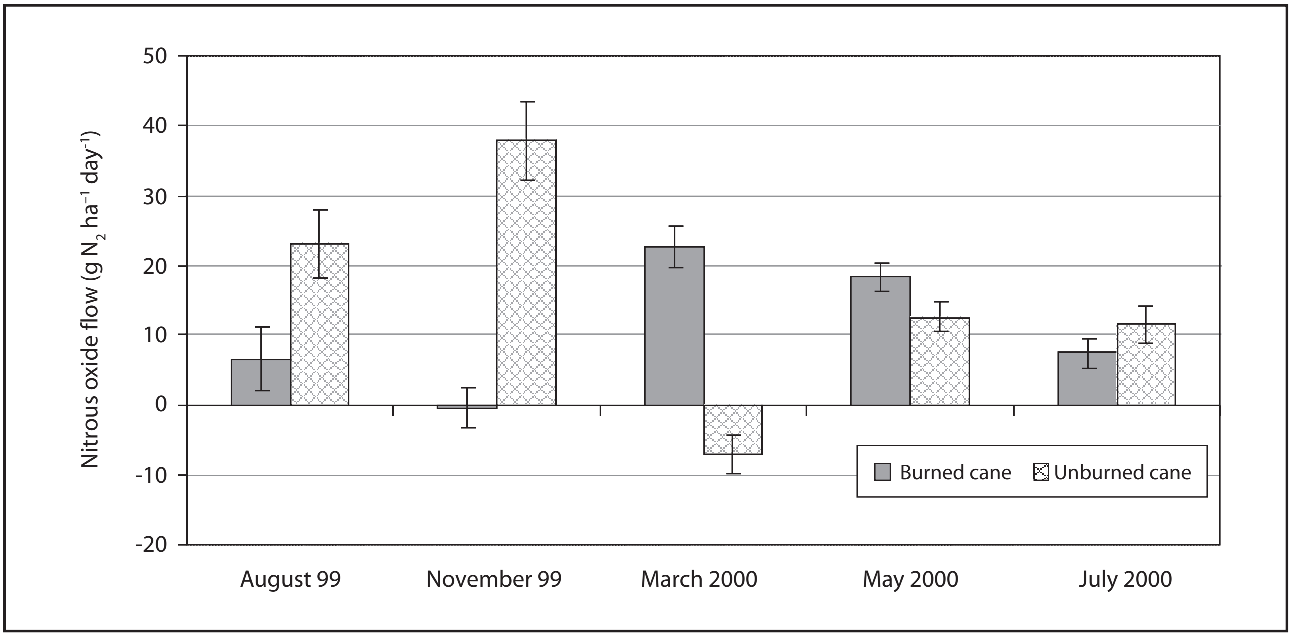

FIGURE 8 Nitrous oxide flow in burned and unburned cane systems. Bars represent the standard error (standard deviation divided by the number of observations).

Few emission factors were measured, especially for nitrous oxide, and seldom for sugarcane residues. To establish national balances, IPCC (IPCC/Unep/OECD/IEA, 1997) proposes using the following factors: 0.005 kg of C-CH_4 released per kg of C, and 0.007 kg N-N_2O per kg of N released in the combustion.

Average vegetal biomass production in the unburned cane system of Situation 1 analyzed was 13.9 t DM/ha. Considering that an equivalent quantity is consumed by fire in the burned cane system, the average release per hectare would be 6 t C and 43 kg N. It is worth reminding that fresh vegetal biomass contains, on average, 430 g C and 3.1 g N per kg of dry matter, i.e., it results in releasing 3 kg C-CH_4 and 0.3 kg N-N_2O, or yet, 35 kg CH_4 and 0.47 kg N_2O. These values may vary according to atmospheric conditions at the time of burning (air humidity, wind intensity) and the sugarcane condition (water and nitrogen content). Calculation is based on the C/N ratio that was measured in this study (C/N = 51), higher than reported by other authors. LIMA *et al.* (2002), while developing the balance of GHG emissions from burning vegetal residues in Brazil, assumes average C and N contents of respectively 42.5 ± 2.1% and 1.27 ± 0.5% (C/N = 33.5) for sugarcane residues. Using these values would imply in the emission of almost 2 kg N_2O/ha. Upon revising the literature, ANDREAE and MERLET (2001) propose other emission coefficients for burning agricultural residues: 2.7 g CH_4 and 0.07 g N_2O per kg of dry matter burned. The use of these coefficients results in a higher GHG release: 37.53 kg CH_4 and 0.97 kg N_2O. These values, however, are proposed for all agricultural residues (corn straw, cotton residues etc.), which are generally dried up before burning. Therefore, the same authors propose using a factor of 0.21 ± 0.10 g N_2O per kg of burnt dry matter for nitrous oxide when burning savannahs or fields.

Methane emissions, regardless of the calculation method and the data used, vary very little, and are in the 35-38 kg CH_4/ha range. The same does not apply to nitrous oxide, whose emissions vary a lot: 0.5 to 3 kg N_2O/ha.

Carbon Accounting (Ceq) in the agricultural phase of ethanol production

Signatories of the UNFCCC – United Nations Framework Convention on Climate Change – predict that the calculation of net emissions should be expressed in CO_2 equivalents, considering the

TABLE 5 Yearly average balance for one hectare of sugarcane field in Situation 1 in kg Ceq. Negative values indicate a reduction in GHG in Ceq.

Source	Burned cane	Unburned cane	Yearly Δ (unburned – burned cane)	Uncertainty level
	kg Ceq/ha.year			
Stock in vegetal biomass	temporary stock			*
Stock in soil 0-20 cm			–1,625	*
Yearly CH_4 flow from soil	–39	–18	21	**
Yearly N_2O flow from soil	323	460	137	***
CH_4 flow while burning	230[a]	–	–230	**
N_2O flow while burning	140[b]	–	–140	****
Total			–1,837	

[a] Central value of the variation amplitude 220-240 kg Ceq.
[b] Central value of the variation amplitude 40-240 kg Ceq.

global warming potential (GWP) of each gas. GWP is a relative measurement, which determines the radiation forcing of a gas, considering CO_2 as a reference that is assigned the value of 1. Based on this concept, the Third IPCC Assessment Report (IPCC, 2001) defined, for GWPs, and for a century-long horizon of 100 GWP years, the values of 23 for methane, and 296 for nitrous oxide. This means that, in terms of radioactive force, one kg of CH_4 or N_20 is as effective as 23 or 296 kg of CO_2, respectively. Expressed on a C-CO_2 scale, known as Ceq (C equivalent), 1 kg of C-CH_4 is equivalent to 8.36 kg of Ceq and 1 kg of N_2O, to 126.86 kg Ceq.

From the previously analyzed four destination components of the sugarcane harvest resulting vegetal biomass, it is possible to compare the burned and unburned cane systems over the period of four years under study.

These results clearly show that from the GHG balance point of view, the unburned cane system is more advantageous than the burned cane one, as 1,837 kg Ceq per year failed to be released to the atmosphere during the period under analysis. However, it is proper to consider the stability of such system. The C stocked in the vegetal biomass deposited on the soil cannot be considered in this balance, as this compartment is very fragile. Due to the half-life observed of 200-265 days, its interference is restricted mostly to the first two years after the unburned cane harvesting system has been in place. In the next few years, roughly, there is almost a stabilization of the C stocked in this compartment, since a balance settles between yearly intakes and outputs. The residual vegetal biomass works like a temporary reservoir, which may be quickly exhausted if the inputs drop. However the presence of such compartment is very important, since it is the C source that keeps stock in a more stable way.

The balance also fails to consider the sugarcane field reform that occurs every 5-7 years, when the inputs are lower. At this time the soil is revolved (ploughed), not only disturbing its superficial layer, but the vegetal residues as well. This specific point of the culture cycle should be studied in more detail. Among the positive effects of the permanent presence of vegetal residues there is the protection against erosion, and the increase of nutrients inputs to the soil (CANELLAS *et al*., 2003).

From a social standpoint, mechanized harvesting is generally regarded as progress for human health. Sugarcane fields burning causes the release of various gases and potentially hazardous organic compounds such as aromatic polycyclic hydrocarbons (SANTOS *et al*., 2002), as well as the abundant emission of carbonated ashes. Recent medical studies (ARBEX, 2001; CANÇADO *et al.*, 2006; ROSEIRO, 2002) demonstrated the connection between sugarcane burning and the increase in respiratory problems, especially in children. Even though the negative impact of soot (ashes) is quite controversial, it is necessary to admit that it forces the population to clean more frequently their dwellings and swimming pools, increasing water consumption (still considered an inexpensive product in Brazil), which represents a serious problem, especially when the level of water is extremely low.

Among the negative effects attributed to banning sugarcane burning, is the impact on the labor market, constantly discussed in terms of employment. The adoption of the unburned cane system is unavoidable and will result in mechanized harvesting. A recent study by Vieira (2003) in Usina da Barra, the world's largest mill, located in the São Paulo state, producing about 4% of sugar and 3% of all the alcohol in Brazil, shows that one harvester replaces 67 persons per hour of operation. On the long run, the burned cane ban will cause 2,117 menial jobs losses, and will create 177 qualified jobs. This net job loss is often pointed out as a major negative effect for banning burning cane. On the other hand, such jobs are of poor quality, constantly criticized as being on the threshold of slave work.

FINAL CONSIDERATIONS

Unburned sugarcane harvesting and leaving the vegetal biomass on the soil restores a considerable part of the organic matter lost with the burned cane harvest system. The comparison between the two handling systems (burned and unburned cane) shows that preserving the vegetal biomass allows to sequester C in the studied soils. The analysis of nitrous oxide and methane during burning and over the complete agricultural cycle, also demonstrates the positive effect on the overall balance, in terms of mitigating GHG emissions. Ethanol has been considered as one of the viable alternatives for replacing fossil fuels, which are the major sources of greenhouse gas emissions to the atmosphere and, consequently, of the acceleration in global warming. As for replacement fossil fuels, for an increased environmental benefit, markedly related to global climate changes, it is necessary to produce bioethanol where it provides a better fixation of carbon in the soil, and with lower greenhouse effect gases emissions associated to its productive process. The information summarized in this document stresses the importance of the soil as an extraordinary means to fix carbon dioxide from the atmosphere. Data from a case study show that mechanized sugarcane harvesting provides a net balance of 1.8 Mg C/ha/year, where the carbon saved in the soil, due to trash decay, may represent 80-90% of the total quantity not issued to the atmosphere. In a sustainable biofuel production business, it is increasingly important to adopt conservationist handling practices that involve cleaner production, to reduce the carbon footprint. Such practices, in addition of being environmentally correct, should also be socially and economically viable, as it will add value to Brazilian ethanol destined for exports.

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5

BRAZILIAN ETHANOL'S GOVERNANCE:

IMPLICATIONS FOR SUSTAINABILITY[1]

Thomaz Fronzaglia and *Renata Martins*

INTRODUCTION

A new dynamism has been established in the sugar & alcohol innovation sector since the redefinition of role of the State in the 1990s and the elimination of the Institute for Sugar and Alcohol. More recently there has been a change of public policy to ensure better use of state resources, through the establishment of cooperation networks between public research institutions and the private sector to improve research on competitiveness and sustainability issues

Interest on sustainability of ethanol have intensified as a result of recent expansion of the sugarcane sector in response to increasing demand after the successful introduction of flexi-fuel vehicles, both for the domestic and international markets (VEIGA FILHO *et al.*, 2008). Monitoring and identifying critical uncertainties have therefore become imperative and also the need to define strategic priorities in the sector and identify organizational and institutional weaknesses that may hinder sustainable development in the sector. Such issues require well planned scientific and technological research.

The application of economic research on organizations and institutions has a relevant role to play because issues of ethanol sustainability go beyond the whole sugar & alcohol chain – ranging from production to consumption, the role of externalities, and institutions; government systems or coordination of transactions. The issue of sustainability therefore calls for debate on the various factors along the whole ethanol production chain. Such analysis should be the focus of research in investment policies in order to promote institutional and organizational innovation in the sector.[2]

This chapter addresses demand for social science research that can be applied to the sustainability of ethanol, but focused on the relationship between the players of the ethanol industry and the potential impacts of regulation that their productive activity can have upon society. This chapter discusses the results of a Research Workshop on Ethanol Sustainability – an effort of *foresight*, organized by the Institute of Agricultural Economics – IEA, – at the São Paulo Agribusiness Technology Agency – APTA, under the project "Public Policy Directions for the Ethanol Industry of São Paulo State" as part of the Public Policy Research Programme, financed by the São Paulo State Research Support Foundation.

[1] The authors thank all the participants and collaborators of the project "Public Policy Directions for the Ethanol Industry of São Paulo State" as well as the participants of the Research Workshop on Ethanol Sustainability which took place in June 2007 at IEA/APTA. The content of this Chapter is a compilation of several contributions received in the event, consolidated on the sole interpretation of the authors who take responsibility for any misinterpretations. The content of this Chapter does not in any way reflect the opinions of the institutions to which the authors are linked.

[2] The study of such a broad issue accomplished through foresight could not define problems for research projects, but only point out questions within important themes of ethanol sustainability which should be targets for public policy including research and development. When defining research problems it is the role of researchers to submit research projects for competitive grants capable of funding research based on the main issues consolidated through foresight exercises.

FORESIGHT AS A POLICY DEVELOPMENT APPROACH

The literature on prospective analysis describes the relevance of planning for science, technology, innovation, business strategies and public policies. The methodological outline discussed in this section describes a wide range of techniques and identifies links between them which are used in the process analysis.

Prospective studies seek to obtain information for decision making within future events in an attempt to anticipate and understand scenarios, behaviour, characteristics and effects of the innovative processes, as well as institutional and technological changes (COELHO, 2003; ZACKIEWICZ, 2001). The application of technological procurement and its many forms of analysis could be important in the allocation of resources and for focussing on the identification of knowledge gaps that need to be addressed by research organizations.

Foresight is a multi-dimensional process for understanding the long term drivers that should be taken into account when formulating plans, public policy decisions and business strategies (COATES, 2001). Qualitative and quantitative techniques are used to monitor signs, indicators and tendencies of the subject in evolution. COELHO (2003) considers that intuitive methods based on specialist consultations are more appropriate and cover a broader range of applications in this process. Even though *foresight* in itself doesn't define policies, it can develop insights into how the future can be constructed (SANTOS *et al.*, 2004) and is more appropriate when applied to the formulation of policies, programme assessment (and their implications), leading to the elaboration of more robust policies that can be enforced more flexibly in accordance with conditions that change over time. However, these processes of *foresight* are becoming increasingly more complex, and therefore new techniques are being applied to reduce the complexity within *foresight*, through the creation of *roadmaps* (SARITAS, 2004).

Roadmapping is a process centred on planning (PHAAL *et al.*, 2004) that has been used for a wide spectrum of purposes and applications, including support behind strategic and long term planning, intra-organization and sectorial inter-organizations from the private sector, based on science and technology through public companies and government policy agencies. It is a systemic process (GARCIA, 1997) which involves an organ for systematic monitoring, providing a tool for analysis of the external environment using prospective techniques like scenario structuring (SCHOEMAKER, 1995). The *roadmap* combines scenario drivers and their interrelation with markets, products, knowledge, resources, development and the implementation of policies.

The creation of a policy *roadmap* might support different levels of analysis, arrangements and future interests such as socio-technical transitions on the macro level and institutional changes, industrial organization, interaction in the supply chain and the organization of research networks. A *roadmap* is capable of encompassing these levels of analysis in order to identify threats or opportunities for company or sectorial sustainability and identify an agenda for public policies. It also involves impact analysis through simulations and prioritizes the most appropriate approaches depending on how the future unravels.

On-hand information in support of public policy making through *roadmapping* can be supplied by specialist technical panels that identify challenges and gaps in knowledge. These gaps correspond to calls for research where resources can be allocated in the hope of resolving problems in the long term. In the short term, emphasis lies on the flow of information and assigned competences capable of influencing policy content and policy making processes. Both forms can interact through mutual adjustment.

PORTER *et al.* (1991) classifies the following set of methods and probing techniques that can be used in the *foresight* process. These are described below in order of their enhancement, promptness, and address of information:

- *Creativity*: interaction of information generating a number of new ideas.
- *Specialist panel*: detection of tacit knowledge and the slightest signals that show ambiguities which are used when information cannot be quantified or modelled.

- *Monitoring and intelligence systems*: sources of pre-organized information for the identification of tendencies and critical events, their relationships, opportunities and threats. This however requires a large amount of information from several sources which, if badly managed, results in information not being systematized, analyzed, or selective.
- *Scenarios* are formations of future alternatives through the analysis of dominant tendencies considering possibilities of disruptions to exploratory or normative processes.
- *Assessment and decision*: are methods for reducing uncertainty and complexity when multiple interests and dimensions are being taken into account.
- *Participative methods* become key elements for *foresight* processes due to the application of democratic principles bringing social legitimacy into their results and have the ability of involving diverse players, creating collective arrangements and processes in harmony with decision and implementation processes. Another important aspect is the fact that information building is more effective because there is widespread strategic information sharing among players in the process. For these reasons the methods need to be well conducted.
- *Impact evaluation* can be complementary when carried out ex-ante, based on the scenarios achieved through survey analysis. This analysis is therefore fundamental to provide innovation systems with instruments presenting concrete elements to support decision makers.

The present prospectus is based on diverse techniques such as creativity, specialist panels, scenarios and participation levels stemming from a reference document designed to restrict the scope, identifying the main issues and levels of analysis. The workshop was divided into four parts. Firstly the *Term of Reference* (FRONZAGLIA, 2007) was elaborated by the workshop coordinator and presents a conceptual approach to the main subjects for discussion concerning ethanol sustainability, including the critical aspects of the present day situation organized into different themes. Secondly, specialists were called on to form four debate panels for each theme, each being made up of lecturers and debaters. Each lecturer (FURTADO, 2007; VIAN, 2007; PAULILLO, 2007; and FERRAZ, 2007) then prepared and presented their *position paper* to the debaters who prepared their own arguments for presentation in the workshop. In stage three, researchers from several learned areas and ethanol industry specialists were invited along with project members and researchers. All participants were heavily involved in energy matters and research activity in the sugar & alcohol sector and specialized in agriculture, environmental institutions, organizations and their coordination mechanisms and governance. Once the debate forum had been organised several contributions were received regarding research and policy topics which were debated and recorded, consolidating the fourth stage.

The event sought a research agenda based on arguments presented in the established scenarios and in accordance with the *Term of Reference* and with the investigation of institutional setups which have the implications on ethanol sustainability in mind. The process for prospective institutional innovation demands resulted in the present report. It comprises specialist opinions on the matters presented by the lecturers serving as substratum for scientific, technological and innovative policy making with ethanol sustainability in mind.

The Workshop had methodological-conceptual aspects as collateral or background themes whereby lecturers were requested to focus their *position papers* on sustainability indicators, their implications for regulation and managerial decisions as well as the methodological and conceptual gaps in existent and proposed indicator systems.

Sustainability penetrates all levels of decision within the economical, social and environmental dimensions which can be addressed in several units of analysis: from the level of allocation and employment of resources, governance of transactions, regulation, property rights and the role of the State, as to the diffuse levels of social tissue and culture that are pervasive in society (WILLIAMSON, 2000).

The role of institutions (NORTH, 1991) and organizations in the coordination of mechanisms that involve ethanol sustainability are therefore considered relevant, emphasizing the approach to transactions in the production chains and the systemic vision of networks/supply chains reflecting important indicators to the sugar & alcohol sector which might direct decisions towards sustainability (FARINA, 1998). In this approach they also discussed the sugar & alcohol sectorial organization (FLIGSTEIN, 2003) and the strategic vision of the sector to the issue of sustainability.

In summary, the conceptual approach considered:

- The relevant role of institutions and organizations and that Sustainability implicates all decision levels.
- Supply-chain management perspective and transaction analysis.
- The Strategic view of the sector for Sustainability.
- Prospection of Institutional Innovation demands.
- The Proposal of public policies in R&D for ethanol sustainability.

Finally, the various sustainability themes were organized according to the conceptual approach taken, in such a form that its organization was easily identifiable in the different panels as follows: bio-energy scenarios and impacts of sugarcane production expansion; coordination for the ethanol market; governance of the sugar & alcohol sector as well as social and environmental responsibility.

RESULTS

Sustainability questioned in the sugar & alcohol sector

The discussion on the search for sustainable energy was amplified beyond the simple substitution of fossil fuels for renewable sources of energy. The debate goes beyond aspects related to the impacts generated by such renewable sources of energy. This chapter addresses innovation in institutions and organizations in the administration of sustainability in the ethanol industry with the following query:

- How can one assess impacts and decide on which private governance systems or regulation with which to address technological development and thereby guarantee more efficiency in the long term in the production and use of ethanol, when considering the environmental, social and economical impacts of this activity?

Research is somewhat disperse between several factors, both promoting and restricting ethanol sustainability. However it is important that we discuss the systems which are capable of governing investment in organizational and institutional innovation, in addition to technological innovation, focusing on the sustainability of the sugarcane agribusiness in São Paulo, ranging from production as much as in its commercialization and consumption.

This section portrays four themes including these governance systems. The first focuses on the bio-energy scenarios and the role of research in identifying and in regulating the impacts of this activity through public policies. The second, addresses the aspect of transactional coordination or ethanol supply chain management, which is relevant for enabling this product to be economically sustainable when facing various problems that degrade transactions and the operation of the chain. Thirdly, it discusses corporate governance, social responsibility, and the signalling mechanisms of sustainability protocol compliance certification in the sugar & alcohol sector. This seeks to discuss what impediments and opportunities on indicator mechanisms between capital markets and consumers can offer sustainability. The fourth theme discusses the application of certification systems for environmental management.

Bio-energy scenarios and the impacts of sugarcane production expansion

Premises

The major public interest in this product and the effects of the industry on society is reflected in the important role of demand surrounding labour and the quality of the environment. Organized civil societies, academics and the State have been endeavouring to raise these issues in discussions with the sector.

In the new millennium the Brazilian government resumed its vision on the strategic character of ethanol considering that bio-fuels substitute their fossil equivalents and reduce the exposure of the economy to the price of petroleum. The State performed the regulating role of this sector between 1940 and 1990 and was also an important player in promoting development of the innovation system for ethanol, mainly through Proálcool.

Besides being a generator of renewable energy contributing to the substitution of fossil fuels and developing a promising bio-energy scenario, the expansion of sugarcane production also made this segment a major transformer of regions around it, resulting in impacts brought through job profile modifications, the environment, local economies and international negotiations.

These micro and macro extents of sustainability opened up the discussion in such a way that a systemization of the factors into economic, social and environmental dimensions is necessary as well as origins and effects of the impacts of the different players involved in regions and the links in the supply chains at their differing decision levels.

Diverse studies on impacts are using indicators in different dimensions with diverse methodologies. However, it is important to Meta-analyze the results of recent research:

- Is there correspondence between results? Have the results contributed to the identification of effective system indicators for monitoring, evaluating and deciding on the impacts of the sector?
- What are the implications of regulation or managerial decisions on these systems, in search of sustainability for the sugar & alcohol sector?
- What are the main methodological shortfalls?

The global demand for liquid fuels from renewable sources can be gradually met by ethanol, keeping the feasibility of new generation technology for the conversion of different raw materials in mind. In this sense, the sustainability of ethanol presented by sugarcane production in relation to other ethanol sources should firstly take scenarios of traditional technology of energy conversion into account in relation to emerging technology which bears the future.

Sugarcane plantations in São Paulo presented a productivity growth rate of 5.92% in tons per hectare between 1996 and 2006. Productivity earnings in recent years have also increased – such was the agricultural (harvesting) year 2005/2006, where there was a growth rate of 3.3% compared to the previous harvest and a record 82.9 tons per hectare. In the 2006/2007 harvest, productivity increased by 2%. This recent progress doesn't guarantee that it will continue. A coordinated effort for directing research investment is necessary between the many research institutions interested in the sector, be them public or private. This raises a serious question:

- What are the uncertainties in relation to economic sustainability of the ethanol sector in the State of São Paulo, considering global scenarios of technological evolution in bio-fuels?

Sugarcane production activities in São Paulo have been expanding at alarming rates. The area harvested in the state grew by an average annual rate of 4.83%, from 2000 to 2006. An expansion of 9.39% was registered in the agricultural year 2005/2006 alone and was much higher than the average rate in the country. The planted area shows an expansion rate of 25% (821.9 thousand hectares – representing an acceleration of 49.45% in relation to the previous year's expansion) adding to the production area of 3.2 million hectares; and resulting in the harvest of 4.2 million hectares in the 2007/2008 harvest. This means that there was a rapid acceleration in the planted area and expansion growth rate. The production area is expected to double in size in the next few years, following the implantation of 40 new alcohol distilleries and drastically changing the agricultural profile of the State of São Paulo regions.

Among the socioeconomic impacts, labour linked to other agricultural activities is being displaced where new mills are being set up. On the other hand the sugar & alcohol sector is a major employer along with significant job quality improvements (BALSADI, 2006). With major progress in automated harvesting without burning (FREDO *et al.*, 2008), it is expected that a reduction in the harvesting period by 2014 (flat areas) and 2017 (sloped areas) will result in the use of five times more harvesting machines and less than 50% of the area being burned.[3] This implies a reduction of jobs of about 210,000 cane cutters in the Central-Southern region, of which 163,098 will be in São Paulo State alone. It reinforces incentives against inhumane labour of manual cutting even more so when compared with the efficiency of an automated cut. The disappearance of this manual employment category is expected in 2017. As sugarcane is one of the last crops to be totally mechanized more positive employment indicators are yet expected.

Remuneration per land usage and market indicators are mechanisms which are unable to direct the use of land and manual labour towards sustainability because market forces lead to the allocation of higher marginal utility, incurring transaction costs while social interests clash with the allocation of sugarcane activity. The presence of the State can therefore point to marginal utility from the social use of natural resources and bring price incentives thus maintaining the social cost of negative externalities from the adjustment among supply chain players, thereby bringing it into equilibrium with society and creating incentives for sustainable land use within sugarcane activity. There is therefore a relevant role for incentives created through the regulation of social interest activities such as environmental protection and the maintenance of food producer *clusters*. For example, livestock systems integrated with sugarcane activity can benefit from technological progress – and with positive social and environmental outcomes (SPAROVEK *et al.*, 2007). Similarly the income generated by land rentals, new and qualified employment and tax collection in municipalities creates a new socioeconomic profile in production areas. However it is not clear if there will be a direct connection between the injection of resources and local development through the creation of opportunities for those in the community who lose their jobs. Therefore, one must question the destiny of this unemployed workforce and if it will be possible to re-train the manual labour force and reallocate it. The substitution of agricultural activities is a process that should be kept under the eye of public administration and adjusted through public policy and programs.[4]

Results

Among the arguments from workshop participants was a scenario based on research reports elaborated scientifically by the Interdisciplinary Nucleus of Energy Planning – Nipe at the State University of Campinas – Unicamp, in partnership with the Foundation of Development of Unicamp and the Centre of Administration and Strategic Studies – CGEE, linked to the Ministry of Science and Technology. They suggested that in order to substitute 5% of the gasoline in the world by 2025 (around 2 trillion litres) without introducing new technology or progress in the agricultural and industrial areas, 102.5 billion litres of ethanol production would be needed. To substitute 10% of the global gasoline in the same time span, 205 billion litres of ethanol would be necessary (LEITE, 2006). However, the North American market alone demands 320 billion litres of alcohol and a further 40 billion litres in Brazil, totalling 360 billion litres.

Based on this perspective, for Brazil to become a major exporter of ethanol, the involvement of human resources and land are necessary factors. One therefore can ask what the state role of São Paulo is in all this. The question doesn't only refer to the São Paulo State Government but to the whole group of São Paulo institutions, organizations, production factors and their performance implications in conjunction with other units within the Brazilian Federation.

There is certain distrust abroad that Brazil is not capable of regularly supplying the volumes of ethanol needed for the addition to gasoline in developed countries, uncomfortably contrary to the desires of those countries and leading to avoid-

[3] Combine harvesting manufacturers are divided into market niches, one like John Deere, Case and Santal who are specialized in heavy machinery for Primary and Secondary harvests of 100 to 200 t/ha, and others like Civemasa, Star and Motocana specialized in small machines for other harvests smaller than 100 t/ha.

[4] Initiatives restricting percentile of area for sugarcane in municipal districts through restrictions on new mills might not be the best form of offsetting inefficient regulation of production activities nor of attending sectorial pressures which compete for factors involved in production.

ance of energy dependence on restricted supplier sources. However, scenarios indicate that so long as privileged production capacity is given, and if technological progress is then incorporated, Brazil will be able to maintain its prominence in the supply of ethanol and even export technology to other countries.

The creation of this market also holds difficulties like the breaching of international trade barriers and the implementation of policies for the addition of ethanol to gasoline in those countries. The challenges are enormous and incidentally – that market still doesn't exist. Besides the addition of ethanol to gasoline, the increase of internal market due to flex fuel cars caused an enormous increase in the demand spurring production and the expansion of mills in several states (TORQUATO, 2006).[5]

The main issue is linked to land distribution and the way in which sugarcane occupies the territory being quite intense nowadays. Production intensity and consumption in the Central-Southern region of Brazil will, in the coming years grow even further, considering the installation of new mills in the area and the use of already installed infrastructure. It therefore becomes important to identify other areas of the country with the potential for ethanol production.

If Brazil was to produce for supplying the projected market, plantations would have to occupy the Central-West region and the rural districts of Bahia state in Brazil, counting on potential improvements on cane varieties towards a drought resistant strain. This would increase producing regions on the maps around consolidated logistics to traders or final consumers. This alternative was expressed in studies as policy for decentralization in search of models for economical development associated with lower cost factor procurement in order to avoid the over exploitation of natural resources, whilst taking advantage of earnings from the formation of energy producer *clusters* based on sugarcane agribusiness.

Mapping shows considerable expansion areas for cane production omitting areas under restriction like Amazonia and sloped areas, and counting on areas with good conditions for cane – soil and climate. Another 12 possible areas are identified in Brazil when other variables are considered for crop expansion, like infrastructure logistics, being 40% in the North-Northeast region and 60% in the Central-Southern region. A study is currently underway to understand climate and soil conditions and favourable areas for cane and the installation of new mills. With current technology each mill (organized in *clusters* of 15) would have a milling capacity of 2 million tons of cane per season, resulting in a total of 22 million hectares of cane in the country – equivalent to the current area for soy. That production would enable Brazil an annual distillation of 195 billion litres of ethanol and would also offer 15% of the electricity demand. Electricity generation induces development. The impacts on the Brazilian economy were assessed and there would be an increment of 12 billion in the GDP (equivalent to the State of Rio de Janeiro). As a result of this type of land organization, the level of development of several areas of Brazil would improve. This process should be planned as part of a national development plan, through the Federal Government multi-yearly Development Plan.

However there are several critical points to be overcome. Sugarcane agribusiness activity on the agricultural front still has a lot to be improved in technological terms along with the creation of human resources to handle the production of 600 new mills throughout Brazil. Where will these technically qualified people come from to work at all these decision levels? We know what happens on expansion and occupation of the soil and in occupied areas, and this is the perspective for as yet unoccupied regions even considering the swings between positive and negative outcomes.

According to FURTADO (2007) supply was historically never an obstacle. In Brazil the problem was always demand because there were always problems of excess supply. The first petroleum crisis brought a major impulse to Proálcool. Later with the petroleum counter-crisis in 1985 came the growing demand for sugar that regulated growth. Continuing the historical perspective of

[5] Sugarcane occupies a relatively small area in Brazilian agriculture, occupying 1,62% of the national agricultural area with sugarcane plantations, taking third place behind soy beans and maize. An eighth of the area in São Paulo State is occupied by sugarcane.

sugarcane agribusiness, traditionally there are complementarities between sugar and alcohol products that benefit in allocation terms because of relative prices. Nowadays the sector positions itself on energy supplier perspectives as the future appears to point to ethanol – especially in the light of instability in petroleum prices. Ethanol has also come to respond to other challenges such as environmental questions like the greenhouse effect.

During the 1990s the demand for ethanol remained stable due to the increased consumption of dehydrated alcohol associated with gasoline. At the end of the nineties and beginning of the current decade the market resumed hydrated alcohol production in anticipation of a new petroleum crisis. With this there was increase in the price of petroleum derived products in the internal market, increasing the difference between the prices of gasoline and ethanol. The introduction of flex cars is responsible for the new demand. Today hydrated alcohol is the main product in the internal market when compared with dehydrated alcohol. The market is stably divided between sugar and ethanol, with grand synergies (FURTADO, 2007).

What is unsatisfactorily is that this expansion in ethanol supply is heavily concentrated in the state of São Paulo. According to FURTADO (2007) the expansion might occur within, or indeed outside this area, certainly being outreaching to other outlying areas – though always around São Paulo. Technological progress can of course, contribute to the expansion of production without the increase of planted areas and new mills. The tendency is that concentration will remain in São Paulo State because sugarcane is competitive in areas with more expensive production factors principally close to large centres where ethanol is mixed and/or distributed. São Paulo has better logistical infrastructure aspects compared with the rest of Brazil. In other words, the cost of transport of sugarcane to the mill, and from the mill to the consuming market is the second reason. The Northeast region could resume in the market as an exporter of ethanol due to its locality. Another aspect is innovation considering technology available. In other words, there has been a virtuous combination in relation to investments and knowledge in the state. There have been large government incentives for expansion and innovation. São Paulo leads in agricultural and industrial productivity accompanying these dynamics and there is an enormous dependence on information. The sugarcane agribusiness became a knowledge-dependant activity, and above all, knowledge of quite a tacit kind, allowing little space for movement. The relationship between the mills, the capital goods industry and inputs became quite intense and close. This reality is not found in other Brazilian regions. In technology terms these efforts have been maintained since the 1920s.

Towards the end of the years 1960-70 structural changes took place with enhanced research into São Paulo sugarcane. Productivity has been growing since the 1980s in particular. Besides becoming highly knowledgeable, sugarcane production activity demands geographical proximity and interactive dynamics between production and research so much in agricultural as in industrial production. São Paulo state unites these conditions which results in the concentration of sugarcane production. Energy and the potential for sugar and alcohol exports are enormous incentives for expansion of plantations in São Paulo state which is not desirable – confirmed in a study carried out by the Unicamp Interdisciplinary Nucleus of Energy Planning.

Brazil can afford to expand sugarcane production but the tendency of concentration, be it economical, or land oriented, aggravated by the inauguration of ethanol pipelines is not desirable. However this is already so and has brought social, environmental and economical impacts. There is a difficult and complex conflict of choices to address which need in-depth study. Technology helps minimize those impacts as long as scientific and technological policies also seek the decentralization of the activity. São Paulo should thus maintain its technological supremacy and will have an important role in the diffusion of already incorporated technology, albeit that the presence of the State is necessary through the national plan for bio-fuel addressed in policies for decentralization. Economical, social and environmental impacts should therefore be addressed, respecting the role of public policies.

The predominant euphoric attitude at this moment – although desirable – is of auto-regulation towards a society of bio-civilization, however some impacts of that expansion are put in check which is a great dilemma.

An area expanding by 5% and 40 new mills within a short term of 10 to 15 years show that in reality there are no policies restraining the overwhelming expansion and that measures should be taken urgently. Otherwise we will lose out in terms of regulation and territorial order. There are producing areas in which the whole sugar & alcohol setup is present with innovation systems – from universities and research institutes to innovative companies supplying equipment and technical support. Other areas just produce sugar and alcohol because they lack links in the network-chain. This is transmitted in the new producing areas of cane and in many cases social dynamics are transformed with the arrival of sugarcane farming. This calls for study considering that there are no solid diagnoses on the impacts of sugarcane in new areas. There are huge regional differences regarding this expansion in that the sector is highly consolidated and organized including what it refers to as technological innovation in the regions of Piracicaba[6] and Sertãozinho, concerning the capital goods sector – different from new areas like Araçatuba which just counts on inputs from farm suppliers. Producers are displaced from their traditional activities by the leasing of areas for concentration of sugarcane. SEADE data shows that 70% of the sugarcane production in several areas indicates the worst indices of Social Responsibility – IPRS (levels 3 to 5).[7] These are precious and precise empirical tasks focussing on regional differences and interested exclusively in the relationship with bio-fuel.

Considering the leasing price of land per hectare for sugarcane which can be as much as 1200 Brazilian Reals (according to IEA/APTA data), the implementation of mechanisms for reorientation of those investments is considered difficult. In the São Paulo state government there have already been attempts at restraining sugarcane expansion into undesired areas. It is the market which is regulating the activity, calling for public policy to better control the activity and trying to minimize the impacts. It is not that zoning is not an interesting option but there isn't a tradition of territorial planning in São Paulo State (or in other Brazilian states).

Instead, concentrated regions co-exist with diversified exploitations and there are mechanisms incentivizing intensive manual labour activities like Pronaf, rural settlements, governmental purchases (Food Acquisition from Family Agriculture Program – PAA), rural tourism and the development of family agriculture (FEAP) which go beyond exportation ambitions of well structured network-chains. There needs to be more concentrated effort on a development policy for family agriculture, mainly regarding the question of other raw material sources for bio-energy, as in the case of the oleaginous sources for biodiesel that can be synergic with ethanol.

In relation to the socioeconomic impacts in the municipal districts, those based on mono-cultures that produce only sugarcane don't attract service sectors, agri-processors or equipment suppliers and one sees only sugarcane burning, the financial situation of cane cutters, impoverishment and a resulting greater number of people included in the Family Benefit Programme where smaller amounts of ICMS tax are collected when the mill is located in another municipal district. These are municipalities that benefit from only a very small part of the ethanol productive chain when talking about agricultural production and the generation of temporary jobs.

On the matter of jobs there is a concrete fact. Sugarcane Industry Association – Unica – agreed with the São Paulo State Government to reduce the period for the eradication of burning in mechanized areas to seven years (by 2014), and brought the deadline forward by 15 years for non-mechanized areas (from 2031 to 2017). Public

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[6] Dedicated capital goods and services sectors in Piracicaba have been there for more than 100 years.

[7] "The São Paulo Legislative Assembly, in partnership with the SEADE Foundation, developed a robust System of Social Responsibility Indicators, highlighting IPRS formulated in 2000 to express the degree of social and economical development of the 645 São Paulo municipal districts. The five groups of IPRS measured from 1 to 5 the differing income and growth levels, longevity and education and it can therefore be seen which municipal districts require more State attention through public policies. In other words, IPRS graduates from group 5 (worst economical and social development) to group 1 (best social and economical development)" (PAULILLO, 2007).

policies are needed at once so that social impacts on employment (more mass layoff of cutters and decreased wage) are softened and that studies seek to locate which occupations and people will be excluded and then how to reallocate the manual labour. As the manual workforce used in sugarcane production comes from areas of depressed economy, public policies must be applied as a way of compensating for the seasonal work lost due to mechanization of the harvest. Furthermore, accidents at work, deaths and contractual relationships all leave side-effects due to working conditions and the lack of public policies regulating the market. Diagnoses and compensations are thus objectives for important research.

Despite improvements in working conditions in cane cutting[8] we cannot fall into the pitfall of extending the burning because there is no affording the use of the manual labour that will be laid off upon total mechanization. The positive role of ethanol in environmental questions is being praised, so maintaining the manual harvest and the burning that this entails cannot be justified. Besides the economical advantages of the use of mechanization in the production we must see the introduction of new higher paid and technical activities. The decline in rural and non-rural employment (agricultural and non-agricultural) should be studied along with training and labour reallocation. These initiatives should be studied in order to have an outline of what solutions are feasible, duly certified in accordance with global demands and preferences for sustainability. This is therefore an important national subject not only in the light of environmental and social aspects but also in economical ones.

The situation regarding the occupation of land with sugarcane instead of being otherwise used for food production is expressive but not so important as part of the whole agricultural area. This could however affect occupation by family agriculture in a more dramatic way. This is the case for settlements that incorporate, or are incorporated by sugarcane through leasing. The cane also occupies flat land recently released through Agrarian Reform which through leasing creates an income for the owners but without however having any possibility of them working as cutters due to mechanization. This can permit leverage over other rural productive activities or make them become totally dependent on the situation of leasing without employing those who actually own the plot of land.

Despite State concern in São Paulo for the formulation of territorial policies and regulation of sugarcane exploitation, this will not be successful if solely aimed at São Paulo State. A policy is therefore necessary, but in harmony with the policies of other states and federal level policy. Policies of territorial character have recently been gaining national importance, many of them even overcoming municipal limits and directed at intermunicipal territories.

The need for planning cannot be disregarded despite the current taboo. Ethanol is an ever growing and important part of the Brazilian energy grid as an important generator of electric power so recognizing the necessity of a regulatory body makes sense.[9]

In summary, understanding social and economical impacts creates demands for studies to back up regulation mechanisms like the very zoning discussed in economical, social and environmental aspects with micro and macro analyses. This difference involves more specific aims behind local, state and federal public policies. There is a lot of demand for information and for indicators that can inspire sustainability policies. There are few indicators but there is a lot of disjointed research, lacking research group institutionalization. One option would be to create a network of research directed at that process. We have researchers with accurate but uncoordinated research, methodological gaps and a lack of unification of that research.

8 The production sector has indeed been indicating its wish to end seasonal and privatized recruiting via informal contractors known locally as "cats" ("gatos" in Portuguese).

9 This taboo derives from historical conflicts by some social segments against interventionalism which led to the extinction of the IAA. The subject of regulation cannot continue as a taboo in the sector, addressing only price controls and quotas etc., as the need to think about regulation is already present when, from an international perspective this is primordial.

Ethanol supply chain coordination

Premises

Inputs and sugarcane production

The presence of cooperatives and supplier associations that provide technical assistance bring more competitiveness to sugarcane producers (whether suppliers or mills) because these organizations have more bargaining power and logistic capacity for meeting larger input demand from agrochemical industries. The administration of these organizations is quite peculiar and a reasonable level of knowledge has been developed on agricultural cooperative management. There is however need for cooperative management training, separation between ownership and control, and for a better definition of property rights in which relationships between cooperative members also need improving. A diagnosis of these cooperatives and associations of suppliers in relation to their administration and economical-financial situation is thus essential, besides continuous professional training in the strategic management of those organizations seeking to improve the Orplana system – the vertical organization model for cane suppliers. One also needs to narrow the link between the Orplana system and the public research institutions, agricultural technology and its economics (FRONZAGLIA *et al.*, 2008).

From a historical point of view the relationship between cane suppliers and mills was always unstable and conflicting. Several papers have previously described this category well with their specificities and necessities. Today when we look at the different links of the sugar & alcohol production chain, we find that independent supplier production – which represents 25% of the cane produced in the state of São Paulo is not very well defined. The same is true for proprietors who lease lands to the mills. The statistics concerning these categories are confusing and reveal neither contract models, proportions of land rentals, shareholders, contractors and active suppliers amongst other "supplier" categories and partners, nor even their technological profiles and agrarian structure. This relationship between supplier (or leaser) and the mill is quite narrow and symbiotic. One therefore needs to question the necessity for studies seeking to improve the coordination of those relationships, technological transfer and maintenance of the competitiveness along with sustainability of the supplier production in conjunction with the mills and the economical alternatives for these producers.

Industrial Processing

This link in the sugar & alcohol production chain is technically quite efficient and requiring qualified professionals has undergone a process of intense training. The concentration process in the sector has reduced managerial costs dramatically. Foreign business groups are significantly encouraging still higher efficiency levels in the administration. The sugar & alcohol sector started to have ever broader interfaces with other production chains, and many new business models have emerged. There are huge synergies with other complex downstream processing, like the chemical, pharmaceutical, nutrition, electrical sectors and industrial equipment industries.

The creation of these new enterprises requires an understanding of business analysis with even more complex synergies. The traditional business models should thus undergo a profound transformation being that the administration of *holdings*, creation of *joint ventures*, participation in *private equity* investments, the creation of technology-based companies (TBC), *spin-offs*, strictly coordinated downstream processing chains, the use of trademarks and high degrees of differentiation are just a few coordination examples that business models look for. These also raise questions concerning the capacity of the sector supplying information for the identification of value creation opportunities as well as the elaboration of contracts with effective benefits. Research between the interfaces of management, economics and law has a lot to contribute in this area.

Financial engineering and business simulation models might be important tools according to the degree of synergies between business units.

- Intellectual property and technological management with the monitoring of scenarios – as yet little developed in the Brazilian tradition of innovation – might well have very important applications for a knowledge and technology keen sector.

- Law, business and economics, particularly anti-trust policy are new and rare issues in Brazilian traditional law schools and may have very important implications in a sector that will undergo corporate restructuring and will adopt new mechanisms for investors in the financial markets as well as strategic alliances, coalitions and acquisitions, and international negotiations.

Commercialization of ethanol

The price of ethanol for the consumer started to suffer substantial increases of 27.5% in the second semester of 2005 and of 25.6% in the period between harvests (December-February 2006). In the mill this increase was 83.2% for hydrated alcohol and of 60% for the dehydrated alcohol in the same period. This price variation corresponded to an increase of 7.9% in the price of gasoline with direct impact on inflation – the primary target of discussion and public concern efforts. It was caused by heavy stockpiling, seasonality and exportation. Stockpiling is strategic for guaranteeing exportation contracts and taking advantage of associated seasonal opportunities. It is however very probable that these prices are maintained close to a parallel maximum of 70% with gasoline, since the demand indicators led to the drop in the world sugar stocks resulting in an overproduction and a price crisis in the harvest of 2007/2008. The price crisis stressed mill capacities and these couldn't meet the production in lieu of the intense consumer market demand, led by fuel distributers (FRONZAGLIA, 2007). Important objectives for research include these recurring crises that the sector is exposed to.

More important than the subject of increases and stockpiling is the relationship between market agents as well as the structure of the distributing market which keeps the ethanol market from degradation. It is worth remembering that the structure of the distributing market is overly concentrated.

The existence of an international market for ethanol and the transformation of the product into a commodity are important for the sustained development of the sector, since these enable financing and several price risk management mechanisms. Several studies are necessary to make standards feasible, elaborate contracts and define operational criteria. However, other coordination models such as vertical integration and long term contracts might offer more efficient coordination depending on the ethanol – its differentiation type, co-products or by-products (IEL/NC and SEBRAE, 2005).

Results

It is important to learn from the evolutionary history of the sector. Due to poor dynamics it was never capable of responding to structural questions. Today many new newcomers are making investments and as a result productive structures should be appraised and characterized for technological equivalence between units and productive areas.

In the ethanol market sectorial structural problems include the inability at self-regulation and sugar mill articulation. The state regulations brought by IAA in the early 1930s were down to the inter-regional competition (NE and SE regions). It generated the economy of the sector with income and fixed prices and the trade risk was administered by the State. IAA tried to resolve these subjects regulating prices, with export quotas and by sharing sugarcane production between suppliers. At the time there were large imbalances between supply and demand. Under this type of regulation there is no economical risk. However, criticism of the regulation as a barrier against expansion brought deregulation and dynamics such as product differentiation, decreased production costs, increased participation in the producing and exporter markets and the utilisation of contracts to bring sustainability to the activity. When the process of market regulation ended in 1999 sugarcane was the last product to be unconstrained – the first being sugar and ethanol soon afterwards.

In the process of seeking self-regulation the coordination model Consecana suffered several amendments and brought certain stability to the sector mainly by reducing the lulls with the warranty of supplies and guaranteed demand from the mill. In doing so they lessened transaction costs in the sector.

The major role of Consecana was to do the approaching for negotiations between supplier and mills as a middle man establishing basic rules.

However if on the one hand the state regulation (when present) didn't (better did not) manage to resolve the conflicts generated between suppliers and sugar mill owners, Consecana on the other didn't manage either. The issues of supply (lack of raw material) and other consents have been resolved in the courts. It should be up to the State to regulate these contracts as well as help in the compliance with them.

The Consecana model responds for only 25% of the supply and there are differences between players, classified as shareholders, third parties, leasers, contractors and partners. In the state of São Paulo, 25% of all the sugarcane harvested is produced by 13,000 cane suppliers organized by Orplana – an association that comprises other smaller organizations such as cooperatives and supplier associations. An analysis is important when seeking to reinforce that relationship created through Consecana.

The results Consecana achieved are important and cannot be overlooked but a broader regulation mechanism is necessary. Ideally the different types of suppliers would be studied – both large and small, identifying the different contractual relationships since the bargaining power of one is different from the other. However, for public policies it is essential to have the description of contract modalities of these different cane supplier categories in São Paulo state, along with the monitoring of each socio-economic and technological profile. The supplier/leaser/industry relationships should therefore be observed more closely. Public research should be covered by production costs, the Consecana negotiation system and the definition of prices, service mix in supplier associations and their vertical appearance in Consecana, with a view to creating contractual and market positioning alternatives and conducting efforts towards public policies among supplier categories.

Consecana made the relationships among suppliers and mills more transparent through the establishment of contract standards, encouraging the reduction of production costs. As well as São Paulo, other states sought to create other Consecanas to regulate the market and coordinate transactions so cane suppliers are paid in agreement with the price of ethanol. When the price falls, producer euphoria drops provoking the question of who will buy the ethanol. Observing the subject of price variations in this way one still sees big oscillations that make the activity quite unstable because supply responds in an uncoordinated form.

Consecana is gradually resolving the relationship problems among agents of the production chain. However, research that better addresses the supply sector is required. Research on suppliers is disperse and rare. There is not, for example, a detailed characterization of these suppliers and what their technological or organizational (amongst others) demands might be and available data comes from Orplana. There are several categories that need to be characterized like drawing up contracts and how they are complied between parties – or not. There are suppliers that are leasing lands to increase their supply. It is necessary to map the aspects of these relationships among agents in the productive chain, especially concerning technology transfers.

It would be interesting to achieve a proposed policy for technology sharing starting from partnerships with mills, or rather, the process for sharing IAC and CTC technology (among others) in order to give more access to small producers and the smaller, lower capacity mills. Coordination of technology in the sector is done by the CTC. The technological transfer to the suppliers and mills that have lesser access needs a policy for technological sharing. Some mills have also formed partnerships with public research setups like IAC/APTA.

The profile changes in the regions that cannot mechanize the sugarcane crop. The exigency for mechanization for some areas such as Piracicaba which are not suitable for mechanization will soon be a problem. What can be done? Some partnerships are being set up so that the cane is exploited in areas that are unsuitable but which still need to be made possible. A technological park exists for maintenance, mill production line and tools – so what is the future of this park? There is an initiative towards studying these variables in Piracicaba which could become unprofitable for cane even though they already contemplate all of the links in the chain. The studies are being developed by the Sugarcane Local Productive Arrangement (APL) in Piracicaba.

However, until a technological solution is feasible[10], regions like Piracicaba, which has the largest number of low volume suppliers and where steepness hinders mechanization, will have to seek to relocate their sugar & alcohol parks. Some 83% of the producers in that region plant up to 30 hectares. Some suppliers will continue in the sugar & alcohol activity while others will leave sugarcane production behind for other products through new strict coordination mechanisms which strategically reposition the mills like for example, differentiation and added value on co-products, residues and organic products, utilization of own trademarks. Ethanol refining can be an option besides functional foods. In other words there are other applications for sugarcane beyond energy.

Financial market demands are revealed by investors selecting projects and new mills covered by normative Instruction ISO 22000 or rather – those with standard coordination to upstream and downstream. Investors' expectations are therefore high in relation to coordination efficiency.

Coordination problems go beyond Consecana, because there is the question of old and new barriers in international trade like regulatory stocking, several taxes and logistical systems. Considering other production chain links (new mechanisms and products that appear like liquid and organic sugar), relationships start to be long term contracts creating more sustainability. This is not the case for ethanol which continues based on market coordination. However new forms of coordination were created, such as the trade organizations Brasil Álcool and Bolsa B, that didn't work due to problems of concentration and anti-trust policy. There are alternative arrangements for the commercialization of ethanol, with small parks where understanding how it all works is of the essence.

The subject of adulterated ethanol is being monitored in such a way that the warranty of product quality is maintained. As for the standardization of ethanol, there is a black market for fuel, adulteration and informal trade on behalf of the mills. These obscure courses of the product need to be studied and reoriented, starting from the creation of incentives for legalization. The government is studying forms of identifying both types of dehydrated and hydrated ethanol to regulate that market and to minimize the availability of low quality fuels. The State then, is not completely ignorant and controls several points over production chain links For instance government attributions in relation to the addition of ethanol to gasoline include export licenses and Cide tax. Abroad, the image that the government controls all ethanol production in Brazil still prevails.

Today ethanol is dealt with by several governmental Ministries, indicating the absence of central monitoring. So public policies do exist and should be improved without creating new policies. Shoddy registration of ethanol sales implicates in non-collection of revenues and taxations like PIS/Cofins. Therefore, in these aspects, the presence of the State is important to better structure these issues, position the external market, as much as address issues related to subsidies and what can be resolved in the OMC.

Variations in prices and regulatory stocks lead to a policy of strengthening the mechanisms for sector governance. One of these is the market of future's contracts for sugar and alcohol, due to the high operation costs, *player* concentration and tax problems in some states that hinder the dynamics of using this derivative for price risk management. Another is the use of financing stockpiling mechanisms through marketable certificates on a secondary market with financial clearance. It is worth remembering that there are times when excess world sugar stocks ebb the outflow of ethanol. Thus ethanol stocks in private company consortia aiming to reduce price flotation can be a way out. The arrival of new *players* like fuel companies brings new dynamics. A closer glance at the market structure should be taken and also at the relationships between mills and *traders* to define the stockpiling outline even for public interest if the case may be. It is necessary though to study

[10] 15% of sugarcane production costs are due to diesel, leading to ideas of installing biodiesel run mills so that costs can be reduced. On that line studies approaching the complementarities of crop rotation. And its use as source of fuel for cane production would be important. Manual labour assisted with light harvesting machines for steep areas are also being studied.

how to structure those mechanisms, which agents participate in it, and the role each plays.

In relation to financial governance there are two levels to be addressed. The first is the financial mechanism of commercialization which is more developed in the sugar market with structured operations. The second is the governance from financing to investment, which is based on third party capital – or rather, long term bank loans. The award of resources through the stock market is restricted and there are only three groups of mills that have released shares to the stock market implicating in the need for transparency and social responsibility. As this was very recent there is no way of assessing their achievements.

Thus the central question concerns what the government involvement should be in the current setting. There is opportunity for state participation through taxation, inspection, gasoline additives policy, and sectorial statistics along with in-depth research investment on these questions raised, counting on representative organizations as partners to create feasible solutions for implementation. This reflects the need for information and for indicators that can identify policies for productive chain sustainability.

Studies on this theme are disjointed and lack group research institutionalization as well as the inclusion of more essential subjects like cyclical crises of overproduction, impact assessment concerning the arrival of new foreign business groups in the country, the concentration effect on both competitiveness and competition as well as its impact on both internal and external sustainable market viability.

Regarding the database on supplier production it is the cane supplier associations such as Orplana, besides mill associations like Udop and Unica, which collect data. There is an enormous apparatus available, comprising universities and research institutions that could create a central database either for public knowledge interest, for project convergence and the construction of a solid base of knowledge integrated in several organizations, or incentivizing network arrangements – even inter-regionally, and of long term durations for the development of research on the issue.

Governance of the sugar & alcohol sector

Premises

The driving forces of several producing sectors of the industrial economy concentrate on the big players in these producing markets (FLIGSTEIN, 2003) as is the case for ethanol, this potentially international commodity where there is still no large global trader. The organization is left to vertical structures from sectorial representations to coordinate price negotiations and raw material standards. The intense and continuous concentration of the sector and the establishment of contracts have relevant roles in these coordination structures for guaranteeing the supply of the raw material, determination of standards and risk administration (ZYLBERSZTAJN, 2005). Centres of concentrated decision power and sectorial promotion have formed and allowed the establishment of sectorial strategies for sustainability of the ethanol industry (MELLO, 2005).

The new millennium opened with the three larger sugar & alcohol groups holding 63% of the cane production and 38% of the sugar production. Until now a lot of acquisitions have taken place despite the arrival of foreign groups. Supply stockpiling for export is a natural mechanism of making the international market feasible and the role of the trading companies is critical for Brazil to remain competitive in the international market. This is reflected in the concentrated stockpiling of ethanol. The strategy sought by traders is a guaranteed supply through vertical coordination which is also sought by large groups and reveals a phenomenon showing that concentration and vertical integration should be increased. The infrastructure for ethanol exportation should also be concentrated in the light of consolidation projects led by large joint venture business groups like Transpetro (Petrobras)/Mitsui, Brenco and the Cosan/Crystalsev/Copersucar/São Martinho consortium for the implantation of a network of dedicated ethanol pipelines ranging from the Central-Western region towards the ports in São Paulo.

Investments in new productive units has been achieved through financing from the National Bank of Economical and Social Development – BNDES, whose portfolio in 2007 totalled 62 operations in the sector, equivalent to R$ 7.2 billion in investment support and totalling R$ 12.2 billion through public resources. This is subject to pitfalls like the 2007 oversupply crisis and the worsening 2008/2009 international financial crisis. On the other hand the sector is becoming more professional, unlocking capital for venture capital investors and launching shares on the stock market. This process already occurs within a few national groups – Cosan, São Martinho and the Guarani Sugar Group – whilst others are getting ready to make a debut in the stock market. This way the corporate governance of these groups becomes well developed reducing the risks to investments made with governmental financing of debt capital.

However, the control of these groups is more exposed to the rules of the market and to concentration. The positive aspect of this new relationship with investors is that they are subject to the preferences of the stocks in relation to sustainability. A second market exists but is reserved for companies with a higher level of corporate governance. There are also investment funds that invest in shares of companies with social and environmental responsibility. These markets have been demonstrating lower risk and better performance. The bilateral selection between funds and sustainable companies brings sustainability to investors as well as those involved in the production.

The possibility of creating a sustainability protocol is under discussion to regulate the parameters of sugar & alcohol sector expansion. Such private governance systems and their incentives have already been well looked into. However, the viability of certification systems and their indications to the market as a form of incentive to comply norms are still very onerous instruments such that their efficiency depends on a series of factors inherent to information costs.

Results

The Governance issue is complex and very wide ranging. The concept of corporate governance over companies also involves social and environmental responsibility, and sectorial vertical governance from the organizations representing the sugar & alcohol sector.

It is important to make the distinction between social and environmental responsibility and corporate governance. The recent momentum for globalization and market integration is accompanied by two occurrences – firstly of products between countries then information exchange, forming an up-to-date partnership. In other words, the impact of a mega-organization like *Nestlè* is global carrying global level consequences and implicating immediate externalities. There is financial turnover response in the case of the stock market. Financial turnover involves logics of risk association and benefits, with shifts in the capital.

Macro and micro policies have much smaller margins for manoeuvre because any deviation of conduct can involve future implications. The investor won't put resources where there is a black box. Transparency is essential. Share prices reflect the roles and preferences of large investors, institutional funds, and individuals.

Society changed its behaviour towards environmental and social aspects and made its requirements part of transparency and sustainability of the business and of market investments. Corporate governance is manifest in this backing. Accessibility to information brought consumer pressure groups, NGOs amongst others and with them, more information. In response to the big scandals in gigantic corporations the São Paulo Board of Stock Exchange created governance levels for differentiated markets – for those with better practices, and this issue is present in the energy sectors like the sugar & alcohol industry.

The aspect of corporate governance with sustainability leading to governance of the sugar & alcohol sector via sectorial governance is an enormous challenge which could help in the improvement of the governance of the sector as a whole. It represents a major challenge recognised as huge for the ethanol industry and a great opportunity to participate in the capital market.

Corporate governance and sustainability are directly associated while sectorial governance works as a lobby. The concept of sustainability is broad, socio-economical and environmental. The indicators are there like the Dow Jones Sustainability. The challenge of corporate governance in association with sustainability implicates in the sectorial governance of the sugar & alcohol sector that, if prompted in its new activity schedule, has the task of devising educational activities.

Raising the subject of corporate governance, one considers the capital flow which is eager for good projects and investment opportunities. Ethanol is an example in this case. Will it be able to take advantage of this capital market? There are several modalities like private equity, stock markets, alliances, joint ventures etc. Will these models be predisposed to be adhered to by sugar mill owners with conservative characteristics, power focussed and culturally dedicated? Might the sugar mill owner be willing to be on the administration advice council along with finance market professionals?

The tendency for sectorial concentration can be positive if it implicates in professionalizing the sector. From the distribution of capital point of view a mega corporation that has 50,000 investors, might be better than traditional family owners of organizations. But reconciling pressure is necessary – on one side the shareholder, the other sustainability. Accounting is necessary over shorter periods for the quarterly profitability score. This challenges money generation in the short term and is the important aspect of governance.

Sectorial governance of the sugar & alcohol sector was always used more as a lobby (which is not socially efficient) than building governance and working with transparency for the market investor and for the consumer. The sugar & alcohol sector still doesn't understand the opportunity of capital market and the sugar mill owners avoid foreign capital. Either the sector begins to use the modern indicator mechanisms integrated into society or it will stay in the archaic industrial economy and easily be overtaken due to lack of financial and human capital access.

Corporate governance becomes ever more important for attracting investments according to growth perspectives with the arrival of big investors in the sector and new financial agents along with future international investors. Two aspects should be considered for sustainability – reputation and corporate governance. Either of these aspects is fragile. There is an immense risk to the country, considering that ethanol is the great protagonist in the energy grid and on export share and a major product in many São Paulo municipal districts that could suffer serious upsets caused by the closure of mills through lack of efficient corporate governance. These aspects must be resolved in order to attract investors instead of speculators. The development of a corporate governance culture is compromised with no market demands. The sector should look to professionalism in planning and build a reputation with Brazilian society as well as with national and international capital markets. This movement began with the São Martinho mill and the Cosan group, but it is also necessary to consider the centrality of that reputation in the sector's command network – or rather – the central command between Unica and Orplana.

There is still the problem of social and environmental responsibility reflected in the agricultural setting in productive advances and their impacts. Brazil is aligning itself with the USA to facilitated exports to this partner without seeking to break the import barriers of the EU. In other words, it is seeking the easiest markets without worrying about investments for sustainability and certification. This is a concerning attitude and culturally part of an "immediatist" industrial age.

The sugar & alcohol sector protocol on sustainability is a voluntary certification and not obligatory. As one can make sustainability certification work in several dimensions it should be made to do so with concern on international trade.

Recent research shows that 90% of sugar mill owners don't want executives involved in their administration, formal relationships with shareholders or long term strategic planning. They centralize their decisions, are not prepared for the future and don't believe in the ethanol market. The lack of professionalization therefore hinders the strategic target of the command unit (Unica) of achieving corporate governance in the sector. Corporate governance involves seeking importance independently from the business and seeks to meet sustainability requirements. When concerning external pressures like environmental, labour, and minority protection and consumer defence code legislations, social pressures etc., the financial markets tend to seek investments in sustainable businesses that don't present volatility or other similar risks. This demonstrates the value creation which is essential for the sector to be attractive. Transparency is needed along with good managerial practices with commitment and always thinking in creating long term importance. Sustainability and corporate governance are ethical.

The process comes down to dialogue with the agents, creating indicators and reporting to the market. To be sustainable it is necessary to discuss it and unite agents. If this is not followed the sector won't receive investments and will be swallowed up by an alternative investment or professional international groups will take over production.

There is no doubt that we ought to have a certification system if we want to sell in the long term. Another important point to make concerns the divulgence of these conditions in the market investment.

From an association point of view a proactive role should exist, ready for inducing social responsible practices like the partnership between Unica and Ethos which is a start. In order to understand how to cope with the question of certification for ethanol, the experiences of other sectors should be observed like the case of coffee (Abic) that altered practices in the sector, especially as all efforts are for turning ethanol into a *commodity*. Certification occurs when the structural process is legitimate, creating a valuable alliance between several players.

In the market of alcohol and sugar, there are large uncertainties; so long term contracts built from strong relationships established over time are essential. Long term contracts bring many possibilities for sector enrichment and sustainability. This would indeed result in a differentiated commodity as today these aspects are not being incorporated into the prices. It is not a question of formal demand but voluntary adhesion, as is the example of the FSC. Aracruz is not certified, so suffers price variation. This however would satisfy only a fraction of the market, because voluntary adhesion by itself doesn't resolve the question. Sustainability doesn't depend on altruistic characteristics of entrepreneurs or companies.

Corporate governance involves price differentiation. So there will be two prices, one for the certified alcohol and one for the un-certified and there will be two supply networks. Informal arrangements are inherent in the Brazilian economy and there are a series of heterogeneities. Today there are various markets alongside a large informal market. The external market might demand the certified market product but the remainder stays internal without certification such is the case of informal milk and its corresponding black market.

Will the market forces lead to change in the behaviour of sugar mill owners? On certain terms the traditional model does not survive long term. The administration profiles of mills change when investors become interested in buying mills. The Vale do Rosário is the type of *private equity* model that puts sugar mill owners out of business. The reality is that the mills are being bought up. Either they change or they won't have access to capital. Sectorial governance is based on corporate governance for the strategic interest of capitalization, modernization and consolidation in the sector looking for more sectorial competitiveness. It is believed that the sectorial governance liaises with corporate governance as a strategy but studies should seek to understand if this is true.

Environmental Management

Premises

The magnitude of the socio-environmental impacts of sugarcane expansion is quite clear. The most serious environmental factors are related to the burning of the cane, vinasse residues and the use of farm chemicals. In other words, there are positive impacts related to the mechanization of the harvest as well as the protection of the soil, substitution of fossil fuels and a reduction in pollution coming from motor vehicles.

Possible technical barriers against export and harm to the social and environmental quality in the state of São Paulo are two concerns converging public interests with those of the sugar & alcohol sector leadership, in the search for the creation of a protocol that defines sustainable productive practices.

Results

The sugar & alcohol sector has a profile with differentiated issues. The objective of environmental certification is to seek access to the markets and avoid the restrictions of no-tariff barriers. For substitution of 10% of the gasoline, 220 billion litres of ethanol is required. Many mills are seeking environmental licensing because an ocean of ethanol is required to supply the demand.

The expansion of the sugar & alcohol sector in Brazil brings several future scenario perspectives. How can one structure and regulate this growth? Environmental issues lack more questions and imply impacts which result from creating new mills in the country. It is necessary to identify who follows rules and who doesn't. There are fitting aspects in terms of conduct that require the role of the State to enforce the laws. One cannot imagine that the way to external capital will be the solution for sustainability, because there is not always a guarantee that sustainability issues will be respected.

An environmental commodity is one which scores well in social and environmental issues. Technology exists for bettering and performing several aspects as for example, organized production associated with the carbon credit market. Precision agriculture is another practice that facilitates environmental management processes.

Technology and the highest production per unit by factor is one of the important aspects when seeking sustainability, but expansion is inevitable anyway because ethanol being a cheaper input and used by more efficient engines make that factor more important creating demand for more cane production. Several phases of production show impacts. Burning and the application of pesticides and herbicides from the air generate an enormous social cost through an increase in respiratory problems.

The rule for new mills should be "no burning". If we were to consider analyzing life cycle systems, we would be thwarted half way. Mechanization leaves an amount of organic matter behind with micro-fauna, soil quality etc. There are machines that collect burned cane and do so better, competing with the manual cutters. Living organisms absorb soot and CO_2 levels are not exempt either. The air is contaminated with particles in suspension and there is a high mortality of animals from burning. Organic cane without burning brought reintegration of the flora and fauna. There is environmental liability in sugarcane regions that must be resolved. The elimination of burning had already been imposed by the Government, but its time limit was extended. Now they are trying to reduce that period again.

There is a close relationship between manual cane cutting and the slave trade and productivity expectation. Of 140 companies inspected, all had labour problems and their recruiting methods need to be studied and regulated. Cane worker earnings fell since the seventies from R$ 2.79 to around R$ 0.80 per ton today. These people risk disablement without access to retirement. Death through exhaustion is a big problem. Since the reduction of working hours people began to intensify their efforts. Shifts began to receive energetic foodstuffs to replace salts and make the person much more productive. The working life expectancy of a cane worker is 10 years. A slave lasted 15 years in the 19^{th} century. Lodging, food and tool costs hamper the cutter from saving money in order to return to their hometowns. In other words they are detained as slaves in economical terms. Informal contracting methods for manual cane cutting and its correlation to deaths should therefore be studied.

Water is another factor utilised in ethanol production and this comes from the environment – 3000 litres per ton of cane. Corn uses even more water. The Guarani aquifer is covered by cane and there have been many warnings concerning its contamination with herbicides. In some areas it is impossible to find a spring that isn't surrounded by cane, leading to pollution by pesticides at source.

Residues like vinasse are 10 to 12 times more than the volume of ethanol produced. There is enough knowledge regarding the use of vinasse as a fertilizer and regulation exists for its handling, establishing that mills plan for discarding vinasse, but often this is not respected and vinasse channels are created through the sugarcane plantations contaminating the soil and subsoil where there is no inspection.

There are no more agricultural expansions in wooded areas in São Paulo State. Slash and burn doesn't exist any more. State wide there are 20 million hectares of arable land and cane is expanding into pasture areas in the north and northwest. Being a low productive livestock area this is positive and offers the opportunity for the better use and conservation of the soil in those areas while still offering livestock integration opportunities. Climatic warming is improving the conditions for producing cane and this expansion is increasing its competition with food production. Like the scenario of global warming there will be a big increase in food prices on a global scale.

The work carried out by the Secretary of Agriculture through IEA/Apta, supporting negotiations on the sustainability protocol was important in subsidising a voluntary agreement, very similar to certification, addressing cilia forests, soil conservation, aquatic resources, the use of pesticides, empty pesticide packaging and effluents, putting weight behind the justification of no tariff barriers. They arrived at a much broader protocol for certification involving economical, social and environmental interests, especially focussing on the issue of burning and that new areas should implement automated harvesting, and through this the onus would be against burning, conservation of the cilia forests and control of pesticides amongst others.

With 3.8 million hectares of native vegetation remaining and cane reaching 5 million hectares, if we were to comply with current legislation, between 740,000 hectares, and 1 million hectares of conservation area should be set aside.

The law says that 20% of the property should be conserved for nature and this is not viable because each property has differing characteristics. The problem is how to make a conservation policy that covers the social cost aspect of the activity. There is no rationality in each property having its own legal reservation, but there still is a need of having compatible reservation areas suited to the needs of São Paulo. Somebody will have to pay for that. Therefore the sector that deforested should reconstitute a continuous area. It would not be rational to scatter 1 million hectares throughout the sugar & alcohol sector, but it is viable to adapt legislation and obligate the restitution of uninterrupted areas, else the cane production environmental certification would be far from reality.

There are many Brazilian certification initiatives in the sector, and they are formed voluntarily involving willpower between several players. We have concrete examples of certification systems like Imaflora that involves most technological aspects and the Ethos Institute concerned more with behavioural aspects. Why was there no adhesion? Because there was not a differentiated public policy for those who adhered to it. At the time there was no great demand for ethanol but when that demand came it increased the demand for certification and more requests for certification were lodged. There are already certified organic sugars being marketed in a differentiated way. Certification involves a system of accreditation and certifications from Imaflora are already demanded.

Noble areas are for agricultural production and areas that are unsuitable for agriculture could be used for legal nature reserves. All of the mechanisms like APP, Legal Reserves, AC – whichever – benefit is social and must be divided between all members of society. The environmental benefit is universal but the cost of the social benefit should be met indirectly by the sugar & alcohol sector which is responsible for devastated areas as well as for its environmental liability and should be targeted by regulators for restitution action, seeking decontamination and creating areas of preservation in non productive areas.

The cost of maintaining the area and its reforestation is not high. Safeguarding the area for 10-15 years is enough for it to recover. The issue of water shortage in some areas could likewise be improved. Several possibilities can be put into place like reforestation farming that has been working very well for family producers, and through this, one can reallocate the labour coming from cane with the recovery of cilia forest areas, biodiversity maintenance, combating erosion and generating water.

The environmental liability of properties is enormous. The shortages of water and bush that allow infiltration have low remedial implantation costs. This has to be put into context – just as the glifosato herbicide which was more intensively applied with the adoption of transgenic crops – in such a way that the value achieved in these impacts is bilateral. Reforestation, for instance is labour intensive and when manpower is dismissed it can be reemployed in re-creating vegetation areas. Although the examples available are not clear in terms of results, reforestation has alternative arrangements that have successfully enabled the implantation of this conservation objective.

One notes that recovered areas are concentrated in cane areas. The correct thing would be to reposition legal nature reserve areas in the state. The certification for ISO 14000 and 22000 require that the whole chain be integrated for certification and often certifications are issued in umbrella form. Society will receive an enormous benefit from conservation and group certifications enable the cost to be met.

Financing the research institutions and universities so that these can attend the sectorial demand for certification in an appropriate manner involves suggested residue analysis amongst others and seeking public policies to provide and implement infrastructure. Environmental certification involves significant analytical requisites for laboratory characterization. In other words, it is necessary to improve Public Institute Research laboratory infrastructure to enable those analyses. In the European Union there is a policy for quality that involves the productive environment with economical and environmental social quality. In the future we will have to be prepared for the demands of a new paradigm of sustainability.

The Dutch Head Office for Sustainability that evaluates ethanol in Brazil shows a concentration of social problems although high technological efficiency. However, more should still be invested in the tendency towards vertical productive expansion. The itinerary should prioritize the consideration of new technology optimization like hydrolysis and mechanisms for training cane cutters with a view to new jobs. It should have a specific technical council to organize a forum for discussion in order to create mechanisms and means for certification. One cannot leave the problem for later. Solid public policy has to be reached to bring importance to environmental norms and certification. Zoning, like public policy is essential, including the establishment of cultural positioning and diversity to add stability to the system.

FINAL CONSIDERATIONS

On the agenda concerning ethanol sustainability as a component of leading Brazilian energy sources, debates related to the economical, social and environmental impacts have been gaining importance thanks to scenarios that point to large expansion of sugarcane for ethanol production. Aspects related to the sustainability of the whole sugar & alcohol sector are also put forward in the understanding of these new dynamics, calling for studies aimed at identifying research issues that contemplate public policies towards sustainability of the whole ethanol production chain.

This chapter had the objective of documenting the June 2007 " Research Workshop on Ethanol Sustainability", as part of the tasks related to the project "Public Policy Directions for the Ethanol Industry of São Paulo State", as part of the Fapesp's Research Programme for Public Policies – PPP.

The workshop was guided by a term of reference focused on several analyses involving economical, social and environmental aspects, whose conceptual approach prioritized the role of institutions and organizations, production chain administration perspectives, the sectorial strategic vision for sustainability, prospective demands for institutional innovation and the proposal of public policies in C&T,I – Science, Technology and Innovation. It sought to encourage discussion around systems of sustainability indicators, implications for regulation, managerial decisions, as well as methodological and conceptual gaps. The workshop was thus structured in four panels: bio-energy scenarios and impacts of sugarcane expansion; coordination of the ethanol market; sugar & alcohol sector governance and social and environmental responsibility.

One perceives a scenario of huge global demand for ethanol in partial substitution for gasoline in developed countries. The production of cane as a raw material for ethanol production is going through a moment of heavy expansion, causing impacts in several areas, calling for profound studies to evaluate economical, social and environmental elements focussing on territorial planning and regional analysis. The production chain with its many parts requires studies on organizational fragilities and multi-focussed coordination. Forms of coordination, governance and sectorial self-management in force have brought great enrichment to the sector but there is a long way to go through research and innovation coordination.

Improvement in commercialization mechanisms and sugar & alcohol sector production chain coordination are paramount. Social responsibility research programs and environmental certification are welcome. There is need for understanding agent indications and understanding those that finance the activity, thus creating incentives for better managerial practices including social and environmental responsibility, transparency and professionalization interpreted through corporate governance, value creation which can be identified by society.

It is also suggested that more articulation is necessary between various agents that are devoted to socioeconomic and environmental studies in the sugar & alcohol sector, motivated by public policies enabling research of a consistent long term type avoiding intermittent efforts. A unification of databases from all of the organizations is suggested through the integration of all those organizations enabling more concentrated research efforts.

Network arrangements were also emphasized as well as the need to support them in a regional and inter-regional form. This includes research funding agencies, private financiers, public scientific and technological research institutions and the productive sector. In agribusiness one sees concrete examples of research consortia and sectorial development. This type of arrangement enables the integration of data sources, as well as between the institutions that deal with and stock information along with those that work with data research and sectorial representations.

Production sustainability and the sustainable use of ethanol in economical, social and environmental dimensions are in dispute for scientific, technological and innovative public policies that reflect the integration of research efforts in understanding agent behaviour in their political and business strategies, creating organizational and institutional alternatives that reflect the national and regional interests in energy generation activities, food production and environmental preservation. This way it hoped to produce concrete answers for Brazilian society.

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6

ENVIRONMENTAL ASPECTS ON THE SUGARCANE ETHANOL CHAIN IN THE SÃO PAULO STATE

Suani Teixeira Coelho, *Beatriz Acquaro Lora* and *Patrícia Maria Guardabassi*

INTRODUCTION

The need to reduce global carbon emissions and the use of fossil fuels has become prominent in the international scene. Particularly Brazilian ethanol used as fuel for vehicles is highlighted, as it displays an extremely favorable energy balance.

Ethanol production rose from 0.6 million cubic meters in 1975 – at the outset of the Proacool Program – to almost 18 million cubic meters in the 2006/2007 harvest season, due to increases in agricultural and industrial productivity (GOLDEMBERG *et al.*, 2008).

According to COELHO *et al.* (2005), subsidies granted to the Brazilian Proalcool Program in the past allowed industrial growth and the modernization of production technologies, rendering production economically competitive with comparatively low production costs. Brazilian ethanol became competitive in comparison to gasoline in both domestic and international markets.

Nowadays, Brazil is the world leader in the production of sugarcane and its major products, sugar and alcohol, and is enjoying a new growth phase as a result of the increase in domestic and foreign demand for fuel alcohol, both as anhydrous ethanol blend with gasoline, and as hydrated ethanol to be used in flex-fuel vehicles (LORA, 2008).

Such growth in the sugar-alcohol industry raises issues regarding the environmental sustainability of the Brazilian production of sugarcane and its products. Abusive environmental requirements eventually jeopardize penetration of the Brazilian alcohol in new markets, which should take industry leaders to take more stringent control actions against the environmental impact of their business.

Actually Brazil, as an efficient producer of food and energy from vegetal sources, manages to balance both products without causing environmental impact and biomes destruction, particularly in the Amazon and savanna areas. Therefore, the new sugar-alcohol international setting demands Brazil to continuously improve its environmental practices in traditional cultivation areas and make sure that new areas are environmentally suitable.

This document will discuss the current situation in the São Paulo state regarding the mitigation of environmental impacts in the sugar-alcohol industry, as this state has adequate legislation and inspection, even if considered by international standards.

ENVIRONMENTAL ASPECTS

The sugar-alcohol industry environmental impact only considers the features of sugarcane cultivation, industrial processing, and final usage. It includes effects in air quality and global climate, in the use of soil and biodiversity, in the conservation of soil, in water resources, and in the use of fertilizers and pesticides. Such impacts may be positive or negative; in some cases the sugarcane industry has very important outcomes, such as in reducing greenhouse gas emissions and the recovery of agricultural lands. Environmental regulations (including restrictions to land use) are quite advanced in Brazil, with an efficient application in the cultivation of sugarcane (MACEDO *et al.*, 2005).

TABLE 1 Impacts of sugarcane cultivation on the environment, according to Embrapa.

Impact on	Type	Classification
Air	Odors	Low
	Smoke	Low
	Dust	Average
	Allergens	Average
Soil	Preservation	Extremely high
	Blanketing	Extremely high
	Increased density	High
	Loss	Average
	Salts	Low
	Biological	None
	Agrotoxic	None
Water	Salts	None
	Biological	None
	Agrotoxic	None

TABLE 2 Impacts of sugarcane cultivation on the fauna, according to Embrapa.

Animals	Ranking of impact on		
	Food	Shelter	Reproduction
Mammals	Average	Low	Low
Birds	None	Low	Low
Reptiles	Average	Average	Average
Amphibious	None	None	None
Invertebrates	Low	Low	Low

The environmental impact of the sugarcane and the alcohol cycle has been considerably reduced over the past 30 years. Embrapa classifies impacts on the physical environment according to Table 1, and those on the fauna in accordance to Table 2[1].

From the standpoint of life cycle analysis – LCA, bioenergy significantly collaborates to sustained development, as it generally causes lesser environmental impact than fossil fuel energy. Furthermore, it provides assurance that local energy will be supplied in the long run, induces new technologies, creates new jobs and income (LUCON, 2008).

Next, the relevant environmental issues regarding the sugar-alcohol industry in the São Paulo state are discussed.

[1] Embrapa presents some indicators for inputs used by sugarcane in the São Paulio state: (i) fertilizers 408 kg K/ha/year, 275 kgN/ha/year, and 146 kg P_20_5/ha/year (ii) corrective, 3t/ha/year; (iii) herbicide, 2 l/ha/year. Source: MIRANDA, Evaristo Eduardo de. (Coord.). Embrapa (s.d.). **Agroecologia da cana-de-açúcar**, 2008. Available at: <http://www.cana.cnpm.embrapa.br/canin.html>.

TABLE 3 Average emissions from vehicles approved by Proconve[2].

Fuel used	CO (g/km)	HC (g/km)	NOx (g/km)	RCHO (g/km)	CO2 (g/km)	Evaporative (g/test)	Fuel intake (km/l)
Gasoline C (with 22% anhydrous ethanol)	0.33	0.08	0.08	0.002	192	0.46	11.3
Hydrated ethanol*	0.67	0.12	0.05	0.014	200	n.d.	6.9
Flex with gasoline C	0.48	0.10	0.05	0.003	185	0.62	11.7
Flex with alcohol	0.47	0.11	0.07	0.014	177	1.27	7.8

* Note: 100% ethanol vehicles sales were virtually replaced by the flex-fuel models.

Air

Impact on air quality[2]

Due to its high efficiency and low production cost, sugarcane ethanol is today one of the best choices to mitigate greenhouse gas emissions from burning fossil fuels. The energy balance (units of renewable energy extracted per unit of fossil energy added) is extremely favorable, reaching 8.9:1, avoiding emissions of 2.86 and 2.16 tons of CO_2 eq./m^3, for anhydrous and hydrated ethanol, respectively[3] (LUCON, 2008).

The consequence is a remarkable performance of this industry, preventing greenhouse gas emissions equivalent to 13% of the emissions from the whole energy industry in Brazil (baseline 1994). For each additional 100 Mtons of sugarcane in the next few years, emissions of 12.6 Mtons of CO_2 eq. can be avoided with ethanol, bagasse and additional surplus electricity (MACEDO *et al. 2005).*

Ethanol produced from corn or wheat in other countries fails to attain the high efficiency of sugarcane ethanol, reaching the 1.5:1 balance, which leads Brazilian ethanol to be considered as an important instrument for emission mitigation.

Major effects of the use of ethanol (pure or as an admixture to gasoline) in urban centers were: elimination of lead compounds in gasoline, reduction of carbon monoxide emissions, elimination of sulfur and particle materials, less toxic and photochemically reactive organic compound emissions (MACEDO *et al.*, 2005).

Ethanol-based vehicle technology has progressed considerably and flex-fuel automobiles present comparable or even lower emissions than those using gasoline with up to 25% anhydrous ethanol. Acetaldehyde emissions produced by the use of ethanol are less toxic than formaldehyde emissions from the use of gasoline (LUCON, 2008). Table 3 shows average vehicle emissions according to Proconve.

The use of ethanol in flex-fuel vehicles positively contributes to improve air quality in large cities, as it considerably reduces the level of hazardous emissions from fossil fuels. In rural areas, the problem of sugarcane fields being burned occurs, being often debated and forbidden by law in the São Paulo state, as described next.

Airborne emissions resulting from burning sugarcane

Sugarcane agriculture relates to impacts on air quality on two very distinctive points: the use of ethanol has led to considerable improvements to air quality in urban centers while slash-and-burn sugarcane trash in the field, on a quite different scale, causes problems with particle spreading and smoke hazards (MACEDO *et al.*, 2005).

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2 CETESB (2007). **Relatório de Qualidade do Ar 2006**, available at: <www.cetesb.sp.gov.br>. In: LUCON (2008).

3 SEABRA, J. E. A.; LEAL, M. R. L. V.; MACEDO, I. de C. **The energy balance and GHG avoided emissions in the production / use of ethanol from sugarcane in Brazil:** the situation today and the expected evolution in the next decade. Nipe, Unicamp, being published. In: LUCON (2008).

Air quality in rural areas is directly affected by sugarcane field slash-and-burn, used as a harvesting technique to make sugarcane cutting easier by eliminating trash and dry leaves.

Slash-and-burn releases large concentrations of particle material, carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (NO_x) and nitrous oxide (N_2O) to the atmosphere, which cause substantial damage to the environment and human health. It causes modifications to the chemical, physical and biologic composition of the soil, impairing nutrients cycling and causing their volatilization, consequently requiring the use of more pesticides and herbicides to control pests and weeds (LORA, 2008).

Furthermore, slash-and-burn removes the natural soil blanket, with favors surface flow of rainwater, fostering the erosion process and impoverishing the soil by the removal of organic matter.

São Paulo state, the largest sugarcane producer in Brazil, led the reduction in environmental impact of sugarcane production when it outlawed slash-and-burn in sugarcane fields in 2002.

Actions to gradually eliminate slash-and-burn in areas compatible with mechanized harvesting began with State Law n. 11241/2002, which rules on the progressive elimination of burning sugarcane trash, forecasting 100% elimination by the year 2031. Currently in effect is 40% of burning area elimination, controlled by Sistema Integrado de Gestão Ambiental – SIGAM (Environmental Management Integrated System), from Coordenadoria de Licenciamento Ambiental e de Proteção dos Recursos Naturais – CPRN (Environmental Licensing and Natural Resources Protection Coordinating Office), of Secretaria do Meio Ambiente do Estado de São Paulo – SMA/SP (São Paulo state Environment Department).

Another, more recent, initiative in this direction was the approval of the Green Protocol (SMA), a cooperation agreement signed by sugarcane producers in the São Paulo state, setting the deadline for the elimination of slash-and-burn earlier, by 2017[4]. Companies that complied with the new protocol received an environmental compliance certificate.

The figure presents the deadlines for eliminating sugarcane field slash-and-burn according to state laws and in compliance to the Green Protocol, as well as the evolution of mechanized harvesting areas in the São Paulo state.

In this context, Resolution SMA 33, issued in 2007[5], contributes for increased speed in eliminating slash-and-burn as new sugar-alcohol enterprises in the São Paulo state will only be licensed by the environmental agency after it has been determined that there will be no burning of sugarcane trash. To limit slash-and-burn in the state, this resolution sets a maximum of 2.21 million hectares, reducing in 4% the licenses to burn granted to the industry relative to 2006, and encompassing 130,000 hectares of sugarcane fields.

Slash-and-burn suppression increases the availability of biomass to the sugar-alcohol industry, already being used to generate electricity or to contribute to ethanol production by making viable the so-called second-generation technologies, such as enzymatic hydrolysis, an alcohol production process from the lignocellulosic fraction of sugarcane bagasse.

On the other hand, increasing harvesting mechanization poses new challenges to the São Paulo state sugar-alcohol industry. Sugarcane harvesting mechanization offers higher productivity, however, it requires some minimum terrain flatness. Current machinery cannot cover areas with slope beyond 12%, which leads to abandoning sugarcane culture in such areas or induces to burning sugarcane trash, either authorized or done illegally. It is expected that new harvesting mechanization technologies will serve steeper terrain; however there will still be uncovered areas that could be subject to new and differentiated environmental criteria (LUCON, 2008).

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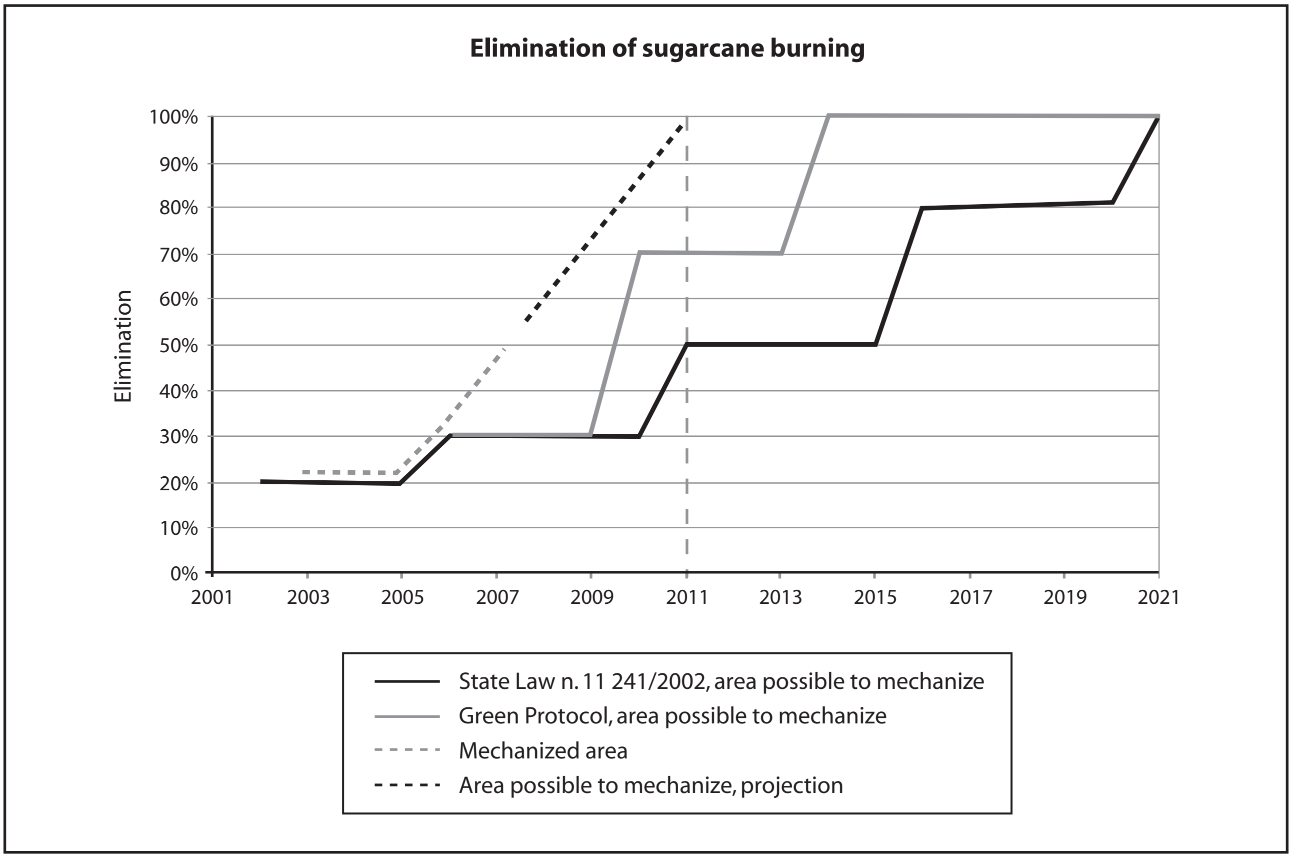
[4] The protocol technical guidelines also include the development of a technical plan for forest recovery, protection, maintenance and recovery of Legal Reservation areas, as well as APP areas; the development of a technical plan for preserving water resources and a technical plan for soil conservation (LUCON, 2008).

[5] SMA Resolution n. n. 33/2007 rules the application of n. n. Law n. 11241/2002, regulated by Decree n. 47700/2003 as to the gradual limits for burning sugarcane trash in the São Paulo state.



Source: Available at: <http://homologa.ambiente.sp.gov.br:80/etanolverde/resultado.asp>.

FIGURE 1 Evolution of mechanized harvesting for sugarcane.

Industrial emissions

Industrial emissions are also under monitoring and control, as boilers release particle material and NO_x. Nevertheless, it is normally accepted that the most significant polluting emission from bagasse boilers is particle material, as NO_2 emissions are very low, virtually considered negligible when boilers are properly set up.

Conama Resolution n. 382/2006 determines, countrywide, maximum air pollutant emissions from fixed sources, defined by pollutant and type of source. Its Appendix 3 defines the emission limits for air pollutants from heat generation processes, i.e., including the external combustion of sugarcane bagasse.

Hence, new sugarcane bagasse-burning boilers will be subject to control on nitrogen oxides, carbon monoxide and particle material, in addition to smoke composed of small dust particles, soot and other materials. Renewable environmental licensing demands improvements to old boilers, especially to optimize burning conditions and to reduce emissions with engineering controls (LUCON, 2008).

There is no specific law or decree for industrial emissions in the São Paulo state at this time, as the aforementioned Conama Resolution n. 382/2006 is in effect.

According to DA COSTA (2008), dispersion studies introduced in the sugar-alcohol mills environmental licensing process has shown pollutant concentration values very close to those defined by Conama Resolution n. 003/1990[6], often taking over 60% of the air quality standard in the air basin[7] where they are in. When mills show dispersion studies showing values above legal levels for NO_x

[6] Conama Resolution n. 003 of July 28th, 1990, which sets air quality standards.

[7] State Decree n. 52 469/07 – Airsheds.

and PM at some points, adjustments are required to chimney stack design or the implementation of control equipments.

Water

Water availability

According to NETO (2008), the impact caused by sugar-alcohol mills on water supply are both quantitative and qualitative by its nature, being capable of degrading water resources by intense usage, causing shortage and also due to the high polluting potential of agro industrial activities and soil use.

The average water consumption of a sugar-only mill is 30m³/ton, and of an autonomous distillery it is 15 m³/ton of sugarcane, and when the mill splits its production equally between sugar and alcohol, the average water intake is close to 21 m³/ton of sugarcane (NETO, 2008). However, this author points out that 21m³/ton of sugarcane does not reflect the water intake and consumption, since it fails to consider water recycling through the circuits, and rational water usage concepts that may interfere positively on the average volume of water used, meaning a much lower intake, depending on the water reuse stage in that facility.

Industrial use water intake and discharge levels have been significantly reduced in the past few years, from about 5 m³/ton of sugarcane used (in 1990 and in 1997), it went down to 1.83 m³/ton of sugarcane in 2004 (samplings in São Paulo[8]). Reuse level is high (total intake was 21 m³/ton of sugarcane, 1997) and the efficiency of the treatment for discharge is above 98%, proving that the efforts of the sugarcane industry towards reducing water intake and consumption were extremely successful.

Such efforts focus on the rational use with maximum reuse of effluents, reduced intake by incorporating new technologies such as dry cleaning of sugarcane, biodigestion of stillage and fertirrigation.

In this aspect, the goal set by CTC (NETO, 2008) for rational use of water is the intake of 1 m³/ton of sugarcane and zero effluents discharge, with full reuse of effluents in the plantation, reduced water supply costs, and lower expenses with the treatment of effluents.

Present impacts of sugarcane culture on water supply are minor under the conditions observed in the São Paulo state[9], due to the absence of irrigation and a substantial reduction in its industrial use, thanks to water recycling processes in industry and the water reuse practices in fertirrigation systems.

According to LUCON (2008), São Paulo state mills have considerably reduced their water consumption over time; however, they are still heavy users in the areas adjacent to the rivers Mogi, Pardo, São José dos Dourados, Aguapeí,and the middle Paranapanema[10]. Nevertheless, state legislation has already implemented charges for water intake from river basins, as well as for effluent discharge[11].

[8] A recent study, carried out by CTC in 2005 (2004 data) in Unica associated mills concentrated in the São Paulo state, with the objective of checking the effect of the policy of charging for water in rationalizing the use of this input in this industry, revealed a drop in water intake to 1.83 m³/ton of sugarcane, which means a reduction to half of the proportional water demand of the sugar-alcohol industry, in comparison to all other industries (13% in 1990 to 7% in 2007) (NETO, 2008).

[9] Embrapa ranks sugarcane at level 1 (no impact on water quality).

[10] SIGRH. Relatório de situação dos recursos hídricos do Estado de São Paulo – síntese. Sistema de Informações para o Gerenciamento de Recursos Hídricos do Estado de São Paulo, jun. 2000. Available at: <http://www.sigrh.sp.gov.br/sigrh/basecon/r0estadual/sintese/capitulo02.htm>.
In 1990, mills used 47 m³/s of water, or 13% of the total urban, industrial and irrigation demand. Current water availability is 893 m³/s (Q7,10), for a reference flow rate of 2,020 m³/s. According to the water balance of the São Paulo state, the total flow rate of 3,120 m³/s represents 29% of the pluviometric precipitation, theoretically being the highest potential that could be explored. For economic reasons, such potential in practice is reduced to 70% of this flow. At first sight, the rain volume of 1,376 mm/year is satisfactory to ensure agricultural production; however, its distribution throughout the year is not uniform. The basic flow rate that feeds watercourses during drought periods is 1,285 m³/s, about 41% of the total flow, being the other 59% relative to direct superficial flow of 1,835 m³/s. The underground water availability in the aquifer is directly related to the basic drainage basin on the area of occurrence (LUCON, 2008).

[11] State Law n. 12 183/05. Implements charges on the use of water resources within the domain of the São Paulo state, the procedures for setting its limits, conditions, values and other measures.

Charging for the use of water is grounded on the principles of "pollutant-payer" and "user-payer", based on the quantity and quality of water intake and returned to the environment. Costs that affect the industrial sector correspond to water intake, consumption and discharge.

According to the National Water Agency (Agência Nacional das Águas – ANA), charging for the use of water favors the adoption of sustainable and adequate practices for the various applications. By inducing the rational use of the resource, waste and contamination should be reduced, and it is expected that supply, sanity and purity indexes will rise. Charging is one way to manage federal and state water resources to generate funds that will allow investing in the preservation of the rivers themselves and their basins.

Water pollution

In the sugar-alcohol industry, effluents are the major potential cause of environmental impact to water resources, being stillage and washing water, with high organic content (COD/BOD), considered as the most relevant liquid residues.

Fertirrigation is used as a solution for stillage and residue water, with obvious advantages. The amount of stillage applied per unit of area was gradually reduced and new technologies were introduced to reduce the risks of contaminating water tables. Numerous studies consider the possibility of soil contamination and observe that there are no significant impacts in applications under 300m^3/hectare (LORA, 2008).

Recycling (stillage and filter residue) yields favorable results in optimizing the use of potassium, increasing the nutrients supply in the field, while efficient reuse of water within the plant and efficient effluents treatment contribute to reduce environmental impact.

Federal laws regarding the use of stillage and its soil application control appears in the 1980s, in the Minter Directive n. 323 (1978), which forbids the release of stillage on surface watersheds and in Conama Resolutions 0002 (1984) and 0001 (1986), which determined, respectively, the study and the development of standards to control effluents from distilleries, and the mandatory requirement of Environmental Impact Studies – EIA/Environmental Impact Report (Relatório de Impacto Ambiental – Rima) for new plants or expansions.

The regulation on use and application of stillage in the São Paulo state is modern; Technical Standard Cetesb/SP P4.231/2006 defines the criteria and procedures to apply stillage on agricultural soil, being the most specific measurement taken in the Brazilian sugar-alcohol industry.

Each liter of alcohol produced generates 10 to 13 liters of stillage. As the Brazilian production is around 16 billion liters of alcohol, it is estimated that the yearly production of stillage is close to 200 billion liters. Currently, all the stillage produced is being used to irrigate sugarcane plantations, being the largest example of water reuse in Brazil and in the world. Sugarcane irrigation using 100 m^3/ha of stillage results in savings on the use of potassium fertilizers worth some US$ 75 to 100 per hectare, in addition to providing plantation irrigation and improving its productivity (BERTONCINI, 2008).

Still according to BERTONCINI (2008), as demonstrated in agronomical research, the soils irrigation with stillage does not significantly alter their chemical, physical nor physicochemical characteristics. Changes that occur to the soil are temporary and result from the degradation of the residue organic load which, in spite of being high (BOD » 20.00 mg/l), is composed of weak acids and glycerols, easily degradable (30% of the carbon contained in stillage). Hence, stillage may be considered a nutritional solution, with predominating potassium ions (1 to 2 kg of K_2O per cubic meter).

However, there are still some doubts and deeper research should be carried out when it is about displacing contaminants in soils having stillage application history, and in situations such as: (i) stillage application at the end of the harvest, close to the rainy season (Southeast Region), on soils with low cationic exchange and no time available for the plants to absorb the nutrients; (ii) application of stillage in the dry season, when the absorption of nutrients by the plants is low and it remains in the soil solution. Intense precipitation at the very outset of the rainy season would foster the percolation of ions to layers beyond the reach of the roots system (buildup layer), and over time leaching would occur (BERTONCINI, 2008).

Another focus of attention and studies under way is the intense and frequent use of stillage in aquifer reload areas, which may cause long-range pollution of underground waters. Apta – Pólo Centro Sul in Piracicaba – is currently developing with Unica a study in this direction, under supervision by Cetesb, which will subsidize the maintenance or revision of Norm P4.231, which defines the criteria and procedures for applying stillage to agricultural soil.

Solutions for stillage include concentration and heat drying processes, which could make the use of stillage viable in locations farther away from mills, or even in other cultures, minimizing its applications in soils historically saturated with stillage. However, these processes involve a high energy cost, being economically viable only where the use of stillage is forbidden in actual application areas.

Heat drying stillage would require electricity equivalent to burning 30% of the bagasse generated at the mill, albeit it would include new options, like the joint drying of filter residue and the production of an organic fertilizer rich in P and K. Treatment of stillage in anaerobic reactors may generate electric power that could be used in heat drying (BERTONCINI, 2008).

Sugarcane washing waters are completely reused in most mills, within the sugar-alcohol industrial process for cooling boilers, for washing equipment or even for sugarcane irrigation. The current trend is to reduce the volume of water used for washing internodes from 6-7m^3/ton of stalks down to 1.0 m^3, as a result of harvesting raw cane (ditto).

When residue waters are not reutilized, their treatment includes decantation and stabilization lagoons, for later pouring into bodies of water.

NETO (2008) points out that since harvesting shifted to raw sugarcane, washing became unfeasible due to the more intense loss of saccharose that would take place in this operation; however, for this purpose dry cleaning technology was developed, thus eliminating the sugarcane washing operation.

Waste generation in the sugarcane industry

In addition to the liquid waste discussed previously, the sugar-alcohol industry also produces solid waste, like sugarcane bagasse (residue from process, used for cogeneration of electricity), trash and tips (available from mechanized harvesting), filter residue (residue from processing stalks to produce sugar), and ashes (resulting from burning bagasse in boilers).

Filter residue and ashes are applied directly on cultivable soil, promoting the recycle of almost 100% of the nutrients that enter the production system, reducing the use of chemical fertilizers.

Mechanized sugarcane harvesting generates 8 to 15 tons/ha of trash which, if laid on the ground improves the soil fertility, due to the return of nutrients by the mineralization process, controls erosive processes and furthers water retention, on top of fostering the soil microbiota (BERTONCINI, 2008).

This new setting requires adequate technologies to solve agronomic problems that provoke environmental effects, such as nitrogen immobilization caused by the high C/N ratio in trash, causing larger and stepped doses of fertilizer, retention of pesticides in the trash, which requires larger doses of herbicides to control weeds; and the discharge of 40-60 kg/ha of K_2O (OLIVEIRA *et al.*, 1999[12] apud BERTONCINI, 2008), from the quick rotting of trash, that should be deducted in calculations for the use of stillage.

Sugarcane offers low costs in alcohol and sugar production because all the energy used in the production process is produced from its own waste. Sugarcane bagasse, together with trash and tips, is the most representative biomass in the energy matrix, being responsible for the supply of heat, mechanical and electric energy in sugar and alcohol production plants, by means of co-generation (GUARDABASSI, 2006).

Co-generation supplies the needs of the sugar-alcohol industry, which in addition to requiring

[12] OLIVEIRA, M. W.; TRIVELIN, P. C.; PENATTI, C.; PICCOLO, M. **Decomposição e liberação de nutrientes da palhada da cana-de-açúcar em cana-de-açúcar**. Pesquisa Agropecuária Brasileira, v. 34, n. 12, p. 2359-2362, 1999.

electric and thermal power, offers waste fuel (bagasse) that is integrated positively in the process (LORA, 2008).

Contrary to what happened at the outset of Proalcool, when bagasse was deemed undesirable, being burned in low-efficiency low-pressure boilers, many mills use, nowadays, efficient equipment which, on top of supplying their own power intake, allows them to sell the surplus electricity to distributors (GOLDEMBERG *et al*. 2008)[13].

Ashes resulting from the incineration of the bagasse contain in average 85% SiO_2, 0.9% P_2O_5; 1.7% K_2O, and 0.6% MgO, so they can be used directly on the soil or used to increment the chemical formula of organic compounds. Another residue generated in mills is soot from chimney stacks that is normally washed with water reused from washing sugarcane. The content of soot is qualitatively similar to ashes, though quantitatively more diluted, as it contains from 30% to 70% water (BERTONCINI, 2008).

Yet according to BERTONCINI (2008), filter residue is generated in rotating filters for extracting leftover saccharose in the production of sugar, and its composition reflects the addition of calcium and phosphor in the bleaching process. It has around 70% water and average contents of; 1.4; 1.0; 0.7; 5.0; 0.5; 1.4; and 19% (dry base) of organic matter, N, P_2O_5, K_2O, CaO, MgO, S and ashes.

Composting solid residues like filter residue and ashes promotes improvements to physical and chemical characteristics of residues, such as: (i) reduction of water content, making distribution in the field easier; (ii) better nutrients balance; (iii) improved moisturization of the organic material, promoting increase in the soil load sites, and consequently the slow release of nutrients and retention of pollutants, in such a way that the use of waste as-is on soils should be always unadvisable. Composting is currently a reality in some sugarcane mills, which are benchmarks for other industries that should promote it, like basic sanitation and animal breeding (BERTONCINI, 2008).

Use of the soil and biodiversity

Sugarcane expansion

Nowadays Brazilian agriculture uses only 7% of the national territory (half with soybean and corn), pastures occupying about 35%, and forests 55%. Agricultural expansion in the last forty years took place mostly on degraded pastures and “dirty fields”, but not on forest areas (MACEDO *et al*. 2005).

The area occupied by sugarcane today is only 0.6% of the territory, and the areas suitable for this culture are at least 12%. Sugarcane growth in areas occupied by savannas was very small; it has replaced other plantations that had already replaced the savanna (usually pastures). In São Paulo, growth occurred with the replacement of other cultures and pastures (ditto).

In 2005 sugarcane covered about 3 million hectares in the São Paulo state; in 2006 these surpassed 4 million and, for 2010, coverage is estimated as close to 6 million hectares (LUCON, 2008).

In order to characterize this expansion scenario, the National Biomass Reference Center (Centro Nacional de Referência em Biomassa – Cenbio), in 2006, carried out a study on the expansion of the sugarcane culture, as well as its influence on the expansion of other cultures, pastures and native forest areas in the 11 largest sugarcane producing Administrative Regions in the São Paulo state.[14]

Between the years 2003 and 2006, the growth of sugarcane culture in the São Paulo state hit 26%. An expressive increase was noticed in the Presidente Prudente, São José do Rio Preto, Barretos and Marília areas, which were not traditional places for sugarcane, but each of them increased more than 40% from 2003 through 2006. In the North of

[13] According to Unica (2009), bioelectricity is the most important new product in the sugar-energy industry, capable of causing a revolution in the technology development process, adding income, improving the competitiveness and sustainability of both sugar and ethanol, and, consequently, promoting market growth. Together, ethanol and sugarcane represent 16% of the Brazilian energy matrix. Sugarcane is, therefore, the second most important source of energy in the country, while petroleum and its derivates occupy the first place.

[14] Administrative regions considered in the study were Araçatuba, Barretos, Bauru, Campinas, Central, Franca, Marília, Presidente Prudente, Ribeirão Preto, São José do Rio Preto and Sorocaba.

the state, in Ribeirão Preto and Campinas, strongly saturated with sugarcane, expansion rates were the lowest, like 10.97% and 9.42% respectively (LORA *et al.*, 2006).

Some reduction in the corn cultivated area was noticed while pastures area remained stable. An increase in heads of cattle per hectare was noticed, i.e. more intense cattle raising[15], with confined animals, and less requirements for grazing.

According to information from SMA, (CARRASCOSA, 2008), in spite of the extremely fast growth of sugarcane culture in the past few years, no replacement of native vegetation with sugarcane cultures occurred, except in very small sites, even considering illegal deforestation.

In this context, problems related to sugarcane expansion are concentrated in the priority areas for preserving biodiversity, i.e., areas without vegetation, however recommended to re-establish landscape connectivity and reconstruction of ecological corridors.

Maintenance of the natural vegetation in the Permanent Preservation Areas is extremely important for the control of erosion and sanding up processes in rivers, to ensure the quality of the watershed, and resources to protect local fauna. However, few properties keep Permanent Preservation Areas in the country. States like São Paulo (art. 197 of the State Constitution) and Minas Gerais have established progressive recovery policies for these areas by environmental licensing.

The riparian forests areas in the sugarcane growing regions within the São Paulo state cover 8.1% of the total area assigned to sugarcane cultivation, and in 3.4% of these there is native riparian vegetation, while only in 0.8% reforesting was carried out. The implementation of riparian forest recovery programs, in addition to protecting springs and watercourses, may promote vegetal biodiversity replacement in the long run (MACEDO *et al.*, 2005).

Like it happens to Permanent Preservation Areas, Legal Forest Reservation areas (federal Law n. 7803/1989) are not maintained in farms. According to SMA mapping, a significant part of the areas noted as priority were already taken by sugarcane before 2003; however, the occupation of these priority areas being lower in later harvests.

Sugarcane producing areas display reduced levels of native vegetation and fragmented remainders, low permeability to biologic flows and extremely reduced organism diversity. (CARRASCOSA, 2008).

Nevertheless, Embrapa studies developed in sugarcane organic plantations pointed to the increase of biodiversity in such types of cultivation, in contrast with traditional methods. According to the study, between the years 2002 and 2008, biodiversity in organic plantations was four times larger than in traditional ones. From 2004 to 2008, 325 species were identified, being 26 amphibious, 239 bird, 43 mammal and 17 reptile species[16].

In September 2008, SMA issued the Agro-Environmental Zoning for the sugar-alcohol industry in the São Paulo state (Zoneamento Agroambiental para o Setor Sucroalcooleiro do estado de São Paulo). This study is based on the edaphoclimatic suitability for growing sugarcane, areas where mechanical harvesting is restricted (due to slope), availability of superficial waters and vulnerability of underground waters, conservation and preservation units, priority areas for biodiversity increase, and air quality in airsheds.

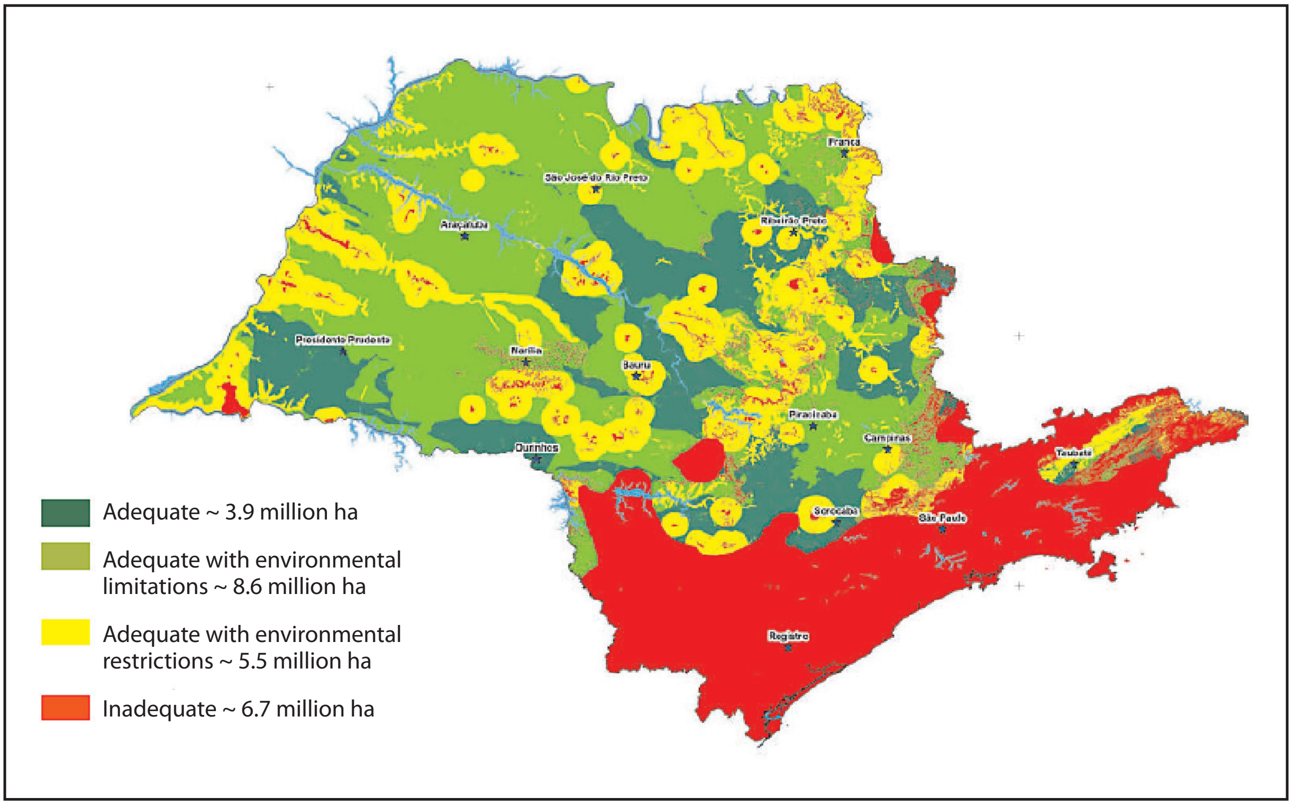
Results show that there are about 3,900,855 hectares in the São Paulo state defined as suitable for growing sugarcane without environmental restrictions. Other 8,614,161 hectares have environmental restrictions, an area of 5,546,510 hectares has environmental restrictions for growing sugarcane and 6,741,748 hectares are deemed unsuitable for growing sugarcane (LORA, 2008), as shown in Figure.

Loss of soil quality and the use of agrochemicals

Traditionally, sugarcane cultivation in Brazil shows soil loss due to relatively mild erosion, if compared to soybean and corn.

[15] This tendency can be verified by calculating the index of the number of cattle by hectare in each county.

[16] News published in the newspaper: YONEDA, F. Lavoura abriga fauna silvestre. **O Estado de São Paulo**: caderno Agrícola, São Paulo, p. 7, 28 jan. 2009.



Source: SMA, 2008.

FIGURE 2 Agro-environmental Zoning for the sugar-alcohol industry in the São Paulo state.

According to BERTONI *et al*. (1998[17] apud MACEDO *et al*. 2005), it may be considered that in Brazil sugarcane cultivation, in comparison with the production of grains in the same area, prevents the erosion of about 74.8 million tons of soil per year (grains: average loss of 24.5 tons/ha/year). Soil loss with soy is about 62% higher than when sugarcane is used, and with castor it's around 235% lower.

Elimination of slash-and-burn in sugarcane plantations and the introduction of mechanized harvesting in the country contribute to part of the trash being left on the soil.

According to ANDRADE and DINIZ (2007), the layer of trash protects the soil from erosion[18] and contributes to improve the organic matter content in the soil, with positive impact on the nutrients balance and for the pedologic microbiology. The presence of trash on the field also reduces the incidence of light on the ground, inhibiting the photosynthesis process, and the consequent germination of some kinds of weed[19].

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17 BERTONI, J.; PASTANA, F. I.; LOMBARDI NETO, F.; BENATTI JR., R. Conclusões gerais das pesquisas sobre conservação de solo no Instituto Agronômico. Campinas, Instituto Agronômico, 2. impressão, janeiro de 1982, Circular 20, 57 p. In: LOMBARDI NETO, F.; BELLINAZI JR., R.: Simpósio sobre Terraceamento Agrícola, Campinas, SP, Fundação Cargill, 1998.

18 Research by Copersucar (2001 apud RIPOLI, 2004) showed that the only effective way to avoid hydric erosion of cultivable areas is to prevent their onset, using techniques that avoid direct contact of the raindrops with the soil surface. Maintenance of the soil coverage is recommended.

19 MANECHINI (2000 apud RIPOLI, 2004) in studies of the effects of sugarcane trash on weed control concluded that over 66% of the sugarcane residues left on the field control weeds yearly with higher than 90% efficiency, being competitive with the most successful herbicide used to treat sugarcane production.

In this sense, the sugarcane culture leftovers on the soil provide better weed control, in addition to helping to preserve moisture and protecting the terrain against erosion, thus even increasing the organic matter content of the soil by cultivation over several years; the dead blanket helps reduce the population of organisms that are hazardous to the culture, by increasing the quantity of predators (TILLMANN 1994[20] apud RIPOLI, 2004).

Cultivation of sugarcane in areas where the soil was impoverished by other cultures contributes to their recovery, adding organic matter and chemical-organic fertilization.

Sugarcane cultivation requires lower pesticide use than citrus, corn, coffee and soy. The use of insecticides is low and the use of fungicides is deemed practically null (MACEDO *et al*., 2005). Among the larger cultures in Brazil (area over 1 Mha), sugarcane uses less fertilizer than cotton, coffee and orange, its intake being equivalent to soy.

According to MACEDO *et al*. (2005), among sugarcane's major pests, borer and sharpshooter controls are biologic; borers have the largest biologic control in the country. Ants, beetles and termites are chemically controlled, and it has been possible to significantly reduce the quantity of pesticides by means of selective use.

FINAL CONSIDERATIONS

Over the Proalcool development period, both national and São Paulo state environmental legislation has significantly evolved, contributing to the sustainability of alcohol and sugarcane production.

Some improvements are obviously possible, and they are being implemented, such as the Economic-Ecologic Zoning and stricter inspection.

Nevertheless, now it is proper to state that production in the São Paulo state is consistent with international requirements.

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7

EMPLOYMENT AND INCOME IN THE SUGARCANE AGRIBUSINESS IN THE BRAZILIAN STATE OF SÃO PAULO

Rodolfo Hoffmann and *Fabíola Cristina Ribeiro de Oliveira*

INTRODUCTION

This paper examines employment and income in sugarcane cultivation, and sugar and alcohol production from sugarcane, taken together as one industry or sector, i.e., the "sugarcane agribusiness", in the state of São Paulo, Brazil. The analysis uses statistical data on people employed in the sugarcane culture, the sugar and ethanol industry in Brazil. This chapter does not cover all employment generated by the expansion of the sector. One important aspect is, for instance, the production of agricultural machinery (in particular sugarcane harvesting machines), and equipment for sugar mills and the ethanol industry. While analyzing sugarcane agribusiness, as defined above, one should recall the multiplier effects associated to the changes taking place, both downstream and upstream considered in this industry.

NUMBER OF PEOPLE EMPLOYED AND THEIR INCOME

Data about quantity, earnings and other characteristics of the people occupied in sugarcane cultivation and the sugar and alcohol industrie, can be obtained from the National Household Sample Survey – PNAD, from the Annual Record of Social Information – RAIS prepared by the Brazilian Ministry of Labor and Employment and also from the Demographic Census. The information in PNAD and the Census is obtained from a questionnaire send out and the reply sent back by persons in the household sample; the Annual RAIS Record of the Labor Ministry is a census of the formal employment market reported by the employers.

Using 2005 RAIS data, MORAES (2007a) observes that the number of employees were 415,000 in the sugarcane production, 440,000 in sugar mills and 128,000 in the alcohol industry, or a total of 983,000 in the sugarcane agribusiness of Brazil, as shown in Table 1.

Table 2 shows the number of people employed in the sector according to 2005 PNAD data. There are some discrepancies between data from PNAD and RAIS; and more research is needed to establish which of these sources better reflects the real situation. The mills often produce both sugar and alcohol, and thus the distinction between employment in these mills is somewhat arbitrary. However, even if we take the aggregate of the two industries, the difference between these two sources remains substantial.

According to RAIS (Table 1), 42% of the employees in the sector as a whole in Brazil are occupied in sugarcane production, while according to PNAD (Table 2) this proportion is as high as 72%. It could be that the reason for this difference is a much higher proportion of laborers in cultivation in the Northeastern region who are not formally registered and thus are not included in the RAIS data provided by the employers. There are also considerable differences between the two sources on average earnings, although the data always indicate average earnings lower in cultivation than in the industry.

According to the 2007 PNAD, the number of employees in the sugarcane agribusiness in

TABLE 1 Number of employees and average monthly earnings in the sugar-alcohol sector in Brazil and the State of São Paulo, in 2005, cf. RAIS.

Geographic unit	Sector	N. of employees	Average earnings*
Brazil	Sugarcane agribusiness	982,604	675
Brazil	Surgarcane cultivation	414,668	647
Brazil	Sugar industry	439,573	691
Brazil	Ethanol industry	128,363	706
São Paulo	Sugarcane agribusiness	385,533	860
São Paulo	Sugarcane culture	220,517	754
São Paulo	Sugar industry	131,867	1,032
São Paulo	Ethanol industry	33,149	887

* Values in R$ of 2005.

Source: MORAES (2007a, p. 895).

TABLE 2 Number of employees and average earnings in all categories of workers in the sugarcane agribusiness, Brazil and in the State of São Paulo, in 2005, cf. PNAD.

Geographic unit	Sector	N. of occupied	Average earnings*
Brazil	Sugarcane agribusiness	719,926	537
Brazil	Sugarcane culture	519,561	429
Brazil	Sugar industry	120,370	723
Brazil	Ethanol industry	79,995	961
São Paulo	Sugarcane agribusiness	251,674	782
São Paulo	Sugarcane culture	153,926	643
São Paulo	Sugar industry	52,781	837
São Paulo	Ethanol industry	44,967	1,196

* R$ of September 2005.

Source: MICRODADOS from PNAD 2005.

the State of São Paulo reached 355,042, of which 194,923 correspond to sugarcane production, 82,347 in the sugar industry, and 77,772 in the ethanol industry. PNAD also registers occupied people who are not employees (employers and self-employed). The total number of people occupied in the sector in the State of São Paulo reached 360,532 in 2007, an increase of 22% over 2006 and 41% over 2005.

Even with such an expansion, occupation and employment in the sugarcane culture has suffered, and will continue to suffer, a strong impact from increased mechanization of the production process. Technological progress in the sugarcane production has been influenced essentially by two factors: i) restructuring of the agricultural production model, aiming at reducing costs and increasing productivity e.g. mechanized harvest can reduce costs by 30% in comparison to the manual harvest (cf. OLIVEIRA, 2002); ii) institutional changes, such as a drastic reduction of governmental intervention in the sugar-alcohol sector, together with the gradual reduction of burning cane during harvest, as noted by MORAES (2007c).

TABLE 3 Area mechanical harvested as % of total area in sugarcane cultivation. Brazil, Center-South, Northeast and São Paulo, 1997-2002.

Year	Brazil	Center-South	Northeast	São Paulo
1997	13.5	15.4	3.2	17.8
1998	23.8	24.9	5.7	26.4
1999	23.0	25.3	5.9	22.3
2000	24.7	28.0	7.6	30.5
2001	29.0	31.0	8.0	33.0
2002	31.8	32.5	9.0	35.0

Source: Idea News (2002). Adapted from OLIVEIRA (2002, p.78).

Legislation[1], which aims at reducing environmental consequences and damage to public health, established that sugarcane burning in areas that can be mechanized has to be phased out by 2021, and in areas that can not be mechanized[2] until no later than 2031. Moreover, according to the Agro-environmental Protocol signed with the state government in July 2007, sugarcane growers and the sugar and alcohol industry of the State of São Paulo have agreed to bring forward the deadline for the elimination of sugarcane burning from 2021 to 2014, in land with slopes up to 12%. They are also committed to improve the proportion of sugarcane not burnt from 30% to 70% of the total in 2010 in the State of São Paulo. In land with slopes above 12%, the date will be brought forward from 2031 to 2017, improving from 10% to 30% the proportion of sugarcane not burnt, in 2010[3]. As noted in BACCARIN *et al*. (2008), more than a governmental option, the signature of the Protocol seems to reflect the entrepreneurial decision to accelerate harvest mechanization. One reason is to obtain easier access to foreign markets for ethanol, in countries with strict environmental laws, but changes in the labor market conditions, with the expansion of formal employment, are also inducing mechanization.

According to information obtained from OLIVEIRA (2002), mechanization is expanding rapidly, so much that between 1997 and 2002 the mechanically harvested area almost doubled in the State of São Paulo, going from 17.8% in 1997 to 35% in 2002 (see Table 3).

Another way of estimating the number of people employed in the sugarcane culture is to use production data (or area harvested) together with technical coefficients. FREDO (2008) calculates that in the 2007/08 harvest, 40.7% of the area harvested in the State of São Paulo was by mechanical means; assuming 132 actual working days during harvest and an average of 8.76 tons of cane harvested manually per worker-day, "it was estimated that around 163,098 people were occupied in the sugarcane harvest".

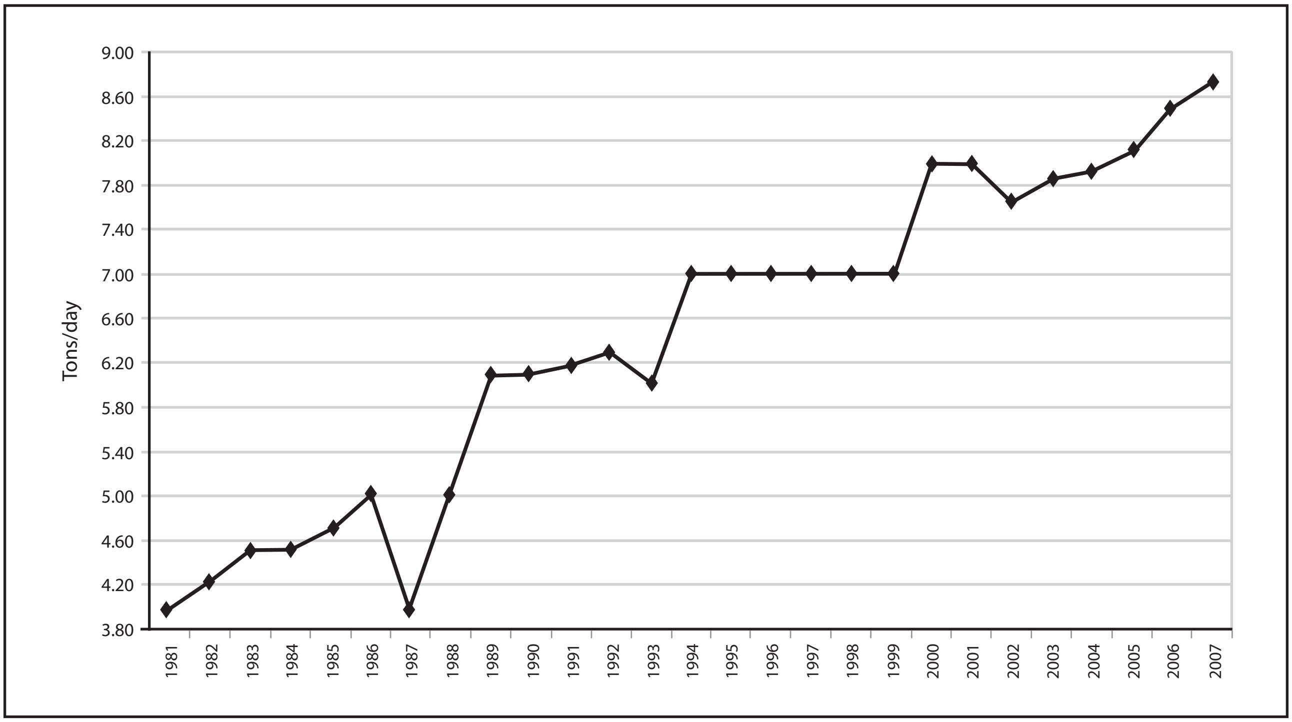
HOFFMANN and OLIVEIRA (2008a) use PNAD data to analyze the evolution of real wages of employees in the sugarcane culture in Brazil, and in the State of São Paulo, for the period 1992 – 2006. From 2001 on, it is obvious that there is a strongly correlation of the wages received by these workers with the value of the legal minimum wage.

When comparing different crops, it is worthwhile to look at the results of the "Employment quality index" defined and calculated by BALSADI (2007a and 2008). This index (IQE, for "Índice de Qualidade do Emprego") shows a substantial

1 Law of the State of São Paulo n. 11241 of 2002.

2 Areas with slope above 12% and rocky terrain. VEIGA FILHO *et al*. (1994) consider that this physical constraint represents almost half (44% to 55%) the area under sugarcane cultivation in the State of São Paulo.

3 See Protocolo Agro-ambiental SAA/SMA/Setor Sucroalcooleiro (Agro-environmental Protocol SAA/SMA/Sugar-Alcohol sector) at: <www.iea.sp.gov.br>.



Source: IEA/CATI, Secretary of State for Agriculture, State of São Paulo.

FIGURE 1 Evolution of average labor productivity[4] in the manual sugarcane harvest in São Paulo 1980-2007.

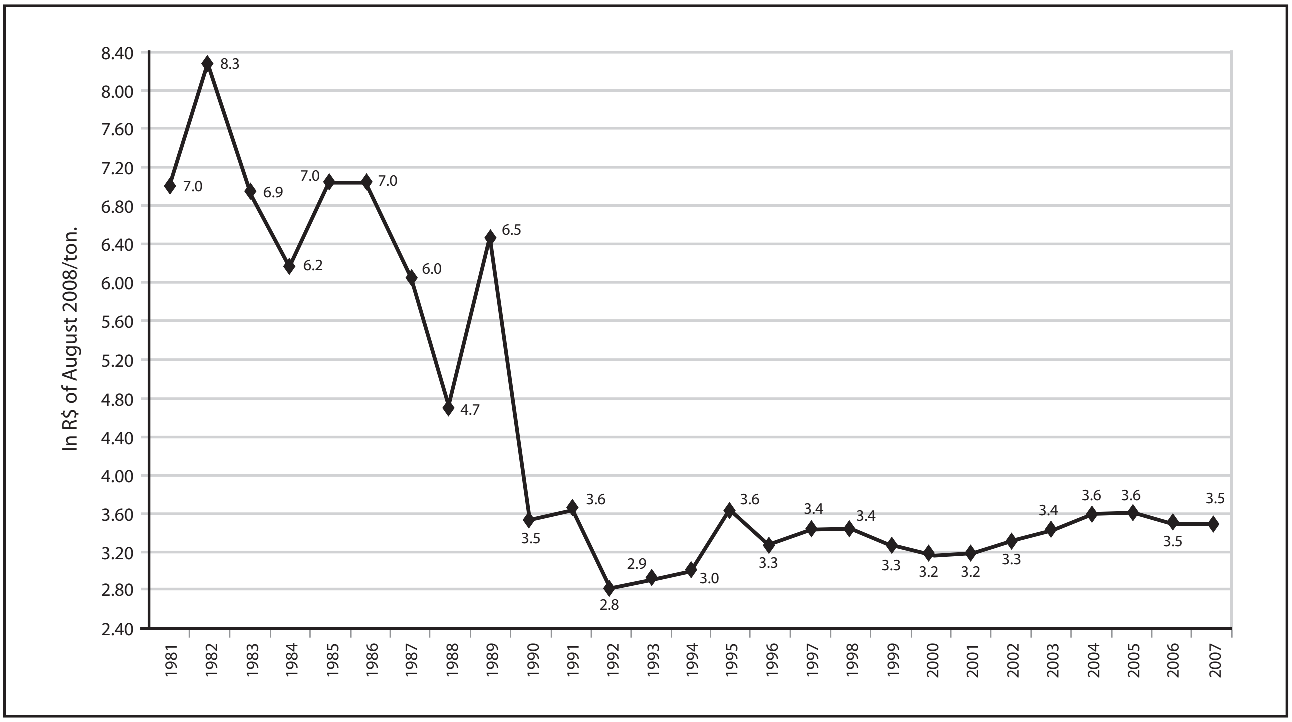
improvement in the quality of employment in the sugarcane culture. IQE for permanent urban workers goes from 51.5 in 1992 to 64.8 in 2004. For temporary urban worker the index goes from 38.2 to 51.6 in the same period. Crops analyzed by BALSADI (2008) includes rice, coffee, corn, manioc (cassava), sugarcane and soya – the last one presents the best indicators of employment quality, followed by sugarcane.

There isl another source of income data for people employed in sugarcane cultivation in the State of São Paulo, done by IEA/CATI, the Institute of Agricultural Economy to the Secretary of State for Agriculture of the State of São Paulo. Data are obtained from questionnaires that the technical staff running the Agriculture Houses supply regularly. Every year in June, data are thus collected on the physical yields and payment per ton of sugarcane harvested. Changes that took place in the sugarcane culture went beyond the advance of mechanization, with the increase in average yields, including also increase in productivity of the sugarcane manual cutter. According to the IEA data, daily productivity of work in the sugarcane harvest, measured in tons cut per working day, shows a growing trend in the last decades. Average productivity per working day was 4 tons/day in 1980, and more than doubled, reaching almost 9 tons in 2007 (see Figure 1)[5].

Up to 1992 there was a declining trend in the average amount paid per ton cane cut in the state of São Paulo. During the 1980s, values paid for harvested ton of sugarcane fluctuated considerably. From 1995 onwards, this value oscillates around R$ 3.30 (see Figure 2). It should be noted that increased productivity in the sugarcane sector is not reflected in an improvement of the wages of laborer, unless the laborer ncreases his/her productivity e.g. by cutting more cane.

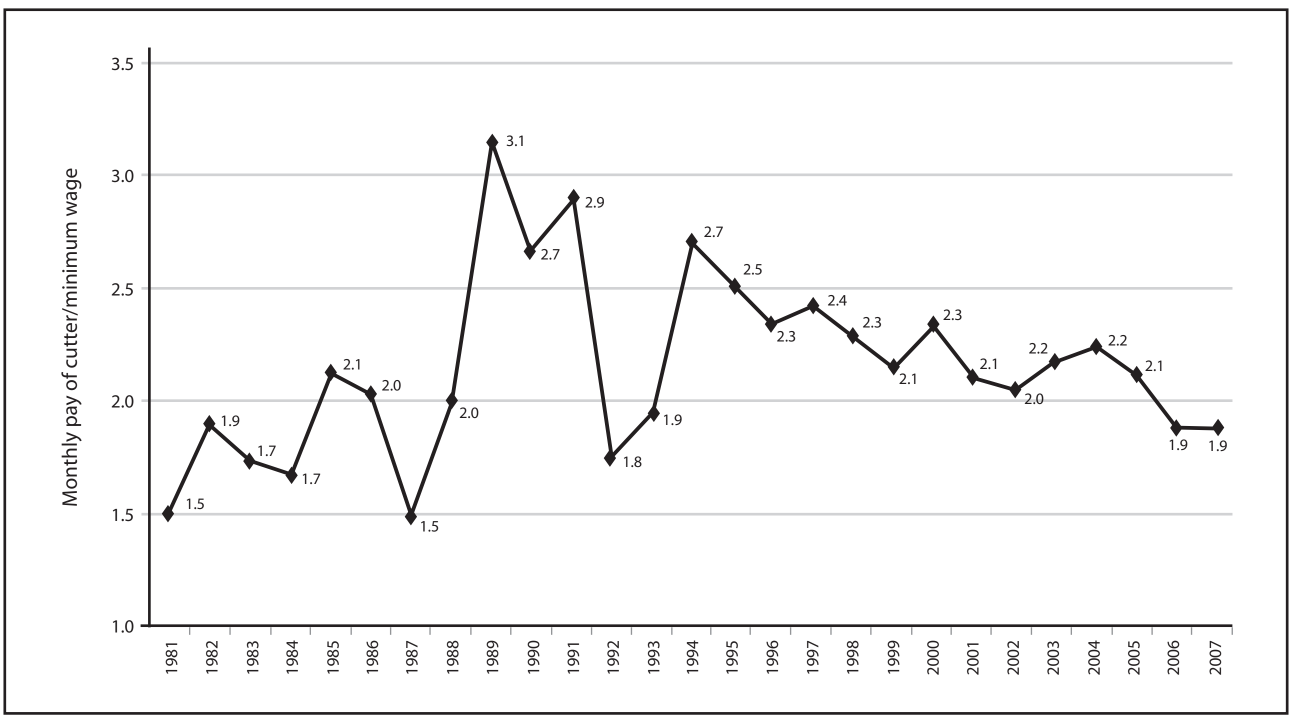
[4] That labor productivity, measured in tons/day, appears as relatively high in 2000 and 2001 is likely due to rounding of the values published by IEA. From 1994 to 2001 values are whole numbers, while from 2002 onwards the site of IEA (www.iea.sp.gov.br) publishes figures with decimals.

[5] No study evaluating the relative importance of the various determinants of such a strong productivity increase is known yet.



Source: IEA/CATI, Secretary of State for Agriculture of the State of São Paulo.

FIGURE 2 Evolution of average pay for harvested ton of sugarcane in São Paulo 1980-2007.



Source: IEA/CATI, Secretary of State for Agriculture of the State of São Paulo.

FIGURE 3 Evolution of the monthly earnings of sugarcane cutters measured in multiples of the current legal minimum wage in São Paulo 1980-2007.

Assuming 25 working days per month, the real monthly earnings of sugarcane cutters did rise 47% between 1994 and 2007, but such increase did not accompany the rise in the legal minimum wage. The ratio was more than 2 minimum wages between 1994 and 2005 and diminishes to 1.9 in 2006 and 2007 (see Figure 3). It should be noted, however, that the value of the minimum wage in June 2007, in real terms, is around twice what it was in June 1994.

OLIVEIRA (2009) analyzes the earnings obtained from harvesting coffee in the red cherry, coffee in the dried pod, oranges, lemons, tangerines and cotton, in the State of São Paulo, from 1995 to 2007, and then notes the rising trend in daily earnings from 2001, which is consistent with the rising trend in monthly earnings of the employees according to PNAD data. However, when comparing payment for contract work in harvesting various crops, she draws attention to the fact that remuneration in the sugarcane harvest is not the highest, but that of in coffee in the red cherry. It seems that the stronger physical effort needed for the cutting of cane does not bring higher remuneration. Apparently other characteristics are more relevant, such as longer duration of the harvest (less urgency in completing the task) and the low value of the product per unit of weight and volume.

There is not much economic research data on the determinants of wages of people employed in the sugarcane agribusiness, namely, studies where multiple regression is used to show how wages depend on the characteristics of the person employed (gender, age, schooling, skin color, personal connections, rural or urban residence) and characteristics of the employment (region, weekly hours worked, main activity of the establishment). HOFFMANN and OLIVEIRA (2008b), using PNAD 2006 data, have shown that after accounting for the effect of the remaining explanatory variables, the person employed in the sugarcane culture earns 23.2% less than the one employed in the ethanol industry. No significant difference exists between the ethanol industry and the sugar industry (Equation 1). An equation adjusted only to employees in the sugarcane culture reveals that temporary workers tend to earn 10% less than permanent workers (Equation 2).

Adjusting an equation for all agricultural workers in Brazil, with data from PNAD 2007, we observe a relatively favorable position of wages earned in sugarcane culture. Taken account of the effect of the other variables of the model, the differential associated with employees' earnings in other crops examined in comparison to average earnings in sugarcane production are the following: –9.9% in coffee, –23.2% in manioc (cassava), –30.1,% in corn, –0,2% in soya, –30,1% in rice and –12,5% in the remaining agricultural activities (Table 5). It is true that average wages in the soya culture are considerably higher than in sugarcane, but this is due to the difference in the level of average schooling, of 5.4 years in soya and only 4.2 years in sugarcane. While in the sugarcane culture 5.7% of the employees are tractor drivers, in the soya culture that proportion reaches 40.5%.

Table 6 shows earnings equations estimated with aggregate data of the national sample survey PNAD from 1995 to 2007 (all earnings in Real (R$) of August 2008), applying as deflator the National Consumer Price Index INPC. From equations 4 and 5 it becomes clear that returns attributed to schooling increase considerably after 9 years have been completed. Over 9 years, each year of schooling determines a 2% increase in the earnings of the employee

Equation 4 shows that the coefficients of the binary variables that signal the crops other than sugarcane are all negative, showing that, after controlling for the effect of all other explanatory variables included in the regression, the employee in the sugarcane culture obtains a higher remuneration, particularly if compared to employees in the cultures of manioc, corn and rice.

As the data used correspond to 12 different years, the equations do capture the impact of the real minimum wage (RMW) on the earnings of the employees. It should be noted that the real minimum wage is measured in hundred Reais (RMW/100), to avoid that corresponding coefficient become too small that it is difficult to identify. According to equation 4 in Table 6, an increase of R$ 100 in the real minimum wage is associated with a 14.45% increase in the wages of permanent employees, formally registered and having some degree of specialization. The terms of interactions that include the RMW, indicate that changes in

TABLE 4 Earnings equations for people employed in the sugarcane-based industry and in the sugarcane cultivation in Brazil 2006.

Variable	Equation 1 Sugarcane-based Industry		Equation 2 Sugarcane culture	
	Coefficient	% differ.	Coefficient	% differ.
Constant	3.0621	–	2.7828	–
Female	–0.2434	–21.61	–0.2440	–21.65
Age				
Age/10	0.3166	–	0.2995	–
(Age/10)[2]	–0.0324	–	–0.0359	–
Schooling				
Schooling <=10 years	0.0245	2.48	0.0184	1.86
Schooling > 10 years	0.1851	23.32[1]	0.0980	12.35[1]
Log (hours worked in week)	0.5892		0.6313	
Color (Base: white)				
Black or mixed	–0.0161	–1.60[2]	0.0401	4.09[2]
Yellow (Asiatic)	–0.0977	–9.30[2]	–0.0428	–4.19[2]
Person of ref. in family	0.1017	10.70	0.0146	1.47[2]
Rural Residence	–0.0538	–5.24[2]	–	–
Region (Base: NE)				
North [3]	–0.1474	–13.70[2]	0.0859	8.97[2]
Southeast (excl. SP)	0.1205	12.80	0.1354	14.50
S. Paulo	0.4640	59.05	0.5310	70.07
South	0.2189	24.47	0.2532	28.82
Center-West	0.2915	33.84	0.4082	50.41
Activity (Base: ethanol ind.)				
Sugarcane culture	–0.2644	–23.23	–	–
Sugar industry	–0.0265	–2.61[2]	–	–
Temporary employees	–	–	–0.1054	–10.00
R^2	58.66		42.41	
F test [4]	112.20		46.30	
Number of observations	1,362		959	

(1) This is the percentage growth in earnings associated with one additional year of schooling, over and beyond 9 years, as calculated, for instance, 100[exp (0.0245+0.1851)–1]% = 23.32%.

(2) The coefficients are not statistically different from zero at a significance level of 5%.

(3) Excluding the rural area of Rondonia, Acre, Amazonas, Roraima, Pará and Amapá.

(4) The values of *F* are statistically significant at 1%.

Note: The dependent variable is the logarithm of the earnings from all work.

Source: MICRODATA from PNAD 2006.

TABLE 5 Earnings equation for agricultural workers in Brazil 2007.

Variable	**Equation 3 – Agriculture**	
	Coefficient	**% diff.**
Constant	2.8703	–
Female employee	–0.1141	–10.78
Age		
Age/ 10	0.2143	–
(Age/ 10)[2]	–0.0242	–
Schooling		
Schooling <=9 years	0.0187	1.89
Schooling > 9 years	0.0704	9.31[1]
Log (hours worked in week)	0.7245	–
Color (Base: white)		
Black or mixed	–0.0250	–2.47[2]
Yellow (Asiatic)	0.1400	15.03[2]
Person of reference in family	0.0850	8.87
Rural residence	–0.0044	–0.44[2]
Region (Base: Northeast)		
North [3]	0.1876	20.63
Southeast (excl. SP)	0.3350	39.80
S. Paulo	0.4314	53.94
South	0.4011	49.34
Center-West	0.4068	50.19
Agricultural crop (Base: sugarcane)		
Coffee	–0.1047	–9.94
Manioc (cassava)	–0.2639	–23.20
Corn	–0.3688	–30.84
Soya	0.0023	0.23 [2]
Rice	–0.3577	–30.07
Other agriculture [4]	–0.1332	–12.47
Employee with no formal register	–0.3795	–31.58
Temporary employee	–0.0923	–8.82
Employee without specialization	–0.1504	–13.97
R^2	57.54	
F test [5]	266.53	
Number of observations	4,745	

(1) This is the percentage growth associated with 1 additional year of schooling after having reached at least 9 years, calculated thus: 100[exp (0.0187+0.0704)–1]% = 9.31%.

(2) The coefficients are statistically not different from zero at significance level of 5%.

(3) Excluding the rural area of the states of Rondonia, Acre, Amazonas, Roraima, Pará and Amapá.

(4) Other crops, except sugarcane.

(5) The values of *F* are statistically significant at 1%.

Note: The dependent variable is the logarithm of the earnings from the main occupation.

Source: OLIVEIRA (2009, p. 150), based on MICRODATA from PNAD 2007.

agricultural wages attributed to changes in the legal minimum wage, have a stronger impact on the formally registered employee than on the informal laborer, and on the permanent employee than on the temporary one; and on the unskilled worker than on the skilled.

Equation 5 of Table 6 shows that, when the effect of the other variables included in the equation is controlled, the employee not formally registered tends to earn 23.75% less than the one registered; the temporary employee receives 10.44% less that the permanent, while employees without specialization 19.61% less than the skilled. This equation allows us, moreover, to verify that the legal minimum wage has a different impact on the earnings of the employees in the various agricultural activities. For the sugarcane employee (activity taken as the base), an increase of R$ 100.00 in the RMW is associated with a rise of 14.71% in expected earnings. The terms of the interaction that considers RMW show how its effect on wages of employees in different agricultural activities is differentiated. Except for soya, the impact of the legal minimum wage on the earnings in the sugarcane culture is stronger than in the other crops, perhaps due to the relative weight of the sugarcane crop in the country's economy, more inspection about the enforcement of labor laws, and more active trade unions.

Finally, it should be noted that employees in the sugarcane culture have a better remuneration when we analyze the information given by workers in the various stages of the productive cycle (from PNAD). However, when we analyze the daily pay in the contracts for the harvest in the state of São Paulo, according to data from the Institute of Agricultural Economy of the Secretary of State for Agriculture of the State of São Paulo, what is paid in the sugarcane harvest is lower than the pay in the citrus harvest (oranges, lemon and tangerine) and in the coffee harvest (in the red cherry and in the dried pod).

DOES SUGARCANE AGRIBUSINESS CONTRIBUTE TO INCREASE INEQUALITY?

The sugarcane culture is highly concentrated. HOFFMANN and SILVA (1986) analyze the con-

TABLE 6 Earnings equations for people employed in agriculture in Brazil cf. PNAD data 1995-2007.

Variable	Equation 4		Equation 5	
	Coefficient	% diff.	Coefficient	% diff.
Constant	2.4213	–	2.4004	–
Female employee	–0.1461	–13.59	–0.1439	–13.41
Age				
Age/ 10	0.2288	–	0.2282	–
(Age/ 10)$^{(2)}$	–0.0267	–	–0.0267	–
Schooling				
Schooling <=9 years	0.0206	2.08	0.0204	2.06
Schooling > 9 years	0.0929	12.01 (1)	0.0937	12.08 (1)
Log (hours worked per week)	0.7192	–	0.7234	–
Skin color (Base: white)				
Black or mixed	–0.0514	–5.01	–0.0507	–4.94
Yellow (Asiatic)	0.3300	39.10	0.3332	39.55
Person of reference in the family	0.0809	8.43	0.0808	8.41

(*continues*)

Variable	Equation 4		Equation 5	
	Coefficient	% diff.	Coefficient	% diff.
Rural domicile	−0.0450	−4.40	−0.0466	−4.55
Region (Base: NE)				
North [3]	0.2792	32.20	0.2776	31.99
Southeast (excl. SP)	0.2494	28.33	0.2508	28.50
S. Paulo	0.4245	52.89	0.4256	53.05
South	0.2502	28.42	0.2506	28.49
Center-West	0.3945	48.36	0.3940	48.29
Agricultural segment (Base: sugarcane)				
Coffee	−0.0919	−8.78	−0.0187	−1.85 [2]
Manioc (cassava)	−0.2494	−22.08	−0.0786	−7.56 [2]
Corn	−0.3029	−26.14	−0.0308	−3.03 [2]
Soya	−0.0651	−6.30	−0.2766	−24.16
Rice	−0.2873	−24.97	−0.0986	−9.39 [2]
Other agricultural activities [4]	−0.1291	−12.11	0.0253	2.56[2]
Non-registered employee	0.0783	8.14	−0.2711	−23.75
Temporary employee	−0.0369	−3.62[2]	−0.1103	−10.44
Employee without specialization	−0.4130	−33.84	−0.2183	−19.61
RMW/100	0.1350	14.45	0.1372	14.71
(RMW/100)*(Non-registered employee)	−0.1159	−10.94	–	–
(RMW/100)*(Temporary employee)	−0.0241	−2.38	–	–
(RMW/100)*(Employee without specialization)	0.0639	6.60	–	–
(RMW/100)*(Coffee)	–	–	−0.0239	−2.36[2]
(RMW/100)*(Manioc)	–	–	−0.0565	−5.50
(RMW/100)*(Corn)	–	–	−0.0909	−8.69
(RMW/100)*(Soya)	–	–	0.0692	7.16
(RMW/100)*(Rice)	–	–	−0.0624	−6.05
(RMW/100)*(Other agricultural activities)	–	–	−0.0510	−4.97
R^2	52.56		52.43	
F test [5]	2,402.80		2,159.20	
Number of observations	60,754		60,754	

[1] Percentage increase in earnings associated with 1 additional year of schooling, beyond 9 years completed, by calculating, for instance, 100[exp (0.0206+0.0929)–1]% = 12.01%.

[2] The coefficients do not statistically differ from zero at significance level of 5%.

[3] Rural areas of the states of Rondonia, Acre, Amazonas, Roraima, Pará and Amapá are not included.

[4] Other crops, except sugarcane.

[5] The values of *F* are statistically significant at the level of 1%.

Note: The dependent variable is the logarithm of the earnings from the main occupation.

Source: OLIVEIRA (2009, p. 152), based on MICRODATA from PNAD (1995-2007).

centration of the area under cultivation and the of production in 19 crops, using data from the Agricultural Census of 1975 and of 1980, and show that the sugarcane culture is the most concentrated amongst all the crops analyzed. It should be noted, however, that concentration of production in the industrial sector is in general far higher than in agriculture. Beans, corn and manioc are crops that typically have a low concentration index in Brazil.

The most recent information about concentration in the sugarcane production in Brazil and in the state of São Paulo is in a paper by RAMOS (2008). Taking into account, moreover, the concentration of economic and political power in the hands of the sugar mill and big land owners, one could say that the sugarcane agribusiness reproduces the high inequality characteristic of the Brazilian economy. This does not mean, however, that the sector's expansion will increase the inequality of income distribution in Brazil.

One way of examining the sector's impact on the distribution of income in general is to consider the income of people employed in that sector as a share of the income of all households in the country.

Let us assume that the household income per capita (y_i) of the i-th household is divided in k components (y_{hi}), as follows,

$$y_i = \sum_{h=1}^{k} y_{hi}$$

Be G the Gini index of the distribution of the household income per capita, be C_h the concentration ratio of the component y_{hi} and be φ_h the share of this component in total income. It can be demonstrated that the Gini is a weighted average of the concentration ratios, namely,

$$G = \sum_{h=1}^{k} \varphi_h C_h$$

It is reasonable to consider that a component contributes to the increase in inequality when its concentration ratio is greater than the Gini index.

Using data from PNAD 2006, it is possible to verify that in Brazil with 53.45 million households and a populstion of 182.34 million, the Gini index is 0.56. Earnings from work by people occupied in the sugarcane agribusiness (sugarcane culture + sugar industry + ethanol industry) represent 0.63% of total income and their concentration ratio equals 0.291. Earnings from work in all other activities represent 75.2% of total income and their concentration ratio is 0.566. These results indicate that a uniform increase in the income of people occupied in the Brazilian agribusiness would contribute to a reduction of income inequality in Brazil.

Still, using PNAD 2006 data, but considering only the State of São Paulo, the Gini index of the household income is 0.52, for a population of 12.13 million households, corresponding to 39.43 million people. Earnings from work occupied in the sugarcane agribusiness represent 1.16% of the state's total income and their concentration ratio equals 0.339. Earnings from work from all other activities represents 77.77% of total income, and its concentration ratio is equal to 0.522.

It is well known that PNAD questionnaires do not reflect very high incomes. This problem is to some extent attenuated when using data from the Demographic Census, which obtains information on people's income from a far larger sample than the annual PNAD. According to the 2000 Demographic Census, the State of São Paulo had 10.36 million households, with 36.61 million people. The Gini index of the per capita household income in the state is 0.593. Earnings from work of the people occupied in the sugarcane agribusiness represents 0.62% of total income and its concentration ratio equals 0.236. Earnings from work in all other activities represent 80.11% of total income; and its concentration ratio is 0.594.

All these results indicate that a small relative increase in the incomes of people occupied in the sugarcane agribusiness would contribute to a reduction in inequality of the distribution of per capita household incomes in the State of São Paulo.

Another way of analyzing the influence of the sector in the overall inequality of income distribution is to separate people occupied in the sector from the total employed population. Instead of a separation of household income into components, it is the population, the total number of persons, which is separated in groups. It is possible to analyze, then, how the global inequality depends on the inequality *among* groups and on inequality *within* groups. For the latter component, a group or sector where inequality within the group is higher than global inequality obviously contributes to increase overall inequality.

A preliminary information about this question is presented in Table 7 with numbers for the Gini index of income in all activities for people occupied that had a positive value for such income. According to PNAD 2006 data, the total number of people with such characteristics in Brazil, comprising employees, self-employed workers and employers, is 78,394,000, with an average income of R$ 883.00 (R$ of September 2006) and Gini index of 0.54. Table 7 shows that the Gini index in the sugarcane agribusiness is lower. The same is true if we separate only the people employed in sugarcane production or those in the sugar and ethanol industries. Moreover, Table 7 shows similar results when only the State of São Paulo is considered: the Gini index equals 0.513 for all employed, 0.439 for people in the whole sugarcane agribusiness sector, 0.357 for people occupied in the sugarcane agriculture, and 0.45 for the occupied in the industry of sugar and of ethanol.

Table 8 shows results obtained from the 2000 Demographic Census in the State of São Paulo. Again, inequality in the sugarcane agribusiness is less than inequality for the total occupied people. What is curious is that, contradicting what is observed from PNAD data, when Census data are taken, inequality in the agricultural component of the sector is higher than inequality in the industrial component of the sector.

The fact that inequality within the sugarcane agribusiness is less than inequality among all occupied people, in Brazil as well as in the State of São Paulo, does not in itself prove that an expansion of the sector could not provoke any increase in inequality. It is also necessary to examine inequality among different sectors, the likely change in the composition of the labor force inside the sector, and the multiplier effects on other sectors. The fact is that the results we obtained do not support the idea that inequality within the sugarcane agribusiness is exceptionally high, or that expansion of the sector would contribute to an increase in the inequality of income distribution in Brazil or in the State of São Paulo.

HARM AND DISPLACEMENT

Even when growth of the sugarcane agribusiness in a region favors an increase in employment and average incomes, the possibility that a number

TABLE 7 Income distribution for people occupied[(1)] in all activities, cf. PNAD data, in Brazil and the State of São Paulo, distinguishing the sugarcane agribusiness.

Area	Sector	N. of people (1000)	Average income (R$)[(2)]	Gini index
Brazil	All	78,394	883	0.540
Brazil	Sugarcane agribusiness	805	722	0.448
Brazil	Sugarcane culture	571	543	0.376
Brazil	Sugar+ethanol industry	234	1,162	0.458
State of São Paulo	All	18,734	1,139	0.513
State of São Paulo	Sugarcane agribusiness	296	1,075	0.439
State of São Paulo	Sugarcane culture	174	784	0.357
State of São Paulo	Sugar+ethanol industry	122	1,488	0.450

(1) Only people with positive income.
(2) R$ of September 2006.

Source: PNAD 2006 MICRODATA.

TABLE 8 Income distribution of people occupied[1] in all activities, cf. 2000 Demographic Census, in the State of São Paulo, distinguishing the sugarcane agribusiness.

Sector	N. of people (1000)	Average income (R$)[2]	Gini index
All	14,818	891	0.564
Sugarcane agribusiness	175	575	0.460
Sugarcane culture	96	494	0.485
Sugar+ethanol industry	79	673	0.399

[1] Only people with positive income.
[2] In R$ of July 2000, when the legal minimum wage was R$ 151.00.

Source: IBGE, 2000 Demographic Census.

of people could be negatively affected by such process is not trivial. It is possible to imagine sugarcane expanding into an area previously occupied by extensive cattle-raising. Production values per square kilometer or employment might rise, but the skillful cattle herder or the proud cowboy will not easily be transformed into a tractor driver. For him the process might be painful, forcing him to search for cattle-raising in other regions. It is necessary to implement measures in order to soften the transition, such as the much quoted retraining and relocation of the labor force.

More immediately evident is the difficulty of manual cane cutters. Given the need to adapt to the requirements of sustainable production growth, including environmental concerns and healthier working conditions, the activity of the cane cutter tends to disappear with the mechanization of the harvest. A large number of those employed in the sugarcane plantations of São Paulo are migrant workers from other states (see CARNEIRO *et al*., 2007; MENEZES, 2007). In this event, it might be necessary to implement new programs geared to the creation of employment opportunities in the regions of origin of these migrant workers (see MORAES *et al*., 2008).

COMMENTS AND QUESTIONS

Besides presenting data to improve the diagnosis of socioeconomic problems associated with the expansion of the sugarcane agribusiness, this paper aims at contributing to the elaboration of a research agenda in this area, in line with the themes and preliminary questions that follows.

a) The analysis of socioeconomic problems related to the expansion of the sugarcane agribusiness cannot be limited to the State of São Paulo. Suffice to recall that a large proportion of the cane cutters occupied in the state are migrant workers from the State of Minas Gerais and from the Northeast. It is obvious that the prospect of Brazil becoming a large ethanol supplier in world markets depends on national policies. This does not diminish the relevance of research and governmental programs that need to be put into action in the State of São Paulo.
b) More research is needed to establish with greater certainty the number of people occupied in the sector and their remuneration. The use of information from the Agricultural Census of 2006 will be very useful, but certainly cannot give a definitive answer to some of the questions.
c) How the concentration of production in the sector compares to other agricultural and industrial activities? Does the sector distinguish itself by some particular concentration of economic and political power?
d) Does the sugarcane agribusiness contribute to an increase in income inequality in Brazil?
e) Is the expansion of the sector likely to reduce or to reinforce inequality between regions in the country?

f) Would it be appropriate to prohibit the pay by harvest contract for cutters in the manual sugarcane harvest?
g) Is there a need to maintain and improve the inspection to enforce labor legislation as in any other sector?
h) What are the potential impacts of the expansion of agribusiness on other economic sectors?
i) How will the competition for arable land and other inputs affect food production due to the sector's expansion?
j) Is it appropriate to establish land zoning, to allow or to prohibit sugarcane cultivation in certain areas? This question of course depends on agronomic considerations and socioeconomic concerns.
k) What kind of programs should be approved in order to help the transition process for those dislodged or affected by the expansion of sugarcane? How can such programs be carried into effectively?
l) As in any sector, enforcement of environmental protection laws is needed. But there are still specific questions that the sector needs to face e.g. sugarcane burning during the harvest. Would it be appropriate to phase out sugarcane burning sooner? How can the legal framework be improvement?
m) Can the expansion of the sugarcane agribusiness shows it will contribute to an increase in welfare for present and future generations?

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8

USE OF THE WATER IN THE PRODUCTION OF ETHANOL FROM SUGARCANE

Gilberto de Martino Jannuzzi

INTRODUCTION

The production of ethanol from sugarcane in Brazil has increased significantly during the last few years and it is expected to continue to expand over the next decades. This is partly the result of the high volatility of petrol´s prices and, also due to the increasing international market for a renewable liquid fuel for the automotive sector. The use of ethanol from sugarcane can also meet the requirements from the Kyoto Protocol by industrialized countries.

Besides being a potential source of renewable energy, contributing to the substitution of fossil fuels, the sugarcane culture is also known for the significant socio-economic and environmental impacts it brings along in the areas this culture gests established. The projected expansion of the Brazilian ethanol production over the next decades would certainly cause significant and diverse impacts in the producing regions. Many of the cumulative effects over time, including more population, introduction of new infrastructure and services, commercial and industrial activities will altogether increase the pressure on the local resources, including fresh water resources. These impacts must be considered by any sustainability analysis.

For the most part, the production of sugarcane in Brazil is rainfed and there is no need for artificial irrigation. However, the use of irrigation is becoming more common as new areas are being incorporated specially in South-Center region of Brazil. Besides the agricultural production, the industrial processing of sugarcane into ethanol is also very demanding on water resources.

TABLE 1 Fresh water use in Brazil.

Sector	Water consumption (%)
Agriculture and cattle raising	61
Urban uses	21
Industry	18

Source: CARMO (2008).

The main point of this chapter is to discuss the current situation of water utilization in ethanol production, the main challenges at the moment and future perspectives to guarantee less impact on the existing water resources.

The chapter is based on presentations delivered at the workshop **"The use of water for production of ethanol from sugarcane"**[1].

SUSTAINABILITY AND THE WATER USE

In general agriculture is the main consumer of fresh water resources in Brazil, as it can be noticed from Table 1. The industrial use of water is increasing in the country and consequently there is more concern with developing industrial systems with reduced water usage.

The most appropriate methodology to analyze and quantify water usage follows the same principles of the life cycle cost analysis (LCA). This

[1] Available at: <http://www.apta.sp.gov.br/cana/>.

methodology quantifies the materials (including water) and energy floods of the whole cycle of production until the final destiny of the product. In case of ethanol this includes the agricultural phase (plantation, harvest, transportation etc.), the industrial phase (washing, fermentation, distillation etc.) and the final use in vehicles. The agricultural part and, especially, the industrial phase, both are most relevant ones in case of the use of water.

Sustainability

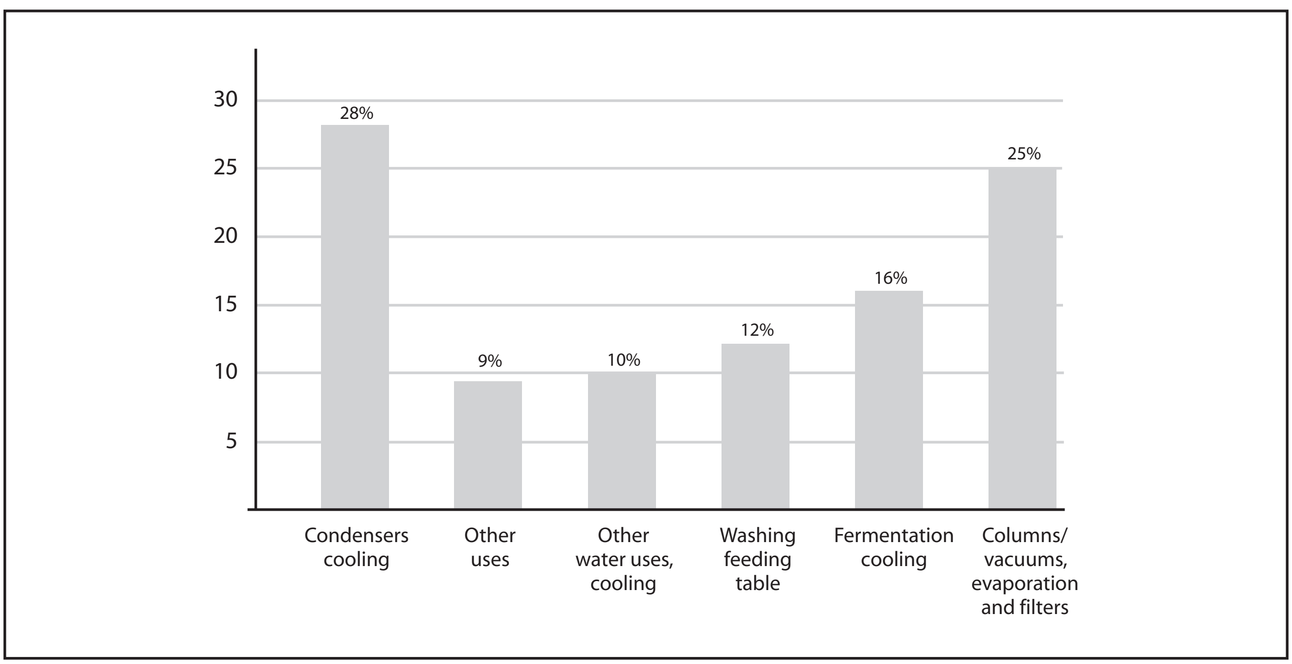
Sustainability is a normative concept; it contains values, perceptions and preferences that precede a technical and scientific analysis. The definition that is most used is the one that is mentioned in the Brundtland report (World Commission for Environment and Development WCED, 1987). Under this concept a society is considered sustainable when it is capable to fulfill the present generation' requirements and also preserve or maintain possibilities so that future generations can also meet their own requirements.

Leite (2008) observes the need to define indicators as to be better analyze questions related to the sustainability of the water use. He shows two concepts to characterize sustainability: water needs and water availability for the production system.

With reference to the amount of water needed for the production of ethanol, during the agricultural period the required amount is minimum, considering the current areas where sugarcane is grown in Brazil. Most of the sugarcane production is concentrated the State of São Paulo where it is cultivated without irrigation. Artificial irrigation is becoming more common in expansion areas that have insufficient or poor distribution of rainfall over the growing period. In São Paulo state where is usual to practice the midyear plantation, or full year plantation irrigation is not used. The winter plantation, which happens in a dry climate, needs a salvage irrigation for security, with the recommendation of having two irrigation with about 30 to 40mm of water, but is not very useful in south-east.

Irrigation is more necessary in the northeast region of Brazil, where the salvage irrigation is practiced after the cane plantation, and when needed a supplementary irrigation is also applied to complement the water deficit.

Although the need for water for industrial processes is more significant there are variations



Source: LEITE (2008).

FIGURE 1 Industrial water usage – distillery producing ethanol (50%) and sugar (50%).

between distilleries depending on the type of system that is being applied. Distilleries using an open cycle (do not reuse the water) have a need of 21m^3 of water/ton of cane. Illustration 1 presents the water distribution usage of a typical distillery operating with open cycle and allocating 50% of cane input for the sugar production and other 50% for ethanol.

The three final uses respond for almost 80% of the water industrial consumption: cooling condensers (28%), production of vacuum on the barometric columns (25%) and cooling of fermentation chambers (16%).

Leite (2008) presents recent developments that has been taken place in different distilleries:

Water cooling of condensers and fermentation chambers – Water in this circuit is been used through a cascade effect – so that the water from the fermentation chambers can be used afterwards on the condensers; this reduces in 16% the amount if water needed. The circuit has now been closed in some distilleries. Systems of evaporative cooling-towers are being employed, and water only is required to replace the amount lost by evaporation or dragging – about 2 to 3% of the water circulation.

There are studies in course regarding the use of colder water in this circuit with further benefits reducing the volume of water in circulation (these studies must be intensified).

The process of sugarcane washing – The cane washing is used as a closed water circuit system with decantation boxes or circular decanters. Dry cleaning systems are also being employed and water is only used when a great deal of inorganic matter is detected on the cane. The washing system using mats continues to be used but with smaller volumes of water employed (the circuit was reduced from 10m^3/ton sugarcane, to 1 to 2 m^3/ton of sugarcane.

Water from the barometric columns – This circuit have been modified, substituting the multi-jets by the barometric columns, in order to produce vacuum during the phase of juice concentration, bringing about a reduction of 30% of the water needed in this operation. Closed water circuits are now a common practice, being applied in evaporative cooling systems by aspersion (spray) or cooling towers. There has been a lot of research and new technologies have reduced significantly the amount of water used.

Cooling water – This is the water used in circuits to cool parts of the milling machinery and turbo-generators. Most of these circuits are now closed, especially in distilleries that are using co-generation systems.

Other uses of water in the industrial processes include: equipment maintenance and cleaning, water for preparation of products, water for milling or diffuser etc.

There has been progress in reducing water use for the industrial processes, particularly in São Paulo. In 2005 the average value of water intake for a industrial plant was of about 1.83 m^3/t. sugarcane. Leite (2008) showed that in spite of an increase of 125% of ton of sugarcane processed in the State of São Paulo, there was a reduction of 26% of water use during the harvest of the period 1990/91 and 2007/08.

The State of São Paulo has initiated signatures of voluntary protocols with the alcohol industry as the Green Ethanol Protocol and also observing the technical indicators of Water Resources Conservation Plan.

THE RIVER BASINS SUPPORT CAPACITY, THE BASINS ASSOCIATION AND THE LICENSING OF NEW DISTILLERIES IN THE STATE OF SÃO PAULO

Special permits are required in the State of São Paulo for retrofits, expansion and/or alterations of distilleries facilities. Environmental licenses are required in these cases and are issue by the State Environmental Secretary.

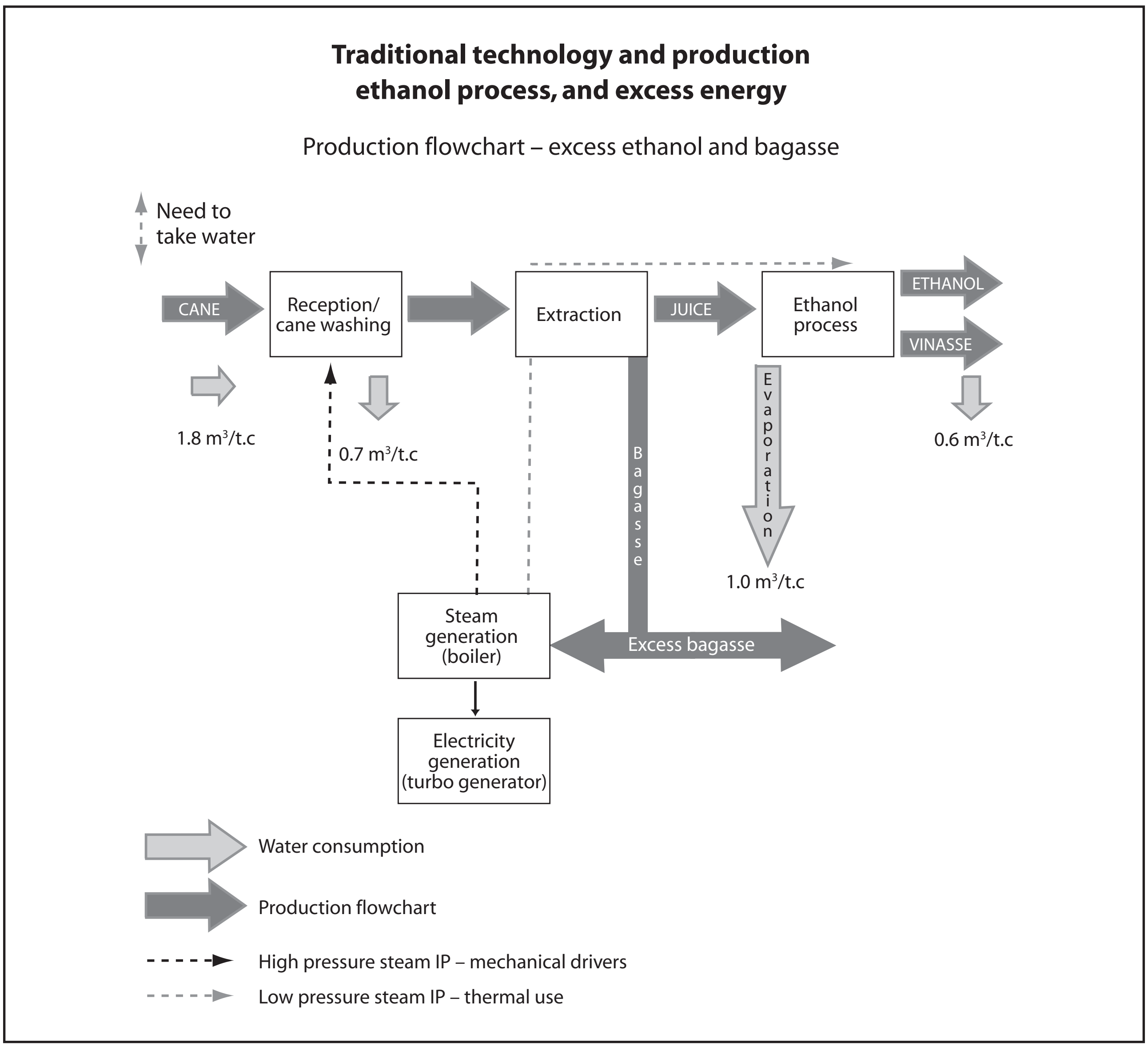
An environmental zoning map has been in place for the State of São Paulo as well. This procedure has mapped regions where sugarcane is allowed to be cultivated. It also indicates the permitted water intake for industrial processes, that vary from 0.7 m^3/ton to 1 m^3/ton of sugarcane.

There are also four environmental control programs in the state with direct impacts on the activities of the ethanol and sugar sector: 1) The control of the quality of superficial and underground water (contamination by pesticides); 2) The controlling of the fauna (maintenance of preservation areas and buffer zones); 3) Atmospheric emissions and 4) agricultural soil preservation and quality.

According to the environmental zoning for the ethanol and sugar sector, the State of São Paulo has 3.9 million ha of suitable areas for sugarcane plantation and related industrial activities, 8.9 million ha of areas with some environmental limitations, 5.5 million ha of areas adjusted with environmental restrictions and 6.7 million ha of inadequate areas.

NEW MITIGATION TECHNOLOGIES FOR THE WATER USE IN THE PRODUCTION OF ETHANOL: INDUSTRIAL PHASE

Carmo (2008) presents new technological developments undertaken by the Dedini, with significant reduction in the water losses during evaporation, as well as using concentration processes of quantity of vinasse, dry washing and



Source: CARMO (2008) apud OLIVÉRIO (2008).

FIGURE 2 Ethanol production: water flow.

vapor uses. These reductions imply that the water that enters with the sugarcane juice (~700 liters for TC) is sufficient for the distillery operations, that is, the plant is self-sufficient in water, and there is no need to bring in outside water.

Figure 2 illustrates the flow of water use in the industrial conventional process of production of ethanol. The points most important are: the stage of washing the sugarcane; the stages of evaporation/condensation in the processes of sugar production and ethanol; the distillation (residual waters, water heater, washing of floor and tanks and discarding); the washers of the gases; the cooling of machinery and water use in boilers.

Some solutions to reduce the industrial water use:

- Replace the washing system of sugarcane by the dry washing system.
- Optimize the evaporation stage, tapping the steam and take advantage of condensation to produce water.
- With regards to the distillation and dehydration processes, new technologies with the use of membranes reduces the necessity of water.
- The concentration of vinasse integrated to the distillation process will be able to contribute significantly for the reduction of water needs.

Water consumption can be significantly reduced with the existing conventional technologies. The net water intake in the industrial process (it does not consider the water that enters with the sugarcane) can fall of 1.83 m^3/ton of sugarcane for 1 m^3/ton of sugarcane using available technologies, and can be further reduced to 0.5 m^3/ton of sugarcane as it was noted during the workshop discussions.

The advances in the rationalization of the use of the water in recent years have been relatively easy and they have not demanded large investments. As from now on, the efforts and resources will be bigger for a lesser reduction.

There are already better water-conserving technologies in the market, and research being done leading to water self-sufficient distilleries. However, the costs are still prohibitive.

NEW MITIGATION TECHNOLOGIES FOR THE WATER USE IN THE PRODUCTION OF ETHANOL: THE INCORPORATION OF THE STRAW FOR REDUCTION OF THE WATER STRESS

There is the option of using cane straw for covering the ground as a practice to conserve water and soil. The coverage by straws helps the retention of the humidity and reduction of the losses of organic matter and soil erosion. It also promotes gradual incorporation of organic substance into the ground. The amount of available straw in sugarcane allows enough vegetable matter to cover the ground to prevent significant losses of water and soil.

Nevertheless, the pursuit of sustainability implies in significant change of the technologies and processes currently used. This change means the adoption of direct plantation, harvest of the raw sugarcane (without the traditional process of burning the plantation prior to harvesting), use of structures of controlled traffic, the use of the straw.

The direct plantation presents as a very promising way to obtain conservation of the water and the ground. Water losses when using the conventional plantation system are about 140 mm/year, while the direct plantation is a little more than 40 mm/year. Soil losses in the conventional plantation and the direct plantation one are, respectively, about 23 ton/ha/year and little more than 5 ton/ha/year.

The traffic generated using current mechanization compacts the soil and hinders the use of direct plantation methods. Currently, 60% of surface of the planted areas are used for traffic of agricultural machinery. Using Structure of Controlled Traffic (ETC), the traffic area is reduced to 5-10% of the planted area.

The harvest of the raw sugarcane is one of the first conditions for the practical one of the direct plantation. However, according to Braunbeck (2008) there is the need to break with the current trend of technological standards in order to meet the goals of environmental protocols for areas with declivities above 12 degrees. This is because of lack of interest of equipment manufacturers of agricultural machinery.

FINAL CONSIDERATIONS

1. About 20 years ago the average water consumption in the State of São Paulo was 5,6 thousand liters for each ton of processed sugarcane, today this relation is of 1.8 thousand liters for each ton, that is a 32% reduction, but we still can and we must do more. New ethanol production technologies, (second generation) might demand more water resources for the processes.
2. Significant progress are already being obtained as we reported during the workshop, such as the water recovery of vinasse, use of membranes for dehydration of ethanol, use of high-pressure boilers and other technological innovations.
3. Significant changes in technologies and processes are necessary for the conservation of the ground and the water, as the pressures will still be higher in the future.
4. Significant reductions in water consumption for industrial processes were achieved as results of negotiations with the State of São Paulo officials and the industry. The environmental zoning was an effective tool to organize the ethanol producing observing local resource limitations.
5. New technologies for water use in industrial processes have been introduced, such as dry systems, membranes for the distillation processes and dehydration. These innovations are becoming more common amongst the producing units. Technologies that they can also make use of the water contained in the sugar for industrial purposes is also being developed, and there are expectations that net excess of water can be achieved. In this way industrial units could potentially export water.
6. The reduction observed in the water intake for the industrial processes in São Paulo can be attributed to diverse factors that have occurred simultaneously: learning curve of operation of sugar mills and distilleries, together with the increase in production scale; scarcity of water reserves in several regions of the State; beginning of collection of fees for the use of the water; increased efforts related to environmental monitoring and more stringent regulation regarding the environmental licensing of new industrial units.
8. The environmental zoning performed in the State classifies regions where the plantation of the sugarcane is allowed, with parameters indicating the permited levels of water intake for the industrial processes that vary of 0.7 m^3/t of sugarcane to 1 m^3/t. The State of São Paulo has 3.9 million ha classified as suitable areas for the sugarcane activities, 8.9 million ha suitable areas with environmental limitations, 5.5 million ha of areas suitable areas with environmental restrictions and 6.7 million ha of inadequate areas.
9. The direct plantation presents as a very promising way to achieve water and soil conservation. Water losses using the conventional plantation methods are of about 140 mm/year, while by the direct plantation is a little more than 40 mm/year. The losses of soil matter in the conventional plantation are about, 23 ton/ha/year whilst by using the direct plantation method it comes down to a little more than 5 ton/ha/year.
10. It became clear also that a more rigorous methodology and data to quantify the water flows in the system of ethanol´s production (including agricultural and industrial the part) are required.

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9

IMPACT OF THE SUGAR-ETHANOL SECTOR:

THE ISSUES GUIDING SUSTAINABLE EXPANSION

Alceu de Arruda Veiga Filho, Tamás Szmrecsányi and *Pedro Ramos*

INTRODUCTION

Raising the pressing issues of development of the sugar-ethanol industry

The economic and social development of a country or a region does not proceed, or is only assessed in quantitative terms, but primarily in quality. Within this last perspective, there is not any objective reason for the State of São Paulo to have more than half of the sugar plantations of the country. Sugarcane is the main crop that occupies the largest cultivated land area in São Paulo. Everything indicates that these are distortions and irrationalities that to be fought on behalf of technical progress, harmony and a balanced environment; there is a need for land decentralization of land, increased and diversified crop production in the State.

In context, we are experiencing an expansion phase of the alcohol market, internal and external, which has led the State of São Paulo to occupy – according to data from the 2006/07 season, to 5.5 million ha with sugarcane, responsible for approximately 60% of domestic production of sugar and ethanol.

What are the potential impacts of this growth? Selected issues relating to concentration of land and an environmental impacts, labor relations, and competition with other factors of production, indicate that it can create difficulties to the productive system.

These problems cannot be solved by the free market forces alone, but require the active intervention by the state and various federal government agencies.

Starting with the land issue, we know that the main feature of the installation of plants is through the incorporation of land owned or leased, to ensure the supply of raw material. In São Paulo the average agricultural area of sugarcane plantations in the 1970s was 8,000 hectares, and is currently around 12,000 ha, and the areas of independent suppliers have remained virtually the same over the past 30 years; that is, between 12 and 45 ha.

Studies on the distribution of cultivated sugarcane planted area show that between the periods 1995/96 and 2002/03, the average area was 31,000 thousand hectares in 2002/03, up 9% from 28,500 ha of 1995/96. These studies also show that sugarcane growers with less than 1,000 ha fell by 21% with an average reduction of 476 ha to 376 ha.

This form of concentration is what is occurring in the new areas of expansion in the west of the state, either in the form of leases and land purchases. One consequence of this land concentration is the disruption of other social and productive activities which may be less attractive than sugarcane, but important locally. Small producers associations, with long historial tradition and deep local social and economic roots can be broken by the impact of local expansion of sugarcane.

Another consequence of this rapid expansion is the removals of other land uses, groves, hedges, fences and any other obstacles that impede large-scale sugarcane plantations. Furthermore, small farmers, who leased or sold their land, hardly come back to farming because they usually sell their machinery and equipment and migrate to the cities. This has already occurred during the first phase of the Proálcool in Brazil (Brazilian National Ethanol Program), back in 1970s and 1980s.

There are also serious environmental issues e.g. those posed by sugarcane burning, the destruction of riparian forests, water sources, and correct application of vinasse and pesticides utilization and their impacts. All of these issues require careful environmental management.

It is well known that sugarcane burning can caused serious environmental damage e.g. on soil microorganisms subjected to extreme heat causes, death of animals, enormous waste of energy contained in the cane trash, loss by exudation of sugar in the stalks burned, increases pollution impacts on human health etc. It also leads to increase water consumption in urban areas as water has to be cleaned up of residues deposited by burning; and also from in houses, yards and service areas. But one the most serious is in health cuased by increases in air pollution.

For the forests and protection of water sources, despite the legislation, there is still much to learn. For example, official surveys during the 1970s compared with today, show the elimination of many water springs that have been dried up by pumping water for irrigation, including sugarcane.

The regulations on the use of vinasse, according to São Paulo State Environment Agency – CETESB 2005, for use in areas near and has proven saturated, is proof that although the organic by-product vinasse is mostly water and nutrients, their use must be controlled because it can lead to the salinisation of groundwater by leaching of these elements, and also cause nitrification of the soil and contaminate groundwater. Studies need to be conducted with much rigor to properly evaluate the problem.

There is the danger of contamination of aquifers, which are underground reserves of fresh water, from herbicides, pesticides and chemical fertilizers. In this case, the concern is that sugarcane is grown around areas of major aquifers in the region of Ribeirão Preto and Jaú / Bauru. This requires careful monitoring with equipment that provides information about contamination analysis and other surveillance measures.

Among the issues selected for debate and discussions, is the issue of labor relations. Although there is demonstrated progress on the formalization of contracts and the abolition of child labor in the State of São Paulo, there still remains problems of compliance with NR 31 (safety and health), and fair payment according to the production of sugarcane harvested.The latter is responsible for the overexploitation of labor in the industry, and has resulted in extreme suspicion of death by exhaustion, as reported in the press and commissioned by the Labor Attorney.

Of course, it is well known the difficulty in complying with the legislation because there will always be ways to by-pass it e.g. to establish production goals accurately strick monitoring by labor unions, and supervision of the officers.

There has been an intense debate on the impacts of ethanol on food prices. In the majority of cases such price global demand for biofuels to meet the increased supply of energy while reducing the use of nonrenewable resources and emitting carbon dioxide, this question becomes strategic, also considering the importance food security, starting to intensify the competition for productive resources, credit and subsidies. This, of course, raises the need to identify the problems derived from competition between them and the need to consider mitigation solutions.

Therefore, we highlight these four crucial aspects to compose a research program to study the evolutionary process of the sugar-ethanol industry: the labor question, the issue of land concentration, environmental issues and the question of the impact on food prices.

This analysis is concerned to: a) current situation, b) existing bottlenecks, c) prospects for the sector development in scenarios with and without structural changes, and d) finalize with the demands of research projects that will mark out public policies business strategies more efficient and sustainable.

Discussion about land ownership Issue

Study the concentration of land as a process that establishes a logic of economic and social characteristics of the sugarcane agribusiness in Brazil is important to properly discuss the economic and social benefits that the expansion would bring. This has been overlooked by prospective studies of the expansion of such agribusiness industry in Brazil.

This logic is the same for the new areas, and it is not small the projected expansion: it is expected that over the next five years no fewer than 77 new production units are built to expand the supply of Brazilian ethanol and sugar, and 35 of them in São Paulo State, 18 in Minas Gerais State, Goias State 10, 9 in Mato Grosso do Sul State, Paraná State and 4 in 1 in Rio de Janeiro State.

Notice that for three moments in the recent period, i.e. 1984/5-85/6 – 1996/7-97/8 and 2005/6-06/7, it was clear that it can be considered as the main manifestation of concentration that characterizes the sugarcane agribusiness in Brazil, namely, to crush predominantly the raw material produced by own factory owners and owners of distilleries in their lands or agricultural establishments.

The increase in the percentage of sugarcane itself in the Central / South between 1985 and 1996 shows that the expansion of sugarcane industry to the states of Central and Western was based on estates formerly formed, and / or alumni linked to the establishment of factories were built by local landowners, or who migrated to the local states. The drop in this percentage between 1996 and 2006 should be viewed with caution, because of what is hereinafter pointed out. However, one can not emphasize a real fall, because the plants as they are being extended, require larger amounts of sugarcane, which usually involves the addition of new cane suppliers. The case of Mato Grosso State is in an example.

Another aspect of concentration can be observed by the systematic information of the raw material source crushed by plants between the periods 1995 / 6 to 2002 / 3. It is possible to highlight two aspects: first, that the average area harvested own by the mill / distillery has evolved into more than five thousand hectares in just seven years, and secondly, that such a development focused on units that already had larger average areas, i.e., the stratum with more than twenty thousand ha.

Another manifestation of the concentration of land underlying the production of cane can be drawn based on data relating only to the supply of cane to the mills and distilleries. The data, which yields the 1995/6, 2004/5 and 2005/6 show that the great expansion that has occurred in São Paulo has been accompanied by a concentration of sugarcane production in the major suppliers/ producers, despite the existing high number of them, the percentage of suppliers that provide more than ten thousand tons per year rose from 53.2 in 1995/6 to 64.9% in 2005/6 having decreased the percentages of all other strata.

The situation existing today can be changed and, moreover, to refrain from getting worse, are pointed out two sets of public policy measures that can be adopted.

The first is general and concerns the need for change in legislation and land policy. It can be argued that few countries have the world's land law as permissive as that of Brazil, there is no restriction on the use of land. To use a fashionable term, the "governance structure" linked to the land issue in Brazil needs to be dramatically changed.

The second one is related specifically to the modus operandi of the agents of the economically strongest cane agribusiness in Brazil, which, given the legal framework allows for the configuration of your current structure. This was a matter of concern for the status of sugarcane crop of 1941, but he was being, especially in São Paulo and after the Second World War, disrespected and openly contradicted by decree in late 1960 and today is totally ignored, although it is a law that has never been repealed entirely. The issue is how to discipline the sector as far as the cane produced by the plant can be milled and establish other rules (regarding prices, forms and criteria for payment, ensuring grinding etc.) regarding the supply of cane for independent producers and their associations.

As noted, the indications are that the main characteristic of the land base of our sugarcane agro-industry remains in expansion, and this is the feature that promotes exclusive ownership of income and, thus, contributes greatly to increase the concentration of wealth that has marked the history Brazil.

Demands for research on land issues:

- Comparative studies of sugarcane production in the various situations of land ownership (Australia, South Africa, USA – Florida, Brazil – NE and CS).
- Studies on concentration of land and income.
- Studies on replacement of the cane on other activities and the impacts.
- Studies on the regulatory role of the state in land use and spatial alcohol sector versus the political power of the alcohol sector.
- Studies on the pricing and distribution of the benefits of by-products between plants and suppliers.
- Studies of economic viability of non-vertical structures of raw material versus the vertical structure of existing production.
- Studies on the formation of economic groups and their business strategies.

Discussion on the issue of labor relations

The present study examined the socio-economic profile of jobs in the sugar-ethanol industry, using information from the governamental employment register (CAGED) of the Ministry of Labor and Employment for the years 2006 and 2007. This source contains monthly data on the total number of accepted and off by economic activity, as well as variables that allow diagnosing the socio-economic profile of workers by occupation, geographic etc.

The analysis involved five groups of occupations according to the Brazilian Classification of Occupations (CBO2002): agricultural workers (involving cane cutters), supervisors, tractor, other agricultural occupations (except cutters) and other non-agricultural occupations (managers, secretaries, drivers etc.).

The sugar-ethanol sector in CAGED is defined within the activities of the National Classification of Economic Activities (CNAE95) IBGE, namely the cultivation of sugarcane (agricultural sector), service activities related to agriculture (agricultural sector), sugar mills (industry), refining and milling of sugar (industry) and alcohol production (industry).

The category of workers that involves cutters accounts for about 70% of hires made in 2006 and 2007, with a slight decrease last year (2007).

What is observed is that regardless of occupation, and more strongly to the cane cutters there is a strong seasonal hiring. There are a large number of persons admitted during the harvest at the end of which is dispensed. The resulting balance between admitted and dismissed in addition to being low for the year 2007, decreased considerably compared to 2006.

For the socio-economic variables present in the CAGED was found that there are great differences in age, educational level and gender of the sugarcane cutters in relation to the other workers groups. The cutters are younger people (better productivity), while tractor operators, for example, are people with older age (more experience). It is observed also that the cutters and other agricultural occupations have less education as compared to tractor drivers and other non-agricultural occupations. Thinking in terms of relocation of the cutters, the quicker and easier would be to relocate to other agricultural functions.

The main concern from the social point of view, is whether there will be time for the retraining and relocation of cane cutters for other functions, either in the alcohol sector, or in other agricultural activities according to the progressive increase in the mechanization of cane harvesting and the mechanization of the agriculture as a whole.

In order to measure the impact of mechanization on workers employed in the harvesting of sugarcane it was estimated a rate of mechanization in the harvesting of sugarcane. With this parameter, and others also obtained for the harvest of 2007/08, as production of sugarcane (3.2 million t) and the amount of sugarcane harvested by a man in a day (8.76 t/day) and 132 days actually worked in the harvest, it was estimated that about 160 thousand people were involved in cutting sugarcane in São Paulo. This means it will be replaced around 2,700 cutters if the mechanization index increases 1% per year.

Demands for research on labor relations:

- Studies on the profile of the labor force employed in sugarcane.
- Studies on first job.
- Studies on layoffs.
- Studies of gender and age of the labor force.
- Studies on child labor.
- Studies of occupation in other agricultural activities and non-agricultural labor force employed seasonally in sugarcane.
- Studies on impacts of mechanization of planting and harvesting in labor relations.
- Studies on migration.
- Studies on impacts of crop productivity in health.
- Studies on the costs of mechanical harvesting x manual harvesting.
- Studies on land use and social occupation of land.
- Studies on the payment system for crop production in the sugarcane.
- Studies on industry competitiveness and the role of labor costs (wages and occupation).
- Studies on demands in their own employment-agricultural sector and other sectors.
- Studies on the payment of cane by productivity.

Discussion on environmental issues

Despite the favorable economic situation in which it is the sugarcane activity in recent years, the role of sugarcane production in regional development has been a much debated in the state of São Paulo. While sugarcane agribusiness seeks to highlight the international market, from the image of a clean production and been environmentally correct, that would be consistent with the environmental sustainability of the planet, workers and local communities who live with the system of production of sugarcane. However, there is another reality, marked by social problems and environmental problems, closely related to a chronically neglected with respect to environmental standards of the country.

If on the other hand, the production of alcohol from sugarcane contributed to the reduction of carbon emissions and the elimination of lead tetraethyl use in the fuels, with positive effects on air quality in large cities, contributing to reduce the greenhouse effect, on the other hand was highly pollutant in areas where it was produced.

This is shown by the aspects related to monoculture, which also negatively affect biodiversity. This has brought the need for intensive use of chemicals that pollute rivers, groundwater, soil, and cause imbalance of agroecology, and the practice of open field burning for the elimination of straw, which affects air quality, destroy soil microorganisms and fauna within the forest, and by pouring the vinasse and cane wash water in the rivers, which led to siltation and fish mortality for many years until the emergence of an alternative use for these wastes.

With regard to progress on environmental preservation areas, the data show that of 18.9 million hectares of farmland in the State of São Paulo, 4.4 million should be dedicated to environmental conservation, or preservation areas and legal reserves. However only 700 hectares fulfill this function, resulting in a debt of 3.7 million hectares.

Most historically “sugarcane” municipalities the state of São Paulo, as Barrinha Dumont, Guariba, Jaboticabal and Pradópolis, currently have less than 1% of natural vegetation, showing a direct relationship between the sugarcane monoculture and degradation of ecosystems. Areas of Permanent Protection (APP), which comprise the set of riparian forests, forests of slopes, headwaters of rivers and springs, defined by the Brazilian Forest Code, were extremely devastated by the expansion of plantations, and only began to be recovered thanks to the pressures State and the prosecutor, although in a very incipient maner.

Still, the evacuation of areas of Permanent Protection for reforestation has occurred at the expense of relocating the cane to areas occupied by other cultures, again focusing on reducing the state's agricultural diversityIn the other hand, the Legal Reserve Areas (ARLs) as defined by the forest code as areas located within a rural property or possession (excepting the permanent preservation), necessary for the sustainable use of natural resources, conservation and rehabilitation of ecological processes, the conservation of biodiversity and the shelter and protection of native fauna and flora, were virtually extinct in the land where grown sugarcane.

Researches conducted in several plants and sugarcane farms in the state, could not identify even one production unit that maintained legal reserve areas in farmland. In all these cases, when questioned about the problem, farmers and plantations owners proved to be outraged and adamant about any argument, stating that the maintenance of legal reserve areas for economically infeasible agricultural production in those properties.

Other issues stand in the relation between the current system or model of sugarcane production and the environment, such as the use and contamination of water resources, large-scale pesticide use, and use of fire.

The first point concerns over the impacts of sugarcane production on water resources refers to one of the most bulky waste generated in the process of obtaining alcohol: the vinasse, also known as stillage. The vinasse is produced at a rate of approximately 13 liters for every liter of alcohol produced. It consists mainly of water, salts, suspended solids and soluble. Because it is one of the most polluting waste and corrosive acids, which resists any kind of treatment usually used for other industrial waste, given their chemical characteristics, the search for an appropriate destination was one of the biggest challenges for the sector. Until the discovery of their potential as soil fertilizer in the mid-1980s, this waste was commonly disposed of in rivers or sacrifice areas, causing serious pollution and fish kills, and nuisance to the neighborhood caused by the bad smell of residue.

When not treated, the stillage becomes a dangerous pollutant, because the aerobic bacteria present in the juice voraciously consume the oxygen of the water, killing life in rivers. The stillage may be disposed in sacrifice areas, usually large storage tanks of the product. In this case, the environmental damage can be given to the contamination of groundwater and its overflow, which threatens the rivers.

Furthermore, when used properly, the stillage is transformed into a powerful organic fertilizer. The form of distribution and quantity of waste applied in the field, as well as its composition vary greatly from plant to plant, which makes it very worrying. Research has indicated that the areas of raw cane can absorb more liquid than the areas where burning is practiced. However there are few plants that have considered this fact in the application of liquid waste in the field, which means that there may be contamination of underground water and aquifers, not only by the waste, but also by pesticides and fertilizers, on the surface of the soil, and are carried into the subsurface.

Seeking to give more specificity to this issue in April 2005 CETESB issued a regulation, reissued in December 2006 (P4.231) defining the criteria and procedures for storage, transport and surface application of vinasse on the ground state of São Paulo.

In this regulation has been established the obligation to submit a "Vinasse Disposal Plan", until April 2nd each year, containing maps and the identification of application areas, channels, tanks, data on land, forms and dosages application, as well as chemical characterization of vinasse to be used (based on the previous season).

Another problem, the use of pesticides in plantations, although it does not seem dangerous, it represents a high risk to the environment, for its interference in ecological systems, and also on the health of local populations by contaminating water. To get an idea of the size of the problem, most of the inhabitants of the municipalities sugarcane consumes water collected from rivers in the region whose treatment does not retain such toxic substances. Other part receives water from aquifers whose recharge areas are in fact covered by cane fields.

Even with the advances obtained in the research field, which has enabled the replacement of many pesticides by alternative methods to control pests and diseases, such as breeding, biological control of pests and the production of insecticides, the use of some classes like herbicide remains high.

Recent studies show that persistence in the soil of the main herbicides used in sugarcane plantations in the region reach even two years, representing a high risk of contamination of rivers, groundwater and underground aquifers. Although there are alternative techniques for the management of weeds, few measures have been observed to reduce the use of such pesticides in the field.

Another problem, the practice of straw burning of cane fields, a solution was found in the past to resolve the issue of increasing the area planted with sugarcane without considerable increase in the cost of the labor force. A practice that has become customary in the majority of farms dedicated to its cultivation, with the main objective to facilitate and lower the cutting sugarcane costs by hand, being used even the mechanical cutting (within the so-called Australian method).

The use of fire as an agricultural practice in the sugarcane has a long time been condemned by experts in various fields, including engineers, biologists, scientists and doctors, despite the vehement opposition of technicians in the industry, claiming that such a practice facilitated the harvesting process, generate jobs, bringing security to the rural worker, and did not interfere negatively on the environment, because it is a fast, localized and controlled, and is still present in the speech of some entrepreneurs in the industry.

A number of studies were conducted warning about the serious risks that the burning of sugarcane has represented to human health. There are various respiratory problems caused mainly by organic compounds generated by combustion of straw, such as polycyclic aromatic hydrocarbons (PAHs), highly carcinogenic compounds, which are found among the gases that make up the "smoke" from burning cane fields.

The effects of burning cane fields before harvest, under the entomological point of view, is a modern subject, because the sugarcane agroecosystem is composed of many arthropods that play an important role in pest control and assisting in the decomposition and mineralization of soil organic matter.

Despite the fact that fire removes much of the insect pests, it also eliminates most of their natural predators, such as the Amazon fly and Cuban fly, which fight the sugarcane borer (Diatrea saccharalis) the major pest of this crop, causing ecological imbalance, which in turn necessitates the use of pesticides.

Although the fire is fast, because of all the preparation done in the cane fields before the fire, it is enough to destroy a still unknown number of species of fauna, from insects to larger predators, causing an ecological imbalance even greater than the practice of monoculture plantation.

The heterogeneous reality of the sector shows that the technology is perfectly capable of reducing environmental problems involving this production model marked by monoculture, by field burning and the use of agrochemicals.

However, the facts show that economic change has been possible only by the pressure exerted by the state and society in the sense of law enforcement, because of the importance of this sector, is that the economic advantages offered by the disrespect some environmental standards, as is the case of APPs, Legal Reserve Areas and the standardization of fire, still outweighs the benefits of ethical behavior to the consumer.

Demands for research for the environmental issue:

- Studies on impacts of fires on human health.
- Studies on effects of gas concentration by the use of fire.
- Studies of alternative techniques for the treatment of vinasse pollution and impacts on water resources by using this by-product non-treated.
- Studies on impacts on flora and fauna of the burning cane.

- Studies of alternative regional production systems of sugarcane in order to recover the legal reserve areas, APPs, riparian and watershed protection.
- Comparative studies of technical and economic methods of biological control and conventional control.

Discussion of the cane and its influence on food prices

The causes of the recent rise in food prices in 2008 in Brazil transcends the impact of sugar and alcohol production, because it is likely the structural sense, not just cyclical and is probably a trend driven by different forces, converging to, by different ways, generating an upward price cycle. This, now it is driven by external variables, but has a high probability of further fueled by internal factors.

These two factors sets (Asian demand and oil prices) would be able to produce short-term external inflationary pressures on food prices, as we faced in 2008, but not likely that this tension is continuously fed the same factors that propel the moment, unanswered production and trade over time as the cushion. The economic history is rich in revealing reversal of growth cycles in prices, changes in production techniques that fundamentally changed circumstances of particular markets and many other situations of innovation that eventually alleviate the inflationary pressures from oil and / or agricultural commodities.

But the cyclical tension on food prices in the Brazilian can become a structural problem for price stability or economic growth (or both), depending on the adjustment process of economic crises of the commodities that we follow. In this sense, there is evidence that Brazil has been pursuing a structural-adjustment in the Current Account Balance of Payments, where the export requirements of "food-grains", "feed-grains", "meat", products of forestry, agro and mineral products have become essential to compensate for the structural imbalance of the "Account Services" and the international trade in manufactured goods of higher technology.

That said, from agriculture and mining would be required in the next decade a growing of exports higher than output growth of these sectors (manufactured goods of higher technology) in order to gain positions in world trade – mainly in these supply chains.

Physical growth of agribusiness exports occurs at rates almost double the production growth in the period 2000-2008, and almost three times compared with domestic consumption, evidence that is taken as the trend continued, would certainly cause problems to domestic supply.

On the other hand, if you look at the projected future growth of production, consumption and exports of these products, we see that the trend of the previous period, on two fronts: a) production and consumption of cereals and grains direct human consumption grow at rates very low, below the population growth, and b) meat (beef and chicken), feed-grains (corn and soybeans) and alcohol, have projected export growth rates of twice the domestic consumption.

Inflationary pressures to which we refer in the beginning, tend to worsen if the pace of growth of production, consumption and exports in the coming years remains the same pattern observed in the seven previous years.

But the issue that now concerns, the impact of the exporter boom of commodities in food prices, is possible that the economic policy to seek new incentives for exports as the primary means of addressing the current account, even if the situation of deficit persistent and strong. This strategy certainly does not alleviate, but likely increases pressure on food prices.

However, there is evidence (that it is not shown here), that the Balance of Payments Account Services has expanded its deficit trends, particularly since 2004 when the economy showed signs of growth. That said, it seems likely that the next decade the export policy at all costs implemented in the period 2000-2008, is recalibrated and pursue the same trend in exports, production and consumption of food, "feed-grains"; meat and ethanol, to pursue the last seven years.

The economic situation (period 2000-2007), although pursue the same goal of adjustment of

1982/84, suggests a structural orientation to a certain specialization of foreign trade competitiveness of the primary sector. If this hypothesis is true the consequences tend to be worrying about the price of staple foods.

Thus, it seems that there are several lines of economic policy (not just one isolated policy to promote the replacement energy), which converge in the same direction as the significant increase in net export of primary sector in order to fill a role in mitigating the structural deficit of the external transactions of the country The implications of this policy have the following potential implications for what interests us here focus on:

1. Pressure on food prices, even in a situation of high exchange rate appreciation, as in 2008, this pressure is weakened by an environment of rising prices of foreign commodities.
2. Show the same trend is inflationary changes in exchange rate policy significantly alter the degree of recovery of the real exchange rate (to lower) the result of some broader policy of adjusting the Current Account of Balance of Payments.
3. In any of the above (1 and 2), management policies of inflation through interest, as has been the tendency of the Brazilian Central Bank, run to cut the growth in domestic demand and GDP, without affecting the specific causal focus on inflation real reasons.
4. The boom exporter shape especially in the production of feed-grains (soybeans and corn) and sugarcane crop in the year 2007 census, affecting the whole 55.8% of the crop. Meanwhile, as the exporter bias is also present in the cattle industry and the pulp and paper, should occur between these sectors intense competition for use of the exploitable area, with consequences of strong appreciation and speculation about the price of land.
5. It is inevitable that the expansion combined of feed-grains, sugarcane, livestock and plantations for pulp and paper, to the rhythm that requires them to consider the external accounts – exert strong pressure by the addition of new areas of culture crops. Just note that between 1995 and 2006 (planting dates of their agricultural censuses) the expansion of crop areas was 34.9 million hectares (83.5% in eleven years), which means the annual rate of increase of 5.7% per year on average.
6. There is evidence that the expansion of the sugarcane as a paradigm of what happens in other agro-export chain, with the features now described happens with falling occupancy of the workforce, because the heavily mechanized production processes adopted. But even when these processes have not yet been adopted – the case of cane-hand cutting conditions are over-exploitation, with severe consequences for the morbidity of the workforce.
7. The various consequences of setting the Balance of Payments by the primary sector, with the election of specific alcohol sector to star in a World Proálcool-configure a pattern of "reprimarization" of the Brazilian economy, characterized by increase in social inequality. It also reveals the possible effects of inflation, which antidotes of economic policy in consistent use by the Central Bank cut every incentive to spread in domestic demand.
8. Ultimately, the model set by the export of primary Balance of Payments becomes the explicit strategy to transfer the "net income sent abroad" in liquidity crises. When the external liquidity is loose, this primary-export policy, act as guarantor for the management of the deficit "Account Services" until the next crisis of liquidity outside of the Balance of Payments.

Demands for research on the issue of impacts on prices:

- Studies on the U.S. policy of ethanol that directly impacts food prices worldwide.
- Studies on the deepening of protectionist agricultural policies of developed countries.
- Studies on the role of reprimarization of exports and inflation effects arising.

FINAL CONSIDERATIONS

It is our belief that a first and important contribution is the fact that the workshop participants have debated and raised questions for discussion by scholars and police makers. This group is not far from the concept of stakeholders, and comprising relevant actors of the context.

Although in many measures, seems to point problems and their causal relationships is to say what should not, want to be away from this moralistic view on the premise that the complexity of economic and social forces to ever break even for researchers The attitude of commitment to equitable development of humanity, and last main body to be pursued (which is no longer a profession of faith, so full of ethical content), but always mark out the analysis for comparison of theory and facts in his light.

On the land issue must be pointed out two sets of policies: the first is general and concerns the need for change in legislation and land policy. It can be argued that few countries have the world's land law as permissive as that of Brazil. The second one is related specifically to the *modus operandi* of the agents of the economically strongest sugarcane agribusiness in Brazil, in the case of the need for discipline regarding the cane owned by the mill itself. It can be milled, as well as define other rules in respect of the provision of sugarcane by independent producers and their associations.

After all, the indications are that the main characteristic of the agrarian base of our sugarcane agro-industry remains extended, and it is the feature that promotes exclusive ownership of income and, thus, contributes greatly to increase the concentration of wealth that has marked the history of Brazil.

From the social point of view on the issue of labor and employment, given the speed with which we see the reduction of occupation by the substitution of machine harvesting sugarcane, the main concern from the point of view, is whether there will be timely for retraining and relocation of cane cutters for other functions, either in the alcohol sector, or in other agricultural activities according to the progressive increase in the mechanization of cane harvesting and mechanization in general own agriculture.

Therefore, it is urgent not only to draw public policies aimed at retraining workers, but it should think, at least at minimum revenue policies for those who may not have better conditions of employment or retraining.

On environmental issues, in turn, the facts show that the economic change from the side of environmental sustainability has been possible only when there is pressure from the state and society towards the enforcement of laws, because what we notice is that the economic advantages offered by the disrespect some environmental standards still override the benefits of ethical behavior to the consumer. Moreover, one should not forget that there is always pressure on the side of the external market, so there is demonstration of mitigation on the side of environmental sustainability.

Finally, upward pressure on food prices by the expansion of sugarcane, the angle of macroeconomic analysis can be analyzed through the various consequences of the adjustment of balance of payments and this leads to consider the nature of the problem as being much more structured than cyclical, since the reprimarization the Brazilian economy and the need to revise the standard.

The analysis conducted on these four topics listed possible to derive findings and conclusions referenced above and also from them one can deduce a number of needs for research studies, composed of:

1. Studies on the regulatory role of the state in land use and spatial alcohol sector vis a vis the political power of the alcohol sector.
2. Studies on economic viability of non-vertical structures of raw material versus the vertical structure of existing production.
3. Studies on the formation of economic groups and their business strategies.
4. Studies on the impact of mechanization of planting and harvesting in labor relations.
5. Studies on the payment system for crop production in the sugarcane.
6. Studies on alternative processing techniques vinasse pollution and impacts on

water resources by using the by-product non-treated.

7. Studies on alternative regional production systems of sugarcane in order to recover the legal reserve areas, APPs, riparian and watershed protection.
8. Comparative studies on technical and economic methods of biological control and conventional control.
9. Studies on the deepening of protectionist agricultural policies of developed countries.
10. Studies on the role of reprimarization of exports and inflation effects arising.

10

GREENHOUSE GASES EMISSIONS RELATED TO SUGARCANE ETHANOL

Joaquim E. A. Seabra, Isaías Carvalho Macedo and *Manoel Regis Lima Verde Leal*

INTRODUCTION

One of the main objectives of biofuels use is the replacement of fossil fuels, contributing to the reduction of dependency on fossil fuels and mitigation of greenhouse gases (GHG) emissions. But the effectiveness of such substitution depends in the way the biofuel is produced. Since all processing technologies involve direct or indirectly the use of fossil resources, the real benefit of a biofuel depends on the net fossil energy savings resulted from its use, also taking into account the GHG emissions associated to its lifecycle.

The environmental advantages of sugarcane-based ethanol, regarding gasoline substitution and GHG emissions mitigation, have been acknowledged since the first comprehensive energy balance and GHG emissions studies were available (Silva *et al.*, 1978; Macedo and Nogueira, 1985; Macedo, 1992). Updating studies have been published since then (Macedo, 1998; Macedo *et al.*, 2004), following the changes in the sugarcane sector and the new parameters for environmental analysis. But the rapid growth of the cane sector in Brazil in the last decade, associated to some legal constraints and technology development are changing important parameters in this evaluation. New cane varieties and productivity, the legal restrictions to sugarcane burning practice and the increased mechanization influence the energy and emissions balance in different ways. Furthermore, cane mills started a strong action in selling electricity surplus, and the use of portion of the cane trash for energy will be seen in the next years. Finally, the ethanol use technology has changed, with the growing fleet of flexible-fuel vehicles.

Recent works (Macedo *et al.*, 2008; Macedo and Seabra, 2008) evaluated the energy balance and GHG emissions for the current situation and for projected scenarios, considering the effects of employment of different technologies in the sugarcane sector. This chapter reports the main results of these studies, as well as the results presented by the main international initiatives promoting the use of biofuels. A brief discussion about the potential of mitigation associated to the Brazilian ethanol is also presented.

ENERGY BALANCE AND GHG EMISSIONS IN ETHANOL LIFECYCLE

Macedo and Seabra (2008) evaluated the energy balance and GHG emissions of the sugarcane sector in 2006 and the expected changes for 2020, considering the effects of the employment of different technologies. Two scenarios were evaluated in the future case: one based on the maximum electricity generation through steam cycles (*2020 Electricity* scenario), and a second one based on the ethanol production from biochemical conversion of the surplus ligno-cellulosic material (*2020 Ethanol* scenario). In both scenarios, 40% of the trash available in the field would be collected to be used as energy source at the mill.

The 2006 results are based on 2005/2006 average conditions, with the best available and comprehensive data from the Brazilian Center-South Region (Macedo *et al.*, 2008). Note that

GHG emissions/mitigation are evaluated for each Scenario specific conditions; scenario implementation schedules are not presented (or needed) for the objective of this kind of study.

However, it must be said that the Electricity Scenario implementation is occurring now in all Greenfield operations, and already in some retrofit of existing units. The Ethanol Scenario, as proposed, still depends on technological development of the biomass hydrolysis/fermentation processes, and it would take longer to be implemented to a significant level in the context of the Brazilian ethanol production (Seabra, 2008).

The data used for 2006 is for a sample of 44 mills (100 M t cane/season), all in the Brazilian Center South. Data have been collected/processed for the last 15 years, for agriculture and industry, for the CTC "mutual benchmarking". The 2020 parameters are authors' projections, based on cane specialists' estimations, while industrial parameters are simulation results, using parameters from the literature.

The systems boundaries considered for the energy flows and GHG emissions and mitigation include sugarcane production, cane transportation to the industrial conversion unit, the industrial unit, ethanol transportation to the gas/petrol station, and vehicle engine performance. Emissions from direct energy use were considered, as well as emissions from cane trash burning in the field and soil emissions, derived from fertilizers application, limestone and residues returned to the soil (stillage, filtercake and cane trash). Emissions mitigation was assessed considering the substitution of ethanol, surplus bagasse and electricity respectively for gasoline, fuel oil and natural gas thermoelectricity.

The results for energy balance and emissions are presented in Tables 1 and 2, respectively. Note that the differences in total emissions are strongly dependent on the co-products credits. The complete elimination of trash burning practice in the 2020 is an important aspect, but the major difference between 2006 and the 2020 scenarios

TABLE 1 Energy balance in anhydrous ethanol production (MJ/t cane)[a].

	2006	2020 Electricity	2020 Ethanol
Fossil energy input	235	262	268
Cane production	211	238	238
Cane farming	109	142	143
Agr. inputs	65	51	50
Transportation	37	45	45
Ethanol production	24	24	31
Chemicals	19	20	25
Equip. and buildings	5	4	6
Renewable energy output	2,198	3,171	3,248
Ethanol[a]	1,926	2,060	2,880
Electricity surplus[b]	96	1,111	368
Bagasse surplus[a]	176	0	0
Energy ratio	9.4	12.1	12.1

[a] Based on LHV (Low Heating Value).

[b] Considering the substitution of biomass-electricity for natural gas-electricity, generated with 40% (2006) and 50% (2020) efficiencies (LHV).

TABLE 2 Total emissions in ethanol life cycle (kg CO_2eq/m^3 anhydrous)[a].

	2006	2020 Electricity	2020 Ethanol
Cane production	417	326	232
Farming	97	117	91
Agr. inputs	57	43	23
Transportation	32	37	26
Trash burning	84	0	0
Soil emissions	146	129	92
Ethanol production	25	24	22
Chemicals	21	20	19
Equip. and buildings	4	4	3
Ethanol distribution	51	43	43
Credits			
Electricity surplus[b]	-74	-803	-190
Bagasse surplus[c]	-150	0	0
Total	269	-409	107

[a] Emissions for hydrous ethanol/m^3 are about 5% less than values verified for anhydrous ethanol.
[b] Considering the substitution of biomass-electricity for natural gas-electricity, generated with 40% (2006) and 50% (2020) efficiencies (LHV).
[c] Considering the substitution of biomass fuelled boilers (efficiency = 79%; LHV) for oil fuelled boilers (efficiency = 92%; LHV).

is due to an actual increase in the system energy efficiency (greater energy output).

This indicates the importance of the better use of sugarcane's energy for further improvements of the already huge potential of ethanol as a good alternative for GHG emissions mitigation. It is worth mentioning that other more efficient technology routes for biomass use will raise in the future, which may lead to even greater environmental benefits related to cane ethanol (see Chapter 18, Part 4).

TABLE 3 Avoided emissions due to ethanol use (t CO_2eq/m^3 anhydrous or hydrous).

	Ethanol use[a]	Avoided emissions[b]	Net emissions[c]
2006	E100	-2.0	-1.7
	E25	-2.1	-1.8
2020 Electricity	E100	-2.0	-2.4
	FFV	-1.8	-2.2
	E25	-2.1	-2.5
2020 Ethanol	E100	-2.0	-1.9
	FFV	-1.8	-1.7
	E25	-2.1	-2.0

[a] E100, or HDE: hydrous ethanol in dedicated engines; FFV: hydrous ethanol in flex-fuel engines; E25: anhydrous ethanol (25% volume) and gasoline blend.
[b] Avoided emission (negative values) due to the substitution of ethanol for gasoline; fuel equivalencies verified for each application in Brazil (MACEDO *et al*., 2008).
[c] Net emission = (avoided emission due to ethanol use) + (ethanol life cycle emission). Co-products credits are included.

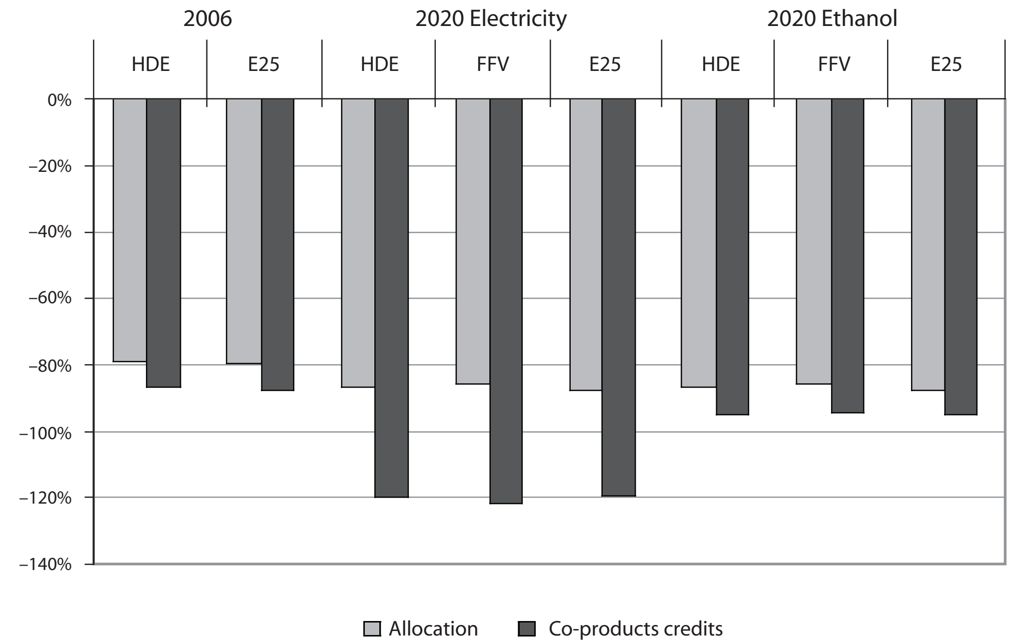


FIGURE 1 GHG mitigation with respect to gasoline: allocation or co-products credits.

GHG emissions mitigation with respect to gasoline is presented in Figure 1, for the different ethanol uses in Brazil. The figure also shows the impacts of emissions allocation (based on energy content of the co-products) in comparison to the substitution criterion for ethanol co-products credits evaluation. The detailed results using the substitution criterion is presented in Table 3.

CO_2 emissions due the direct land use change were assessed in the study as well, using the cane expansion analysis presented by Nassar *et al*. (2008), data for soil carbon stocks from Amaral *et al*. (2008) and the IPCC methodology to estimate land use change emissions. As indicated in Table 4, negative emissions were verified in all scenarios, due to the increase of soil carbon stocks. This was expected, since the expansion areas for sugarcane include a very small fraction of native lands with high carbon stocks, and some degraded land (Macedo and Seabra, 2008). As for the indirect land use change effects, the authors suggest that within its soil and climate limitations, the strict application of the environmental legislation for the new units, and the relatively small areas needed (~5 Mha, until 2020), the expansion of sugarcane until 2020 is not expected to contribute to ILUC emissions. More details about the indirect land use change is presented in Chapter 11.

INTERNATIONAL ANALYSIS

Even though there is no consensus on the basic principles about the sustainability of biofuels, the need to lead to GHG emissions reduction (compared to the equivalent fossil option) is one of the most relevant aspects. With such goal, international initiatives aimed at promoting the use of biofuels have been established in different countries, paying attention to other sustainability criteria as well. In this section we present the analyses of the main international programs on the GHG emissions related to the sugarcane ethanol life cycle.

EU Directive

The European Union Directive on the promotion of the use of energy from renewable sources established a mandatory target of a 20% share of energy from renewable sources in overall Commu-

TABLE 4 Emissions associated with LUC to unburned cane.

Reference crop	Carbon stock change[a]	Emissions (kg CO_2eq/m³)		
	(t C/ha)	2006	2020 Electricity	2020 Ethanol
Degraded pasturelands	10	-302	-259	-185
Natural pasturelands	-5	157	134	96
Cultivated pasturelands	-1	29	25	18
Soybean cropland	-2	61	52	37
Maize cropland	11	-317	-272	-195
Cotton cropland	13	-384	-329	-236
Cerrado	-21	601	515	369
Campo limpo	-29	859	737	527
Cerradão	-36	1040	891	638
LUC emissions[b]		-118	-109	-78

[a] Based on measured values for below and above ground (only for perennials) carbon stocks.

[b] Considering the following LUC distribution – 2006: 50% pasturelands (70% degraded pasturelands; 30% natural pasturelands), 50% croplands (65% soybean croplands; 35% other croplands); 2020: 60% pasturelands (70% degraded pasturelands; 30% natural pasturelands); 40% croplands (65% soybean croplands; 35% other croplands). Cerrados were always less than 1%.

nity energy consumption by 2020, and a 10% share in transport. According to the sustainability criteria defined by the Directive, the energy from biofuels should be taken into account in the national targets only if the GHG emission saving from their use is at least 35%, when compared to the equivalent fossil (petrol or diesel). With effect from 1st January 2017, such emissions saving should be at least 50%, and from 1 January 2018, at least 60% for biofuels and bioliquids produced in installations in which production started on or after 1st January 2017.

In order to avoid a disproportionate administrative burden, a list of default values was laid down for common biofuel production pathways. For the Brazilian sugarcane ethanol (used in Europe), the default value is 24 g CO_2eq/MJ, which leads to an emission saving of 71% compared to gasoline (see Table 5). The Directive imposes that the land use change emissions should be taken into account, using a proposed methodology. A bonus of 29 g CO_2eq/MJ could be applied if biomass is obtained from restored degraded land under specific conditions provided by the Directive. As for the indirect impacts of the land use change, the Directive states that the Commission should develop a concrete methodology to minimize greenhouse gas emissions caused by indirect land-use changes. To this end, the Commission should analyze the inclusion of a factor for indirect land-use changes in the calculation of greenhouse gas emissions and the need to provide greater incentives to sustainable biofuels which minimize the impacts of land-use change and improve biofuel sustainability with respect to indirect land-use change.

RTFO

The Renewable Transport Fuels Obligation (RTFO) requires suppliers of fossil fuels to ensure that a specified percentage of the road fuels they supply in the UK is made up of renewable fuels. The target for 2010/11 is 3.5% by volume. Emissions reductions with respect to the equivalent fossil fuel should be 50%, taking also into account the emissions due to land use change wherever possible. Default values considered for the sugarcane ethanol produced in Brazil and used in Europe are presented in Table 6.

TABLE 5 EU Directive disaggregated default values for the Brazilian sugarcane ethanol pathway.

Step	Default value (g CO_2eq/MJ)
Cultivation (e_{ec})	14
Processing ($e_p - e_{ee}$)	1
Transport and distribution (e_{td})	9
Total	**24**
GHG emission saving	**71%**

Source: EU DIRECTIVE, 2009.

CARB

Through the regulation referred as the California Low Carbon Fuel Standard (LCFS), the Air Resources Board (ARB/Board) staff is proposing to reduce emissions of greenhouse gases by lowering the carbon content of transportation fuels used in California. One standard is established for gasoline and the alternative fuels that can replace it. A second similar standard is set for diesel fuel and its replacements. Each standard is set to achieve an average 10 reduction in the carbon intensity of the statewide mix transportation fuels by 2020. In addition, the LCFS is designed to reduce California's dependence on petroleum, create a lasting market for clean transportation technology, and stimulate the production and use of alternative low-carbon fuels in California. Reformulated gasoline mixed with corn-derived ethanol at 10 percent by volume and low sulfur diesel fuel represent the baseline fuels.

Emissions from land use change were included in the evaluation for biofuels. Using the GREET and GTAP (to assess land use changes) models, different biofuels pathways were analyzed. The original pathway document for sugarcane ethanol, published in February 2009, was for baseline ethanol produced in Brazil, transported to and used in California. The emissions were estimated as 27.4 g CO_2eq/MJ, plus 46 g CO_2eq/MJ due to land use change (see Table 7). Two other scenarios were later added to the analysis, incorporating issues related to the mechanical harvesting and the electricity co-product credits (see Table 8). Innumerous critics were raised with respect to the land use change analysis, and committees were assembled in order to improve the analysis. In the future new values should be reported by the Board.

EPA

The Renewable Fuel Standard (RFS) program was created under the Energy Policy Act (EPAct) of 2005, and established the first renewable fuel volume mandate in the United States. The Energy Independence and Security Act of 2007 (EISA) increased the volume of renewable fuel required to be blended into transportation fuel from 9 billion

TABLE 6 Fuel chain summary for Brazilian sugarcane ethanol under the RTFO.

Module	Carbon intensity (kg CO_2eq/t etanol)
Crop production	348
Feedstock transport	49
Conversion	0
Liquid fuel transport	93
	175
Total	**665**

Source: RFA, 2008.

TABLE 7 GHG emissions summary for sugarcane ethanol.

Components	GHG emissions (g CO_2eq/MJ)
Sugarcane farming	9.9
Ag chemicals production and use impacts	8.7
Sugarcane transportation	2.0
Ethanol production	1.9
Ethanol T&D	4.1
LUC	46
Total[a]	**73.4**

[a] Include emissions from ethanol combustion.

Source: CARB, 2008.

TABLE 8 Summary of baseline pathway and two additional scenarios.

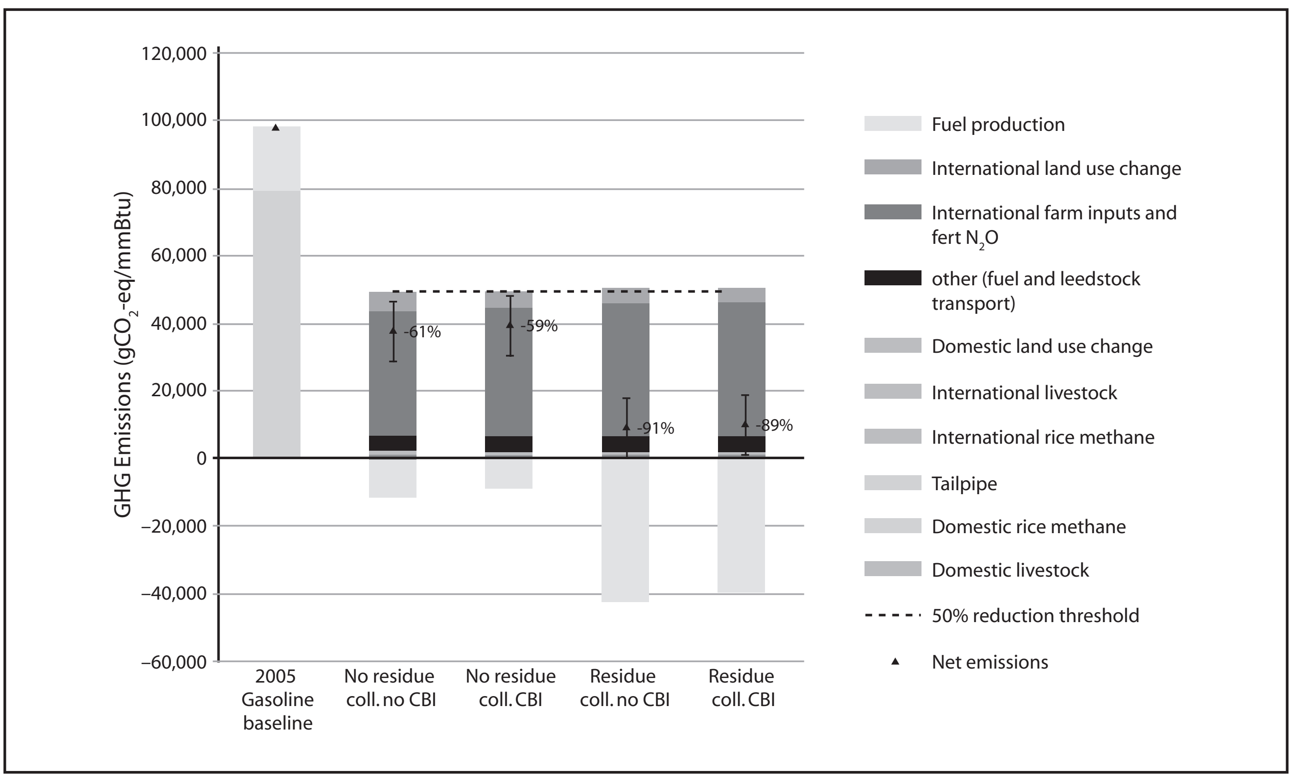
Pathway description	WTW GHG emissions[a] (g CO_2eq/MJ)
Baseline Pathway Brazilian sugarcane using average production process	27.40
Scenario 1 Brazilian sugarcane with average production process, mechanized harvesting and electricity co-product credit	12.20
Scenario 2 Brazilian sugarcane with average production process and electricity co-product credit	20.40

[a] LUC emissions are not included.

Source: CARB, 2009.

gallons in 2008 to 36 billion gallons by 2022, and established new categories of renewable fuel (conventional and advanced biofuels) and set separate volume requirements for each one. The term advanced biofuel (e.g., ethanol derived from sugar or cellulose) means renewable fuel, other than ethanol derived from corn starch that has lifecycle greenhouse gas emissions and at least 50% less than baseline lifecycle greenhouse gas emissions.

In the original evaluation, the US Environmental Protection Agency (EPA) estimated the GHG emissions reduction related to the Brazilian sugarcane ethanol as 44% (100 years, 2% discount rate), including the effects due to land use change. The analysis was later revised for the Regulatory Impact Analysis, and aspects related to direct emissions as well as indirect effects were changed. Four scenarios were evaluated, considering pathways assuming most crop residue of the leaves as well as stalks would be collected (and therefore available for burning as process energy) or without the extra crop residue being neither collected nor burned as fuel. EPA also analyzed pathways assuming the ethanol is distilled in Brazil or alternatively being distilled in the Caribbean (CBI). The



Source: EPA, 2010.

FIGURE 2 EPA results for sugarcane ethanol by lifecycle stage with and without residue collection and CBI.

emissions reduction for these scenarios ranged between 59% and 91%, as indicated in Figure 2.

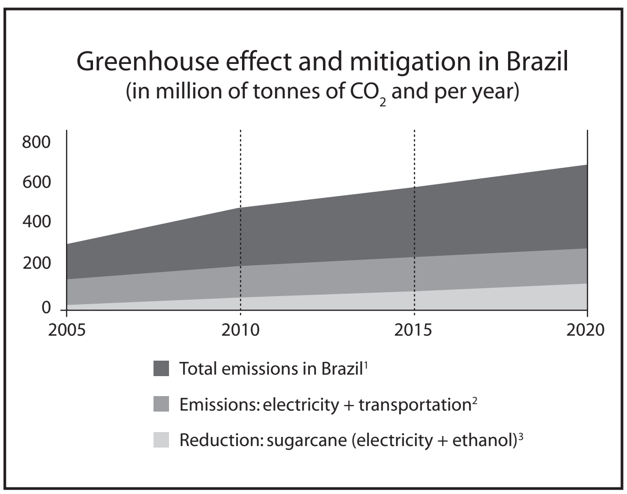
ETHANOL AVOIDED EMISSIONS IN THE BRAZILIAN CONTEXT

The contribution of sugarcane ethanol for GHG emissions mitigation in Brazil is substantial. Meira Filho and Macedo (2009) show that in 2006 the mitigation related to ethanol (and cogenerated electricity surplus) represented 22% of final emissions from the Transportation and Electricity sectors, and it could represent 43% in 2020 (see Figure 3). Total emissions in Brazil in 2006 (related to energy, production and use, in all sectors) were 350 Mt CO_2eq, and they are projected to reach 720 Mt CO_2eq in 2020 (EPE, 2007 apud Meira Filho and Macedo, 2009). Considering such values, the ethanol sector avoided the equivalent of 10% of 2006 emissions, and would be able to avoid 18% in 2020.

In the current scenario, climate change may bring to the countries important adaptation costs; one option is to reduce the negative effects through emissions mitigation, which could lead to lower damages and adaptation costs. Recent analyses indicate the need to stabilize atmospheric CO_2 concentration at 450 ppm. For such level, the mitigation costs could reach US$ 180 per tonne of CO_2 avoided between 2020 and 2030 (Souza and Macedo, 2009).

Meira Filho and Macedo (2009) estimated, thus, the mitigation cost related to the sugarcane ethanol, assuming the gasoline displacement and electricity surplus. Based on an average mitigation capacity of 2 t CO_2eq/m^3 and a mitigation cost of US$ 100 per tonne of CO_2eq, the authors calculated the additional value of ethanol as US$ 0.20 per liter. This value (i.e. additional to the equivalent value of the displaced gasoline) represents one of the externalities of the ethanol use, which is not remunerated (internalized), but should be considered in the elaboration of policies to support ethanol production and use.

The use of biofuels worldwide may be an important tool to meet the emission targets established to control global warming. As an example, the effect on global temperature of the ethanol use in Brazil as a substitute for gasoline could be assessed. Meira Filho and Macedo (2009) estimated that the increase of planet's mean temperature would be 0.0004 °C higher in 2100, if ethanol use remained at the same level of 1990. Similarly, the increase of the atmospheric CO_2 concentration would be 0.05 ppm higher (see details in Meira Filho and Macedo (2009)).



[1] Excluding deforestation. Estimates: EPE, PNE 2030.
[2] Emissions from the transportation and electricity sectors. Estimates: EPE, PNE 2030.
[3] Mitigation, sugarcane: ethanol + electricity (scenario study).

Source: SOUZA e MACEDO, 2009.

FIGURE 3 GHG emissions mitigation related to ethanol use in Brazil.

FINAL CONSIDERATIONS

At present the use of cane ethanol as a substitute for gasoline represents one of the main options for GHG emissions mitigation. Despite the uncertainties related to the impacts of direct and (mainly) indirect land use change, it is not likely that the cane expansion in Brazil would lead to higher ethanol emissions, because of the combination of the relatively low demand for new areas and the great potential for areas release due to the conversion of low grade pasture (most of them degraded pasturelands). Regardless, this topic deserves intensive research efforts, aimed at the development of suitable methodologies and analysis tools, in addition to the collection/production of more accurate data on the carbon stocks for different crops and native vegetation.

N_2O emissions derived from N-fertilizers application and residues that are returned to the soil deserve special attention as well. Studies (e.g., Crutzen *et al.*, 2008) suggest that emission factors provided by IPCC underestimate nitrous oxide emissions, and some experimental results pointed to the same direction for particular cases in specific regions (Allen *et al.*, 2010; Denmead *et al.*, 2009). However, it is important to note the huge variability of these emissions with respect to climate, soil, crop, tillage practices etc. Recent experimental analyses (Boddey, 2009) have showed that, for the Brazilian case, the emission factors would be even lower than those reported by IPCC.

Finally, cane ethanol co-products must be highlighted. Today the electricity surplus became a consolidated product of the cane mills, and a rapid growth is expected for the near future. Furthermore, as indicated in this work, as other more efficient technologies using sugarcane residual cane biomass are employed in the future, the environmental benefits related to the sugarcane products could be even greater.

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11

LAND REQUIREMENTS FOR PRODUCING ETHANOL IN BRAZIL

Luís Augusto Barbosa Cortez, Manoel Regis Lima Verde Leal, André Meloni Nassar, Marcelo M. R. Moreira, Sabrina Feldman, Miguel Taube-Netto and *Andres da Silva*

INTRODUCTION

Biofuels production depends essentially of: solar energy, fertile land, water, atmosphere (with oxygen and carbon dioxide), in addition to human and financial resources as infrastructure and investment. From all factors, land usage may be the one that expresses the most limiting physical restriction on the planet. A study by Doornbosch and Steenblik (2007) on the land availability for bioenergy in the world (see Table 1 below) evidenced that the availability of proper land for bioenergy production is concentrated in two continents, South America and Africa.

The land areas shown as available indicate previous deduction of the areas required for future food agriculture, urbanization, and infrastructure, as well as areas having potential for agricultural use, but that are occupied by forests, and some reserved for grazing. The total 440 million hectares is a reasonable land area to supply future biofuel demands, as long as high-yield raw material options are selected, such as sugarcane, palm (*dendê*), and beets, as shown on Table 2 and in the following text. It is important to notice that from this total, 250 Mha are located in Central and South America, and 180 Mha are in Africa, comprising 90% of the total. In spite of its wide land availability for bioenergy production, Africa does not have the infrastructure, technology, and qualified labor, in addition to social and political instability that will hamper large-scale bioenergy production on the short to mid-term.

TABLE 1 Land available for producing biomass for energy in the world in 2050 (Gha).

Region	Total land	Rain-fed cultivation land	Adequate land, covered with forest	Plowable lands in use	Land that will be necessary in the future for buildings, food, and infrastructure	Additional available lands	Land for bioenergy
North America	2.1	0.4	0.1	0.2	0.0	0.00	0.00
South & Central America	2.0	0.9	0.3	0.1	0.1	0.25	0.25
Europe	2.3	0.5	0.1	0.2	0.0	0.08	0.04
Africa	3.0	0.9	0.1	0.2	0.1	0.44	0.18
Asia	3.1	0.5	0.0	0.6	0.1	-0.07	-0.07
Oceanía	0.9	0.1	0.0	0.1	0.0	0.04	0.04
Total	13.4	3.3	0.8	1.5	0.3	0.74	0.44

Source: DOORNBOSCH and STEENBLIK, 2007

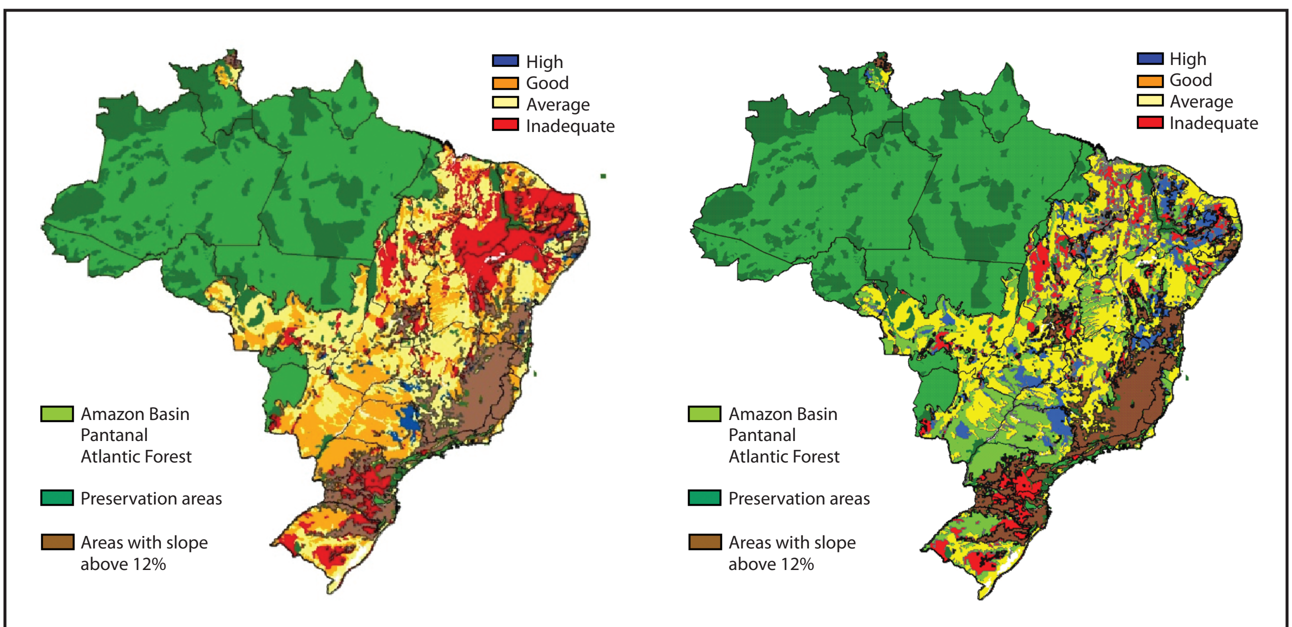
TABLE 2 Land required to replace 10% of current world consumption of gasoline and diesel[1, 2].

Biofuel	Raw material	Yield (t/ha)	Necessary land (Mha)
Ethanol	Sugarcane in Brazil	6,000	25
Ethanol	Sugarcane in the world average	4,550	33
Ethanol	Corn in the USA	3,500	43
Ethanol	Corn in the world average	1,960	77
Biodiesel	Soybeans	500	270
Biodiesel	Castor Beans	500	270
Biodiesel	Palm trees in Malaysia	4,700	29

[1] 150 billion liters (120 billion liters of gasoline)
[2] 135 billion liters (120 billion liters of diesel)

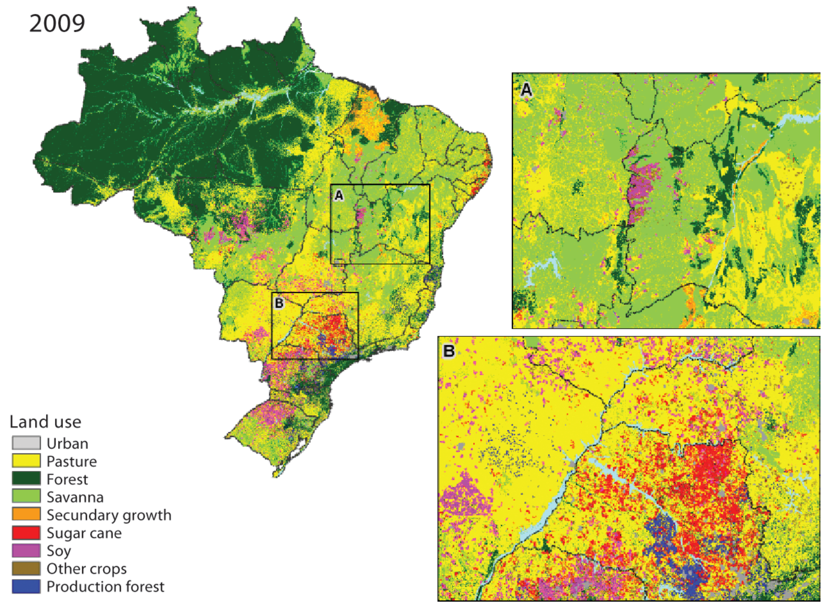
Source: prepared by the authors of this chapter. Data from world averages and other FAO countries, 2008.

In another study carried out by Leite *et al.* (2009) the conclusion was that to replace the equivalent to 10% of all the gasoline to be consumed in the world in 2025, estimated in 1.7 trillion liters/year, 204 billion liters/year of ethanol would be required. To produce such volume from sugarcane in Brazil, about 34 million ha would be needed, considering an annual agro-industrial production of 6,000 liters of ethanol/ha. The same study mapped the Brazilian regions suitable for cultivating sugarcane according to their different productivity levels due to soil and climate (Figures 1 and 2). Even excluding the Amazon, Pantanal, and steep sloped areas, the study showed that there are areas with high yield (81.4 t/ha) 7.9 Mha; medium yield (71.3 t/ha) 113.9 Mha; low yield (64.8 t/ha) 149.2 Mha, totaling 271.0 Mha. This area could produce around 18.6 billion tons



Source: LEITE *et al.*, 2009.

FIGURE 1 Potential for sugarcane without irrigation (left) and with irrigation (right).



Source: GOUVELLO, 2009.

FIGURE 2 Use of land and changes in the use of land in Brazil.

of sugarcane. However, with salvage irrigation, the total of adequate land (303.6 Mha) could produce around 21.1 billion tons of sugarcane.

On the other hand, the quantity of land required to replace a fraction of the petroleum derivates consumption strongly depends – as it is known – on the raw material used and its agricultural yield. Table 2 makes it clear that sugarcane ethanol and palm tree biodiesel are the ones presenting the best agro-industrial yields. Here the importance of agricultural productivity is noticeable, strongly influencing the use of land, as well as the fact that some cultures, like sugarcane, are able to produce their own processing fuel (bagasse), still leaving the trash, with all its unexploited energy potential.

This demand for land for biofuel production has aroused some reaction, mostly from developed countries, markedly Europe and the USA, about a possible conflict in using fertile land around the world to produce food versus biofuels, on top of causing undesirable environmental impacts (SEXTON *et al.*, 2009; FAO, 2008).

It is worth mentioning that the use of land for agricultural purposes in the world is around 1.5 billion ha. Comparatively, the use of land for producing biofuels, including ethanol from corn in the USA, from cereals in Europe, and sugarcane in Brazil is around 25 million ha, i.e., about 1.6% of the total. Additionally, the land used today for pastures in the world are close to 3.5 billion ha, being 200 million in Brazil, i.e., almost 25% of the total area of the country.

Obviously, these points related to fertile land usage in the world are an issue that includes discussing the planet's support, i.e., how many we are and how many we will be, and what is the food consumption pattern for this population. A very important point to be considered is the improvement of pasture usage, as it has enormous potential for clearing lands adequate for agriculture; an increase of only 10% of pasture productivity would free 350 Mha for cultivating food or bioenergy.

It is important to stress the political and commercial features of this discussion, since there is a strong agricultural protectionism in the developed countries, which now see their markets threatened by "modern bioenergy", which can be exported. In this sense, it is important to mention that when bioenergy is not exported, like e.g., "traditional bioenergy", no further concern and criticism in the marketplace is given to it. Traditional bioenergy represented 10% of the energy consumed in the world in 2006, while modern bioenergy used in transportation represented only 0.3% (REN21, 2008). The exact quantity of land used for producing traditional biomass is unknown, also for its extractivism characteristics.

An estimate of breakdown of biomass use in 2006 was attemped by by Goldemberg (2007), and summarized in Table 3.

According to the table above, traditional biomass, and manure, used with extremely low efficiency) represents over 80% of the total biomass used for energy generation purposes; biofuels comprise only 1.5% of the total. The annual biomass production through photosynthesis is estimated at 3,000 EJ, hence little more than 1.5% of this total is exploited as a source of primary energy. The conversion of traditional biomass into modern biomass represents a major challenge, and is a tremendous opportunity to improve efficiency and sustainability in using this important source of primary energy.

This demand for land for bioenergy has raised considerable debate worldwide, also fueled by relatively new concepts such as direct land-use change (LUC), and more recently by indirect land-use change (ILUC). While methodologies for estimating LUCs have demonstrated a reasonable reliability level, determining ILUCs with minimum reliability remains a challenge. The mathematical models used in ILUC studies show a series of limitations and inconsistencies, presented in detail in ORNL, 2009.

TABLE 3 Biomass end use (2006).

	Mtep	EJ
Traditional biomass	950	40
Modern biomass	216	9.01
Bioethanol	16	0.67
Biodiesel	1.6	0.07
Electricity	32	1.33
Heat	166	6.94

Source: GOLDEMBERG, 2007.

USE OF AGRICULTURAL LAND IN BRAZIL

Soil in Brazil is considerably anthropized in this early 21st Century, i.e., its surface is considerably modified by human action, which removed most of the original vegetal topping/cover, exception made to the Amazon and the Pantanal. The only region in Brazil that preserves its original vegetation, at least by 80%, is the North Region, precisely where the Amazon is, the region with the widest biodiversity in Brazil, and precisely where the sugarcane culture is virtually inexistent.

Another point to be made is that sugarcane expansion for ethanol production will take place almost completely in lands currently taken up by pastures, but which were originally covered by medium complexity bushes (*"cerradão"*). This means that over more than a century ago these areas were deforested, today being occupied by low-productivity pastures. Therefore, the change in land use in Brazil for the sugarcane expansion will take place in Center-West regions, in either degraded pasture or low-productivity land (< 0.7 UA/ha).

Data from *Instituto Brasileiro de Geografia e Estatística* – IBGE, (Table 4) show sugarcane as the third agricultural activity in the country, after soybean with about 21 Mha, and corn with 14 Mha. Sugarcane today occupies about 7 Mha in Brazil. It should be noted that this area produces both sugar (Brazil is the world's largest producer and exporter) and ethanol. It may be said that ethanol fuel production in Brazil uses around 4 Mha, i.e., around 0.5% of the total country area, or about 8% of the total currently cultivated area.

Furthermore, sugarcane expanded over the past few decades without compromising the food industry; on the contrary, it is possible to say that being a high-yield culture and high income per hectare, sugarcane brings wealth to the countryside and fosters its production.

In a recent study by a working group coordinated by C. Gouvello (2009), sugarcane geography in Brazil (see the Figure 2) was again evidenced,

TABLE 4 Area occupied and yearly production by annual cultures in Brazil.

Culture	Cultivated area (10^6 ha)	Production (10^6 ton)
Soybean	20.6	58.0
Corn	13.8	51.3
Sugarcane	6.7	515.8
Beans	3.8	3.3
Rice	2.9	11.1
Wheat	1.9	4.1
Coffee	2.2	2.2
Other	5.9	–
Total	57.8	

Source: IBGE, 2008.

as well as the importance of the sugarcane-pasture relationship regarding sugarcane expansion and how all this can take place without jeopardizing meat production while reducing GHG emissions, considering that their integration may even free up land presently occupied with degraded pastures.

AGRO-ENVIRONMENTAL ZONING FOR SUGARCANE IN BRAZIL

From a recent study by the Ministry of Agriculture (MAPA, 2009), the so-called agro-environmental zoning of sugarcane, it may be drawn that there are about 65 million hectares adequate for cultivating sugarcane in Brazil (Table 5 and Figure 3). This land today has low socio-economical and environmental value and does not justify its use with the current productivity figures.

FUTURE DEMAND FOR SUGARCANE ETHANOL IN BRAZIL

From the data shown in Tables 2, 4, and 5, it is possible to state that Brazil is exceptionally able to produce a significant part of the world's future ethanol demand due to its availability of adequate land for cultivating sugarcane with low socio-economic impact (65 Mha), excellent agro-industrial productivity, human and infrastructure resources.

BRAZILIAN MODEL FOR LAND USE (BLUM)

In early 2008, the International Negotiation and Trade Studies Institute (Instituto de Estudos do Comércio e Negociações Internacionais – ICONE) set up a partnership with the University of Iowa's FAPRI-CARD (Food and Agricultural Policy Research Institute – Center for Agricultural and Rural Development), to work out a partial balance economic model that made it possible to analyze and project the dynamics of the major Brazilian agricultural industries on a 10-year window. The first version of the model was developed within

TABLE 5 Synthesis of areas for sugarcane expansion in Brazil, considering suitability of prevailing classification and land use types in 2002.

Brazil	Adequacy classes	Adequate areas by type of land use by adequacy classes (ha)				
		Ap	Ag	Ac	Ap+Ag	Ap+Ag+Ac
Total areas in Brazil	High (H)	11,302,343	600,767	7,360,310	11,903,110	19,263,420
	Medium (M)	22,863,866	2,126,395	16,496,736	24,990,261	41,486,996
	Low (L)	3,041,122	483,326	731,077	3,524,448	4,255,525
	H+M	34,166,209	2,727,162	23,857,046	36,893,371	60,750,416
	H+M+L	37,207,331	3,210,488	24,588,123	40,417,819	65,005,941

Note: Adequacy classes H: High; M: Medium; L: Low – Current use: Ac: Agriculture; Ag: Animal breeding; Ap: Pasture.

Source: MAPA, 2009.

Source: MAPA, 2009.

FIGURE 3 Areas suitable for sugarcane cultivation based on agricultural classification, currently used for pastures, animal breeding, or agriculture.

the scope of the "Study of Low Carbon for Brazil" project of the World Bank, which was interested in assessing GHG (greenhouse gas) emission scenarios in various Brazilian industries.

This was how BLUM – Brazilian Land Use Model, came to being. In just two years it matured and enabled ICONE to set up a wide intelligence network with specialists from various Brazilian and international universities and research centers. For example, the Federal University of Minas Gerais (UFMG), the Brazilian Agricultural Research Company (EMBRAPA), the National Space Research Center (INPE), the Alternative Energies Center (CENEA) in Fortaleza, the Brazilian Bioethanol Science and Technology Laboratory (CTBE), Luiz de Queiroz Agriculture School (ESALQ-USP) of the São Paulo State University, the Remote Monitoring Laboratory of the Goiás State Federal University (LAPIG), the Strategic Studies and Management Center (CGEE), all in Brazil, could be mentioned among others. International examples include the CARD and the World Bank itself.

Today BLUM has in its record two remarkable international accomplishments: 1) the results shown by US-EPA (Environmental Protection Agency) on GHG emissions from sugarcane ethanol, within the scope of the laws referring to the *Renewable Fuel Standard* (RFS 2), corroborate the results obtained by ICONE and submitted to that agency in 2009. Based on BLUM, ICONE has proven that sugarcane ethanol is an advanced biofuel, with lower GHG emissions than those initially suggested by EPA; 2) BLUM was integrated to the FAPRI model and included in its Outlook 2010,

TABLE 6 Projected global supply/demand of ethanol.

Billion liters	2009		2010		2015	
Country	**Offer**	**Demand**	**Offer**	**Demand**	**Offer**	**Demand**
World	83.4 (40.9)	82.2 (40.3)	101.4 (49.7)	99.4 (48.7)	168.6 (82.6)	147.3 (72.2)
USA	42.4 (20.8)	42.4 (20.8)	49.2 (24.1)	49.2 (24.1)	61.7 (30.2)	60.5 (29.6)
Brazil	27.5 (13.5)	22.0 (10.8)	29.7 (14.6)	25.9 (12.7)	54.0 (26.5)	47.2 (23.1)
European Community	3.4 (1.7)	4.8 (2.4)	4.4 (2.2)	6.0 (2.9)	6.0 (2.9)	9.2 (4.5)
China	3.1 (1.5)	8.5 (4.2)	3.4 (1.7)	8.8 (4.3)	12.8 (6.3)	11.5 (5.6)
India	1.7 (0.8)	0.8 (0.4)	1.8 (0.9)	1.6 (0.8)	9.3 (4.6)	2.1 (1.0)
Indonesia	0.7 (0.3)	0.18 (0.1)	2.2 (1.1)	0.6 (0.3)	6.5 (3.2)	1.1 (0.5)
Malaysia	0	0	0	0	0	0

Source: IEF, 2010.

executed for the first time with a model specific for Brazil integrated to the worldwide FAPRI models.

BLUM's major difference is its capacity to reflect the local reality of Brazilian agro-business using a methodology based on variables recognized by the academic community as determinants of the Brazilian agricultural industry dynamics. ICONE innovated in the model methodology for two reasons: 1) by suggesting geo-referenced information from remote monitoring analyses that contribute to embodying information on areas offering expansion potential for agro-business, considering physical, environmental, and legal constraints; 2) by projecting endogenous pasture areas, which were not considered by other land use models; 3) by differentiating first-harvest cultures (that require land for production) from mini-harvests and winter cultures (that require no additional land, as they are planted in the areas already used for first-harvest cultures); 4) for focusing on the national agricultural dynamics, dividing Brazil in six different regions with their respective peculiarities, which is essential for a more accurate land use analysis; 5) BLUM's structure, in its elastic features of price and competition, considers homogeneity, symmetry and add-ability economic conditions.

Several improvements are still needed in BLUM, such as the distribution of the demand for land at IBGE-level micro-regions, incorporating deforestation and deforested lands occupation data from the Amazon and *Cerrado* biomas, assessment of competition and replacement between productive uses, based on data from remote monitoring, and incorporation of transportation infrastructure improvements and their impact on agricultural production.

FEATURES OF BLUM

BLUM encompasses soybean, corn (first and second harvest), cotton, rice, beans (first and second harvest), sugarcane, wheat, barley, raising cattle for meat and dairy, poultry and eggs, and swine, and is based on two large modules: supply and demand, and land use.

In the first module, demand is projected nationwide, and is composed by domestic demand, net exports (exports less imports), and final inventory (only milk, eggs, and meat demands do not include the final inventory variable), which respond (negatively) to price, as well as exogenous factors, such as GNP, population, and exchange rates. The supply is composed by domestic production (sum of the production in all six regions) and the initial inventory (this one only for cereal, sugarcane, and its derivates), and gives the profitability of each commodity, which on its turn depends on the respective cost, productivity, and price of each product.

Prices are determined from the demand and supply balance, which interact dynamically until simultaneous balance is achieved in all markets considered.

The land use module comprises two effects: scale and competition. The scale effect is the one that determines the fraction of the total area available in each region (estimated by remote monitoring) actually taken by agriculture. It is assumed that the higher average agricultural profitability, the higher will be the scale effect. The competition effect is the one that divides the total area occupied by the various specific production uses (types of culture and pasture) in each region, as a function of the profitability of the activity itself and its competitors. The distributed area and productivity compose each individual product's production in each region which, added to the initial inventory, determine the national supply of that product. This relationship ensures the interaction between the land use and the supply/demand modules in the model.

In addition to the competition for land, there are interactions between the sectors analyzed, as well as between a product and its by-products. For instance, between the meat and cereal sectors, the demand for animal foodstuff from the supply of meat, milk, and eggs (basically corn and ground soybeans) is one of the components of the domestic demand for corn and soybeans. In the case of the soybean complex, ground soybeans and soybean oil are components of the demand for soybeans, which is determined from the grinding ratio. Likewise, ethanol and sugar are components of the demand for sugar.

MAJOR BLUM APPLICATIONS

The results obtained by BLUM are long-term projections, at national level, for domestic demand, net exports, inventories, prices and, at regional level, for planted area, pasture area, production, productivity, and stratified bovine and swine herds. The model is a tool that allows to quantitatively assess the change in land use and GHG emissions from the growth of the demand for foods, biofuels, and fibers.

Periodically, baseline scenarios will be generated, and various alternative scenarios may be simulated, both from different macroeconomic scenarios (changing variables exogenous to the model) and by different technology and domestic demand or export scenarios for one or more products (changing variables endogenous to the model).

Furthermore, the model may simulate the response of the Brazilian agricultural industry to international price projections. Thus, BLUM can be used as a tool for multiple purposes and analyses by public policy developers, the private sector, and the international scientific community.

For the private sector, various scenarios may be simulated in order to serve as a tool for defining long-range strategic plans, and for decision-making in investments. From the results obtained with the model, it is possible to forecast the demand for fertilizers, pesticides, as well as agricultural machinery, to define location and production capacity of industrial plants as a function of regional agricultural production and technology to be adopted, to make decisions regarding international trade, private policies related to sustainability, to assess impacts of agricultural and environmental policies on the Brazilian agri-business, among others.

For the public sector, the results of long-range projections serve for formulating agricultural policies related to infrastructure (particularly logistics), investments in regional rural education, in research and technology (making it possible to simulate various technological scenarios), to the environmental impact of agricultural expansion, to climate changes, to agricultural credit, to environmental legislation, to food safety, to regional incentives to agricultural development, to international negotiations, and to sustainability, among others.

Finally, as the model presents area allocation results in six different regions, each of them predominantly located in one bioma, it is possible to determine the kind of natural vegetation converted into agriculture. This means that the model is capable of projecting which type of native vegetation will be converted, in case an increase in the total area used by agriculture is forecasted. Breakdown by regions and the inclusion of pasture areas in the model are extremely important advantages in comparison to the other leading economic model projections available, and it may allow to significantly improve the consistency and accuracy of analyses on the direct and indirect effects of land use, hence, on the greenhouse gas emission calculations.

FINAL REMARKS

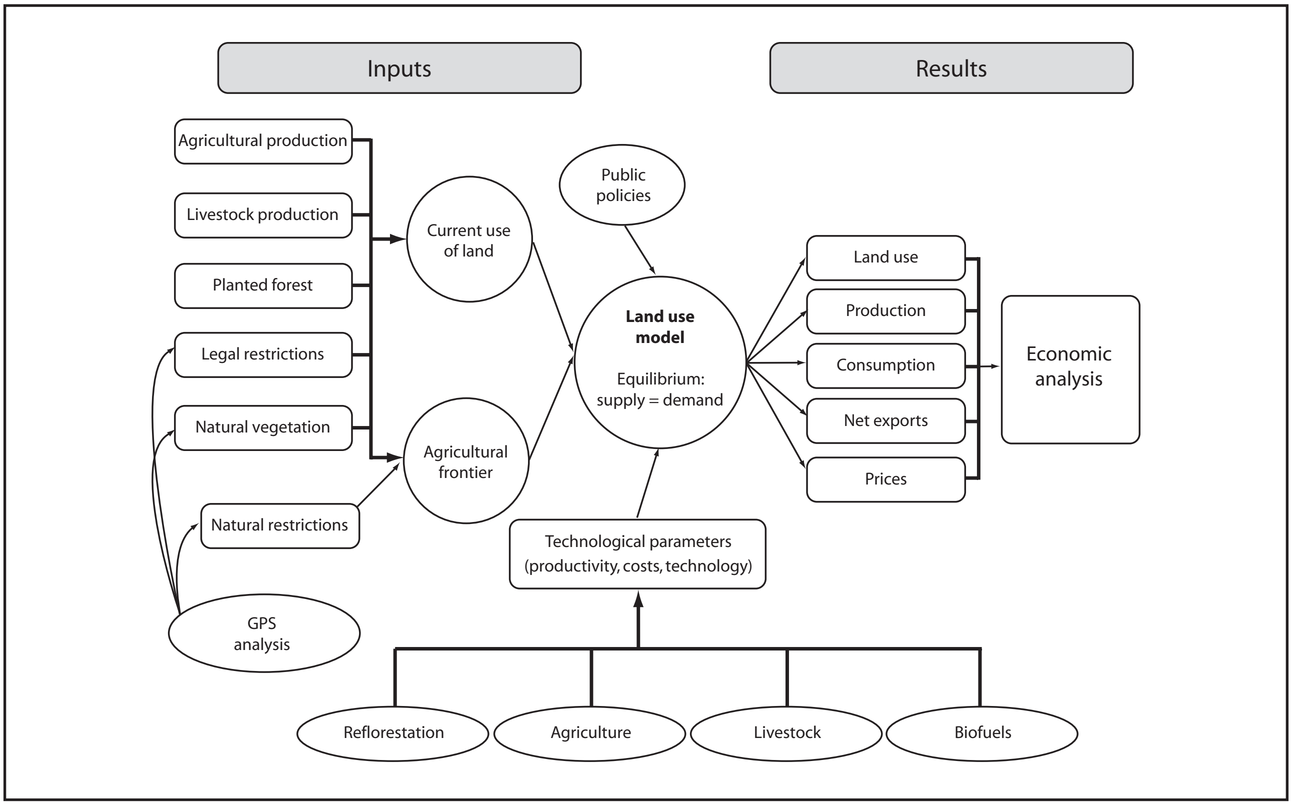
Regions in which Brazil was divided into in the BLUM

South (Paraná, Santa Catarina, and Rio Grande do Sul), Southeast (São Paulo, Rio de Janeiro, Espírito Santo and Minas Gerais), Center-West, *Cerrado* (Mato Grosso do Sul, Goiás, and part of Mato Grosso within the *Cerrado* and *Pantanal* bioma), North Amazon (part of Mato Grosso within the Amazon bioma, Amazonas, Pará, Acre, Amapá, Rondônia, and Roraima), MAPITO and Bahia (Maranhão, Piauí, Tocantins, and Bahia), Coastal Northeast (Alagoas, Ceará, Paraíba, Pernambuco, Rio Grande do Norte, and Sergipe).

Factors that may lead to a lesser use of land for bioenergy in Brazil and factors that may contribute to increased food production associated to the sugar-alcohol industry in Brazil

Study of bioethanol and animal breeding integration dynamics in Brazil

This text refers to a study carried out to explore the integration potential between sugar-alcohol, animal breeding, and agriculture industries with sugarcane field reforms. For this purpose, available technology in a mill with a certain grinding capacity per harvest is considered, with capacity for processing bagasse for producing hy-



Source: ICONE.

FIGURE 4 Methodology diagram of the Brazilian Land Use Model – BLUM.

drolyzed bagasse and animal foodstuff preparation to supplement feeding bovines in pasture areas of the mill and/or sugarcane suppliers, and for confined cattle. The study considers the production of soybean and corn in sugarcane field reform areas that normally occur 5-6 years after planting, and that represent 15% of the total area utilized for planting sugarcane. These grains are considered in producing animal foodstuff together with natural bagasse, hydrolyzed bagasse, yeast, and molasses.

At the outset, the following situation was studied: Given an area of 100,000 hectares occupied with cattle breeding (reproduction and meat), low-tech (typically 0.7 animal unit per hectare), is it possible to implement a distillery processing 2 million t/year of sugarcane, occupying 28,000 hectares of this area, and still produce, with the benefits from integration, the same quantity of meat per year. It was shown that with pasture supplementation, confinement, soybean and corn planting in reform area, without any additional external input, the response is positive.

The positive answer to the question above can be built with simple calculations on spreadsheets, involving experimental data available in the technical literature. However, another question was posed: Which methodology allows analyzing the interactions between the production of bioethanol, grain, and meats, taking into account the technology and economic change dynamics over time?

It was shown, by means of a mathematical programming model, the evolution over time of activities such as calf acquisitions, use of pastures for breeding and gaining weight, use of food supplements, use of confinement for gaining weight and selling cattle, in a way to maximize meat production. Also represented in the model were the formulation of the foodstuff for pasture supplementation and confinement using hydrolyzed bagasse, natural moist bagasse, yeast, ground soybeans from the soy planted during the reform, and corn also from the reform areas. Calf acquisition costs and cattle sales were obtained from historic series of the Brazilian domestic market.

TABLE 7 Indicators *versus* bagasse availability.

Item										
Available bagasse (%)	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
Pasture area (ha)	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000
Confined capacity (c.g)	2,425	4,850	7,275	9,699	12,130	14,549	16,974	18,600*	18,600*	18,600*
Supplementation capacity (c.g)	3,889	7,778	11,667	15,556	19,450	23,333	27,222	31,111	35,000	38,889
Average occupancy (U.A./ha)	0.68	0.69	0.71	0.72	0.74	0.76	0.78	0.79	0.79	0.80
Annual meat production (ton)	14,444	15,450	16,537	17,929	19,325	20,714	22,089	23,104	23,104	23,115
Average meat production (kg/ha)	200.62	214.58	229.68	249.01	268.40	287.69	306.79	320.89	320.89	321.05
Average profitability (R$/ha)	123.69	129.21	134.66	140.04	145.43	150.73	155.97	159.45	159.45	159.45
Average slaughter age (months)	34.49	33.70	32.95	32.14	31.44	30.83	30.29	30.00	30.00	30.01
% Traditional handling	87.75	76.88	67.45	59.52	52.65	46.67	41.34	38.35	38.35	38.36

Key decision variables represents calf quantity acquired in month m for sale in month n, being sent for confinement in month i, if convenient (to be determined by the model), being that, on a specific month of the planning horizon (typically 120 months for a better representation of breeding dynamics), the total of pasture areas being used is less or equal to the area available for cattle breeding (72,000 hectares, in the aforementioned study). Typical animals weight gain figures are drawn from literature, for each month, in extensive breeding, in pastures with food supplementation and in confinement.

Table 7 shows the use characteristics of a 100,000 hectares area, with 28,000 hectares taken by sugarcane, remaining 72,000 hectares for

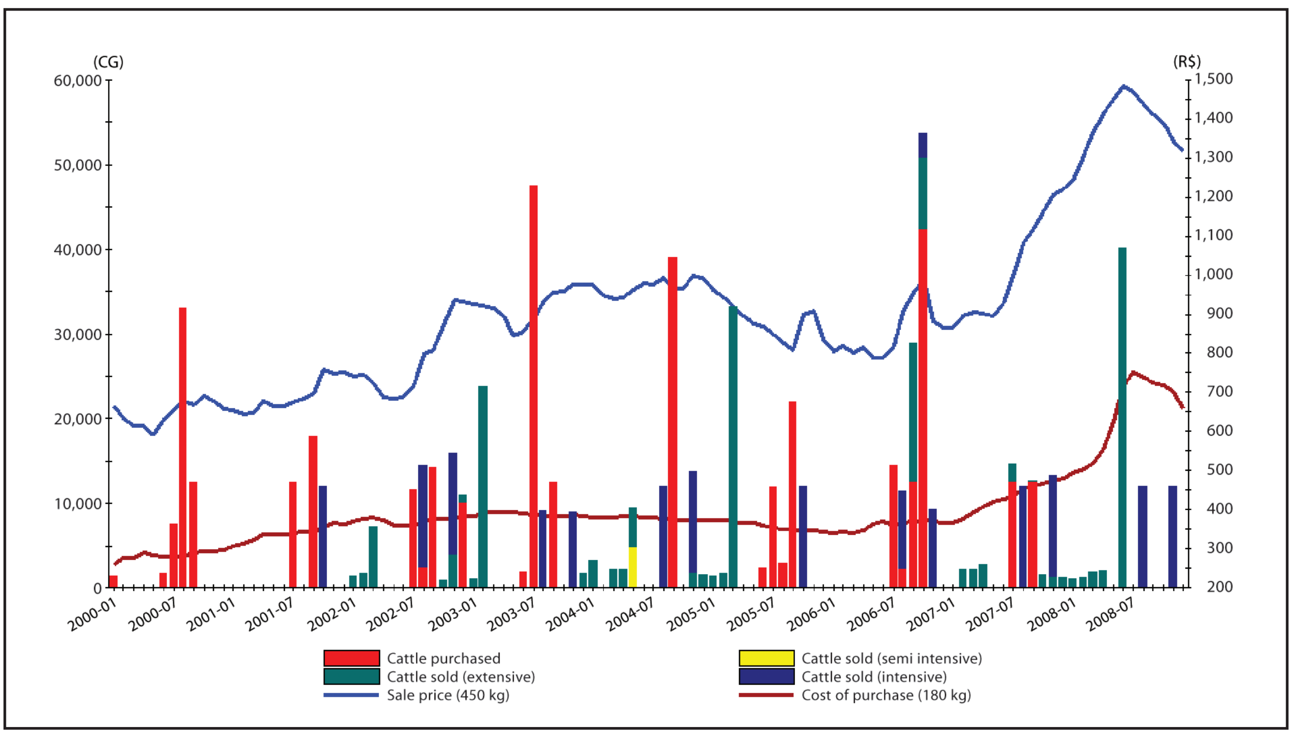


FIGURE 5 Calf purchase cost and cattle sales price dynamics, and buy/sell activities.

pastures (used for breeding and/or breeding and weight gain), with variable percentages of bagasse being made available for animal foodstuff.

In these years, the limiting factor is the availability of grains, not bagasse.

It is noticeable that production in confinement reaches the limit of 18,600 cattle heads at the level of 8% of natural bagasse available, because the limiting factor is the production of grains, as we are assuming that grains supply is solely from reform areas. This hypothesis ensures favorable conditions for life cycle analysis (LCA) and direct land-use change (LUC)/indirect land-use change (ILUC). Obviously, the study may be expanded to include the supply of other ingredients to compose animal foodstuff. Also noticeable are the gains in the meat production per year, in the average slaughter age and, consequently, in the profitability.

The methodology analysis considered a calf purchase cost and cattle sale price dynamics over a period from 2000 through 2009, shown in the Figure, where the total meat production is maximized by buying and selling at optimum quantities and times (months).

This methodology may be used in more complex situations, such as the one shown on Figure 6 which considers a sugar, ethanol, and electricity plant, enlarged to optimize its economic performance by integrating grains and cattle production activities.

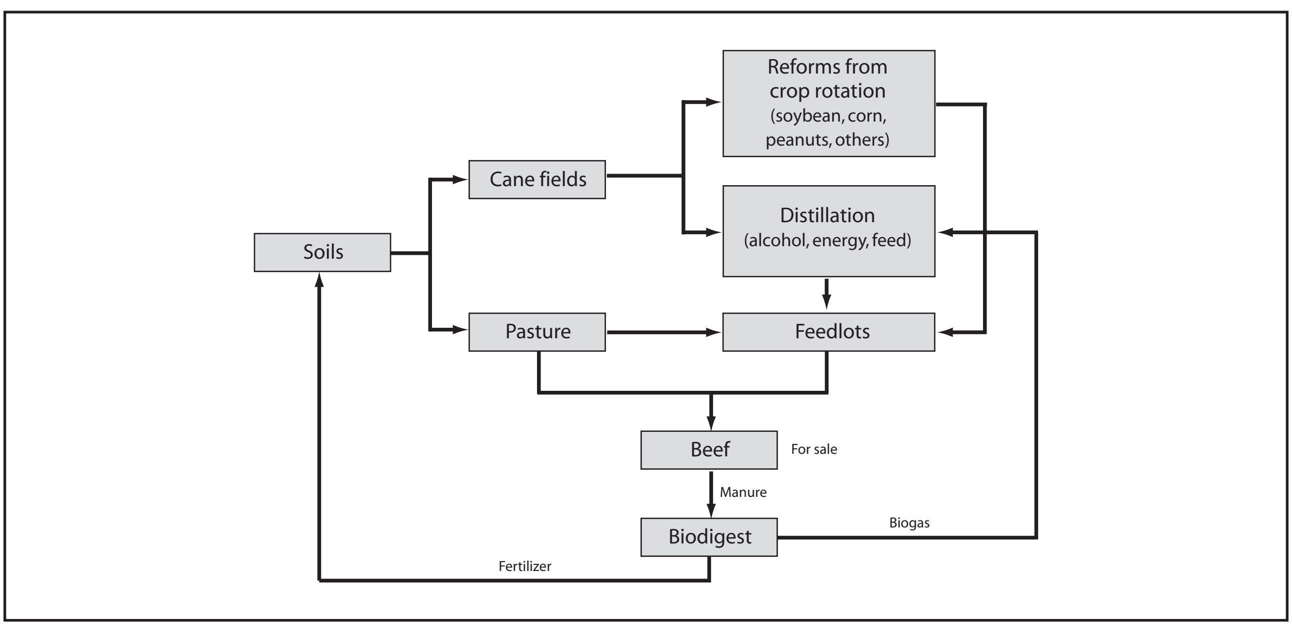
It is also possible to study the interactions between the interests of mill owners, cattle breeders, and meat packers at the level of one single plant or a cluster of them, considering logistic, technological, economic, and environmental aspects.

The mathematical model was programmed using the algebraic language AIMMS-Advanced *Integrated Multidimensional Modeling Software* which includes the CPLEX solver, thus facilitating the development of systems for Supply Chain Planning usually associated to ERP – Enterprise Resources Planning environments currently used by mid – and large-sized companies, as in several sugarcane processing mills.

Spin-offs from this project shall introduce interesting issues for the bioethanol sustainability agenda in its micro and macro aspects.

Development of second-generation technology (hydrolysis)

The average agro-industrial ethanol productivity, measured in liters per hectare per year, in Brazil was 6,000 l/ha/year, and increases slightly more than 1% per year (Table 8). It may be in-



Source: UNISOMA.

FIGURE 6 Schematics indicating the integration of sugarcane-pasture exploiting waste.

TABLE 8 Expected productivity of agro-industrial yields, considering the possible contribution from cellulosic ethanol.

	2005	2015	2025
Sugarcane productivity (tons/ha/year)	70	82	96
Pol (%) sugarcane	14.5	15.9	17.3
Industrial efficiency (%)	83.5	90.0	90.0
Liters ethanol/ha/year	6,000	8,200	10,400

Source: LEITE *et al.*, 2009.

creased by the addition of the expected productivity from second-generation technologies, such as enzymatic hydrolysis, which may – as soon as in 2015 – have commercial processes for converting cellulose, and in 2025, hemicellulose. Hypothetically, considering these contributions, the agro-industrial productivity may reach 8,200 l/ha/year in 2015 and up to 10,400 l/ha/year by 2025.

It should be noted that the impact of the contribution from second-generation technologies on land use is important and, therefore, the adopted hypothesis, in spite of being a little optimistic, fully justifies an ambitious research program that includes collection of trash, and the full exploitation of the energy resources from sugarcane.

Integration of Bioethanol Plants with Agricultural Greenhouses

The incorporation of new areas to sugarcane production will require, likewise, restructuring other agricultural production sectors in Brazil. In this sense, the sheltered cultivation of food cultures is a segment of the Brazilian agri-business that could benefit more from this tremendous challenge. Just as an example, sheltered culture, or plasticulture, in the São Paulo state occupies an area of only 1,450 ha, concentrated in three definite areas: silviculture (production of seedlings), ornamental culture where the participation of the Holambra Cooperative (São Paulo) represents over 30% of the total sector sales (R$ 1.3 billion); and a blossoming sector in fruit culture and vegetables. In the latter, São Paulo state holds an important share, comprising over 70% of the total fruits and vegetables production, with R$ 6.6 billion turnover.

Sheltered cultivation in Brazil still has little structure, both in technology and in marketing. The best example may be the consumption of vegetables in Brazil. The average Brazilian consumes around 40 kg per year (excluding potatoes), i.e., less than half the average of the USA or Europe, or close to one-third of the average in Asia. The lack of consistent quality and high prices, if compared to other foods, explain this low consumption and point out the high potential for this segment's growth.

Modern production technologies in agricultural greenhouses are a solution for these problems. Sheltered cultivation solves the problem of between-harvests production, offers improved quality with less agrochemicals, and its high productivity allows for competitive prices to the consumers, as well as reduced losses. In modern greenhouses it is possible to obtain productivities of 650 tons/ha of salad tomato (over 10 times the national average, including industrial tomatoes).

The inherent high investment and high operating costs are the leading factors preventing the development of such technology. To reduce these costs, the solution would be adding value to the by-products of bioethanol production. The use of the CO_2 from the fermentation vats (to increase the photosynthesis rate) and the recovery of low-temperature (35 to 65 °C) residual heat (for greenhouse heating and demoisturizing), the use of bagasse, and the use of stillage (to prepare nourishing solutions), would render the necessary investments in this segment viable.

A standard mill processing 12,000 ton/day of sugarcane with a daily production of 1 million liters/day of ethanol can provide all the heat and CO_2 necessary for producing 60 ha of hydroponic tomatoes. This greenhouse complex would produce the equivalent to 36,000 tons of tomato per year (R$ 43 million in sales at CEAGESP 2009 prices), on top of opening over 900 direct permanent jobs. In environmental terms, GHG sequestration would be around 15% of the total produced by fermentation vats. Finally, this project would stimulate the development of a new corporate image, as this integration would represent an innovative response of the sugar-alcohol industry to Brazilian agriculture, especially in the production of food and the generation of new, sustainable jobs.

Integrating land use, water use, and CO_2 emissions issues in expanding the ethanol production in Brazil

Among the themes linked to sustainability in the production of biofuels, CO_2 emissions are discussed due to direct land use change (LUC) and indirect land use change (ILUC), use of agricultural water (Hydrologic flows), as these are themes that have a strong impact on the biofuels production viability analysis.

For instance: taking the case of a basin in the Center-West region, sufficiently large to encompass several mills (cluster) and a large sugarcane field, we could consider the following:

- on CO_2 emissions: assuming that sugarcane will expand over degraded pastures, a widely accepted hypothesis nowadays, changing the soil use from degraded pasture to sugarcane will incorporate C in the soil, in this case, improving the emissions balance due to LUC.

Carbon stock in soil dynamics is a very complex subject for involving a large number of variables, such as: soil use history, type of soil, current agricultural handling, local climate, and others. Macedo and Seabra (2008) present the Brazilian situation in terms of sugarcane expansion to produce ethanol, reminding that from 1985 through 2002, there was no sugarcane expansion for ethanol, since the production of this biofuel remained practically constant throughout this period. Nassar *et al*. (2008), MAPA and CONAB studied the sugarcane expansion in recent years, based on satellite images, field researches, and EIA/RIMA studies of new production plants, showed that the expansion (Macedo and Seabra, 2008) of sugarcane took place over areas with established cultures (mostly soybean and corn) and pastures, and that areas covered with (natural or planted) trees represented less than 1.5% of the lands used. In pastures, occupation by sugarcane occurred mostly in degraded or low-productivity areas (abuse by stampede, no fertilization).

A literature study by Amaral *et al*. (2008) allowed a preliminary assessment of carbon stock in the most common types of soil in the new sugarcane areas, both in the soil as well as above it. Tables 9 and 10 present these figures for clayous soils with high and low activity (HAC and LAC, respectively), and the IPCC default values.

These figures are preliminary, and many experimental measurements must be taken in a more controlled and systematic way to offer additional reliability. However, they are much more adequate to represent the sugarcane culture expansion in the recent past, and probably within the next few years, than those used by various authors (e.g. Searchinger *et al*., 2008, and Fargione *et al*., 2008).

An estimate of GHG emissions by the change of land use was made by Macedo and Seabra (2008), considering that at least 70% of the pastures replaced by sugarcane fields were natural (not planted), and having various levels of degradation, that the sugarcane will be harvested unburned, and various alternative cultures, is shown on Table 11. The situation in 2006 (partial burned sugarcane) and 2020 (unburned sugarcane and collecting 40% of trash to general surplus electric power, supplementing bagasse) are also shown to indicate the expected trends.

From Table 11, within the hypotheses considered, sugarcane expansion in the new frontier is causing, and will continue to cause, a net gain in carbon stocks in the soils involved.

However, this demand for lands for bioenergy has raised considerable debate worldwide, also fueled by relatively new concepts such as direct land use change, and more recently by ILUC. While methodologies for estimating LUCs have demonstrated a reasonable reliability level, determining ILUCs with minimum reliability remains a challenge. The mathematical models used in ILUC studies show a series of limitations and inconsistencies, presented in detail in ORNL, 2009.

TABLE 9 Stock figures in the soil for different cultures (tC/ha).

Culture	Default IPCC		Experimental		Selected values
	LAC	HAC	HAC	Other	
Degraded pasture	33	46	41	16	41
Natural pasture	46	63	56	–	56
Cultivated pasture	55	76	52	24	52
Soybean	31	42	53		53
Corn	31	42	40		40
Cotton	23	31	38		38
Cerrado	47	65	46		46
Open field	47	65	72		72
Cerradão	47	65	53		53
Burned sugarcane	23	31	35-37	35	36
Unburned sugarcane	60	83	44-59		51

Source: MACEDO and SEABRA, 2008.

TABLE 10 Soil carbon stock figures above ground (tC/ha).

Degraded pasture	1.3
Cultivated pasture	6.5
Soybean	1.8
Corn	3.9
Cotton	2.2
Strictly cerrado	25.5
Open field	8.4
Cerradão	33.5
Unburned sugarcane	17.8

Source: MACEDO and SEABRA, 2008.

- On a second hypothesis, admitting that there was no "domino effect", whereby the pasture occupied with sugarcane would move elsewhere (ILUC), but that this occupation of the pasture by sugarcane would be absorbed by the activity itself, since the use of 25 Mha of pasture by sugarcane would simply increase density from 0.7 UA/ha to 0.8-0.9 UA/ha, making the average distance between cattle heads in Brazil drop from 100 m to something like 97 m. Another possibility would be higher integration of pasture with sugarcane, freeing a significant area of land, maybe half (100 Mha) of it. Estimating biofuels need around 30 Mha, some 70 Mha would be made available for other uses. In other words, even the Amazon and other environmental sanctuaries could be recomposed, in this case making a reverse ILUC, i.e., instead of the ILUC causing a supposed increase in emissions, with the pasture-sugarcane integration, there would be a likely increase of the C stock, thus considerably improving the emissions balance, making it less negative.
- In this same hydrographic basin, previously occupied by degraded pastures and having an equally degraded hydric balance (it is important to keep in mind that the hydrologic damage was done by deforestation, over a century ago), there would also be, with the introduction of sugarcane, an increase in the level of underground water, reduced soil erosion, and a more regular river flow.

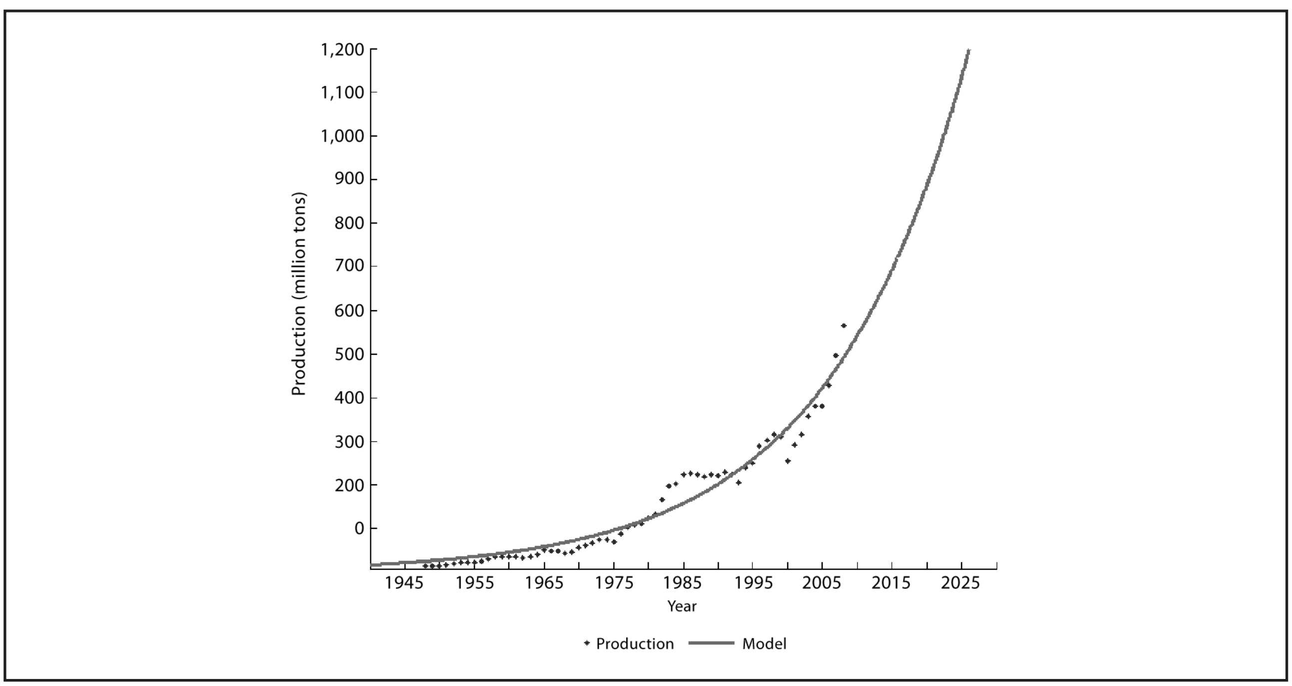
TABLE 11 GHG emissions due to the replacement of various cultures with unburned sugarcane.

Replaced Culture	Change in carbon stock	Emissions (kg CO_2eq./m³)	
		2006	2020
Degraded pasture	10	-302	-259
Natural pasture	-5	157	134
Cultivated pasture	-1	29	25
Soybean	-2	61	52
Corn	11	-317	-272
Cotton	13	-384	-329
Cerrado	-21	601	515
Open field	-29	859	737
Cerradão	-36	1,040	891
GHG emissions due to LUC		-118	-109

Source: MACEDO and SEABRA, 2008.

FINAL CONSIDERATIONS

Among other positive socio-economic impacts, ethanol production in Brazil, and the outlook of its expressive expansion in the next few years, also posed the need for rural and agricultural zoning, which at the same time preserved environmental sanctuaries (Amazon, Pantanal, Atlantic Forest among others), and protected indigenous reservations as well as food production in the country.



Source: MAPA, 2009.

FIGURE 7 Projected sugarcane production growth in Brazil, up to 2025.

The rapid growth of the sugarcane culture in Brazil (see Figure 7), motivated by both the international demand for sugar/ethanol and the domestic demand for ethanol has been nurturing this industry, which is undergoing change at both technological and corporate levels. It may be said that these good times may last for some decades yet, in view of the considerable international interest in really sustainable biofuels, the possible future domestic demand for bioelectricity, and also the growing demand for green plastics. Even under a significant increase in the agro-industrial activity, that may reach some 11,000 liters/ha/year, the demand for new areas for sugarcane in Brazil should take place almost wholly in pasture areas; hence, the urgent need to know thoroughly the situation of areas taken by pastures in Brazil.

Therefore, it may be said that this significant expansion of sugarcane, with the correspondent use of land, will lead the country not only to improve the sustainability indicators related to the sugar-alcohol industry, but also to other agricultural activities, mostly cattle breeding for meat, a large user of lands in Brazil, still having productivity indicators far below what is expected.

Thus, sugarcane expansion may actually be a milestone in land use in Brazil, considering the high likelihood for further expansion, its good productivity and sustainability indicators, as well as the perception of both Brazilian and international society that biofuels production should follow much stricter criteria than those currently used by the food industry.

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Part 3

A NEW MODEL FOR SUGARCANE MECHANIZATION SYSTEM

Paulo Sérgio Graziano Magalhães
and *Oscar A. Braunbeck*
(organizers)

1

INTRODUCTION

Paulo Sérgio Graziano Magalhães and *Oscar A. Braunbeck*

The perspective of a significant increase on ethanol demand as a renewable biofuel energy source requires, without doubt, an increment of the raw material production in quality and quantity in a sustainable way. To supply this demand, specialists have foreseeing the need for expansion of the cultivated area of sugarcane from the current 7.3 million hectares in 2008/09, to 14 million hectares in 2030. This expansion will require major changes in the whole productive system. Therefore agricultural production technology for sugarcane should be improved with focus not only on productivity, but mainly in the reduction of environmental impacts.

Considering the current bottlenecks of the agricultural production and the goals to be reached, along 2007 and 2008 several workshops[1] were held to discuss with the technical and scientific community the expectations in terms of R&D&I to build a new model of sugarcane production from the agricultural point of view. This new model is presented and discussed in this part of the book.

The section begins with the discussion presented by Souza and Van Sluys on the challenges of the genome-base technology and biotechnology of the sugarcane. The authors point out that one of the challenges is to achieve new productive varieties adapted to the several existent environments in Brazil. The genetic improvement is limited by biological barriers that can be overcome with the transgenic techniques, or strategies of vegetable improvement. This could enlarge the potential of the already existent cultivars as well as the development of new cultivars by "marker-assisted breeding". The chapter presents, in clear manner, which are the actions that are being taken in this field of science, the groups that are involved and what is necessary to guarantee top quality research in sugarcane biotechnology and to qualify geneticists in Brazil.

In the third chapter, Gazaffi *et al*. what has been accomplished in terms of genetic-improvement and the progresses obtained in the genetic mapping of sugarcane. The authors describe how improvement occurs, its stages, the material selection, evaluation and experiments. They explain what the genetic mapping is and the strategies that have been used to construct the sugarcane genetic maps. The importance of the molecular markers and the existent limitations in the case of the sugarcane are discussed and the benefits of its use in the genetic improvement appeared. The mapping of QTL's (quantitative trait loci) that has been used to name the chromosomes areas that contain genes (or locus) that control the polygenic characters, and the results obtained for sugarcane are also presented.

In this new model an important and interesting approach is presented by Leal in the Chapter 16 of the Part 4 regarding a new cane known as "energy cane" replacing partially the current sugarcane. This transformation is associated to the fact that the electric power generated from sugarcane will

[1] These workshops were part of the project "Guidelines for public politics for sugarcane industry in the state of São Paulo" financed by FAPESP.

have a more important role in the Brazilian energy mix. For that is necessary to alter the system now employed for the raw material remuneration at the mill where today only the sucrose content is evaluated. In the "energy cane" the straw (tops and leaves), that today in many places is no longer burned as form of facilitating harvesting and currently mostly wasted will be used economically in the boilers for electric power generation. The content of fiber present in the stalk should also be valued, not only for a more efficient bagasse burning, but for production of ethanol by hydrolysis. In this way it should also be considered by our geneticists how to obtain varieties that produce larger amount of biomass per hectare per year.

Another important approach discussed here is the photosynthesis potential that can be extract from sugarcane. As the objective is to obtain the total use of the sugarcane where the whole biomass is useful to the industry, the challenge is how to maximize the transformation of solar energy in to recoverable energy. This is one of the great challenges that our researchers will have to face in the coming years, because although sugarcane is one of the most efficient photosynthesizers in the plant kingdom, (it is a C-4 plant, able to convert up to 2 percent of incident solar energy into biomass), the photosynthesis process in sugarcane is not yet totally dominated.

This discussion is completed with the following chapter by Buckeridge *et al.*, on the routes for the production of cellulosic ethanol in Brazil. Besides the current route, the authors discuss the generation from the acid hydrolysis of the bagasse, second generation; of the cellular wall using microorganisms enzymes, third generation; and the fourth generation that would comprehend an integration of all the generations, but with a new raw material (sugarcane varieties) modified genetically and capable to accomplish modifications in the cellular wall that would turn into a more efficient the process of the third generation. The chapter presents the potential and the barriers that exist in each one of these routes, and discusses the necessary progresses in the field of research to achieve a production of renewable energy in a clean and efficient way.

Changing the approach from Chapter 8 on begins a discussion from the agricultural point of view. Rossetto *et al.* discuss how sugarcane production has been exploring the soil, this limited resource. Which are the actions that were accomplished along these years to minimize the action that degrade and pollute the soil and which are the research needs to reach sustainability. The authors show how the cultivation of sugarcane for many years is affecting the chemical, physics and morphologic properties of the soil. They also approach the problem of the erosion, and the technological progresses that appeared as a consequence of the crop system without burning, and how it was possible to reduce the loss of soil from 100 t/ha^{-1}, or more in some cases, to less than 7 t/ha^{-1}. The conservation tillage methods such as no-tillage and minimum cultivation are among the new technologies that are being implemented for sugarcane cultivation. With this technology, as example of what happened in cereals, it is possible to reduce soil compaction, to obtain increments of the organic matter and in soil fertility, larger productivity and longevity of the ratoon.

However, as point out by the authors, this practice is not yet totally viable for sugarcane as a consequence of the intensive traffic of vehicles during whole process of crop production, where the soil in about 60% of its extension is crossed by heavy machines. The solution of this problem requires to break paradigms and the development of specific technology for sugarcane e.g. as is the case of the Bioethanol Science and Technology Laboratory (CTBE). This proposal schematized illustrated in Figure 1 consists of using a wide frame equipment (Structure of Controlled Traffic – ETC) specially designed to execute all operations involved from the planting to the harvesting of the sugarcane, with a minimum contact between tires and plants. This is possible because the wheels of the equipment run along permanent tracks (spaced 12 m from each other), which are previously defined and georreferenced. This reduces the traffic of agricultural implements in the sugarcane fields to less than 10% of the planted area. Such conditions will enable gains in productivity and increase the longevity of the ratoon, thanks to the improvement

FIGURE 1 Controlled Traffic Structure (ETC) proposed by Bioethanol Science and Technology Laboratory – CTBE – as part of the Low Impact Mechanization (MBI) project for sugarcane production.

of the physical structure and of the biochemical properties of the soil. Reduction of losses of nutrient and of soil water will also occur through the use of this system. The mechanization of low impact (MBI) involves changes in the two main pieces of the current sugarcane mechanization: the agricultural tractor and the sugarcane harvester.

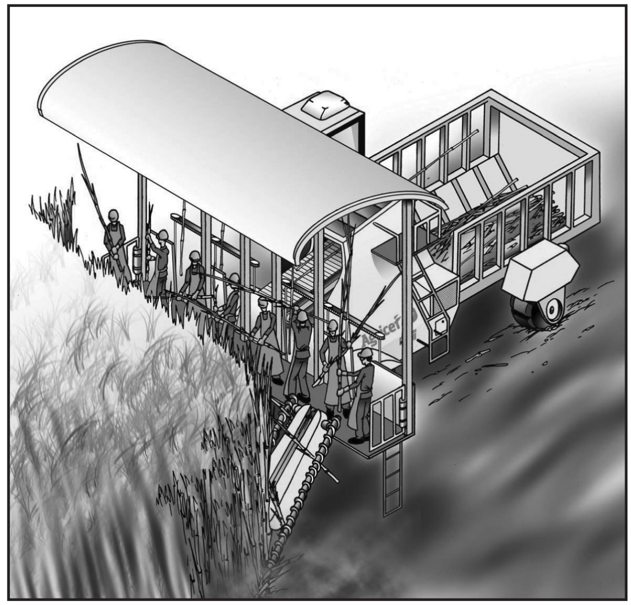
If the maintenance of the trash (composed by green and dry leaves and top of sugarcane) in the field brings evident benefits to the production of the sugarcane, as mentioned by several authors presented by Rossetto *et al.*, it has also some drawbacks, as delay ratooning causing a reduction in cane yield when temperatures are low and the increase incidence of pests' population that shelter and multiply under the trash mulch affecting the quality of the raw material. This theme is discussed in Chapter 11 where Parra *et al.* describe the main pests and diseases that commit the production of sugarcane and how the incidence of these can be affected by changing cultivation methods. The principal objective of the chapter is to show the perspectives using biological control and what should be accomplished, in research terms, so that the measures control alternatives contribute to maintainable production of the sugarcane.

Cantarella and Rossetto, in Chapter 9, present the solicitations of the plant in terms of nutritious. Sugarcane as a tall semi-perennial grass of the genus *Saccharum* (family Poaceae) has a great demand of minerals nutrients that constitute from 3 to 5% of the whole dray material produced and removed from the field. In that way it is necessary to replace, through organic/chemical fertilizer, these nutrients. The authors affirm that there is a vast accumulated experience in fertilizing and nutrition of the sugarcane for soil conditions in Brazil, the result of studies accomplished by several research centers, and discus the needs of the plant and the methods recommended for soil fertilizing. However, the fertilizing technology is not yet totally solved, and gaps exist in this context that needs to be study so that ethanol can be obtained in a sustainable way. The authors also look at some items, among them the problem of the handling in long period Nitrogen fertilizer in green sugarcane.

The vinasse, a by-product of the ethanol distilleries, that was a huge problem for the sector some years ago, today due to its chemical constitution, is used through fertirrigation as a source of nutrients for the soil. The composition of the vinasse is very variable as function of several factors, with chemical elements that were absorbed by the sugarcane, coming from the soil, such as potassium, sulfur, phosphorus, nitrogen, calcium, magnesium, besides the micronutrients, whose concentration varies from field to field. In spite of this, vinasse use can cause negative impacts to the environment and its application should under clear criteria. Several questions of how to treat this residue especially with a perspective of tripling sugarcane production in a near feature become a critical issue. Alternatives for vinasse use should be found, as concentration, biodigestion, incineration or proteins production. This is the theme of the Chapter 10 produced by Mutton *et al.*

Braunbeck and Magalhães present a technological evaluation of the mechanization of the sugarcane. They discuss here that the development of the mechanization of the sugarcane followed the existent model for cereals production, in spite of the crops present very different characteristics. These agricultural machines and available equipments were adapted for sugarcane cultivation and harvesting, generating difficulties to the sector. The authors show the existent antagonisms in the current model and they defend the hypothesis that it is necessary, from the economical and environmental point of view, to develop specific mechanization solutions for the sugarcane, focus in the reduction of the field traffic. The development of this technology will bring benefits to the sustainability of the sugarcane plantation activity promoting the reduction on investment and increment in the productivity. In this chapter again the problem of the protection of the soil and of the use of the trash is approached, emphasizing the need of maintaining a fraction of the trash over the soil and the benefits that this practice brings to the environment. The authors defend the adoption of the no-till cultivation method for sugarcane, but point out that to introduce this innovations it is necessary to make investments in research and necessary development to eliminate, or to draw round, the associated obstacles related to the those changes.

In Chapter 13 Magalhães and Braunbeck synthesize what was discussed in the workshop of sugarcane crop and straw harvesting for the ethanol production. There are many difficulties for harvesting green sugarcane (without burning) in current model which requests high investments, presents low field efficiency, high consumption of fuel, degrades the soil, and eliminates the small and medium producers. The lack of available technology to pick up the straw, which represents a third of the sugarcane crop energy and remains on the soil to waste is also discussed. The author present some alternatives that can be explored and the investment need in R&D in this area is pointed out. One alternative for reducing the impact caused by the necessary and inevitable mechanization of the sector is the employment of harvest aid equipments for sugarcane, as shown in the Figure 2. This equipment, capable of harvesting several row simultaneously, depends on two pickers for each row to remove the stalk, cut by the machine and conducted to the platform in front of him. The pickers have to direct the sugarcane stalk to the mechanism for de-trashing before it is send to a storage wagon attached to the device. Design concept maximized the pickers' time spent locating and cutting sugarcane stalk and removing the leaves. In medium to high yields, the picker productivity can be increased by 40 to 60% over conventional manual harvesting, guaranteeing in this way the rural employment and mainly the quality of life of these pickers. Due to designed balance in the device dimensions which guarantees low center of gravity, this equipment should work in areas with slope of up to 40% that, together with its low acquisition cost and maintenance, should assist the needs of most of the sugarcane small/medium growers that otherwise would be forced to abandon the activity. The author mentions yet other emerging technologies that need investments to become economically viable and contribute to the sustainability of the system, such as the use of the precision agriculture (PA) and automation of the field systems.



Source: AGRICEF-FEAGRI/UNICAMP.

FIGURE 2 Green sugarcane harvest aid.

This subject is approached again in greater detail by Ynamassu and Martin-Neto in the Chapter 14. In sugarcane, the progresses in the use of precision agriculture technologies are still modest, in spite of the technological advantage in ethanol production. These are probably due to the difficulty in obtaining tools and support that aid in the measurement of the crop space variability. In this context the role of the automation according to the authors, has been the replacement of labor in the search for the increase of efficiency and competitiveness. The adoption of the PA introduces changes not only in the form of administration of the property, but it also demands transformations in the market of machines and equipments, because the adoption of electronic equipments for monitoring and control will demand standardization of communication protocols as fundamental aspect to enlarge the versatility in the use of the equipments of different manufactures. The authors outline the research opportunities in the instrumentation area and automation for handling of the trash, monitoring of the soil and of the dynamics and reactivity of the organic matter.

With authority, the subject of the logistics of the sugarcane agricultural sector is discussed by Braunbeck and Albrecht Neto in Chapter 15. The logistics of the transport involves variables of the agricultural and industrial areas of the company, besides those specifically inherent to the transport; therefore a good logistic administration allows reducing the production costs significantly. The authors divide the chapter in three items, first the cut logistics, loading and transport of the sugarcane. Nowadays these items have been the subject of several studies comprising a series of technologies which include optimization of the employed materials in the production of trucks to the use of the information technology and precision agriculture. Secondly, they approach the problem of the trash, today left in the field, but that soon should be used to generate energy and it will require new logistics, depending on the technology that will be used in trash recovery. On the third part, the authors discuss the problem of logistics of distribution of residues from the agro industry such as vinasse, filter cake and ashes that are associated to transport operations with varied importance depending of the amount produced.

Arraes *et al*. synthesize the result of the workshop of Administration accomplished in the Center of Technology for Sugarcane CTC in Piracicaba in Chapter 16. The authors show how the progresses of the information technology have been aiding in the agricultural administration, demanding changes in the culture and in organizational practice. As the adoption of the of processes administration models, integrating the core functions of the enterprise: the industrial production, the human resources, the finances and the relationships with suppliers and customers – ERP´s (Enterprise Resource Planning), made possible to obtain and processing the information allowing to enlarge the temporary frequency and the number of variables to consider in the decision support system. The adoption of precision agriculture is a direct reflex of the administration technologies. In their final considerations, the authors suggest some alternatives that could promote the technological progress in the administration of the sugarcane sector.

In the last chapter of this section of the book, Leal *et al*. present the potential of using other crops as a source for ethanol production. Although more than 90% of the current world ethanol production is made from corn and sugarcane, a growing interest exists for other renewable sources. In this chapter, the authors consider two groups, one already consolidated by crops with technology for agricultural production well developed, and another composed by species that showed high biological potential of production on an experimental level, but lack the technology for appropriate agricultural production to the Brazilian conditions.

2

SUGARCANE GENOMICS AND BIOTECHNOLOGY:

STATE OF THE ART, CHALLENGES AND ACTIONS

Glaucia Mendes Souza and *Marie-Anne Van Sluys*

Sugarcane belongs to the botanic group known as *Saccharum officianale*, domesticated since 7 000 BC. The process of domestication started in New Guinea from where seedlings were taken to Continental Asia. In China and India, prevailing favorable conditions allowed the development of two different species, *S. sinense* and *S. barberi* respectively. From approximately a century ago, selective breeding produced *Saccharum officinarum,* also known as Nobel Clones. These varieties have been progressively replaced by modern varieties from crossings between *S. officinarum* and *S. robustum,species* which currently predominate worldwide. As sugarcane is a hybrid plant, the identification of genes of greater economic interest is a laborious and lengthy process e.g. it takes about 15 years to release a new commercial variety. This gives an indication of the difficulties involved in developing new commercial varieties.

In Brazil, increasing commercial pressure to improve sugarcane productivity faces the challenge to develop new varieties adapted to the different conditions in the country. For example, it is estimated that to supply internal and external demand, Brazil will have to duplicate sugarcane production within the next 5 to 7 years, requiring investment in new mills, expansion of cultivated area, increase productivity and better cane varieties etc. The expansion of sugarcane to new areas must also include the preservation of unique biomes and biodiversity. In São Paulo State, Brazil's largest producer of sugarcane, increasing productivity with new varieties of higher sucrose content is particularly attractive as this will limit land area use. Land available for sugarcane expansion in the short term is located in the Central Plateau which suffers from water shortages. Therefore the development of new sugarcane varieties resistant to drought will be necessary if sugarcane is to be cultivated in pastures land, to avoid the "cerrado" and tropical forest areas. Producers in the Northeast can also benefit from new cultivars resistant to drought as they could increase productivity quite significantly in this region.

Genetic improvement is, however, limited by two biological barriers: sexual reproduction, in the case blooming plants, and cellular equilibrium that guarantees the correct signaling between the cells, tissues, and organs of the whole plant and, ultimately, its interaction with the environment. In the first case transgenic techniques can be a possible alternative in the short run, but it is necessary to know which gene needs to be modified or introduced. Of the various breeding strategies aimed at the development of varieties with new characteristics, it seems that better understanding of the biological network may effectively lead to cultural management, thus increasing the potential of existing cultures, as well as the development of new ones, through "assisted genomic selection".

The use of biological systems with tools from genomics opens the possibility for integrating know-how on different areas, and together with the use of statistics, can help to improve the management of new sugarcane varieties.

Informatics and the identification of relevant biological characteristics to address specific problems are the pillars of what is currently called "biological systems", or a systematic approach that offers considerable potential to improve crops of economic value. Its application to sugarcane could made a significant contribution particularly to our understanding of the sucrose content, resistance to biotic stress (i.e. pathogens), abiotics (i.e. drought tolerance). The genetic diversity available to breeding programs can be explored using genomic and biotechnological approaches to accelerate the exploitation of the most promising varieties.

Brazil uses sugarcane bagasse in co-generation in sugarcane distilleries or as animal feed that increases significantly the overall efficiency of the system. One challenge will to develop enzymatic and acid hydrolysis processes that can use cellulose and hemicellulose as feedstock, increasing ethanol production even further. From an energy point of view, 2/3 of sugarcane is not used in the production of bio-ethanol.

Some varieties of sugarcane have been developed by breeding programs (i.e. the Inter-University Network for the Development of the Sugar/ Alcohol Sector – Ridesa, the Sugarcane Center of Technology – CTC, and the Sugarcane Centre of the Agronomy Institute of Campinas – IAC), adapted to different Brazilian conditions such climate and soil, that are highly productive and with high sugars or fiber content. A good example of RIDESA breeding program is the Centre of Agricultural Sciences (CCA) at the Federal University of São Carlos – UFSCAR.

The sugarcane breeding program (PMGCA) has 36 years of research experience. Over 16 years the PMGCA/CCA/UFSCAR has developed 48 new improved sugarcane varieties suitable for differing environmental conditions and mechanical harvesting, all of which have been made available to the sugarcane sector. Currently Ridesa and the CTC are jointly responsible for about 95% of the varieties planted in Brazil (CTC for 30%, and Ridesa for 65%). This shows that the public sector is able to create and spread the technology to the sugar/alcoholic sector. The success is due to the close partnership among universities and the mills/ distilleries, and good communication channels between research and industrial sectors. Currently RIDESA has the largest public collection of sugarcane genotypes of Brazil. CTC (ex-Copersucar) has probably one of the most important private germoplasm collections of the world.

The use of molecular techniques based on the systemic analysis of genomics data, can help in the selection and trials of cultivars adaptable to specific environments; and create the conditions for acid and enzymatic hydrolysis that will be one of the main challenges of sugarcane biotechnology.

Another major challenge will be to develop new strategies in biological research to create the basis for the development of biofuels in Brazil. It would be necessary to stimulate the creation of integrating mechanisms between the sugar and alcohol sectors with genetic improvement programs of sugarcane and advance biological research, integrating genomics, molecular, biochemical and physiological data, as a response to new environment requirements. A good example is the project Sucest, supported by Fapesp through the Onsa Genome Program, which is the outcome of more than 200 researchers of 50 research groups who have identified and analyzed 238,000 ESTs of sugarcane from 26 libraries of cDNA from 13 cultivars [1-3]. However, the impact of this study is still rather limited, and therefore it is necessary to implement an efficient program to identify research gaps and develop a basic research to increase productivity, in the medium and long term, in the productive sector.

The efficient use of sugarcane as a source of renewable energy depends on the integration of characteristics that control plant growth, the volume of biomass and its adaptation to the environment. In all cases, the genetic stability associated to the agronomic characteristics of the variety is fundamental. A better understanding of the plant growth and the optimized use of the nutrients is necessary to develop an efficient and environmentally sustainable agriculture. Within this perspective it is important to provide research funding to support diversification of control mechanisms for efficient use of carbon and sugars, in angiosperms through comparative analysis involving sugarcane and other models. The results should contribute to tuned manipulation of homeostasis of energy by crossing or transgenesis.

The process of energy and biomass generation has been analyzed only at cellular or on micro-organism level and has shown a complex net of reactions. Genes related to sucrose content were identified[4] and through a study with transgenic plants was found that they are responsible for the increase of the synthesis of sugar. This work was carried out by researchers at the Institute of Chemistry and the Institute of Biosciences of USP, in collaboration with CTC[5-7]. Moreover, studies of transcriptome in sugarcane identified around 700 genes associated to sucrose content, lignin and drought response[8-9]. Despite the fact that the role of several individual genes has been demonstrated, the biggest structure of the system remains unknown. After 50 years of research with sugarcane, the process and enzymes involved in the accumulation of sucrose have been identified and used to produce transgenic plants, but the results are not encouraging, probably due to the complex systems regulations. Transgenic sugarcane plants have been obtained with several agronomic characteristics of commercial interests[10-26], including water stress[27-28]; varieties, with regeneration capacity; and transgenic plants of Brazilian sugarcane genotypes have already been described[12, 17, 29, 30]. The development of transgenic plants is a necessary step to better understand and control the regulating routes of the plant's carbon metabolism.

Research on generation of vegetative transformation methodologies must be encouraged. The process of biobalistic transformation is not very efficient with sugarcane, depending on the gene or genotypic and plant generation efficiency. The genetic transformation by *Agrobacterium tumefaciens* needs also to be investigated and applied to sugarcane[11, 31-34]. With proper manipulation and control of conditions of *in vitro* culture, age/type/stage of embryogenic culture and methods of transformation, and by improvement of the virulence of the genealogy *A. tumefaciens,* it has been demonstrated that it is possible to increase the efficiency of the transformation of this specie via *A. tumefaciens.* Despite the intrinsic difficulties of this method in sugarcane, further attention should be paid to the advantages offered by *A. tumefaciens,* as it has the advantage of be able to transfer relatively long segments of DNA with few resetting, integration of a short number of copies of the transgene, simplicity and lower procedural cost.

Whatever the desirable agronomic trait maybe, this will have to be incorporated to breeding programs by means of crossbreeding or transgenesis. So, efficient markers and the know-how of the genetic potential associated to the cultivars are essential. Sugarcane has a complex genome that varies from cultivar to cultivar as the genome is hybrid and poliploide. With about 760 to 926 Mbp, the size of the basic monoploid genome of *Saccharum* is about twice the size of rice (389 Mbp), similar to the *Sorghum bicolor* Moench (760 Mbp), and significantly smaller than the corn (2500 Mbp). The size of the genome of one somatic cell (2C) of the modern culture R570 (2^{nd} = about 115) was estimated as 10,000 Mb[35].

In function of such characteristics, focused access to allelic diversity in germplasm database, through the use of the traditional genetics, becomes extremely difficult. The SUCEST project opened up a new perspective in the development of breeding programs with advanced molecular techniques. After the ESTs progression, genetic maps were obtained from cultivars of interest and molecular markers have been developed, that further support breeding programs[36-39]. The complete genome of a sugarcane cultivar is not yet available and should be promoted by Brazilian research groups to improve biotechnological research on sugarcane, while at the same qualifying Brazilian geneticists and breeders. The progression of the sugarcane genome and the comparison of the genome of several cultivars will create the conditions to establish a platform for in-depth studies on the diversity of the germoplasm of *Saccharum* genus. Contrary to the ESTs sequence, the genome sequencing will permit the identification of regulation areas, comparative studies of the evolution of chromosomal regions and other plants pattern, and identification of potential allelic variation observed among cultivars. The understanding of the genomic structure of sugarcane in terms of physical location of the genes and allelic proportion, as well as genetic ambiance where they were introduced, will improve our understanding of the genetic ambiance where they have been inserted; it will also enable a better understanding of the epigenetic effects over the genetic expression of sugarcane.

Consequently, it will be possible to increase the efficiency in the use of biotechnological tools for a better result for this culture e.g. the transformation of plants. It is possible through sequencing of a complete genome, to identify the regulatory regions of the genes (promoters) and genomic sequences that allow the transgenic expression in a controlled way, and tissue-specific. Several sugarcane promoters have already been identified e.g. tissue-specific expression data[40, 41], induced by insects[42] and of transposons[43]. Studies of this nature are important as they provide greater freedom to operate and to have intellectual property rights in an area dominated by foreign biotechnology companies.

The identification of molecular markers associated to phenotypes of interest is extremely important for the genetic improvement of sugarcane, avoiding the crossing between related parents. In this way it is possible to take maximum advantage of heterosis, based on the information from the identified quantitative characteristics – QTL. The molecular markers will also serve as tools in the evaluation and guidance for the introduction of the genetic variety in *Saccharum.* Genetic variety is fundamental to obtain cultivars resistant to pests and diseases and improving the most important economic characteristics such as sucrose and biomass volume.

The result of such studies could be used by public and private institutions with banks of sugarcane germplasms, to better understand their genetic variability. This will allow the establishment of *core collections* of available germplasms, and identify new ones. The genetic change by transgenics will enable existing species of sugarcane to improve their commercial lifetime, particularly in new sugarcane growing areas.

Studies on environmental interaction of sugarcane and the investigation of molecular mechanisms on physiologic responses and biochemical characteristic of the different cultivars are extremely important for the basic understanding of sugarcane. The identification and characterization of genes related to herbivores and pathogens is also one of the biggest challenges facing functional genomics. Studies have already been carried out on the characterization of the transcriptome of sugarcane to biotic stresses (sugarcane borer and endophytic nitrificant bacteria), abiotic stresses (dry and phosphate deficiency) and hormones responses[8]. Many candidate genes tolerance to insects have already been tested and incorporated to the main genotypes of sugarcane[15, 44-50]. Resistance proteins as a soybean inhibitor protease[17] or the *cry protein of Bacillus thuringiensis*[51] increase resistance to the borer *D. saccharalis,* the most recurrent pest in Brazil. Moreover, the characterization of cysteine proteases inhibitors brought a new perspective in the control of pathogens e.g. growth inhibitors of the fungus *Trichaderma reesei*[52], suggesting that this can also be used in the control of sugarcane fungus infections. The interaction plant-insect is considered as a dynamic system, subject to continuous variations. Plants develop different mechanisms to reduce insect attachs, including specific responses to activate different metabolims, changing considerably their chemical and physical characteristics. On the other hand, insects have also developed several strategies to overcome the plants' defensive barriers, permitting their feeding, development and reproduction. Studies have shown adaptation of insects and proteases inhibitors through general increase of the expression of proteasis genes. Therefore it is important to continue to investigate this matter so that we understand the behavior of the borer, one of the most serious plagues of sugarcane in the Northeast Region; and more recently also in the Southeast region; it is very important therefore to develop new diseases and pest control strategies.

Several aspects point to changes in sugarcane production and productivity in the near future and this requires a serious study of the potential impacts of climatic change on sugarcane, to put it in the right track. It is already known that there is an increase in photosynthesis (50%) and biomass in the stem (60%), in response to higher CO_2, which suggests productivity increases over the next few years[53]. At the same time very little is known about the mechanisms of temperature increases, for example. A further aspect relates to climatic changes associated to high consumption of fossil fuels and hence worldwide pressure to produce fuels of biological origin. Thus, it is important that Brazil starts to use sustainable renewable energy in harmony with the environment that accrues also social and environmental benefits.

A further possibility is to produce biofuels from polymeric compounds of cellular walls. Cellular walls are constituted of cellulose, hemicelluloses and pectins, intertwined in such a way that it is extremely difficult to extract energy in their chemical connections efficiently. It will be necessary to understand not only how the wall is built (biosynthetic processes), but also how the degradation processes works, if we are to dismount the cellular wall and learn how to use the energy that it contains. Within this context we can also apply our knowledge from studies of hydrolases, fungi and ligno-cellulolytic microorganisms that degrade the vegetable walls from the diverse Brazilian biodiversity. This can be done by identifying and purifying new fungi, enzymes, microorganisms and insects that can degrade cellulose and other constitutions of the wall. This should be in conjunction with industrial and fermentation process so that the new technologies have immediate commercial applications in the sugarcane sector.

Based on research experience in genomics in the State of São Paulo, we believe it is necessary to integrate the efforts of biologists, physiologists, biochemists, mathematicians and computer scientists to develop an integrated Research Program in Bioenergy. With biological sugarcane mapping, using biological system tools we believe it is possible to shape responses adapted to existing cultivars; and as last instance, contributing to increasing productivity necessary in a context where keeping environmental equilibrium is fundamental for future generations. It is important and urgent that Brazil acquires expertise in these fundamental aspects, to increase our capacity of “Freedom to Operate” in Biotechnology, training personnel to work in universities, and innovation agencies of the private and public sectors.

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3

SUGARCANE:

BREEDING METHODS AND GENETIC MAPPING

Rodrigo Gazaffi, Karine Miranda Oliveira, Anete Pereira de Souza and *Antonio Augusto Franco Garcia*

INTRODUCTION

Sugarcane is a plant species of great importance for Brazilian and world agriculture, being primarily grown in tropical and subtropical regions. Its main products are sugar and ethanol, the latter presenting high economic and environmental interest because as a renewable energy source, it can compete with petroleum derivatives (Goldemberg, 2007; FAO, 2008).

According to Daniels and Roach (1987), sugarcane is considered an allogamous species of the Poaceae family (Gramníneae), genus Saccharum, in which six species are generally recognized: *S. officinarum* L. (2n = 80), *S. robustum* Brandes and Jeswiet ex Grassl (2n = 60-205), *S. barberi* Jeswiet (2n = 81-124), *S. sinense* Roxb. (2n = 111-120), *S. spontaneum* L. (2n = 40-128), and *S. edule* Hassk. (2n = 60-80). *S. officinarum* L. stands out from the others due to its desirable industrial properties and high sucrose levels, and it is commonly called "noble cane" (Matsuoka *et al.*, 1999a; Landell and Bressiani, 2008). However, the modern varieties correspond to interspecific hybrids with high genetic complexity because they present high ploidy and aneuploidy levels (Heinz and Tew, 1987; Matsuoka *et al.*, 1999a; Landell and Bressiani, 2008). It is believed that, among the cultivated varieties, there is a great contribution of varying proportions of the genome of these species (Matsuoka *et al.*, 1999b). In this context, sugarcane is considered to be the cultivated species with the highest genetic complexity (Manners *et al.*, 2004).

Several authors have described sugarcane breeding methods and strategies (Stevenson, 1965; Blackburn, 1983; Berding and Roach, 1987; Berding and Skinner, 1987; Breaux, 1987; Heinz and Tew, 1987; Hogarth, 1987; Tew, 1987; Machado Jr. *et al.*, 1987; Matsuoka and Arizono, 1987; Peixoto, 1986; Matsuoka, 1988; Bressiani, 1993, 2001; Arizono, 1994, 1999; Pires, 1993; Landell and Alvarez, 1993; Machado Jr., 1993; Matsuoka *et al.*, 1999a, 1999b; Creste *et al.*, 2008; Landell and Bressiani, 2008). The purpose of this chapter is to briefly present the main stages of a breeding program, as well as the concepts of genetic mapping, that is, the development of genetic maps and QTL (Quantitative Trait Loci) mapping for sugarcane. Genetic Mapping should be studied because it allows a better understanding of the genetic architecture of quantitative traits, which information could be considered in the future for breeding programs aiming to make them even more efficient through marker-assisted selection (MAS) (Mohan *et al.*, 1997; Morgante and Salamini, 2003; Charcosset and Moreau, 2004; Takeda and Matsuoka, 2008).

BREEDING METHODS

Despite the genetic complexity of sugarcane, obtaining new genotypes for it is relatively easy due to mechanisms of vegetative propagation. Such programs are based on the generation of a segregating population with genetic variability, followed by several stages of selection and cloning of the superior genotypes. It is important to mention that each breeding program adopts specific strategies according to their needs and objectives. However, the period from the crossing until the identification of the desired genotype may demand from 10 to 12 years (Matsuoka *et al.*, 1999a; Landell and Bressiani, 2008).

The success of a breeding program depends on several factors, among which is the appropriate choice of parents to maximize the chance of gains with selection, experimental designed to have good accuracy, and the correct choice of the desired traits and their assessment periods. Some of the features to be considered for selection are the soluble solid content (Brix), sucrose content, diameter and number of stalks, fiber content, early maturity and resistance to pests, diseases lodging and flowering (Matsuoka *et al.*, 1999a, 1999b). In most cases, these traits are controlled by various loci known as QTL.

Overall, a sugarcane breeding program include the following stages: i) generating the population with genetic variability; ii) selection and cloning in the early stages; iii) evaluation of clones in experiments using appropriate designs; and iv) trial competitions.

i) Generating the population with genetic variation

Traditionally, genetic variability in a breeding program is obtained through crosses between parents that present the desired traits. To this end, the choice of parents and crosses are planned so that the probability of finding better genotypes is maximized. One of the criteria used is the choice of parents with good performance for traits of economic interest, which is clearly the case for cultivars used commercially (Matsuoka *et al.*, 1999a). It is noteworthy that this can lead to the narrowing of the genetic base and, consequently, to problems associated with inbreeding depression. With the aim of overcoming these problems, the selection of parents may be based on genealogies and/or genetic divergence obtained with molecular markers (Lima *et al.*, 2002).

After the choice of the parents, it is necessary to define a strategy to obtain the segregating population. For sugarcane, two widely used approaches are biparental crosses (full-sib family) and polycross (Matsuoka *et al.*, 1999a; 1999b; Landell and Bressiani, 2008):

a) **Biparental crosses**: a segregating population is obtained from a cross between two parents, allowing for the identification of the male and the female. This is the type of cross most often used in practice because it takes into account both the general capacity of combination of the parents and the specific capacity of the crossing combination.

b) **Polycrosses**: certain genotypes are used as male parents and crossed with a single genotype used as female. In this case, only the one parent is known. The main advantage of this approach is the possibility of producing a larger number of seeds in relation to the two-parent cross, as well as a greater variability within each progeny (half-sib family).

Annually, a breeding program generates populations composed of thousands of seedlings, which are later submitted to selection. The number of seedlings varies according to each program and depends on technical and economical factors.

ii) Selection and cloning in the early stages

The main challenge for the breeder is to find superior genotypes in a segregating population and propagate them. However, in the earlier stages, selection cannot be intensive for traits that are highly influenced by the environment. Initially selection is done for traits with high heritability and using low intensity. Throughout the selection stages, the availability of stalks per genotypes increases gradually, allowing the implementation of experiments with high levels of accuracy and increased selection intensity. The size of plots and number of repetitions will vary depending on the availability of stems and specific traits of the breeding programs.

In contrast to some plants such as maize, sorghum, soybeans, among others, sugarcane allows the propagation of a given genotypes, which makes it possible to explore heritability in a broad sense; that is, in addition to additive variation, it is possible to explore dominance and epistatic interactions (Visscher *et al.*, 2008). At the initial stages, measurements are obtained based on individual observations, and in the latter stages they are obtained based on averages of replications. For these reasons, selection for traits of lower heritability is performed only at later stages, which can increase the gains with selection. According to the results presented by Skinner *et al*. (1987), Matsuoka *et al*. (1999a) commented that in the early stages, selection would be more effective for Brix and resistance to rust and smut. However, the results should be interpreted with caution because estimations of heritability may vary according to the population and the experimental conditions (Visscher *et al*., 2008).

Several strategies may be used in the early stages for planting and selection such as individual planting, bunch planting and families planting, because in that period it is not possible or very difficult to cultivate the plants under experiments with statistical designs.

Individual plant selection: consists of planting genotypes with a greater distance between individual plants to avoid competition. This strategy is recommended only for the selection of traits with high heritability, such as Brix, flowering, and disease resistance (Matsuoka *et al*., 1999a). Thus, this strategy can be considered in situations where it is possible to evaluate every individual genotype, which, according to Skinner *et al*. (1987) and Matsuoka *et al*. (1999a), can be accomplished in an breeding program. At this stage, many genotypes are discarded visually based only on their vigor. In other words, only the superior genotypes are measured.

Bunch planting (Mangelsdorf, 1953): consists of planting five to 10 seedlings in bunches, allowing natural selection to act by eliminating inferior genotypes. One advantage of this type of planting is the possibility of assessing several stalks simultaneously in the same area. Skinner *et al*. (1987) argued that there are successful examples of the implementation of this technique. However, Matsuoka *et al*. (1999a) indicated the impossibility of evaluating tillering as a disadvantage because this trait is positively correlated with the capacity to tillering and also productivity.

Family selection: is based on situations in which more than a two-parent cross or polycross are available, and the progeny are evaluated according to the average behavior of the individuals. In this approach, the concept of heritability is explored at means levels, which in the early stages, allows the selection of traits that would not be evaluated if this selection was considered at individual levels. When considering the progeny as a whole, it is possible to perform studies of the interactions between genotypes and environments (Hogarth and Bull, 1990; Bull *et al*., 1992; Jackson *et al*., 1995a, 1995b; Bressiani, 2002; Landell and Bressiani, 2008), identify superior crosses (Skinner *et al*., 1987), and to automate the process (Landell and Bressiani, 2008). As a result, some breeding programs prefers to apply this strategy, choosing the families that present higher phenotypic means. However, this procedure may cause the discharge of superior genotypes that are in families with low means and high variance (Matsuoka *et al*., 1999a).

iii) Evaluation of clones in experiments

The selected genotypes in (ii) are compared based on experiments using appropriate statistical design. A feature of these experiments is the large number of genotypes being evaluated and the limited number of stems available for the repetition and/or replication of the experiments in other environments. An appropriate design for this stage is the augmented blocks design (Federer, 1956).

With the use of such an experimental design, it is possible to control some environmental variables. This allows selection for traits that are influenced by the environment, which was not addressed in the previous stage; for example, the evaluation of the capacity of regrowth. Matsuoka *et al*., (1999a) reported that it is not advisable to use a high selection intensity due to reduced experimental accuracy. Skinner *et al*. (1987) suggest that selection intensities between 10 and 30% can be considered. It is of note that these values should not be generalized because they may vary according to the characteristics of each breeding program.

At the end of each experiment, the genotype number is reduced and the availability of plant material is increased. This results in experiments with more repetitions and also replicated in differents environments, which increases the experimental accuracy, making it possible to evaluate the traits with low heritability.

iv) Competition trials

After several selection stages, the remaining genotypes are tested in experiments with high level of accuracy, which is done also including commercial varieties as checks. In this stage, it is common to peform analysis of stability, with the goal of finding genotypes that response better to certain environmental conditions.

In Brazil, such experiments are usually implemented in randomized blocks design (Matsuoka *et al.*, 1999a; Bidoia and Bidoia, 2008) that are often repeated in different environments and assessed over a number of cuts. The genotypes that are superior at this stage are recommended as new cultivars. An interesting feature of this stage is the fact breeding programs and industrial sector have an extensive involvement, which reflects at this stage. Therefore, the experiments are very close to the agronomic practices used after the cultivar is released.

GENETIC MAPPING

The importante traits considered in a breeding program are generally result of the combined action of several genes and the influence of environmental conditions. The term QTL (quantitative trait loci) has been used to specify the chromosomal regions that contain genes (or loci) that control these polygenic traits (Falconer and Mackay, 1996).

With the recent advent of molecular markers, it is now possible to study these regions more easily. Molecular markers are fast and efficient tools for genomic studies because they detect polymorphisms directly at the DNA level and do not suffer any kind of environmental influence (Souza, 2001). Based on these polymorphisms, it is possible to identify relationships between genotype (assessed based on molecular markers) and phenotype (assessed in appropriate experiments), which ultimately could increase the efficiency of breeding programs, through Marker Assisted Selection.

QTL mapping can be defined as a process of inferences across the entire genome trying to associate genotype and phenotype. These results include information on the number, position, effects, interactions of QTL alleles within loci (dominance) and among loci (epistasis), pleiotropic effects of the QTL, and interactions between QTL and the environment (Zeng, 2001). Therefore, it requires a population that presents genetic variability and high linkage disequilibrium. In this context, first a linkage map was obtained and it is the basis for future localization of regions that controls the quantitative traits. For this, sophisticated statistical methods are required, which demands strong computational support due to the complexity of analysis.

Genetic maps

The majority of the populations used for the development of genetic linkage maps are derived from inbred lines (for example, F2, Backcrosses, Recombinante Inbred Lines). The statistical methods in such cases are established and implemented in various software packages, such as MAPMAKER/EXP. However, obtaining inbred lines is impractical for sugarcane, mainly due to high inbreeding depression that exists. Thus for sugarcane, the mapping population is usually a full-sib family derived from two-parent cross between non-homozygous parents (Lin *et al.*, 2003).

For sugarcane (and various other species for which there are no available inbred lines, such as passion fruit and eucalyptus), an alternative that has been widely used was the pseudo-testcross strategy (Grattapaglia and Sederoff, 1994). This approach provides two individual maps (one for each parent) through the identification of polymorphisms in a single dose marker for each parent (Grattapaglia and Sederoff, 1994; Shepherd *et al.*, 2003; Porceddu *et al.*, 2002; Carlier *et al.*, 2004). Based on this approach, linkage maps for *S. officinarum* ('LA Purple') and *S. robustum* ('Mol 5829') were developed using RAPD, RFLP and AFLP markers in a single dose (Guimarães *et al.*, 1999). Other studies were conducted with differents parents but commercial cultivars was rarely considered in this type of study (Sobral and Honeycutt, 1993; Al-Janabi *et al*., 1993; da Silva *et al*., 1993; da Silva *et al*., 1995; Grivet *et al*., 1996; Hoarau *et al*., 2001). However, from either biological or statistical point of view, it is desirable to integrate the information contained in these individual maps into a single one. This can only be done with the presence of heterozygous markers in both parents, which are essencials in the integration process (Barreneche *et al*., 1998; Wu *et al*., 2002a; Garcia *et al*., 2006; Margarido *et al*., 2007; Oliveira *et al*., 2007).

The development of integrated genetic map using molecular markers with different segregation patterns has major advantages because it increases the saturation of the map and also can represent better the polymorphism variation across the genome. Specifically, for polyploid species such as sugarcane, co-dominant markers can be useful to gather linkage groups into their respective homology groups (da Silva *et al*., 1993; Grivet *et al*., 1996). Moreover, statistical power for QTL mapping can be increased when integrated maps are used (Maliepaard *et al*., 1997). However, in a full sib family each segregating locus may differs at the number of alleles, as well as at their linkage phases, making it difficult to detect recombination events (Maliepaard *et al*., 1997; Wu *et al*., 2002a).

Wu *et al*. (2002a) proposed a statistical method based on maximum likelihood, which allows for the estimation of both the recombination fraction and the linkage phases between loci in full-sib families. This method allows the development of an integrated genetic map that is a result of the combination of several types of information generated from different types of molecular markers with variable information content. This approach was used by Garcia *et al*. (2006) and Oliveira *et al*. (2007), who developed integrated genetic maps consisting of 357 markers distributed over 131 groups of co-segregation from a cross between two pre-commercial cultivars of sugarcane (SP80-180 x SP80-4966). These results were superior to those obtained when the same data were analyzed using the JoinMap program, which indicates, in this case, a greater efficiency in the estimation of linkages and linkage phases of the method proposed by Wu *et al*. (2002a). Initially, a software called OneMap (Margarido *et al*., 2007) was developed, which allows for the development of genetic maps in full-sib family, considering the approach proposed by Wu *et al*. (2002a). However, in its new version, the methodology was adapted for a multipoint approach based on Hidden Markov Models (Lander and Green, 1987; Jiang and Zeng, 1997; Butcher *et al*., 2002; Wu *et al*., 2002b). It is important to note that this software has also been used for other outcrossing species such as citrus, pinus, eucalyptus and passion fruit.

Despite the great superiority of these new approaches, it is still only possible to use markers that show 1:1 and 3:1 fashion, which are known to be less informative than other types such as markers that segregate in 1:2:1 or 1:1:1:1 fashion, in the case of diploid species (Wu *et al*., 2002a). For sugarcane, the presence of autopolyploids is also complicated because there are few studies focusing on the development of genetic maps with markers with different doses (da Silva, 1993; da Silva *et al*., 1995; Ripol *et al*., 1999). Overall, these factors make it difficult to obtain linkage groups and the ordering of markers within these groups, resulting in less saturated maps with less coverage of the genome. Furthermore, the integration of maps from parents is not always possible.

QTL mapping

Similar to linkage maps, QTL mapping also has several statistical methods available that were mainly developed for inbred lines, such as single markers analysis (t-test, analysis of variance, simple linear regression and likelihood ratio test (Weller, 1986, Edwards *et al*., 1987; Stuber *et al*., 1987, Lynch and Walsh, 1998), interval mapping (IM) (Lander and Botstein 1989), composite interval mapping (CIM) (Zeng 1993, 1994; Jansen and Stam 1994), and multiple interval mapping (MIM) (Kao and Zeng, 1997; Kao *et al*., 1999). These methods are implemented in software platforms such as the QTL Cartographer (Basten *et al*., 1999). From a theoretical point of view, there are several advantages of the MIM models over the others (Zeng *et al*., 1999). They provide useful results for breeding programs, for example, for assessing breeding values of each individual that can be used in marker-assisted selection.

For sugarcane, several QTL mapping studies were developed using the analysis of individual makers, or interval mapping (for example, Grivet *et al*., 1996, Guimarães, 1999; Hoarau *et al*., 2001; Ming *et al*., 2001, 2002; Kido, 2003), generally considering the pseudo testcross strategy. Among the results, it could be point out the identification of RFLP probe that is associated with resistance to rust that showed a segregation pattern 3 (resistant):1 (susceptible) in the progeny (Grivet *et al*., 1996). Guimarães (1999) detected an RFLP probe associated with sugarcane flowering. Ming *et al*. (2001, 2002) detected 36 QTL regions for sugar production, stem weight, number of stalks, and fiber and ash content. Kido (2003) mapped QTL regions for several agronomic traits in crosses of two Brazilian species of sugarcane detecting 11 QTLs for Brix, 9 for stem diameter, 7 for tiller number, 21 for stalk height, 6 for fiber content, 2 for percentage of sugar, and 3 for productivity. It becomes clear that advances in sugarcane breeding can be achieved with QTL mapping.

In populations derived from a full sib family, as in the case of sugarcane, there is an additional complication: the linkage phases between different loci and QTL are not known and should be estimated. This complicates linkage analysis and QTL mapping in these cases. Lin *et al*. (2003) presented a statistical method based on interval mapping that estimates linkage and linkage phases between marker loci and QTL simultaneously, considering all types of markers (informative and partially informative). However, this model considers only the information between a pair of flanking markers (probabilities are not obtained via multipoint analysis). To avoid the problem of the lack of knowledge of linkage phases between QTL regions and markers, they are considered as parameters in the mixtures model, which makes the likelihood complex, in addition to presenting computational difficulties when obtaining estimates of linkage phase between QTL regions and markers. The proposal of Lin *et al*. (2003) was important because, to our knowledge, it was the first mapping model that used an integrated genetic map using markers that show different segregation.

To avoid some of these limitations, Gazaffi (2009), Gazaffi *et al*. (under development) and Pastina (2010) developed approaches for QTL mapping in this case, expanding the approach by Lin *et al*. (2003) in the context of composite interval mapping (Zeng, 1993, 1994) and using multipoint probabilities (Jiang and Zeng, 1997). However, there are no statistical models available for multiple features in both the context of CIM and MIM, which would allow for the study of the genetic basis of the correlation between traits and the interaction of genotypes and environments, in a full sib family. In addition, it is expected that more sophisticated approaches will be available in a near future.

FINAL CONSIDERATIONS

Currently, sugarcane breeding programs benefit from methods developed for the estimation of genetic parameters. Additionally, the development and dissemination of molecular markers has enabled the unraveling of the architecture of quantitative traits through QTL mapping.

It is important to mention that, for sugarcane (an autopolyploid species), proposals have been made for genetic mapping that consider polyploidy (da Silva, 1993; da Silva *et al*., 1995; da Silva and Sorrells, 1996; Ripol *et al*., 1999; Doerge and Craig, 2000; Wu *et al*., 2001; Luo *et al*., 2001; Luo *et al*., 2004; Wu *et al*., 2004; Cao *et al*., 2005), although the approach used in most practical situations corresponds to the application of mapping similarly to what occurs in the diploid species. This approach is based on the use of markers that segregate at 1:1 and 3:1 ratios. However, several different patterns of segregation can occur (Grivet *et al*., 1996; Edmé *et al*., 2006), and only part of the genetic polymorphism is considered in this approach, which impedes the complete study of the genetic architecture of quantitative traits in polyploids. We hope that, in the future, these species can be studied in details, by developing models that consider this genetic polimorphism.

A common criticism made in QTL mapping concerns the results obtained for a particular population are not necessarily repeated in other crosses because only part of the variability of the species is sampled (Flint and Mott, 2001). One possibility to alleviate this problem would be to conduct QTL mapping in several full sib families, followed by the search for corresponding polymorphisms in others genotypes via associative mapping (Salvi and Tuberosa, 2005). This type of study can only be conducted with the presence of a high rate of polymorphism. For this reason, SNP markers are used in such studies (Kruglyak, 2008). It is believed that by reducing the cost of this type of technology results for sugarcane will be available in the near future.

QTL mapping studies also aim to find regions that control quantitative traits. However, there is interest in finding polymorphism at the gene and individual nucleotide levels (Mackay, 2001). For this purpose, one option would be to conduct fine mapping studies (Mott and Flint, 2001). However, such studies are expensive and burdensome. The development of DNA microarray technology allows for eQTL (expressed QTL) mapping (Jansen and Nap, 2001; Schadt *et al*., 2003) because the gene expression of individuals of a certain population can be used as a phenotype to obtain regions that control this expression. The main advantage of this approach is that a single DNA chip allows for a simultaneous genetic expression profile of hundreds or thousands of genes for a single individual. The phenotyping of a segregating population would allow the observation of which genes present QTL regions that are coincident with the QTL regions associated with agronomic traits. Thus, it is possible to infer which genes are responsible for the control of the phenotypes under study. The use of eQTL also allows the study of epistasis from a new perspective, for example, through the reconstruction of gene networks (Jansen and Nap, 2001; Zhu *et al*., 2004). Although it still presents few practical results, this approach would allow for studies of the genetic architecture of traits of economic importance in great detail.

We believe that genetic mapping studies have allowed for a better understanding of the genetic control of traits of economic interest in sugarcane. However, such knowledge can still be expanded if we consider other approaches that require the development of statistical models and new biotechnology tools. The main contribution of these studies is the possibility of incorporating this information into breeding programs, either by selecting regions that control traits of interest or by guiding new strategies.

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4

THE STRATEGY FOR REGIONAL SELECTION FOR THE DEVELOPMENT OF ENERGY SUGARCANE CULTIVARS PROFILES

Marcos Guimarães de Andrade Landell, Silvana Creste, Luciana Rossini Pinto, Mauro Alexandre Xavier and *José Antonio Bressiani*

Sugarcane is one of the main crops cultivated in Brazil, and grows well in latitudes between 31° and 5° of the south hemisphere. This tropical climate range usually shows shorter and colder days, and such weather conditions may be increased close to the Tropic of Capricorn which is the most traditional region of sugarcane cultivation in Brazil's Center-South. These tropical areas are mainly characterized by a rainy summer followed by a dry winter season. Surrounding areas of lower latitude are usually characterized by long periods of an extensive drought season, showing concentrated rain distributions during the crop cycle, and also by higher maximum temperatures, which may result in a higher evapotranspiration rate, affecting the accumulation of sugarcane biomass. The major climate components that control sugarcane growth, yield and quality are temperature, light and available water (CAMARGO, 2005).

In Brazil, sugarcane is cultivated in a variety of different soils, such as Latosols, Argisols, Nitosols, Cambisols, Neosols, Vertisols, Plinthosols etc. Within each one of these classes there is also a great variability in the chemical potentiality, which is responsible for conferring specific characteristics for each type, enabling their classification on eutrophic, mesotrophjfic, distrophic, acric, mesoalic and alic soils in this universe (PRADO, 2008).

Brazilian sugarcane expansion areas comprise mainly "cerrado" (savannah) areas, including west and northwest area of São Paulo state; south of Minas Gerais state, eastern Mato Grosso do Sul state, Goiás, Tocantins, and Maranhão states and west of Bahia state. Although these areas are located in different latitudes, they have some particularities when compared to traditionally occupied regions by this crop. For instance, these areas have a greater water deficit along the year and also remarkable differences regarding vegetative growth, flowering, sucrose accumulation and resistance against pests and diseases. For this reason, sugarcane genetic breeding programs have adopted specific strategies for the development of varieties locally adapted to these new environments, re-orientating the hybridization and selection processes, as well as establishing regional experimental stations for selection (LANDELL, 2008).

The hybridization process (crossing) is the main procedure used up to now to generate genetic variability on sugarcane in order to perform the selection of superior individuals. A population of sugarcane seedlings that has this condition will be much higher and bigger is the variability of the parents involved in the hybridization process. A careful characterization of the productive environment where the seedlings are introduced allows breeders to isolate important environment factors, facilitating the selection of regional-adapted genotypes Thus, the environment mapping of representative sugarcane cultivation regions is an essential procedure to be considered in hybridization (choice of the parents) and selection phases.

Deviations on relative behavior of genotypes due to differences of the environment are known as the genotype x environment interaction (*G* *x E*). Knowing such interaction is important for breeders to define their initial objectives, i.e., if the aim is the development of varieties for a broad range of environments or for a specific environment (BORÉM, 1998). ROBERTSON (1959) defined two types of *G x E* interaction: simple and complex. Simple interaction does not show greater difficulties for breeders, considering that a superior genotype in a specific environment will also probably be it in other environments. Nevertheless, the complex interaction is the most prominent one, where an inversion of behaviors is observed, reflected by the impair genotypes responses to environmental variations.

Adaptability and stability of the variety are other aspects that must be taken into account. Adaptability refers to the ability of a variety to take advantage of environmental variations in a positive way. Stability refers to the ability of a variety to show a predictable behavior due to environmental changes. There are two main types of stability: static and dynamic. Static stability occurs when a variety has a constant behavior, independently of changes in the environment, and does not show deviations related to its behavior. It is also known as biological stability and it is more closely related to traits that are less influenced by environment (qualitative traits), as well as the sucrose accumulation curve (maturation) and coloring of stalks, for example. On the other hand, dynamic stability, also designated as agronomic stability, is more associated with quantitative traits. It is characterized when a determined genotype responds to an environmental variation in a predictable way. This stability, if well estimated, consists on an important tool for varietal management. Therefore, a promising variety must show a high yield and stability in different environmental conditions (LANDELL, 2008). Thus, for a good classification of a cultivar regarding its agronomic potential, it is necessary to associate the know-how on the productive environment with the individual performance. Thus a cultivar may be classified as: a) stable, when it has a reasonable response to most favorable growing conditions but also shows an average response in non-favorable conditions; b) responsive, which shows great responses in favorable growing conditions, but does not adapt to more restrictive environments; and c) rustics or low maintenance cultivar, which, contrary to the responsive cultivar, is the most adaptable to restrictive environments, but does not have good performance in favorable cultivation conditions.

So, a new cultivar should be characterized according to its performance in different production environments. An estimative of how a genotype behaves under environmental changes may be determined by quantifying the *genotype x environment* interaction. Under the genetic context, it is possible to quantify this interaction through the instability of the genotypic expression of homozygous and heterozygous alleles (CRUZ, 2003). Several authors have studied this interaction, and developed concepts and indexes of stability, describing methods to estimate phenotypic stability in plants.

Among all methods suggested to evaluate the genotypic performance, one of the most traditional is analyses of groups of experiments. This method considers that a genotype which shows less variance will be the most stable. However, it is very common that low-variance genotypes also show low yield.

Methods based on regression have been widely accepted and used, because with them it is possible to describe the individual responses of different genotypes in a group of environments. These methods estimate an index to each environment studied from the average performance of genotypes. However, to obtain a straight line in regression, theoretically, production and the environmental index must have normal distributions. Some methods will be better described as following:

a) FINLAY and WILKINSOM method (1963): it proposes a calculation of the response for each cultivar regarding the environmental index, which will be obtained by the average of genotypes in a given environment. The regression coefficient ($\underline{b}$) will be the estimative of a genotype stability, knowing: $\underline{b} = 1$ represents the average stability (agronomic stability), $\underline{b} = 0$ represents a cultivar completely stable (biological stability). Best cultivars will be those which is possible to associate higher yield with $\underline{b} = 1$.

b) EBERHART and RUSSEL method (1966): provides information about the relative performance of each genotype in relation to the environmental average, as well as in relation to its linear response. For these authors, the ideal cultivar will be those which show superior average yield, wide or general adaptability ($\underline{b} = 1$) and high predictability or stability ($\sigma^2 = 0$). Main contribution of this method was to enable an estimative environmental index through the difference of average yield in each environment regarding total average yield, which makes possible the stratification of the studied environments.

c) TAI method (1971): it is based in a methodology that estimates the adaptability (linear response of a given genotype, $\underline{b}_i$, under environmental effects) and the stability (linear response in terms of the magnitude of the error variance in relation to the error associated to GA_{ij} interaction). A perfectly stable genotype would show $\underline{b}_i = -1$ e $\lambda_i = 1$. This corresponds to the biologic stability, i.e., a theoretical stability that is unlike to be found in traits of agronomic interest linked to yield.

VERMA *et al*. method (1978): it is a modification of former methods, dividing the evaluation environments in two subgroups, which would represent either favorable or unfavorable environments, according to the deviation related to the general location average. Thus, this method consists of an evaluation of a genotype response through linear regressions into two environmental groups: unfavorable (negative environmental index, $\underline{b}_1$) and favorable (positive environmental index, $\underline{b}_2$). But it is necessary to have a large number of environments, in order to each subgroup has a minimum number of locations that allow valid statistical comparisons. According to VERMA *et al*. (1978), there are three types of genotypes:

- Ideal genotype: high yield capacity, low response to unfavorable environments ($\underline{b}_1 < 1$) and responsive to favorable environments ($\underline{b}_2 > 1$).
- Genotypes indicated to favorable environments: responsive to favorable environments ($\underline{b}_2 > 1$), but sensitive to adverse conditions of the environments ($\underline{b}_1 > 1$).
- Genotypes indicated to unfavorable environments: not responsive to favorable environments ($\underline{b}_2 < 1$), but not so sensitive to adverse conditions of the environments ($\underline{b}_1 < 1$).

Lately, AMMI (*Additive Main Effects and Multiplicative Interaction Analysis*) method has been used by many researchers in plant breeding. It is a matrix method that builds new variables (AMMI0, AMMI1, AMMI2,..., or AMMIF) which are independent to each other and capture *G x E* interactions. Usually, first two AMMIs are enough to capture most part of *G x E* variance and allow the interpretation through Biplots. This analysis combines, in just one model, additive components for main effects (genotypes and environments) and multiplicative components for *G x E* interaction. Therefore, it is very useful to identify genotypes of high yield and largely adapted, as well as to define the so-called agronomic zoning (DUARTE, 1999).

Figure 1 shows an example of the application of this method in sugarcane. Genotypes and locations closer to the IPCA1 axis in AMMI1, and close to the intersection of IPCA1 or IPCA2 axis in AMMI2 are considered the most stable. The most productive genotype, IACSP94-4004, is located in a distant region of IPCA1 axis, indicating an adaptation to more specific conditions, while cultivar IACSP93-3046, also very productive, has shown high stability, positioning itself closer to IPCA1 axis.

Some authors recognize the ideal genotype as the one with high yield capacity and responsive to favorable environments, besides being little affected to unfavorable conditions. However, there are cultivars that despite having an average behavior under unfavorable environmental conditions, they are salient in the best environments, being

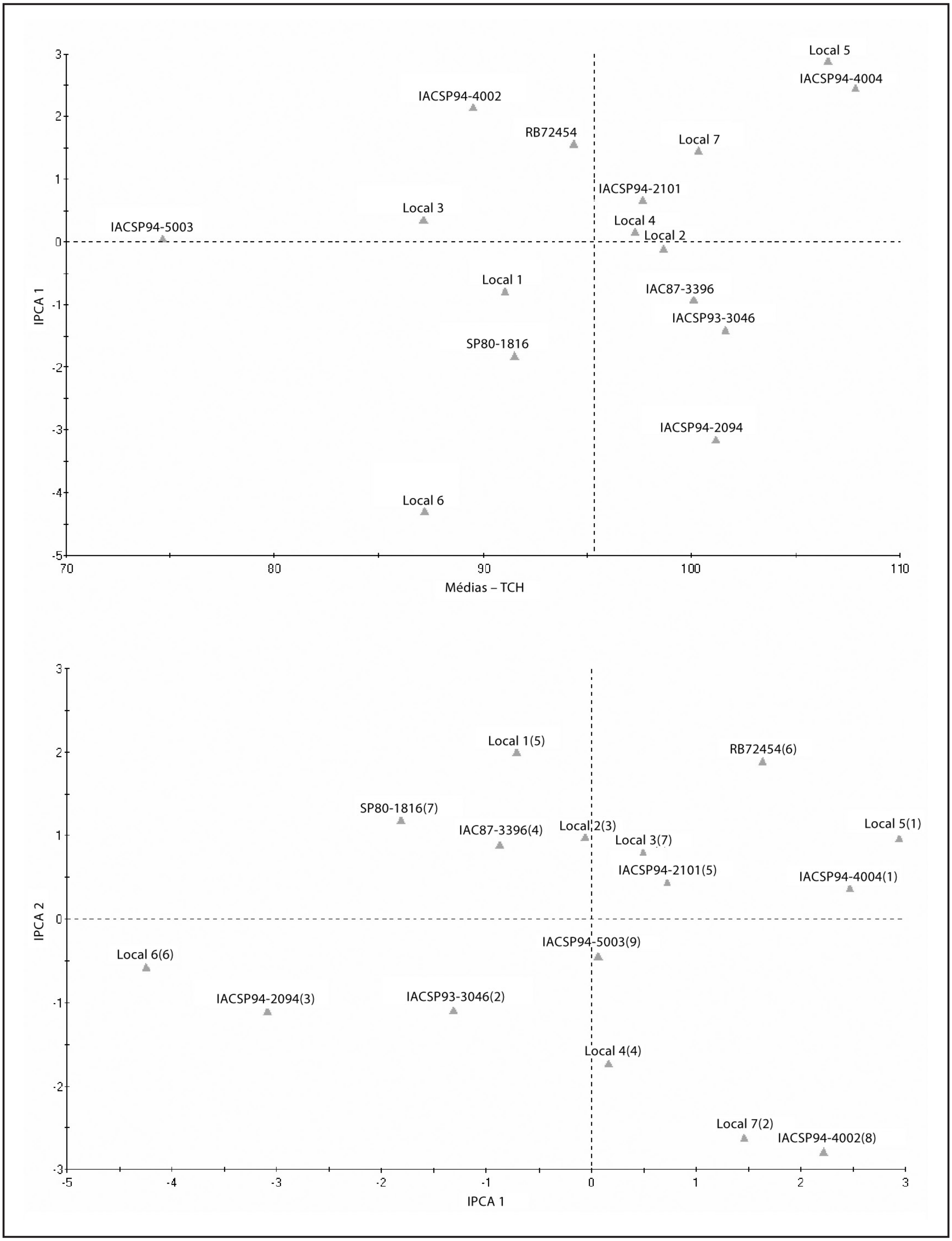

FIGURE 1 Biplot of AMMI analyses and average TCH (1st biplot); AMMI1 and AMMI2 analyses (2nd biplot), for IAC network essays (ESTADUAL 2002), with nine genotypes in seven environments (average TCH for four cuts performed in the middle of harvesting time).

characterized as responsive or demanding. Others are distinguished only in unfavorable environments and are denominated rustics or not demanding. Frequently, cultivars that fit this last group have lower yield potential.

Regional selection has the advantage to allow for a better characterization of a new cultivar, regarding its performance on several yield environments. Studies on phenotypic stability enable one to summarize the huge amount of information obtained from an experimental network, characterizing the yield potential, adaptation to environmental conditions and stability of new cultivars (RAIZER, 1999). Therefore, new sugarcane cultivars have been recommended specifically for different production environments, in association to their specific agricultural management and harvesting period. So, this strategy allows the breeder to take maximum advantage to explore the genetic potential of new cultivars. Nevertheless, considering that Brazilian sugarcane expansion cultivation areas show specific environmental conditions, the possibility of obtaining cultivars more adapted to these new environments drastically decreases when the initial phases of sugarcane breeding are conduced in environments which are very different from commercial planting.

Regional selection minimizes environmental diversity and its interactions with the introduced population. This strategy does not avoid the selection of wide-adapted genotypes based on the average of several places; yet, choosing a specific selection for each place should provide superior gains as described by BRESSIANI (2001).

In addition to the environmental adaptation for yield traits, another aspect of great importance in regional selection concerning the relative importance of traits related to yield. For instance, the ability of a genotype to keep a good tillering ability becomes more important in “cerrado” areas, which is also an indication of tolerance to drought. Other major features for adapting to these particular conditions are: ratooning ability, maintenance of density during the cycle of the crop and the absence of flowering. Such characteristics play an important and strategic role in the selection process.

Qualifying sugarcane production environments is an essential tool for regional selection. Sometimes, although the breeders’ task of selecting superior individuals is somehow impaired, particularly when working with different environments of production (soil, climate, biotic factors), and phytotechnic management (MONTALVÁN, 1999) regardless of characterizing, it in relation to its edapho-climatic potential. The qualification of the production environment provides with the necessary support for the perception of a superior genotype, and propitiates the adoption of suitable management strategies. Such strategies must gather more heterogeneous environments, from the stratification of equivalent sub-regions, in which the interaction $G x E$ is less significant. The stratification or ecologic zoning is a useful procedure, yet having its efficacy restricted due to the occurrence of uncontrollable environmental factors such as rains and variable thermal amplitude.

Hitherto, several breeding programs have adopted regional selection strategies. In the early 90’s the *Instituto Agronômico de Campinas – IAC* (Campinas Agronomy Institute) established seven different regions for selection in São Paulo State, based on edapho-climatic parameters. In such regions, IAC has introduced populations of seedlings which have been continually evaluated for many years. After they are considered regional pre-cultivars, they are multiplied and distributed for an experimental network comprising ten states from the Brazil’s Center-South region, in order to have their phenotypic stability evaluated. Recently, *Centro de Tecnologia Canavieira* – CTC and Canavialis sugarcane breeding programs have also decided to adopt this strategy. Similar procedures have been widely used throughout the world, by sugarcane breeding programs from Australia (COX *et al.*, 2000), South Africa (SASA, 2004) and Caribbean Islands (KENNEDY, 2000).

Thus, in theory at least, by the end of the regional selection process, a new variety should be obtained in a shorter period of time, around 6 or 7 years. Furthermore, observations built up during successive years on distinct cycles of plants (cane and ratoon cane), together with the

TABLE 1 Singular features aimed on the selection process in each of the regions of IAC Sugarcane Program.

Region	Major features	Phytosanitary problems
01 Piracicaba	Increase on agricultural yield potential and tolerance to aluminum in sub-surface.	Brown rust
02 Ribeirão Preto	Higher shooting ability during drought periods.	Mosaic leaf virus, leaf scald
03 Jaú	Higher resistance to leaf diseases, and higher yield performance in low fertility soils.	Brown, smut leaf scald
04 Mococa	Higher maturation potential under low water deficit conditions.	Brown rust
05 Pindorama	Higher shooting capacity during drought periods.	Leaf scald, nematodes
06 Assis	Higher maturation potential under low water deficit conditions.	Mosaic leaf virus, brown rust red stripe leaf
07 Adamantina	Ability to accumulate increased levels of biomass during vegetative growing period.	Smut
08 Goianésia	Ability to tolerate long periods of drought and absence of flowering.	Smut

interaction of subsequent agricultural years, is now used as the major selection criteria by breeders (LANDELL, 2004).

Table 1 shows the principal traits in each of the selection regions from IAC Sugarcane breeding Program. Actually, one could take advantage of the edapho-climatic regional context where genotypes are inserted, inferring the selection opportunities for each of these places. For instance, in Piracicaba region soils with high level of aluminum are very common (alic soils), therefore, the selected materials in this condition have greater possibilities of being tolerant to higher aluminum levels on the soil. In this same region, climatic condition favors rust disease occurrence. So, Piracicaba region propitiates unfavorable environment to selection of tolerant genotypes for this disease.

As a result of this breeding strategy, the *Instituto Agronômico de Campinas* has released since 2004 twelve sugarcane regional cultivars with a more specific adaptation profile, in order to include regions that were poorly contemplated by current sugarcane breeding programs, like surrounding regions of Mantiqueira and Assis. For next few years, varieties originally developed for "cerrado" areas will be released by all sugarcane breeding programs, bringing considerable gains on varieties currently cultivated.

In order to define a cultivar regarding its agronomic response profile, it is necessary to better understand the productive environments and the individual performance of the genotype. This has permitted introduction of new sugarcane cultivars more suitable to different production environments associated to the type of agricultural management and harvesting time during production. Such specificity allows exploring at maximum the genetic potential of new cultivars in different production sites.

An example of varietal recommendation is presented in Table 2. Cultivars are recommended for harvest time and type of production environment.

TABLE 2 Management recommendation of sugarcane cultivars, according to production environment criteria, responsiveness and harvest season.

	Environment			**Responsiveness**			**Season**		
	Superior	**Medium**	**Inferior**	**Resp.**	**Rustic**	**Estable**	**Autumm**	**Winter**	**Spring**
CTC 1	■	■		■			■		
CTC 2		■	■		■	■		■	■
CTC 3	■			■					■
CTC 4	■			■				■	■
CTC 5	■	■		■			■		
CTC 6	■	■		■		■		■	■
CTC 7	■	■		■			■		
CTC 8		■				■		■	■
CTC 9	■	■		■		■	■	■	
IAC 86-2210	■	■				■	■		
IAC 87-3396		■	■		■	■		■	
IAC 91-2195		■				■	■		
IAC 91-2218	■			■				■	
IAC 91-5155		■	■		■	■		■	■
IACSP 93-6006		■				■		■	
IACSP 93-3046	■	■	■		■	■		■	■
IACSP 94-2094		■	■		■			■	■
IACSP 94-2101	■			■				■	■
IACSP 94-4004	■	■		■		■		■	
PO 88-62		■		■		■		■	
RBT 72454	■	■				■	■	■	
RB 835054	■	■		■		■		■	■
RB 845210		■				■		■	
RB 855113	■			■					■
RB 855156		■	■		■		■		
RB 855453	■	■		■			■		
RB 855536	■	■		■		■		■	■
RB 867515		■	■	■		■		■	■
RB 92579	■	■		■		■		■	■
RB 925211	■	■		■		■	■	■	
RB 925268	■	■		■		■		■	■
RB 925345		■	■		■	■	■	■	
RB 928064	■					■		■	
RB 935744	■	■		■		■		■	■
SP 80-1816	■	■		■		■		■	
SP 80-1842		■				■	■	■	
SP 80-3280	■	■		■				■	
SP 81-3250	■	■		■		■	■	■	
SP 83-2847		■	■		■	■		■	

(continues)

	Environment			Responsiveness			Season		
	Superior	Medium	Inferior	Resp.	Rustic	Estable	Autumm	Winter	Spring
SP 83-5073									
SP 84-1431									
SP 84-2025									
SP 86-42									
SP 86-155									
SP 87-365									
SP 89-1115									
SP 90-1638									
SP 90-3414									
SP 91-1049									

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5

THE IMPORTANCE OF THE GERMPLASM IN DEVELOPING AGRO-ENERGETIC PROFILE SUGARCANE CULTIVARS

Silvana Creste, Luciana Rossini Pinto,
Mauro Alexandre Xavier and *Marcos Guimarães de Andrade Landell*

INTRODUCTION

Sugarcane improvement programs play an important role in the sugar-alcohol industry, as they are the source for developing varieties, the main technological input for sugar and ethanol production. Over the last three decades, important gains were achieved in agribusiness, mostly resulting from breakthroughs in genetic improvement. Among its objectives, the increase in stalks sugar content was always one of the major goals, as improving such feature reflects an economic interest, as harvesting, transportation, and milling costs remain practically unchanged. However, a new paradigm for energy production is rising based on biomass production: to use the whole plant, dissociated from sugar production.

The energy cane concept proposed by ALBERT-THENET (2003) emphasizes the differentiation of sugarcane varieties with high fiber content from those previously produced to obtain sugar and bagasse, leading to the development of varieties with characteristics favorable to power generation. This particular type of sugarcane foresees high fiber content (25%), 100 tons/ha.year productivity, 25% of trash/cane, 12% Pol% cane, which would provide around 50 tons of fiber per hectare/year.

One important aspect in the development of high biomass yield sugarcane varieties relates to using energy as a primary function to optimize and select clones and/or varieties. In this context, clones may be selected by their primary energy – PE, i.e., megajoule per ton of sugarcane (MJ/tc). This concept considers the total energy from sugarcane, including fiber, saccharose, and reducing sugars – RS, and is given by the formula: MJ/tc = 18 x kg fiber (dry matter) + 16 x kg saccharose + 15.6 x kg reducing sugars. This equation may be used to optimize sugarcane cultivars for maximum power generation, i.e., in the selection of the so-called energy cane, as fuel cane should deliver a primary energy of 1,100 MJ/tons of cane per year (LEAL, 2008).

In this new concept, improvement programs will have their focus redirected to developing cultivars compliant to this new varietal profile.

Particularly in Brazil, the growing demand for ethanol fuel, as well as the need to ensure the country's competitiveness in the international trade and its leadership in bioenergy generation, doubtlessly poses new challenges to improvement programs. It is estimated that by 2025 average productivity in Brazil will rise from the present 79 t/ha to 90-100 t/ha, with a change in the varietal profile, which should be directed to biomass production, for power co-generation, and for the production of ethanol from cellulose.

To obtain this new biotype, it is essential to know the taxonomic and evolutionary relationships of sugarcane, as well as the genetic improvement background of current varieties.

GENETIC RESOURCES IN SUGARCANE

Sugarcane is a grammineae of the *Poaceae* family, *Andropogoneae* tribe, and *Saccharum* genus, characterized by a high level of ploidia, and frequent aneuploidia. Sugarcane cultivars feature alogamy and high heterozygosity, generally not tolerating endogamy (HOARAU *et al.*, 2007).

The *Saccharum* genus encompasses six species: *S. officinarum, S. robustum, S. spontaneum, S. barberi, S. sinense,* and *S. edule*. *S. officinarum* clones (2n = 80), the domesticated species, are also known as noble canes for their sweet taste. *S. robustum* (2n = 60 – 80) and *S. spontaneum* (2n = 40 – 128) are considered wild species. *S. barberi* (2n = 81 – 124) and *S. sinense* (2n = 111 – 120) are known respectively as sugarcanes from China and India, having contributed with few genes to present cultivars. Most likely these two species derived from natural hybridizations between *S. officinarum* and *S. spontaneum*. *S. edule* (2n = 60, 70, 80). It is considered an ornamental species cultivated in gardens in New Guinea and the Fiji Islands, without having contributed to modern cultivars (DANIELS *et al.*, 1975).

The six *Saccharum* species with the genera *Erianthus*, *Miscanthus, Narenga*, and *Sclerostachya* compose an intercrossing group known as the "*Saccharum* Complex" (DANIELS *et al.*, 1975), which represents the genetic variability for sugarcane improvement.

ROACH (1989) divided sugarcane improvement in three stages, from its outset in 1890. The first stage comprised crossing and clone selection of *S. officinarum*, which were used in the first sugar plants worldwide. Though these clones had good industrial qualities (high saccharose content, low fiber, and low impurities), they did not have vigor nor long life, and were very susceptible to pests and diseases. The second stage involved the development of interspecific hybrids between *S. officinarum* and other species, mainly *S. spontaneum*, followed by successive retrocrossings of interspecific hybrids with noble cane (*Saccharum officinarum*), to recover the saccharose content existing in the recurring ancestor, in a process named nobilization (BREMER, 1961). This stage represented the quantum leap in the genetic improvement of sugarcane, providing the sugar-alcohol industry with a new performance in raw material, reflected in highly productive varieties, with good tillering capacity, proper stalk diameter, more resistant to pathogens and pests, and resprouting capacity after several cuts (ROACH, 1972; JANOO *et al.*, 1999). Adoption of planned hybridizations resulted in more than doubling the potential yield of sugarcane varieties. One important variety produced in this stage was POJ2878, obtained by Dutch improvers in 1921 in Java, which became a very important ancestor, present in the majority of modern varieties genealogy in all countries that cultivate sugarcane. The third stage involved exploring the hybrids developed in the second phase as parents. However, due to the success obtained in stage II, reflected on the gains in recurring selection progenies, little effort was made to use other accesses of *S. spontaneum* and *S. officinarum*, or other existing clones within the "Saccharum Complex". As a consequence, the improvement of sugarcane is based on a few parental ancestors, which were widely intercrossed, producing hundreds of varieties, determining a narrow genetic base for culture. For this reason, gains obtained in improvement have become ever more limited, yet those resulting from genotype versus environment having become more expressive than genetic gains *per se*. For this reason, Brazilian improvement programs have been trying to develop regional varieties, adapted to specific environments. It is estimated that only 13 clones were used in the initial crossings, of which eight *S. officinarum*, two *S. spontaneum*, one probably natural hybrid between *S. spontaneum* and *S. officinarum*, and two clones of *S. sinense* (available at: <http://www.ars-grin.gov/npgs/cgc_reports/sugar.html>.

Analyses based on DNA polymorphisms have revealed a wide genetic variability between accesses of *S. officinarum* coming from different origin centers (AITKEN *et al.*, 2006). On the other hand, *Saccharum spontaneum* is the species presenting the widest variability within the "*Saccharum* Complex", with chromosomes number varying from 2n = 40 to 128, yet existing euploid and aneuploid forms. Ample variations in morphologic and physiologic characteristics have been observed in collections of *S. spontaneum*

(MARY *et al.*, 2006). Therefore, it is a fact that the genetic variability found in the genes set used by sugarcane improvers is little representative of the genetic variability existing in both the genus and the "*Saccharum* Complex". According to the division proposed by ROACH (1989), it is timely to include a fourth stage in the sugarcane genetic improvement, focused on the implementation of a genetic base enlargement program, to explore new sources of germplasm to develop varieties having the characteristics for biomass production. Along this line, varieties with high potential yield, displaying characteristics adequate for mechanized planting and harvesting, well adapted to the Brazilian "cerrado", as well as an improved energy balance at lower production costs should represent the portfolio of sugarcane varieties in the next two decades.

Within this context, sugarcane genetic improvement will require new sources of germplasm. In Brazil, the largest germplasm collection (and also the best represented) is located in Camamu, Bahia, and was owned by Copersucar, today under the management of Centro de Tecnologia Canavieira – CTC (Sugarcane Technology Center). This collection has about 4,500 accesses, including many representative of the "*Saccharum* Complex". However, its use is restricted to CTC. The other three existing collections belong to the sugarcane improvement programs of Rede Interuniversitária de Desenvolvimento do Setor Sucroalcooleiro – Ridesa (Inter-University Network for the Sugar-Alcohol Industry), Instituto Agronômico de Campinas – IAC (Campinas Institute of Agronomy), and Canavialis – Monsanto. IAC´s and Ridesa's collections are essentially represented by crossing parents, with few representatives of the "*Saccharum* Complex". Canavialis is setting up a replica of the USDA collection, however, like Copersucar/CTC, its use will be restricted. Therefore, it is essential for Brazil to endeavor establishing a sugarcane germplasm collection for public use, representative of the genetic diversity existing in the "*Saccharum* Complex". Hence, usage and introduction accesses policies for the "*Saccharum* Complex" have to be implemented. Priority should be given to those species having highest potential use in improvement, such as *S. officinarum* and *S. spontaneum*. Nevertheless, the genera *Erianthus* and *Miscanthus* are adapted to unfavorable environments, being *Miscanthus* adapted to cold, and *Erianthus* to drought, both having high yield for biomass, hence very interesting for bioenergy.

Germplasm characterization studies carried out in other countries have identified very promising accesses for *S. spontaneum, S. officinarum, Erianthus*, and *Miscanthus* to be used in genetic improvement, most of these accesses not being represented in the collections existing in Brazil.

In view of the aforesaid, we consider that the sugarcane germplasm issue is strategic, and a national emergency – issue in Brazil. The unavailability of access to new sources of genes by Brazilian improvement programs may cause a loss of competitiveness to the country in the generation of varieties with adequate characteristics for producing ethanol, as other countries have initiated programs focused on energy cane, exploring species and genera in the "*Saccharum* Complex".

Currently, the implementation of a public collection depends almost exclusively on the accessibility to international sugarcane collections, as for the time being the largest collections existing in Brazil are not open to international exchange. The two world leading Saccharum collections, known as World Collection for their importance, are: the USA collection, kept in Canal Point (Miami), represented by 2,426 clones of various *Saccharum* species, in addition to 95 clones de *Mischantus*, and the one in India, kept in two places, Kannur, with 1,381 accesses to the Saccharum genus, and Coimbatore with 825 items of the "Saccharum Complex". The one in India is considered better than its American counterpart, as it is well characterized. However, access to these materials is very difficult. The Miami one is easier to access, though many materials have been lost due to storms and difficulties in preserving accesses representing species and genera, which are not well adapted to the American weather conditions. Other important collections are those in Australia, South Africa, and Cuba. The Cuban collection is well represented by species of the "*Saccharum* Complex", due to several collection expeditions in the places of origin over the past 20 years.

However, due to the importance of sugarcane in Brazil, the introduction of germplasm should be made with caution, as there is a risk of introducing, together with the genotypes of interest, a new disease or pest, jeopardizing the national sugarcane culture. Therefore, we think that a public sugarcane germplasm collection should be implemented, made up by representatives of the existing collections in Brazil. Importing germplasms would be solely for those materials not represented in the existing collections. Thus, it is necessary to implement policies on usage and introduction of accesses for sugarcane. Furthermore, all introduction, exchange, and quarantine procedures should follow the international guidelines described by FAO (FAO, IBPGR Technical Guidelines for the Safe Movement of Yam Germplasm), otherwise the national security of Brazilian cane culture might be jeopardized.

CONTRIBUTION OF SUGARCANE GERMPLASM IN CULTIVARS DEVELOPMENT FOR BIOMASS PRODUCTION

Sugarcane programs have always prioritized saccharose content as the main feature to be maximized; consequently, a considerable part of the genes contributing to increase fiber content were gradually eliminated from the current varieties' genetic background. Fiber and Pol characters hold a negative correlation, i.e., the direction given to the biotype of the sugar-alcohol cane then, where saccharose content was a priority, gradually reduced the fiber content of the varieties so far selected. Also, there was no interest in obtaining varieties with high fiber content, as such characteristic, when present in high concentration in a genotype, makes it difficult to extract juice industrially. For this reason, a new pool of genes must be explored to ensure success in developing varieties for bioenergy generation.

For such purpose, it is essential that Brazilian improvement programs strive to enlarge the genetic base of this culture by means of genetic introgression programs, mainly exploring accesses of *S. spontaneum* and representatives of the *Erianthus* and *Miscanthus* genera.

Studies like these have been conducted in countries interested in sugarcane for bioenergy, such as in Barbados (*West Indies Central Sugar*), Australia, China, and the USA (*Louisiana State University Agricultural Center and Texas & AM University*).

Characters like vigor, which contribute to biomass and fiber production, may be found in accesses of *Saccharum spontaneum* and related genera, like *Miscanthus*. *Miscanthus* species have been used mostly by European forage improvement programs as an energy culture (CLIFTON-BROWN *et al.*, 2008). Special attention should be paid to *S. spontaneum* clones, which are well adapted to Brazilian conditions, and offer high potential for producing biomass.

According to WANG *et al.* (2008), sugarcane genotypes having closer relationship to *S. spontaneum* than to current sugarcane cultivars present potential for power generation. Genotypes derived from *S. spontaneum* with favorable characteristics, such as adaptation to adverse conditions and displaying string growth on resprouting, may present competitive costs in comparison to other prospective species/genera.

The Mauritius improvement program (*Sugarcane Breeding Program from Mauritius Sugar Industry Research Institute* – MSIRI) has invested in genetic base enlargement programs by interspecific hybridizations between *S. spontaneum* and *S. officinarum* clones. In these hybridizations, the major difficulty has been the asynchronous flowering of *S. officinarum* and *S. spontaneum*. To circumvent this problem, induced flowering in photoperiod chambers has been used, enabling the breed of commercial clones of *S. officinarum* with *S. spontaneum*, to introgress the wild genoma in the commercial background, a strategy that has been making it possible to increase fiber content with acceptable saccharose levels and other commercial attributes. Though negative correlations have been found between Pol and fiber, it was possible to select families with positive correlations between these characters, allowing the selection of clones FS1 that combine desirable Pol%Cane and fiber%Cane characters, of interest for both the production of improved varieties and parents to be used in improvement programs (RAO, 2007).

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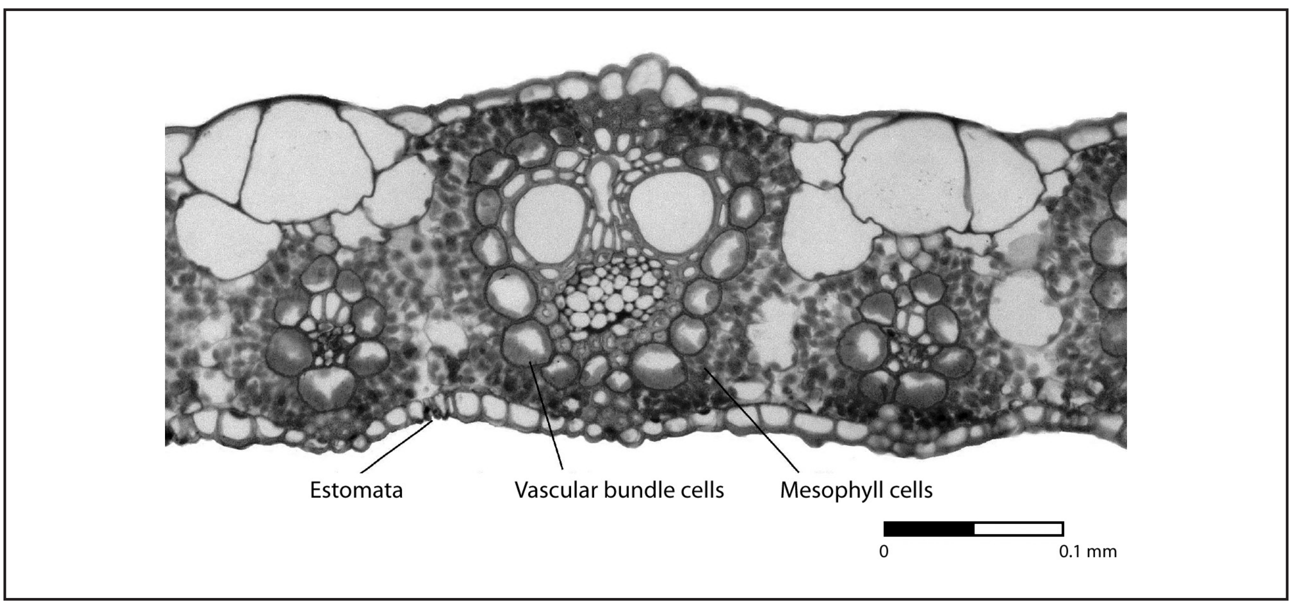
6

PHOTOSYNTHESIS IN SUGARCANE AND ITS STRATEGIC IMPORTANCE TO FACE THE GLOBAL CLIMATIC CHANGE

Amanda Pereira de Souza and *Marcos Silveira Buckeridge*

The photosynthetic process consists of two couple reaction. The first, called photochemical phase, refers to the reactions related to light capture, electron transport and the formation of reducing power (i.e. NADPH and ATP). The second phase is the biochemical, where carbon dioxide (CO_2) is captured and transformed into compounds that link carbon atoms together and therefore retain the energy absorbed by the light reaction (BUCKERIDGE *et al.*, 2008). In the photochemical reactions, the light captured by leaves is capable to provoke changes in chlorophyll molecules present in the chloroplasts and these changes start the transportation of electrons through the electron transport chain, formed by highly specialized proteins. At the end of the process one NADPH and one ATP molecule are formed. These compounds carry the energy and are used in the biochemical phase of photosynthesis. During this phase, CO_2 enters the mesophyl through the stomata (Figure 1), and it is assimilated by an enzyme called Rubisco (Ribulose-1,5-bisfosphate carboxylase/oxygenase). The process of carbon assimilation starts when the carbon of CO_2 is incorporated into a molecule of ribulose-1,5-bisphosphate (RuBP), what starts the so called Calvin Cycle. This cycle forms compounds with 3 carbon atoms, named 3-phosphoogliceric acid (3-



Photography: Débora C. C. Leite.

FIGURE 1 Cross section of a sugarcane leaf showing a stomata, a vascular bundle cells and the mesophyll cells.

PGA). Every two 3-PGAs formed, one molecule of sugar with six carbons is synthesized. The sugars are then polymerized to starch stored in leaves or transported to the growing organs as sucrose.

The plants use this process to perform a type of photosynthesis that is called C_3, since the enzyme that captures the CO_2 inside the cell forms primarily a compound containing 3 carbon atoms (3-PGA). However, certain plants (e.g. sugarcane, maize and sorghum) have been modified during evolution so that they contain complementary metabolic pathway where, instead of incorporating carbon from CO_2 in a 3-carbon acid, they incorporate into a 4-carbon acid and because of that this type of photosynthesis is called C_4. We even refer to a given plant species as a C_4 or C_3 species depending on its metabolism.

The functioning of the C_4 photosynthetic system is directly related to the anatomical features of the leaves where it exists (FURBANK, 2000). Leaves of C_4 plants have two types of chloroplasts, the ones that occur in the mesophyll cells and the ones present at the vascular bundle cells (Figure 1). In this system, the differential feature is that the Calvin cycle (i.e. the cycle C_3) occurs only in the vascular bundle cells (TAIZ, 2004). This process permits the concentration of CO_2 in the vascular bundle to reach 10 times the atmospheric concentration within cell that contains Rubisco. This mechanism makes the C_4 photosynthesis system naturally more efficient than the C_3 one.

In all C_4 plants, the CO_2 is initially fixed in mesophyll cells by an enzyme named PhosphoEnolPyruvate Carboxylase – PEPc, which forms oxaloacetate, an acid of four carbon atoms. This acid is then converted into malate or aspartate and one of these, depending on the species, diffuses to the cells of the vascular bundle, where it is decarboxylated and released as CO_2. This CO_2 will be refixed by Rubisco, which feeds the Calvin cycle. A compound of three carbon atoms that comes from the decarboxylation reaction, returns to the mesophyll cells and is subsequently used as a precursor for regeneration of phosphoenolpyruvate (FURBANK, 2000). However, C_4 can present biochemical variations in relation to the type of decarboxylating enzyme presents in the cells of the vascular bundle. These changes give rise to three different subtypes of C4 photosynthesis: NADP-ME ($NADP^+$ – *malic enzyme*), NAD-ME (NAD^+ – *malic enzyme*) and PCK or PEPCK (*Phosphoenolpyruvate carboxykinase*) (SAGE, 2000).

Sugarcane, along with maize and sorghum, is considered a C_4 plant of the subtype NADP-ME (BOWYER, 1997). There is evidence that sugarcane can also work as a PEPCK type (CALSA JR. and FIGUEIRA, 2007), similarly to maize, that uses the PEPCK pathway to catalyse the regeneration of oxaloacetate in the cytosol (WINGLER *et al.*, 1999).

The rate of photosynthesis in a plant is dependent on the environmental changes, as well as to intrinsic features of plant, such as the demand of photoassimilates and the expression of certain genes.

In sugarcane plants, depending on the availability of water and nutrients, the rate of photosynthesis will vary according with light intensity. Under natural conditions, the photosynthetic rate in sugarcane is directly related with the variation of solar radiation during the day. This happens because enzymes that participate on the photosynthetic process (like the enzymes mentioned above) are regulated by light.

When measured during the day, it is observed that the period in which sugarcane plants photosynthesise from 8am to 4pm, the highest photosynthesis rates are observed at midday (~45 µmol $CO_2.m^{-2}.s^{-1}$), being therefore consistent with the local changes in the Photosynthetic Active Radiation – PAR. Although being slower, the stomatal conductance rates (that afford entrance of CO_2 into the mesophyll cells), also changes follow the variations in PAR. The changes in enzyme activity related to photosynthesis during one day are predominantly dependent on PEPc, which increases its activity to 170% during the period of higher carbon assimilation (DU *et al.*, 2000).

The C_4 plants are more efficient to use water. When we divide the amount of CO_2 that enters the leaf by the amount of water released by transpiration, it can be observed that C_4 plants are capable to absorb more carbon per water molecule when compared with the C_3 plants. However, although very efficient in using water, sugarcane can drastically reduce its photosynthetic rate under conditions of drought. Water deficiency provokes a series of chemical and physiological alterations in plants, resulting in acclimation mechanisms that afford their survival. Among these alterations are the decrease in growth rate, leaf area, stomatal closure, senescence and leaf abscission and also the expression of stress-related genes (TAIZ, 2004).

In experiments with water deficit, it has been observed for sugarcane a decrease in leaf area, probably related to decreased leaf expansion and, a decrease in photosynthesis rates and biomass accumulation (INMAN-BAMBER *et al.*, 2005; SMIT, 2006). A reduction in photosynthesis rates under drought conditions is possibly correlated with stomatal closure, what prevents entrance of CO_2 in the leaves and latter on to the formation of reactive oxygen species – ROS as a consequence of severe stress. ROS tend to oxidise photosynthetic pigments, membrane lipids, proteins and nucleic acids, reducing the contents of chlorophyll and electron transport proteins.

C_4 plants present an optimal temperature for growth higher than the observed for C_3 species. This is because usually the former are plants that inhabit tropical and subtropical regions. Furthermore, elevated temperatures can cause problems. They lead to a rapid loss of water due to evapotranspiration and provoke dehydration (MACHADO, 2001). This dehydration leads to rupture of membranes, reducing plant metabolism and consequently the rates of photosynthesis and growth.

EBRAHIM e colleagues (1998) demonstrated that when sugarcane plants were grown at 45 ºC, the internodes were shorter, the leaves dried earlier and there was an increase of tillering when compared to plants grown at 27 ºC. Also, lower growth rate and sugar accumulation were observed.

Under lower temperatures, photosynthesis is also negatively affected. When cultivated in 10 ºC, the photosynthetic rate of sugarcane was reduced in approximately 20% in relation to plants cultivated at 30 ºC (DU, 1999). The reduction in the photosynthetic rate in this case is related with the high demand of energy necessary to activate the enzymes and also due to the range of optimal temperature for photosynthesis in these plants, which is around 30 ºC.

Another factor that interferes with the photosynthetic process that is becoming increasingly important during the last years is the increase in the concentration of CO_2 in the atmosphere. This greenhouse gas is increasing due to the intense utilization of fossil fuels that are used as sources of energy for humans, as well as due to the land use change (BUCKERIDGE and AIDAR, 2002). When cultivated under elevated CO_2 concentrations C_3 present an increase in photosynthesis rates and consequently an increase in the amount of biomass produced (WAND *et al.*, 1999; POORTER and NAVAS, 2003).

Although this is a quite common response for C_3, the C_4 plants presents varying results. In the case of sugarcane, de SOUZA *et al.* (2008) showed the effects of 720 ppm of CO_2 (concentration expected for around 2050) during 50 the first 50 weeks of growth. During this period, an increase of c.a. 30% in the photosynthetic rate was observed with the induction of expression of genes related with the electron transport system and with the enzyme PEPc. There was a reduction of stomatal conductance, which led to a better water use efficiency.

These results demonstrated that sugarcane photosynthesis under elevated CO_2 is possibly related with the increase due to the fact its light capture systems increase efficiency. This change in light capture pattern may be associated to a change in the capacity of consumption of photoassimilates, which is directly dependent on growth because, in general, the photosynthetic rate is regulated by the activity in sink organs (PAUL, 2001).

In sugarcane, McCORMICK, CRAMER and WATT (2006), observed a sink-source relationship that was dependent on a stronger sink and higher photosynthetic rate. These authors did not find significant changes in the contents of sucrose that could be associated with the observed increase in photosynthesis. However, they suggested the possibility of a regulation of the photosynthetic rate could be related with the concentration of glucose.

FIGURE 2 Culms of sugarcane after 75 days growing in open top chambers (OTCs) with elevated CO_2. Left (four groups of culms) = control; right = grown in OTCs.

On the other hand, WU and BIRCH (2007) showed that the increase in sink strength in sugarcane lead an increase in the electron transport system which was followed by increase in the concentrations of sucrose in internodes under intermediate stage of development.

Under elevated CO_2, it has been observed that after 75 days, sugarcane presents an increase of 177.98% in the fresh mass of culms (Figure 2), what is thought to increase sink due to the allocation of more biomass to this organ. These data indicate that the plant will be capable to accumulate more sugar at the end of the growth period. Indeed, de SOUZA *et al*. (2008) observed that after an average increase of 60% of biomass accumulation in culms, there was about 30% increase in sucrose after 50 weeks.

More recently, de SOUZA and BUCKERIDGE (unpublished) found that the electron transport rates are significantly higher in plants of sugarcane growing under elevated CO_2, confirming previous observations in gene expression observed by de SOUZA *et al*. (2008).

The discoveries mentioned above posses the possibility that the changes in gene expression related to the electron transport system and higher CO_2 are possibly correlated with the increase in biomass production and sucrose concentration in culms of sugarcane. This knowledge opens opportunities for the selection of new varieties and/or genetic transformation of sugarcane plants in order to obtain higher photosynthesis rates and therefore higher productivity.

Although these results sound quite promising to be used for increase in productivity, it is important to remember that the increase in the concentration of atmospheric CO_2 used in our experiments are not natural and that this has consequences to the society that are negative in many ways.

On the other hand, for new technologies to be developed on the basis of our discoveries, deeper studies will be necessary in order to understand the possible consequences for the source-sink relationship in the plant. One of the ways is searching into the collections of varieties currently available in Brazil and other countries to try to find plants that would present even higher sensitivity to elevated CO_2. For genetic transformation, it will be necessary to develop a stable and secure methodology for transformation and latter on evaluate the general physiological responses of the plants to elevated CO_2, comparing them with non-transformed individuals.

Even though the way seems the have been paved to understand how plants of sugarcane will respond to the global climatic changes, many studies have yet to be carried out in order to understand what will be the metabolic and physiological responses in the future. For instance, experiments that combine elevated CO_2 with elevated temperature and water stress are necessary. Such studies were performed with sugarcane in Florida (USA) showed that an increase of up to 6 ºC combined with drought did not cause loss of photosynthesis (VU, 2009a, b).

Another important issue will be to include physiological responses in modelling of sugarcane production so that the effects of elevated CO_2, temperature and water stress on growth in the field would be considered (DA SILVA *et al.*, 2008). The production of integrated models is important for decision making regarding sugarcane cropping in Brazil due to the strategic importance that this crop has to energy security in this country nowadays.

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7

ROUTES FOR CELLULOSIC ETHANOL IN BRAZIL

Marcos Silveira Buckeridge, Wanderley Dantas dos Santos and *Amanda Pereira de Souza*

INTRODUCTION

The climatic changes and the elevation in the costs of the petroleum together with the strategic needs of production of energy have been motivating an unprecedented run towards production of alternative fuels, preferentially from renewable sources. In this scenario, Brazil stands out due to the pioneer use of the ethanol obtained from the sugarcane as fuel since the 1970s.

Besides the tradition, highly selected varieties, sophisticated industrial processes, climate and readiness of agricultural lands guarantee Brazil a comfortable leadership in the production of sustainable ethanol. However, to preserve that position in the currently competitive market, Brazil needs to maintain compatible investments in the generation of new technologies and formation of competences. Nowadays, the conversion of lignocellulose or plant biomass into fermented sugars for ethanol production has been considered as a promising alternative to increase the production of necessary ethanol to meet the world demand.

Cellulose is principal component of the biomass, being the most abundant polymer on Earth. It is formed by a linear chain of glucose molecules covalently linked to each other. Such linkages can be broken to liberate fermentable sugars. However, cellulose is very well protected by the plants, so that they are not easily used by predators. For that reason, the net yield of the conversion of cellulose into free glucose and afterwards into ethanol is not favourable with the current available technologies. The development of technologies to obtain favourable yields will make possible a better use of that rich and renewable raw material found not only in the sugarcane bagasse, but in any other sources of plant biomass (wood, leaves, peels etc.) now wasted or used for less noble purposes. The development of technologies capable to disassemble the plant cell wall requests a deeper understanding of the cell wall structure and physiology from sugarcane as well as of other plant systems. At the same time, the study of enzymatic systems present in microorganisms that feed from cellulose and, therefore, already capable to produce specific enzymes for such a purpose, might help us using the available energy in these polysaccharides.

PERSPECTIVES IN CELLULOSIC ETHANOL PRODUCTION

The ethanol production starting from the sugarcane is accomplished, nowadays, with great efficiency, by fermentation of the sucrose present in sugarcane juice. This process has been named the first-generation ethanol. As opposed to this, the perspective of production of ethanol from cellulose is named the second-generation ethanol.

The research in second-generation ethanol can be divided into four rotes on the basis of the science that will have to be developed in order to produce bioethanol. These routes are 1. chemical hydrolysis – CH; 2. enzymatic hydrolysis – EH; 3. autohydrolysis – AH and 4. pentose-coupled hydrolysis – PH.

In route 1 (CH) the cell walls of sugarcane would be pretreated and subsequently subjected to acid treatment in order to produce free fermentable sugars. In this case, free-fermentable sugars do not include pentoses. In route 2 (EH) pretreated biomass is subjected (either after acid hydrolysis or directly) to enzyme hydrolysis. Route 3 (AH) is characterized by the use of modified biomass (modified cell walls obtained from a selected variety of genetically modified plants) with enzymes that might or might not have been produced from genetically modified microorganisms.

A negative effect of using acid or basic solvents to loose and break polymers of the plant cell wall to release fermentable mono and oligosaccharides (CH) is the economical and ecological costs of reusing or releasing their residues in the environment. On the other hand, EH phase will demand a larger input of studies and technology to be available commercially. One of the most important bottlenecks in this process will be the production of hydrolytic enzymes/microorganisms selected/modified for that purpose in commercial scale. For what we defined here as the fourth route of the cellulosic ethanol, we expect that microorganisms and plants would be genetically transformed so that very well adapted cocktails of enzymes, produced by transformed fungi, would be used in the process with a raw material (bagasse and/or trash) obtained from genetically transformed sugarcane plants that would have its own cell walls changed to make it more suitable for enzymatic hydrolysis (Figure 1).

Besides the methods of wall hydrolysis, the progress in the knowledge on the physiology of plants used for the ethanol production and the employment of tools of genetic and industrial engineering should play important roles in the increase of the productivity of the ethanol, independently of the phase. However, before detailing some of the aspects of these phases, it is necessary to know what a cell wall is.

The Cell wall

Every plant cell has a wall. It determines the size and the shape of the cell, confers mechanical resistance and protection against the attack of predators and pathogens, delimits the size and chemical-physical properties of the molecules that have access to the interior of the cell, controls the humidity level and it can still work as a storage of minerals, such as calcium as well as carbon and therefore energy. Furthermore, it promotes the adhesion among the cells and is related with shape of the plant organs.

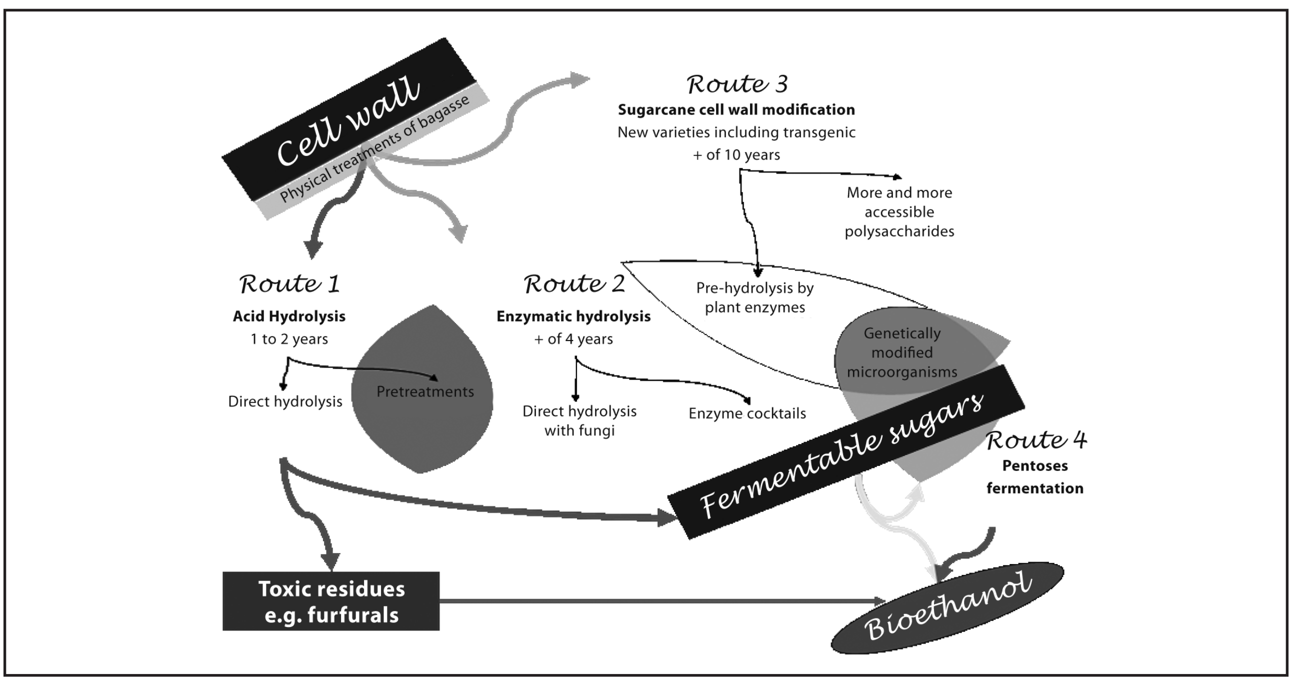

FIGURE 1 Routes to develop cellulosic ethanol.

The cell wall is composed by a polysaccharides mixture, proteins, phenolic compounds and mineral salts. The polysaccharides represent about 90% of the dry weight of the wall and they consist of cellulose, 20% to 40% of the cell wall, hemicelluloses (15% to 25%) and pectins (~30%). That matrix is highly organized and dynamics and could become more rigid or loose rigidity according biological adaptation.

Thirty six cellulose chains are thought to be packed to form a microfibrils, which are long and resistant. The hemicelluloses are a heterogeneous class of polysaccharides classified according to the monosaccharide composition. These molecules are attached to the surface of the cellulose microfibril surface forming the cellulose-hemicellulose domain of the cell wall (Figure 2). The hemicelluloses prevent the molecules of cellulose to collapse, but they also allow a weak interaction among the fibres forming a network. For that reason, they are also called cross-linking glycans (CARPITA, 1993). The cellulose-hemicellulose domain is, in general, submerged in a third domain composed of pectins, a class of highly branched and heterogeneous polysaccharides. Among other functions they are thought to determine the porosity of the wall and, when hydrolysed, their fragments can act as signal for the presence of pathogens and insects (BUCKERIDGE *et al.*, 2008).

The main hemicelluloses found in plants are xyloglucans, glucuronoarabinoxylans and mannans, which are formed by a main chain of glucose, xylose and mannose, respectively. Such main chain can be branched with different monosaccharides (Figure 3). Xyloglucans are the most abundant, being found in most eudicots. Glucuronoarabinoxylans occur in larger proportion in cell walls of grasses (Poaceae) while mannans have a wide distribution, but usually appear in low proportion, except in some groups of ferns (Pteridophytae; SILVA, 2005a). In general, one can say that all the hemicelluloses occur in all plant families, but in different proportions. One important exception is a class of hemicelluloses called mixed linked glucans. They are composed of an unbranched chain of glucosyl residues that are β-1,4 this chain being regularly interrupted with β-1,3 linkages. This hemicellulose occurs mainly in the order Poales (which include Poaceae), how-

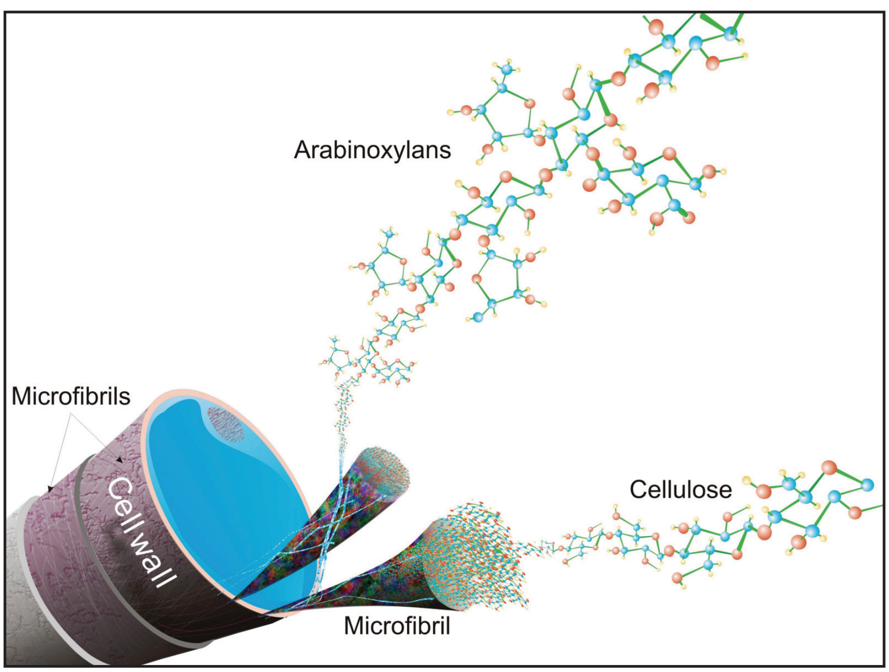

FIGURE 2 Plant cell wall scheme. The figure shows a microfibril structure with 36 cellulose chains. One of the cellulose molecules was prolonged in order to show its fine structure composed by β-1,4 linked glucose residues. One of the hemicelluloses from sugarcane (glucuronoarabinoxylan) also appear in detail with its long xylan chain branched with arabinofuranose and some glucuronic acid unities attached.

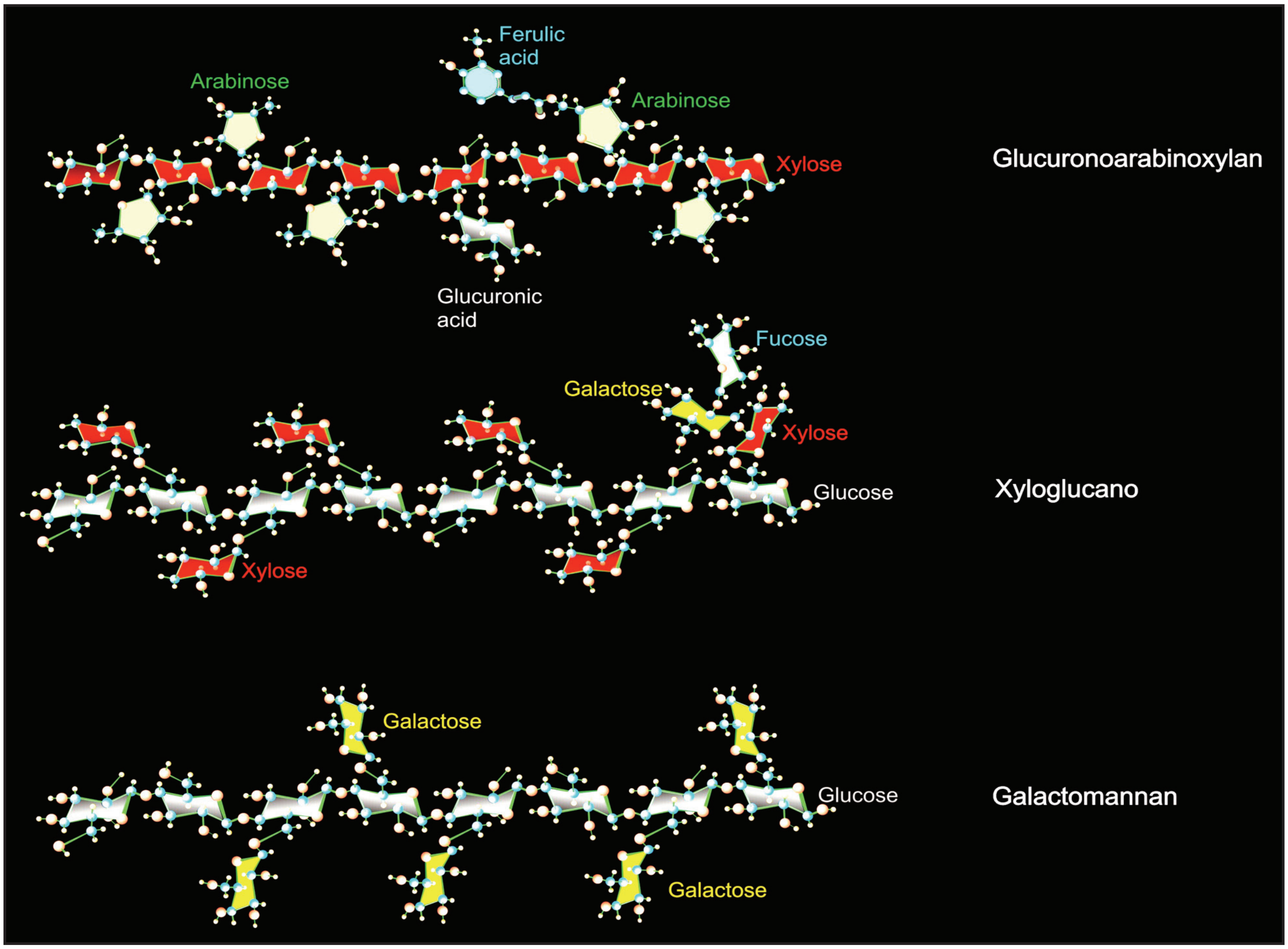

FIGURE 3 Chemical structure of some important hemicelluloses.

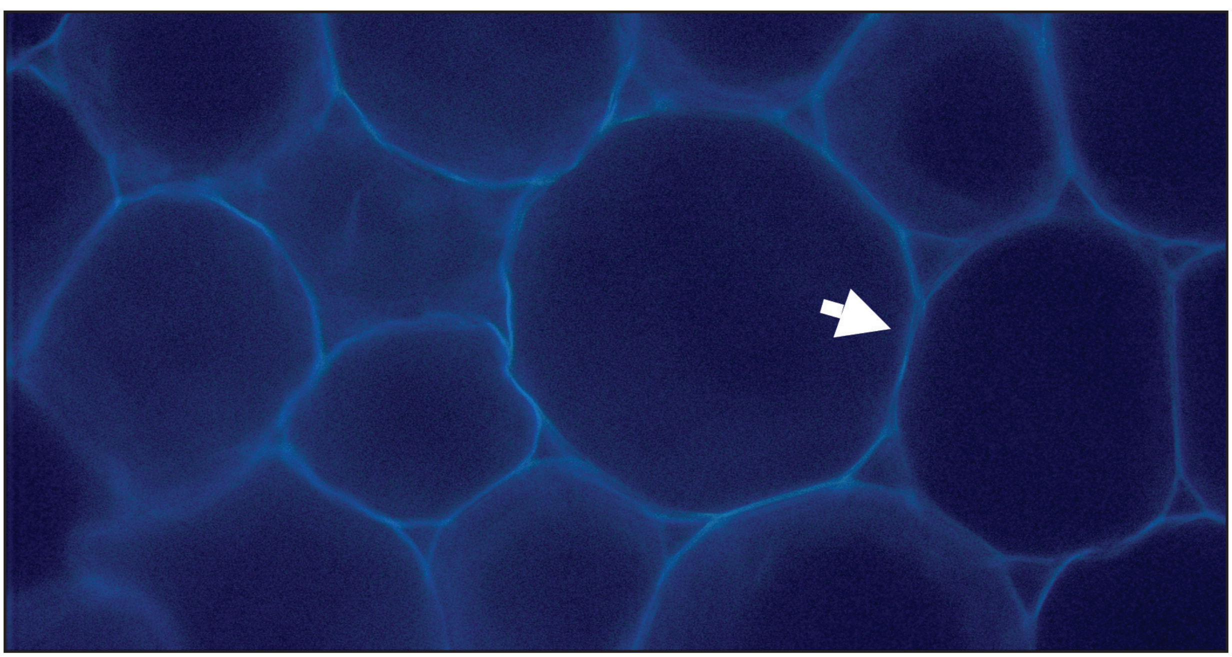

FIGURE 4 Parenchyma cell wall from sugarcane. The white arrow indicate autofluorescence of cell wall due the presence of phenylpropanoids.

ever, they are also present in lichens (an association of fungi and algae) what suggests the genes needed to synthesize mixed linked glucans must be present in most of the species of higher plants (BUCKERIDGE *et al.*, 2004).

Sugarcane cell walls

Sugarcane belongs to the family Poaceae (the grasses), which also includes corn, sorghum, wheat and rice e.g. species of this family display a typical wall architecture that distinguishes them of the other plant groups. While most of the plants have the xyloglucan as main hemicellulose, in grasses is glucuronoarabinoxylans (SAAVEDRA, KAVACSONYI, 1988; SOUZA, 2007) plays this role along with β-(1→3), (1→4)-glucans, although they also have small proportions of xyloglucan and mannan. Glucuronoarabinoxylans and β-glucans are relatively abundant in all the sugarcane tissues, whereas mannans occur in very small proportion (SILVA, 2005b). Xyloglucan appear to be absent, although genes related with its metabolism seem to be conspicuous (LIMA *et al.*, 2001; Crivellari, unpublished).

When examined through fluorescence microscopy, primary cell walls of grasses display auto-fluorescence (Figure 4). This phenomenon is due to phenylpropanoid esterified to some of the arabinosyl residues of the glucuronoarabinoxylans. Ferulic acid esterified to the vicinal polymers may undergo dimmerization, and cross-linking such polysaccharides. Cross-linked polysaccharides are more recalcitrant to enzyme attack (DOS SANTOS *et al.*, 2008, Figure 5).

FIRST GENERATION ETHANOL: THE FERMENTATION OF THE SUCROSE

As mentioned above, the current process of ethanol production from sugarcane is accomplished by the extraction and fermentation of the broth that contains approximately 15% of sucrose (MACEDO, 2008). Before fermentation, performed

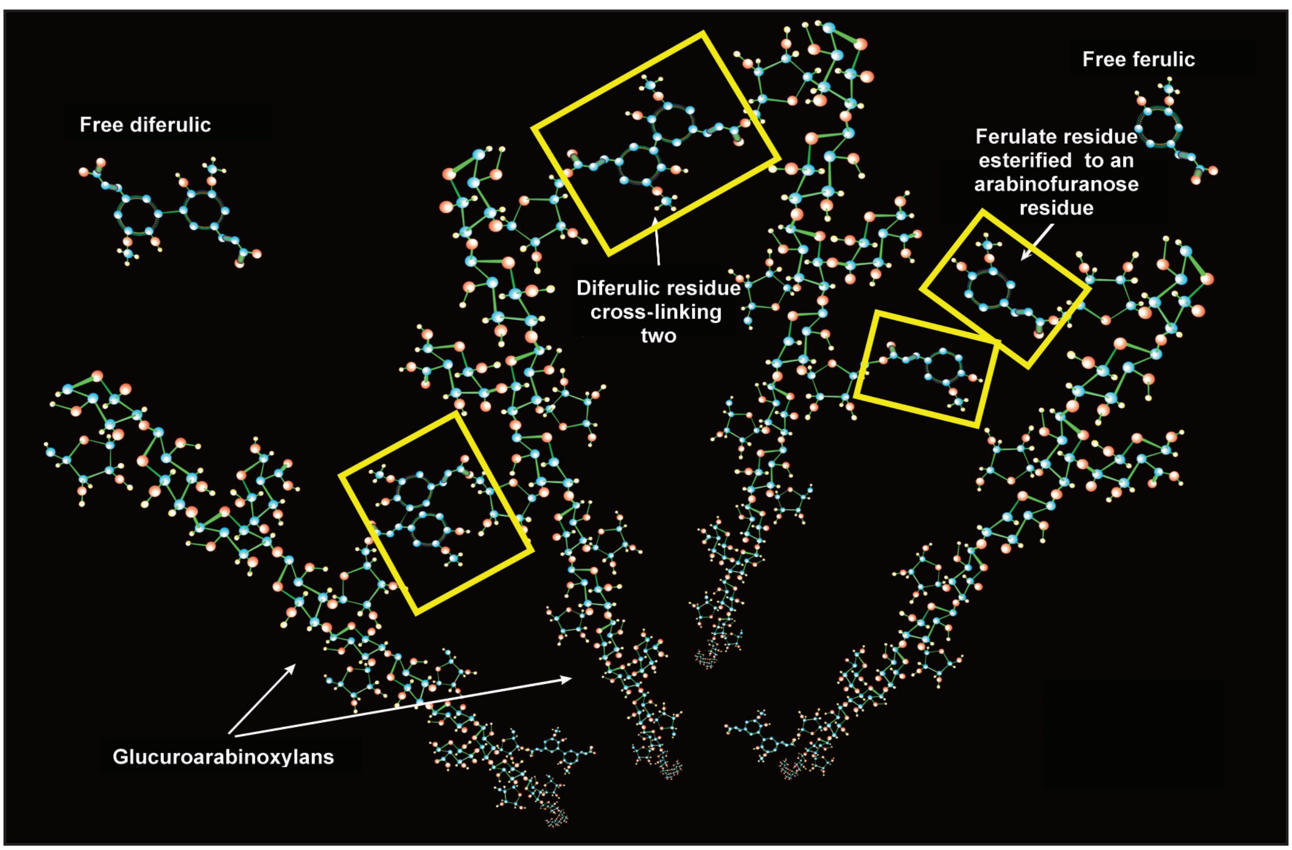

FIGURE 5 Glucuronoarabinoxylans cross-linked by diferulate residues esterified to arabinose of vicinal polysaccharides.

by selected lineages of *Saccharomyces cereviseae* yeasts, the broth is sterilized and purified. The produced alcohol is then separated from the water by distillation. The energy to move the processes comes from burning part of sugarcane bagasse that generates heat and electricity. About 10% of the biomass is burned to produce electricity, whose excess is sold to energy distribution companies. With more efficient techniques of conservation of the energy produced by burning of the bagasse, such excess might reach up to 45%. Furthermore, about 40% to 50% of the trash (straw) of the sugarcane that today is maintained in the field could be recovered and incorporated to the biomass for ethanol production (MACEDO, 2005). This excess of biomass, will be able to be used, in the future, for the production of cellulosic ethanol.

SECOND GENERATION ETHANOL: OBTAINING FERMENTABLE SUGARS FROM CELL WALLS

In order to produce ethanol from plant biomass it is necessary to disassemble the cell wall in order to obtain fermentable monosaccharides. However, it has been previously pointed out how complex the structure of the wall is. Therefore, the process of hydrolysis must to be soft enough to preserve intact the monosaccharide that will be used for fermentation. Currently acid hydrolysis is being studied as a potential form to disassemble the cell wall. Although the process is possible in practical terms, it is not efficient enough to allow the commercial production of ethanol.

The basic process of acid hydrolysis consists in using a strong acid to attack the glycosidic linkages among monosaccharide residues of a polysaccharide. Figure 6 illustrates the process in a simple way. The acids usually applied for the acid hydrolysis in laboratory, are sulphuric, hydrochloric or trifluoroacetic acids. There are advantages and disadvantages in relation to each one. While the sulphuric and hydrochloric acids discriminate little among different glycosidic linkages attacking cellulose and hemicelluloses in a similar way, the trifluoroacetic acid breaks preferentially the weakest linkages such as the alpha linkages present in the hemicelluloses branches.

In grasses the glucuronoarabinoxylan branches are α-linked and these are the first ones to be

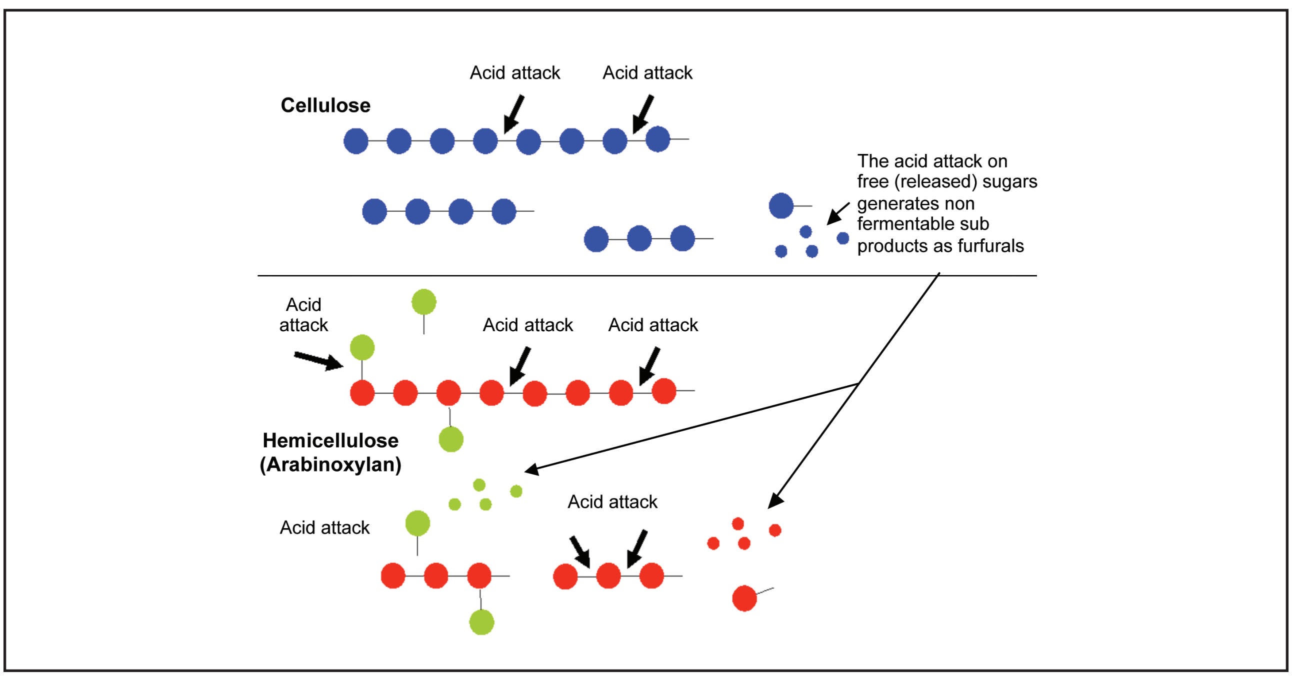

FIGURE 6 Acid hydrolysis of cellulose and branched hemicelluloses as arabinoxylans. Small balls represent products of acid degraded sugars as furfurals and hydroxyfurfurals. Glycosidic linkages are represented by lines between bolls. Each collared ball represents a monosaccharide residue: Blue is glucose, red is xylose and green is arabinose.

broken. Only later, the β-1,4 of xylan main chain are broken. Cellulose linkages are the last to be hydrolysed due the presence of several weak molecular interactions, the absence (or very low level) of water inside the microfibril structure and also because the microfibrils are covered by the hemicelluloses. The problem in a process of polysaccharides hydrolysis containing α and β linkages is that, as the time necessary for hydrolysis is different, the monosaccharides released early in the reaction mixture tend to degrade. This process is sometimes called caramelization (by similarity to the formation of the caramel during the preparation of sugar syrup). If the degradation is very intense furfurals are formed and these compounds are toxic for the yeasts that will be used in the fermentation stage. Thus, by acid hydrolysing a hemicelluloses/cellulose mixture, the temporal displacement among the breaks of the glycosidic linkages of each linkage type becomes limiting for the production of fermentable monosaccharides.

In industrial processes, acid hydrolysis has been accomplished with sulphuric acid (H_2SO_4). However, technical and operational difficulties result in a high cost of the final product. About of US$ 0.80, against US$ 0.35 and US$ 0.27 per kg of ethanol obtained from starch and of the sucrose, respectively. Part of this cost is attributed to the fact that for the hydrolysis to happen in an efficient way it is necessary to heat up the polysaccharide mixture in an acid solution. The temperature is about 100 °C to 120 °C and the ideal concentration of sulphuric acid is about of 3% (BUCKERIDGE, 1990). In the specific case of the sugarcane, this cost is minimized by still using a part of the bagasse as fuel.

Another difficulty is related to need of neutralization of the hydrolysed solution in order to carry on the fermentation. In general, for the neutralization, calcium hydroxide (limestone) is used. However, when proceeding in that way, the sulphuric acid is converted into calcium sulphate and cannot be recycled (MARK, 2006). That is the principal factor that contributes to the high cost of the technique. To develop acceptable levels of commercialization (<US$ 0.36/kg) it will be necessary reduce the costs associated with consumption and reuse of the acid as well as improve in the productivity and efficiency in the biomass conversion (KAYLEN *et al*., 2000; GOLDENBERG, 2007).

ACID HYDROLYSIS

In order to improve the perspective of the use of the acid hydrolysis in commercial scale, the Brazilian company DEDINI – Basic Industry invested in research to make the process most profitable and, now, the company have said to have managed to reach a reasonable level of hydrolysis mixture with the sulphuric acid and ethanol as solvents for lignin, but the costs still above the desirable level. Nonetheless, this kind of research must to allow a reduction in the use of the acid.

Another proposal, made by a group of Chinese scientists, is the substitution of the neutralization process for an electro-dialysis process. It consists in the application of an electric potential among two compartments separated for a semi-permeable membrane electrically charged. Such a process allows an economy up to 55% in the sulphuric acid consumption (CHENG *et al*., 2008).

Furfurals naturally formed during acid hydrolysis can be used as raw material in production of solvents and resins for fibreglass and other plastic materials. So, its commercialization could become profitable and contribute to reduce the cost of the cellulosic ethanol (RODRIGUES, 2008). Some groups are developing controlled vapour-explosion of the sugarcane bagasse. This technique exposes the fibres, increasing the surface of contact necessary for breaking of the microfibrils as by chemical as by enzyme approaches (PAULO SELEGHIN JR. and GLAUCO CAURIN, personal communication).

Beyond strictly chemical hydrolysis, chemical treatments might to be associated with enzyme hydrolysis. Together, they have a good potential to produce fermentable sugars starting from lignocellulosic biomass. This technology is rather close to becoming commercial and it will be a point of strategic importance for the cellulosic ethanol production. Considering the actual stage of development, and that research continues in the same pace, chemical hydrolysis is expected to reach commercial viability in 2 to 5 years.

ENZYMATIC HYDROLYSIS

In the long term, a commercially viable ethanol from lignocellulosic materials is thought become possible through the use of the biochemical machinery of microorganisms (fungi and bacteria) to disassemble the cell walls. The problem is that, as well as fungi developed strategies to invade the cell wall, plants had also evolved to improve their defence mechanisms. In this way, although there are fungi capable to degrade plant cell walls, the latter are quite recalcitrant to the degradation. One of the ways that grasses developed to resist to the enzymatic attack by microorganisms seems to have been the by the use of ferulic acid – FA cross-linkages among hemicelluloses (Figure 5).

Lignin is an irregular polymer of phenolic alcohols that is quite resistant to the enzyme attack. It accumulates only in secondary cell walls of certain specialized tissues such as fibres and vascular tissues of the plants (xylem). However, in grasses the dimmers formed by FA accomplish a *quasi*-lignification in the whole extension of the cell wall, even in parenchyma cells. Ferulic acid has antioxidant properties which are largely used by the food industry and its presence (together with other hydroxycinnamates) is thought to grant protection against UV light and free radical chain reactions. When reduced to a free radical, it stabilizes the additional electron by resonance, stopping the chain reaction by reacting with another FA (DOS SANTOS *et al.*, 2008). In grasses FA is esterified to glucuronoarabinoxylans and once dimerized across the whole cell wall it locks the cell wall distension capability, ceasing cell growth and also resulting in an additional difficulty for microorganisms that may attack the plant. Certain fungi developed feruloyl-esterase enzymes capable to separate the feruloyl residues from the xylans, making the cell wall more susceptible to the attack by xylanases (enzymes able to hydrolyse xylans).

To reach cellulose, that is the principal compound of the cell wall, the fungal still needs to hydrolyse the other hemicelluloses that interact with the microfibrils. For that reason, fungi such as *Trichoderma* and *Penicillium* produce large arsenals with more than a hundred glycosidases and dozens of different cellulases, proteases and lipases, to name but a few. In order to develop an effective technology to convert the wall polysaccharides into fermentable sugars and subsequently to ethanol, it will be strategic to understand the processes related with the attack of each enzyme and enzyme sets about each linkage in the cell wall. However, for that strategy to be really efficient, the fine structures the polysaccharides and the hydrolytic enzymes will have to be carefully studied.

There are some key steps that can help us to guide the route for a third route of cellulosic ethanol production:

a) There are a great number of studies with microorganism enzymes showing how they attack polysaccharides of cell wall. Two roads have been taken in parallel to maximize enzyme production and to understand fungi performance: one is search for more efficient species and other is the genetic transformation of fungi. Beyond improving large scale production of enzymes and heterologous expression of proteins, such knowledge will also help to figure out the industrial hydrolysis process.
b) There is some knowledge on the structure of glycosidases of cell walls of fungi and plant itself. Such piece of information we make us able to design improved enzymes.
c) We know the glycosidic linkages that must to be broken in order to liberate monosaccharide (SILVA, 2005b). Starting from those data and obtaining a complete map of the cross-linking patterns among cell wall polymers we can begin a systematic and detailed scrutiny of enzymes and methods to obtain a maximized hydrolysis of lignocellulosic biomass.
d) We partly know the identity of sugarcane genes related with the metabolism of synthesis and degradation of the cell wall in the sugarcane (LIMA *et al.*, 2001). Among these genes there are several capable to degrade the cell wall. Complete identification of genes identity and expression patterns will help us to obtain the control of those genes making

us able to activate them at the desired moment during the process. On the other hand, such kind of information might help to design rational (optimized) hydrolytic processes with adequate enzymes in a logical order rather than simply adding an enzyme cocktail to the lignocellulosic suspension.

Search, selection and engineering of fungi and enzymes

Studies accomplished with sugarcane straw (trash) indicate that *Aspergillus terreus*, *Cellulomonas uda*, *Trichoderma reesei* and *Zymomonas mobilis* might be useful for degradation of the lignocellulosic material (SINGH *et al.*, 2008). Brazil, with its high biodiversity has a large potential to find new and interesting microorganisms. For example, our group have been assaying the cellulolytic activity of more than 50 species of fungi of the soil of the Brazilian savannah (cerrado) and still works in on selected species for industrial use as *Penicillium citrinum* (data not published). Other important strategy is to understand and control the expression of enzymes produced by fungi. Gustavo Goldman (USP-RP/CTBE/INCT by Bioetanol), recently discovered that *Aspergillus niger* species, for instance, has only one transcription factor (XLnR) that regulates the expression of all the genes related to the polysaccharides degradation, while in *Trichoderma*, other transcription factors are important for these same genes (personal communication). Goldman intends to manipulate the mechanisms of regulation of the genetic expression in order to obtain mutants capable of continuously produce enzymes in the presence of substrate, without genetic expression undergoing retro-inhibition by the products of the enzymatic action, as happens naturally.

Another type retro-inhibition or inhibition by the product occurs at the level of the catalysis. The probability of products to adhering into the catalytic site of the enzyme scales with the product concentration. The activity cannot only stop completely, as it might even revert to the reaction direction. In Brazil a group has been working with an approach that consists in stick the glycosidases onto the hemicellulose in order to reduce the local concentration of the enzyme products. To do that, the group of Sandro Marana is trying to link a cellulose binding domain – CBD to hemicellulases (personal communication). CBD are an enzyme domain found in some cellulases that sticks to the microfibril provoking a local change of conformation (i.e. decreasing crystallinity) so that catalysis becomes more efficient. A protein "arm" positions the catalytic site in the exact place where the disorder promoted by CBD exposes the cellulose molecules to the enzyme attack. As the products are soluble whereas the substrates are not, the high local substrate/product ratio confers an additional advantage to the enzyme attachment when compared to soluble enzymes activities.

The amino acids positioned out of the active site of the enzyme define the specificity of the associated enzymatic action. There are two approaches used to study the relation between the structure and function of enzymes in order to afford an accurate approach of engineering of enzymes. A bottom-up strategy is accomplished by a methodology named directed evolution. Small variations in the amino acids sequence produce enzymes with different properties. Variants, whose catalytic efficiency of interest increased, are selected and the subjacent structural variations are analysed. A top-down strategy is the structural study of enzyme families. The different glycosidases are clustered in families. However, the great majority doesn't have their tertiary structure elucidated, or has only few representatives whose structures were elucidated. The groups of Igor Polikarpov (USP-Scar-INCT by Bioetanol) and Munir Scaff (UNICAMP/INCT by Bioetanol) among other groups are studying the tertiary structure of enzymes by crystallography and atomic modelling. They have already managed to crystallize and to solve the structure of xylanases of *Trichoderma reesei* (GALUBEV *et al.*, 2000; ROJAS *et al.*, 2005). They are focusing their work on the creation/enhancement of models of protein folding that can be used to foresee the tertiary structure on the basis of the sequence of amino acids and that can be used in the engineering of enzymatic catalysts.

Using the knowledge on physiology, biochemistry and molecular mechanisms to improve the access to cellulose

Although the basic structure of the hemicelluloses is well known (composition and proportions among the glycosidic linkages), it is very important that we study their fine structure (i.e. the precise positioning of the branching on the main chain of a polysaccharide or the precise distribution of different linkages in the main chain) because the properties of hemicellulases are strongly related with the fine structure.

Specific enzymes might be used in order to reveal the patterns of branching and/or distribution of the glycosidic linkages in the main chain (proportions among linkages β-1,3 and β-1,4 in mixed linked glucans and among the mannoses and glucoses in mannans etc.). We discovered that cellulases of *Trichoderma* can work as a restriction system similar to the restriction enzymes used on DNA, but acting on the fine chemical structure of the hemicellulose polysaccharides (TINÉ *et al*., 2003, 2006). Beyond helping to elucidate the fine structure of polysaccharides, this kind of Information is valuable in order to understand catalysis mechanisms and, thus, to set up a research platform dedicated to increase the efficiency of those hydrolases.

Our group has also been studying the composition and fine structure of cell wall in organs of sugarcane during development. We have been investigating the role of phenolic compounds in the recalcitrance of the cell wall to hydrolytic attacks by inhibiting enzymes from phenylpropanoid pathway in different intensities with metabolic modulators. By evaluating the susceptibility to xylanase and cellulase, we found that very low reduction in cell wall phenylpropanoid content make the bagasse more accessible to enzyme hydrolysis (data not published). We are now developing a new methodology in order to modify lignocellulosic material in large scale without the need genetically engineer plants and subsequently licence them as a new OGM. We named this approach *physiological engineering*. This has the advantage to putatively permit the improvement of bagasse properties for a better hydrolysis in any cultivar of sugarcane.

The global climatic changes are the great propeller of the search for renewable fuels and our group studies the effects of environmental changes on the sugarcane and species of interest for renewable energy in Amazon areas, as *Senna reticulata* and *Euterpe oleracea*. Our objectives are to understand the mechanisms of biomass accumulation and to gauge the potential to responses of these plants to climatic changes.

Sugarcane plants incubated in atmosphere of CO_2 of 720 ppm (expected concentration for 2050) presented an increase in the photosynthetic rate and an increase in biomass about 60% in the culm (DE SOUZA *et al*., 2008). In these plants, we observed the super-expression of genes related with cellular expansion as xyloglucan endo-transglycosilase – XTH, with the photosynthesis and with the inhibition of the expression of genes related to the phenylpropanoid pathway (intermediary of the lignin biosynthesis). Parallel, the group of GLÁUCIA SOUZA, with which we collaborate, observed that plant with high productivity of sugars express XTH with larger intensity and they have also been inhibited expression of the cinnamil orto-methyltransferase – COMT, from the phenylpropanoids synthesis.

At this time we are performing the studies on the role of XTH in the cell wall metabolism and the process photosynthetic in sugarcane. An increase the productivity of the sugarcane by inducing the expression of the photosynthesis genes that answer to high CO_2 may be expected. With this, the plant could not only produce more sucrose, but also more cellulose even in low CO_2 (see more details in the Chapter 6).

In order to manipulate the plant enzyme machinery to self-disassemble the cell wall, we also need deepening our knowledge on signalling mechanisms and expression of genes related to the cell wall in sugarcane. A recent work from our lab (unpublished) showed that a gibberellin plant hormone interferes with wall expansion and sugar metabolism in seedlings of sugarcane. This seems to shed some light into ways to manipulate plant metabolism towards modified walls.

SUGARCANE DESIGNED FOR AUTOHYDROLYSIS

Our group is focused in understanding both the relationship between the expression of the genes related to the biosynthesis and hydrolysis of the cell wall as those related with the carbohydrates metabolism in general. In 2001, we participated of the SUCEST (sugarcane expression sequence tags) project and found 459 genes related to the metabolism of cell wall (LIMA *et al.*, 2001). Whereas genes related with cell wall degradation are hardly expressed during the growth, great part of the genes involved with cell wall biosynthesis appear to be fully activated, what suggests that the plant is growing and cells are expanding. However, these hydrolase genes must be expressed in specific conditions as the leaf senescence, building of plasmodesmata, and other kind of differentiation. If we obtain control of the expression of these genes we could induce the plant to express them and produce the enzymes at the time as the crop or in inactive forms that might be triggered in the planta. This will reduce the need to introduce fungi enzymes. We also would induce sugarcane plants to express heterologous genes that would become active under certain conditions, during the processing of biomass. In another study, an endoglucanase E1 of *Acidothermus cellulolyticus* that optimally works in 81 °C and pH 5 was expressed in the apoplast of several plants including *Arabidopsis* and rice. The enzyme was activated in raw extracts after the crop and after an acid pretreatment, but it didn't cause degradation of cellulose *in planta* (DAI *et al.*, 2000). However, studies in our laboratory indicate that the presence of hemicelulose and phenylpropanoids might prevent the access of E1 to cellulose. Hence, it is important to study what enzymes are necessary to break lignin (lacases and peroxidises), as well as hemicelluloses (feruloyl-esterases, xylanases, lichenases etc.). Later on, the heterologous expression of those enzymes can be studied previously in *Arabidopsis* or *Physcomitrella* or directly in sugarcane, addressing them for cellular compartments in order to obtain their action in the suitable moment. As sugarcane presents polyploidy its transformation and the long term stability of the heterologous gene is not easy to obtain. However, Helaine Carrer and from (ESALQ/INCT by Bioetanol), and at least one enterprise Allelyx, has been working in sugarcane transformation for a long time and has already obtained good results.

Simultaneously with transformation development, we need to search for hydrolytic enzymes of cell wall produced by sugarcane and other plants of interest as well as the signalling mechanisms involved in regulation of the expression of those genes in order to control those signalling mechanisms. Our group, in collaboration with Edivaldo Ximenes (University of Brasilia (UNB)/INCT by Bioetanol) and Maria de Lourdes Polizeli from USP-RB/INCT by Bioetanol, is investigating ideal conditions (which enzymes are produced, how long it takes to produce, in which order and proportions, pH and temperature optima, and how to avoid inhibition by the reaction products etc.) to digest sugarcane bagasse with the highest efficiency.

Another approach that can be called energy-cane project is to induce modification in types and amounts of hemiceluloses present in the wall controlling the amount of lignin in order to maximize production of polysaccharides convertible in ethanol. Such a plant could be used for hydrolysis with enzymatic cocktails of high efficiency, genetically modified fungi or even for enzymes expressed by the plant itself. In spite of the high degree of knowledge we need to obtain in order reach this goal, the cell wall manipulation and introduction of genes is, in fact, possible. We believe that these fourth routes of ethanol technology production will become viable in about 10 years. Together with these "pro-ethanol modifications", we must deep our knowledge and develop improvements in sugarcane physiology in order to prepare cultivars able to grow in non-ideal environments both to attend expansion necessities as well as to adapt it to changes waited to occur because of global warming.

In order to reach these goals, we need to prioritize research lines as the complete sequencing of sugarcane genome and some key-fungi such as (*Trichoderma*, *Aspergillus* and *Penicillium*), mapping of the wall-related genes, mechanisms of physiologic control (hormones, transcription factors), as well as in the structure and efficiency of enzymes.

Figure 7 summarizes the four phases of ethanol technology development integrated to each other.

FERMENTATION OF PENTOSES

Sugarcane hemicelluloses are rich in xylose and arabinose. *Saccharomyces cereviseae*, the microorganism employed in the production of alcohol starting from sucrose, has very low efficiency in fermenting pentoses. The presence of pentoses in fact inhibits the fermentation of the hexoses by *S. cereviseae*. A perspective is the prospection and use of other species of fungi, better adapted to fermentation of pentoses. Species such as *Pachysolen tannophilus* are capable to use xylose efficiently and other pentoses (less efficiently) after they consuming the glucose and cellobiose available (HINMAN *et al.*, 1989).

USING OTHER SOURCES OF BIOMASS FOR CELLULOSIC ETHANOL

The reason why sugarcane bagasse should be a priority in research programs to study cellulosic ethanol in Brazil is the existence of several mills that are adapted to use sugarcane as raw material. But in a future scenario, in which the technological barriers to obtain large scale production of ethanol starting from lignocellulosic ethanol will be overcome, other sources of raw material might come into the scene.

The eucalyptus is now commercially the largest source of cellulose available, although its production is directed to papermaking. However, the bark of eucalyptus, now wasted, may be an interesting carbohydrate source that can be used in the future as raw material for production of cellulosic ethanol. Some years ago, our group surveyed the composition of the cell wall of the eucalyptus in a project financed by a paper company Suzano Papel and Celulose LTD. Our group has already fractionated eucalyptus bark and found that they have a typical type I cell wall, with higher amounts of pectins and xyloglucan as the main hemicellulose. The group led by Carlos Labate has also performed studies of carbohydrates in the bark from different eucalyptus varieties. They found that some barks are hexoses rich presenting up to 5% of sucrose in its composition. Labate is also

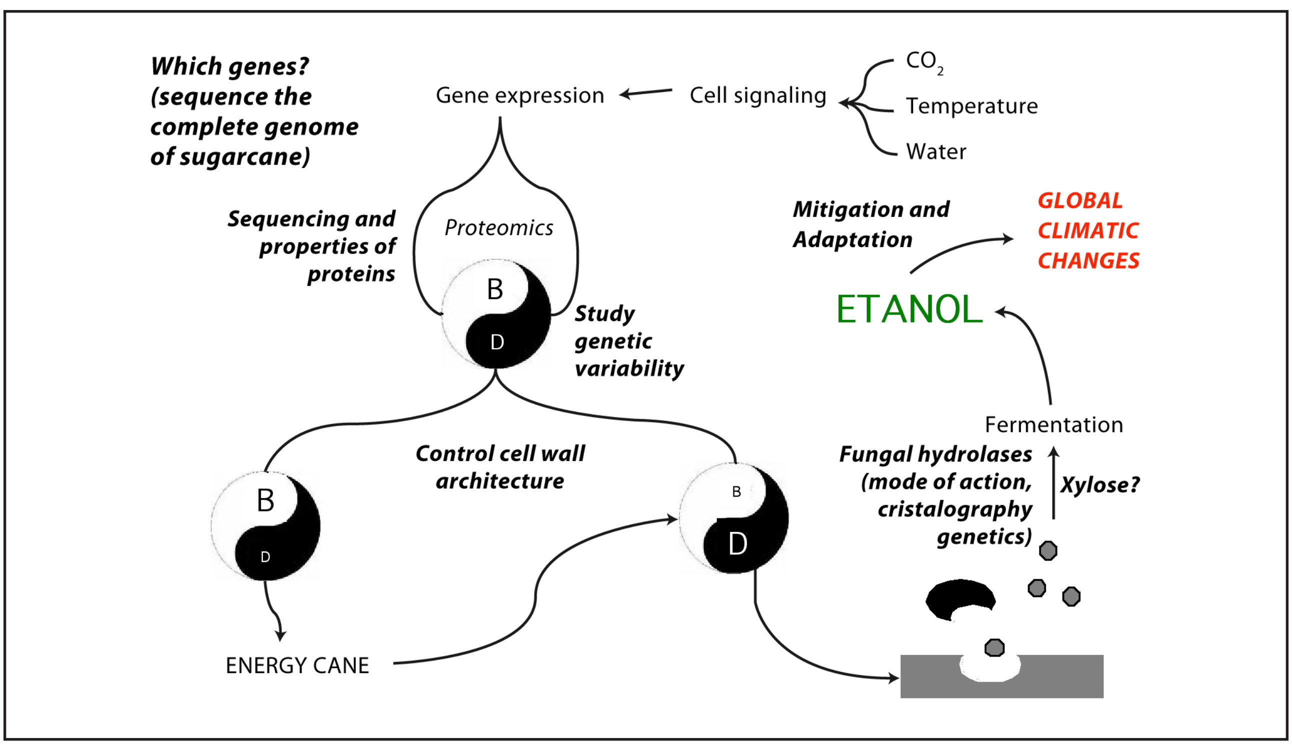

FIGURE 7 Routes to cellulosic ethanol using sugarcane bagasse.

interested in studying cellulases with specificity for those raw materials, as those found them within the digestive treatment of termites and other wood specialized insects (personal communication). Besides the knowledge on the composition of the eucalyptus cell wall, the pulp was already studied with relationship to the attack of fungi enzymes (MEDEIROS *et al*., 2002).

Coffee dreg is another rich source of polysaccharides. It is rich in mannan and cellulose that might be digested by a mannanases and cellulases (LISBON *et al*., 2006). There are several other possibilities, but mentioned above can be seen as examples that could complement and eventually overcome the production of sugarcane-based ethanol. The peduncle of the banana bunch is a residue that can be obtained in relatively great amounts and has composition similar to sugarcane bagasse (not published) and can be digested by a similar mixture of fungi enzymes (MEDEIROS *et al*., 2000).

Even with the focus on the ethanol of high technology, it is important that we do not forget to give some attention on the physiology of other plants of interest for ethanol production, be it from sucrose, starch or cell walls. We needed to invest in plants to increase productivity and precocity in order to reduce the need of expansion of the planting areas. In the same way, it is important produce varieties that are more resistant to the drought, elevated temperature, cold and pathogens in order to adapt to the effects of the global climatic changes in course, as well as to assist to the demand for varieties capable to be cultivated in new areas with non-ideal climate as the traditional ones.

Our group are also investigating the mechanisms of natural cell wall digestion in both fruits and carbohydrate storage seeds (by far the most efficient systems know to degrade cell walls and use the sugars as sources of energy) by determining enzymes involved, the expression sequence and the composition and structure of the cell wall of seeds in order get hints that help us to design an optimized process of hydrolysing cell wall and seeking to the production of alcohol through the maintainable use of native seeds.

Seeds of species native to several Brazilian biomes, among them the Atlantic forest and of the Savannah, accumulate great amounts of cell wall polysaccharides (BUCKERIDGE, 1990; BUCKERIDGE *et al*., 1995; MAYWORM *et al*., 2000). In some cases, it is possible to extract carbohydrates in large quantities, possibly for industrial scale. We have, for instance, developed a process to obtain galactomanan starting from *Dimorphandra mollis* seeds (PANEGASSI *et al*., 2000). Thus, a possible strategy for bioenergy production would be to develop technologies to co-produce an eco-ethanol starting from reserve polysaccharides of some native species seeds from savannah and Atlantic Forest. Our group has been studying these biological systems for many years (see BUCKERIDGE *et al*., 2000 for a review) and we believe that the development of technologies to produce bioethanol from storage cell wall polysaccharide from seeds of native tree species would stimulate the use of agroecosystems in association with sugarcane crops and restored native biomes. At the same time, we would like help to protect these biomes from destruction due crop expansion. Through the last 15 years we have been studying the biochemical and physiological mechanisms involved in the processes of degradation of those polymers. We purified several enzymes (BUCKERIDGE *et al*., 2000) and cloned related genes (ALCÂNTARA *et al*., 1999, 2006; LISBON *et al*., 2006; BRANDÃO, 2009), as well as investigated the hormone control mechanisms of cell wall degradation in those study models (SANTOS *et al*., 2004; TONINI *et al*., 2006).

The idea is to introduce genes in fungi, bacteria or yeasts to make them able to express hydrolases that attack galactomannans and xyloglucans from legume seeds. Then, we could use the yeast to degrade the polysaccharide of the seeds to produce monosaccharides and, to proceed, to promote the alcoholic fermentation. Indeed, some of the most interesting species to be used for this purpose would be *Dimorphandra mollis* (40% yield) and *Sesbania virgata* (21% yield) of galactomannan and *Hymenaea courbaril* (40% yield) of xyloglucan (BUCKERIDGE *et al*., 2000).

The amount of ethanol to be produced it is relatively small in relation to sugarcane production and potential. However, the environmental advantages of regenerate forests allied to the sugarcane plantations are huge. This strategy, we denominated The Midway (BUCKERIDGE, 2007), has the potential of producing an ethanol that could be certified as low environmental impact process and assure some market slices.

FINAL CONSIDERATIONS

The cellulosic ethanol, beside the biodiesel, is a promising source of sustainable and efficient fuel able to support a significant part of the universal demand for liquid fuels, such as the propelling of vehicles as well as to feed fuel cells. Several methods for obtaining ethanol are in experimentation and they are all important in order to Brazil to keep its leadership in this field so that the technological value of the biofuels can be reverted in our favour while the product moves forward to become a commodity. In this route, the sugarcane blunts with large advantage being the plant on which we must deposit our largest efforts in short term. By developing completely a viable technology to produce ethanol from cellulose, we should be able to adapt the technology to convert virtually any source of biomass in free fermentable sugars to produce ethanol and other unforeseeable applications. At the same time as the focus should be placed in the development of technologies related to pretreatment, hydrolysis, fermentation and distillation, we need also to keep research on the improvement of crops, including their physiology and agronomy.

Bioenergy production is an attitude of extreme importance for us to face the serious environmental challenges related with the effects of the global warming. Although the bioenergy is not the only solution for this problem, it certainly will contribute to mitigate the emissions of fossil fuels.

Another equally important challenge is the preservation of biodiversity. The productivity increase expected in the next 10 to 15 years, should be used to reduce the need of crop expansion to produce fuel. At the same time, the recovery of forests should be encouraged, and, if possible, they can occupy space amid the sugarcane plantations and help to produce energy.

The production of ethanol from cellulose with high efficiency and sustainability will not be task of a few scientists, but the result of the integration among several research groups specialized in different areas of the physiology, ecology, biochemistry, genetics, enzymology, physics, chemistry and engineering, to name but a few. The industrialized world is gradually changing its energy matrix. It is a event perhaps without similar in the history and Brazil is one of the leaders. We can develop a new technology, reduce the production of greenhouse gases and, at the same time, use it to recover the biodiversity, integrating sustainability and technological development. Perhaps it is not too much to say that Brazil has the chance of leading a transition among old *Homo sapiens sapiens*, a powerful but pollutant species, towards to a *Homo sapiens ambiens*, a new and still more powerful and balanced species.

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8

FERTILITY MAINTENANCE AND SOIL RECOVERY IN SUGARCANE CROPS

Raffaella Rossetto, *Fábio Luis Ferreira Dias*, *André César Vitti* and *Heitor Cantarella*

INTRODUCTION

The search for quality of life among current and future generations is the central issue behind human activities. Agriculture in the 21st century can no longer be dissociated from the principles of sustainability, in which economic development must necessarily walk hand in hand with social development and environmental conservation. The sugarcane industry, known in the past as environmentally degrading and polluting, after significant changes, is moving towards sustainability.

Soil is considered a heritage of a nation. It is a constantly changing limited resource. In this sense, it is essential that it be understood as a resource to be preserved for future generations. There are many definitions of "soil". The Brazilian Soil Classification System (EMBRAPA) defines soil as: "a natural body consisting of three-dimensional, dynamic, solid, liquid and gaseous parts, formed of mineral and organic matter, which occupies most of the surface cover of continents on our planet, containing live matter, and vegetated in the nature within which it occurs, eventually having been modified by anthropic interferences". This definition contains important concepts: the existence of live matter as a soil component; its three-dimensional nature, in other words, soil is not only the land surface that is visible, but also has depth; and the fact that soil may have undergone anthropic interferences, in other words, change by agriculture or other human activity.

THE IMPACT OF SUGARCANE CULTIVATION ON SOIL

Traditional agricultural operations and their consequences

From ancient civilizations to this day, agriculture starts with soil preparing operations, in which layers are revolved to control weeds break up compaction, thereby improving the physical conditions for root growth and water storage.

Soil preparation also aims to incorporate corrective amendments such as limestone or gypsum or organic fertilizers, thus preparing for good crop yields. However, soil plowing and disking operations involve oxygenation, which encourages microbial and small animal communities to develop; these communities degrade the soil organic matter. Such organisms use organic matter as a source of C and other nutrients, decomposing it and, as part of its respiratory mechanism, eliminating CO_2 into the atmosphere.

For this reason, converting an area of native vegetation into an agricultural plot for any crop, especially when applying traditional farming operations (plowing, soil disking), results in a decline of soil organic matter concentrations (Lal, 2002), and consequently loss of C in soil, usually quantifiable in chemical analysis. Added to the loss of soil organic matter is an undesired environmental effect: loss of CO_2 and other gases into the atmosphere, which increases the greenhouse effect. For this reason, adding organic matter is a highly recommended practice for sustaining agricultural systems.

BLUM (1988) defined soil degradation as loss of quality, or partial or complete loss of one or more soil functions. Ecological functions of interest for agriculture are: soil as an agent supplying nutrients, air, water, support for roots, facilitating the production of plant material, and renewable energy. Another soil function is its filtering, buffering or storage ability, for instance, of rainwater. Soil is also a *habitat* for the flora and fauna. The intensity with which soils perform each of its functions is very important for its sustainability. Soil degradation decreases its ability to carry out its functions, leaving it unable to support vegetation. The extreme case is desertification. Agricultural operations done without due respect for soil conservation techniques cause major losses and accelerate the degradation process.

Surveys of degraded areas, done in Brazil in 2005 (FAO 2008), have shown that 15.97% of Brazilian soils are degraded in some measure, as follows: 1.29% (110 mil km^2) mildly degraded; 4.99% (427 mil km^2) moderately degraded; 7.29% (624 mil km^2) severely degraded; and 2.4% (205 mil km^2) very severely degraded.

The main causes of soil degradation are physical (erosion, compaction), chemical (loss of organic matter, contamination, salinisation), or biological (loss of organic matter and the resulting reduction of microbiological communities). Once degraded, soil recovery is a long-term task involving multidisciplinary actions to reestablish the previous balance and sustainability (Griffith and Dias, 1998).

Soil fertility and the longevity of sugarcane crops

Contrary to what has been observed in other countries after decades of sugarcane plantation in the same soil, productivity in Brazil has remained unchanged or even increased significantly. Novel management technologies developed during years specifically for Brazilian soils may explain this situation; examples include: improved soil preparation techniques, mechanization of agricultural operations, soil conservation techniques, the development of superior varieties, nutrient recycling, fertilization and irrigation techniques, and several others.

Naranjo *et al.* (2006), from Mexico, have studied the effects of long-term sugarcane crops on the fertility of a fluvisol cultivated for 5, 10, 20 or 30 years. No changes in soil organic matter or exchangeable K, Ca and Mg and CEC were found across the years of farming. The authors found that total C (17%), total N (21%) and total P (37%) soil content declined in 30 years of farming. Losses occurred mainly within the first 20 years. However, these fertility losses were not accompanied by decreased sugarcane yield; in fact the yield increased 67% between the 5th and 30th year of farming due to agricultural practices such as bred varieties and more adequate N and P fertilization.

Sugarcane farming for long period on the same soil may improve its chemical and physical attributes, as demonstrated by Mubarak *et al.* (2005) in clayey soils (> 54% clay) in the Sudanese semiarid region. In that study, the soil attributes after long-term sugarcane farming (more than 40 years) were compared with farming for less than10 years and with the native soil vegetation. Agricultural practices included: deep sub-soil tillage, disk cultivation and leveling followed by plot formation every 4 or 5 years, with plots reformed every year. Soil organic matter content was significantly higher in the sugarcane crop cultivation period(8.2 g kg^{-1}) compared with that of native vegetation (2.1 g kg^{-1}) and a shorter time of sugarcane cultivation (6.6 g kg^{-1}).Farming had no effect on total soil N, organic C or soil density in the 0-10 cm layer. At 10-20 cm depth more total N accumulated in long term-cultivated soils (0.46 g kg^{-1}) compared to native vegetation and short term cultivated soils (0.26–0.33 g kg^{-1} respectively). In this layer, soil density in the long-term cultivation period was lower than that of native vegetation and short term cultivated soils. At 20 to 30 cm depth, total N and soil density remained unaltered, but organic C content was significantly higher under native vegetation (4.9 g kg^{-1}) compared to short-term farming (1.7 g kg^{-1}).

Organic matter content did not decline when sugarcane was farmed over 25 years on a same soil (cohesive latosol in the coastal board region of Alagoas, Brazil)compared with native plant soil (content of C= 26 g kg^{-1}). There was a decline in total C content (C=19 g kg^{-1}), in organic matter and aggregate stability in soils cultivated for only 2 years, suggesting that agriculture disturbs soils, especially in the initial phases of its implementation (SILVA *et al*., 2007).

Cerri and Andreaux (1990) assessed the content of C in forest soils cultivated for 12 or 50 years in the state of São Paulo, and found that C content declined by 46% after 50 years farming compared to forested areas. Based on the natural abundance of C technique, which evaluates the 13C/12C ratio – which is lower in forest-originated organic matter (C3 plants) compared to sugarcane=originated matter (C4 plant – the authors estimated that after 12 years farming, 80% of the organic matter was still originated from the forest, white after 50 years farming, this number was 55%. The increase of C in sugarcane-originated organic matter is slower than the decline of forest-originated C in organic matter, resulting in lower C values in sugarcane cultivated soil across the years compared with the content of C in forests.

Skjemstad *et al*. (1999) compared soil samples from uncultivated sites with soil samples from recently planted sugarcane crop areas, and also with regions where sugarcane had been cultivated for many years (with burning of trash); there was little change in total C and the labile fraction in soils. These authors concluded that sugarcane farming increases organic matter humidification in proportion to the duration of sugarcane farming. Evidence of this has been gathered from organic C redistribution in the profile of sugarcane cultivated soils. Areas where sugarcane has been cultivated for many years have soils with lower levels of surface organic; these levels increase in the subsoil compared to recently implanted areas. Magnetic resonance imaging spectroscopy of C-13 found no differences in the chemistry of organic matter molecules in soil layers in the same site, but suggested differences among sites.

Noble *et al*. (2003) compared soil attributes in areas with sugarcane crops with and without burning to assess the changes in soils under different forms of management 6 to 9 years after implantation. These authors also compared long-term sugarcane crops, grass pasture areas and fallow areas. The increased addition of protons to the system with trash compared to burning was 0.71 kmol H^+ ha^{-1}.year. The added amounts of protons according to management were 1.38, 3.81 and 0.87 kmol H^+ ha^{-1}.year respectively for continuous sugarcane farming, pasture, and fallow periods. Although acidity, in the case of sugarcane, may be due to trash decomposition, both acidity and decreased amounts of bases may be reverted with management strategies, such as liming. Organic C increased by 4 $t.ha^{-1}$ after treatments with cane trash (treatment without burning) compared with treatment with burning, after a 9-year period. For treatments with pasture coverage, organic C increased to 9 $t.ha^{-1}$ in a 6-year period compared with the time under continuous sugarcane plantation, clearly demonstrating the huge potential of pastures to sequester C in tropical environments. Exchangeable cation data show variations only in the surface layer (up to 10 cm depth), suggesting that the influence of cane trash and pasture coverage occurs only superficially. Increased CEC (pH 5.5) in the treatment with cane trash, compared with burnt cane, and pasture compared with the continuous cane system, were 0.67 and 0.75 cmolc kg^{-1} in the 0–10 depth layer. From 9 to 31% of the amount of cations in the soil were not retained by the CEC, suggesting a potential for loss of these cations in the soil. In this study, analysis of oxidizable organic C by potassium permanganate showed a linear correlation with total organic C in all situations, indicating that the proportion of different organic matter functional elements were not affected by burning, continuous cane farming, or pastures.

Maia and Ribeiro (2004) evaluated morphological and physical property changes of an abrupt fragipanic dystrophic yellow argisol under continuous sugarcane farming in Coruripe, Alagoas state. These authors compared three different cane plots, one with native forest vegetation and two with sugarcane crops for 2 and 30-year periods. Sugarcane farming changed the surface horizon morphologically, yielding an Ap horizon, and changing the structure of the first two horizons of the profile. Continuous cane farming decreased macroporosity, and thus increased available water, since more micropores were available. Because microporosity increased, there was a significant decline in the hydraulic conductivity of superficial horizons. No significant soil density variation was observed. Compaction in Ap and AB horizons was observed, due to sugarcane farming and the presence of densification (cohesive nature) in the Bt horizon in all profiles.

The C content in soil is generally recognized as an important component of soil fertility and its physical processes. Moreover, there is a strong connection between the organic matter content and the biological life of soils, which are important for the sustainability of the system. Recent studies have suggested that the quantity and quality of organic matter returning to the soil system, such as roots and rhizomes, may be important factors for systems in future. Bell *et al*. (2007) emphasized the importance for "soil life" of maintaining organic matter, and have indentified more indicative lines of management.

With the aim of investigating the presence of worms in different management forms and cultures in the KwaZulu tropical region, Natal, South Africa, Dlamini and Haynes (2004) found that pastures (kikuyu) contained more worms than the native forest, and that cane under a raw cane harvest system contained more worms than burnt cane. Burnt cane was the situation with fewer worms in this study, which evaluated 11 different crop and/or management situations. The number and mass of worms correlated positively with soluble C; C linked to microbial biomass and soil pH. Eleven different worm species in several crops were found, although sugarcane supported only two or three species.

Erosion

Erosion results from water and wind removing finer soil particles, which are transported to other sites, resulting in decreased soil depth, loss of functions and, in extreme cases, loss of soil itself. Erosion may also contaminate water bodies.

Prove *et al*. (1995) have measured erosion in cultivated soils under traditional operations or minimal cultivation in Australia. Losses ranged from 47-505 $t.ha^{-1}.year$-1, with an annual mean of 148 $t.ha^{-1}.year^{1}$ in areas under traditional ratoon farming. This wide range was due to rainfall differences between the study sites. Erosion losses were below 15 $t.ha^{-1}.year^{1}$ with minimal cultivation practices.

Sparoveck and Schnug (2000) applied remote sensing and the universal soil loss equation (USLE) in Brazil to estimate mean losses due to erosion at 31 $t.ha^{-1}.year^{1}$ in the Central-South region in sugarcane cultivated areas.

The impact of erosion on sugarcane cultivation occurs mostly because of the extension of cultivated areas and the fact that soil preparation and planting takes place during the intensely rainy season. Impact is minimal when the full soil conservation technology is applied. Sugarcane is generally known as a conservationist agricultural activity, wherein soil losses are small compared to other annual crops, especially if burning is not done before harvest and the trash is left to protect the soil. Major movement of soil takes place only during planting, every 5 or 6 years on average. Data from the Agronomy Institute of Campinas (Instituto Agronomico de Campinas) in the state of São Paulo, reported by De Maria and Dechen (1998), have estimated soil losses due to burning of trash at 8.3 to 23.2 $t.ha^{-1}.year$ depending on the soil type, on a 5-year average. These numbers are 62% lower than those of soybean plantations.

Cultivation of cane over trash with harvesting without burning of trash required drastic technological developments. Maintaining the trash results in drastically decreased soil erosion losses, which were already low compared to other crops. Table 1 shows soil loss data as a function of differentiated trash management. It can be seen that losses decrease by 32% when trash is kept on the surface compared to the conventional burning of sugarcane plantations.

Izidorio *et al*. (2005) presented a case study assessing nutrient losses due to erosion in a red eutroferric latoso in Guariba (São Paulo state) with burning of trash for harvesting,showing that eroded sediment analyses indicated enrichment rates of 1.62 (organic matter), 4.30 (P), 1.17 (K),

TABLE 1 Soil losses due to erosion in sugarcane with or without trash.

	Soil losses (t/ ha^{-1})
Sugarcane – no trash	39 to 108.6
Sugarcane – (mean plant cane + 5 harvests), no trash	8.3 to 23.2
Sugarcane with surface trash	6.5
Sugarcane with incorporated trash	13.8

Source: DE MARIA and DECHEN (1998); BERTONI *et al.* (1982).

1.33 (Ca), and 1.24 (Mg) times compared to the original soil. Soil and nutrient losses as a function of the type of erosion obeyed the following order: furrows > global > inter-furrows. These losses were spatially dependent, and the authors found few sites with losses above the estimated limit for the type of soil being studied; they further stated that even without trash, conservation conditions of physical and chemical properties occurred in nearly of the study area.

AGRICULTURAL PRACTICES FOR SOIL SUSTAINABILITY

Several agricultural practices have been developed for sustainability. Such practices constantly undergo changes, and are evidence of multidisciplinary efforts. The efforts of private initiatives together with public institutions for seeking technological development in the sugarcane industry are noteworthy.

Production environments for sugarcane

Sugarcane cultivation that respects agroecological zoning is a determining factor for sugarcane yields and a starting issue for sustainability. Production environments – the sum of interactions among surface and especially subsurface soil attributes – may be defined in the appropriate sites for sugarcane; the declivity grade where soils occur, associated with climate, may also be taken into account. Production environment components are represented by depth, which is directly related with water availability and the volume of soil explored by roots; by fertility, such as the source of nutrients for plants; by texture, which is related with the level of organic matter, cation exchange ability and hydric availability; and by water as part of the soil solution, which is vital for plant survival. Adequate management, such as soil preparation, using lime, vinasse and irrigation, may increase soil yield and, therefore, its production environment. Chemical conditions of soils directly affect production environments.

Table 2 shows the chemical criteria of the subsurface layer of soils, adopted by EMBRAPA (1999), with specific modifications for sugarcane crops in italics, made by Prado (2004). According to Landell *et al.* (2003), the chemical status of the subsurface horizon is a determining factor for sugarcane yields, where the correlation with yields (TCH) increases with subsequent harvests. This study also showed that ratoon yield decreased significantly according to the following order of soil chemical attributes: eutrophic > mesotrophic > dystrophic > acric > alic (Figure 1).

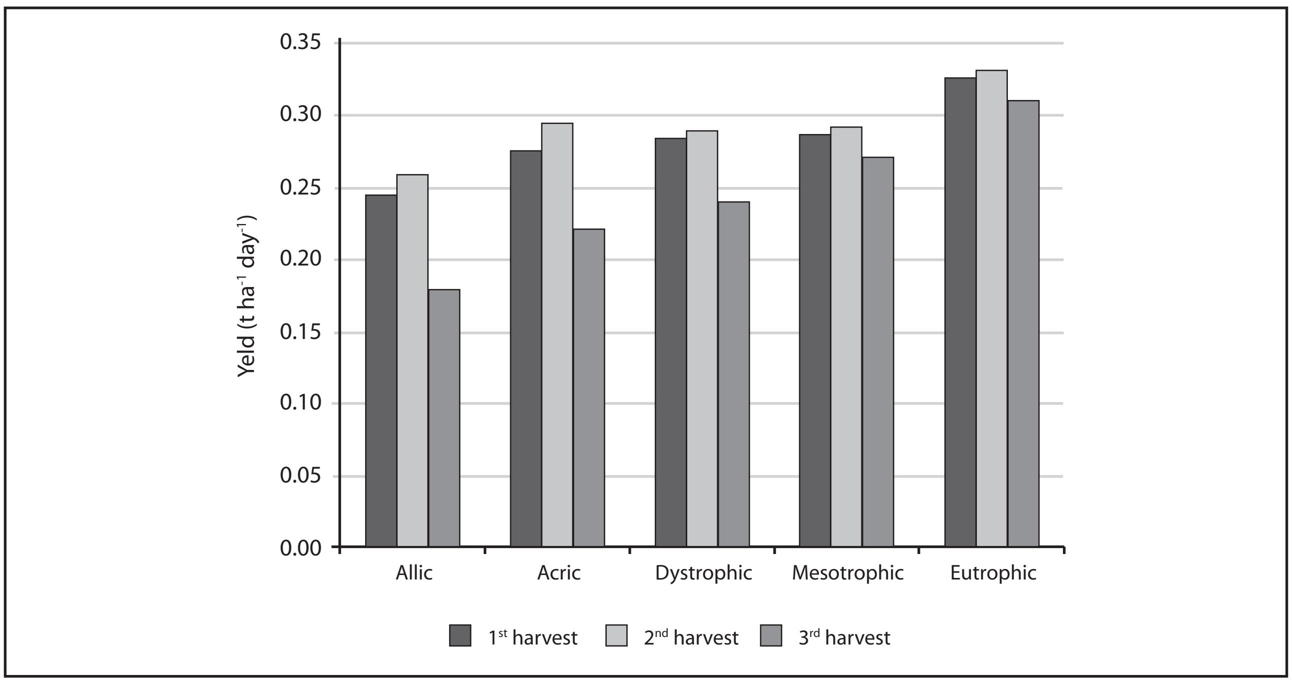
In Prado *et al.* (2007) work, the same cane varieties were planted in Goianésia and Ribeirão Preto (São Paulo state). Both regions had similar rainfall (1,435 mm), but with a more irregular yearly distribution in Goianésia, which has a longer deficiency period compared to Ribeirão Preto. There is also more evapotranspiration in Goianésia, which results in more water loss in soils. Soils were similar, a red acriferric latosol with a very clayey A moderate (LVwf) texture, a representative soil class in central-southern Brazil. Five varieties (IAC87-3396, RB72454, RB855486, SP80-1816, and SP80-1842) in three harvests were evaluated in both sites. Higher water deficiency and evapotranspiration in Goianésia resulted in lower sugarcane yields compared with the Ribeirão Preto region. The mean reduction of the three harvests was 16.8% in stalk yield. Although the soil class was similar at both

TABLE 2 Chemical-pedological criteria of the soil subsurface layer.

Soil	V	SB	m	Al^{3+}	RC
Eutrophic	≥ 50	*≥ 1.5*			
Mesotrophic	*30-50*	*≤ 1.2*			
Mesotrophic	*> 50*	*< 1.5*			
Dystrophic	*< 30*		*< 50*		*> 1.5*
Acric					≤ 1.5
Mesoallic			*15-50*	*≥ 0.4*	
Allic			> 50	0.3-4.0	
Alluminic			≥ 50	> 50	

V = base saturation (%).
SB = sum of bases ($cmol_c$ kg^{-1} soil).
m = aluminum saturation (%).
RC = retention cations ($cmol_c$ kg^{-1} of clay).

Source: PRADO (2004).



Source: LANDELL *et al*. (2003).

FIGURE 1 Sugarcane yield across harvests.

sites, the production environment classification differs. The higher climate restriction in Goianésia moves the production environment classification from D1 in Ribeirão Preto to E2 in Goianésia.

Among the five varieties, RB72454 interacted with the production environment, where its yield was more affected by the water restricted conditions of Goianésia (GO). Other varieties (IAC87-3396, RB835486, SP80-1842 and SP80-1816) did not interact, showing that these varieties are more stable.

Sugarcane production environments in central-southern Brazil may be found in Prado (2005). A1 environment soils, considered as high potential soils for sugarcane yields, include argisols, latosols, nitisols, gleysols, cambisols, andchernosols, as long as they are eutrophic, eutroferric or mesotrophic, with medium/high CEC and high water availability. Lower yield potential soils are those that do not store water, such as acric soils, or shallow and allic dystrophic soils with a low CEC, such as neosols, allic argisols, and allic latosols.

Soil conservation – direct drill planting and minimal cultivation systems

Sugarcane cultivation in Brazil has been carried outwith intensive use of agricultural machinery and implements and significant movement using plows and heavy disking. The first studies for implementing direct drill planting or minimal cultivation aimed mostly to reduce planting operational costs. Perticarrari and Ide (1986) tested and developed implements for deep sub-soil tillage and elimination of ratoons to reduce and optimize soil preparation operations. In these authors' experiments, ratoon yields increased in both clayey and sandy soils in a comparison between minimal and traditional cultivation.

The main reported advantages of minimal cultivation are less machine use, decreased soil preparation operating costs, maintenance of trash on the surface, decrease or elimination of terraces (below 5% declivity) without erosion issues, increased soil conservation, decreased soil compaction, increased operational yield, the possibility of planting during rainy seasons, increased ratoon yield and longevity; in the middle and long terms, improved physical conditions of soils and increased soil organic matter content and fertility.

In general, direct drill planting similar to grain farming practices is difficult to adopt for sugarcane crops. Compaction is practically inevitable, because of intensive mechanization requirements and long term farming without movement of soil. Maintenance of trash has made drastic compaction avoidable, although even in this case deep sub-soil tillage operations are often required. In this context, minimal cultivation has been more successful.

Coleti (2008) listed the following situations for minimal cultivation and the operations involved in this process:

1) Over preexisting sugarcane plantations – chemical or mechanical elimination of ratoon cane (two-row eradicator), rectification of tracings, application of corrective agents, deep sub-soil tillage with roller and front disks, furrowing and planting.
2) Over pastures – chemical desiccation of pasture, marking and building conservationist structures (terraces and paths), application of corrective agents, deep subsoil tilling/roller, furrowing and planting.
3) Associated with legumes to form dry matter – chemical desiccation of the previous sugarcane plantation, correction and/or adaptation of conservationist structure, application of corrective agents, broadcast sowing of leguminous crops (*Crotalaria juncea*, *Crotalaria spectabilis*, guandu beans), deep sub-soil tilling/roller, summer fallow, incorporating plant mass preferably with knife roll, wait for drying of plant mass, furrowing and planting. Development and use of deep sub-soil tilling/roller facilitated minimal cultivation operations for sugarcane by decompacting the soil without causing it to lose its structure. Direct drill planting and minimal cultivation systems for sugarcane are not indicated in low fertility acid soils, in which case liming is indicated. Because of the need to incorporate lime and, with other practices, "build" soil fertility, it is suggested that this step be carried out before adopting the new system. Sites with significant soil pest attacks should also undergo pest control approaches before adopting minimal cultivation.

Spacing of cane rows, permanent plots and controlled traffic

Soil compaction and treading on cane rows are two factors that recognizably reduce sugarcane yields and the lifetime of sugarcane plantations. Intensive mechanization has compounded these issues; for this reason, traffic control in sugarcane plantations has become paramount for sustainability.

It is common to control traffic in sugarcane plantation in Australia. Machine tracks always compact the same inter-row, separating the plots where cane rows are present. Spacing generally is 1.5 m, but the gauge of machines is 1.83 m. An option is to control traffic and to investigate spacing to reduce treading on rows. A possibility is double spacing (known in Brazil as pineapple spacing). Braunack and McGarry (2006) studied the physical properties of soil in a double spaced sugarcane plantation (0.3 m between cane rows) reaching 1.8 m spacing and with controlled traffic, comparing it with a single spaced (1.5 m) sugarcane plantation with normal traffic. Soil density and resistance to the penetrometer measured on cane rows were higher in the 1.5 m spacing plantation, and hydraulic conductivity was lower, indicating that the double spaced system resulted in less compaction. Cane yields were not significantly different between these two planting systems.

Braunack and Peatey (1999) studied the effect of treading on the haulout unit on wet and dry soils. Treading on rows in wet soils reduced yields significantly. The most significant changes occurred at 20 cm depth, resulting in increased soil density and decreased hydraulic conductivity.

In Australia, after years of declining sugarcane yields because of factors such as orange rust, soil pests, and intense mechanization, minimal soil movement concepts together with crop rotation, green fertilization, and lower fertilizer doses (especially nitrogen) are practices that have gained acceptance. Minimal cultivation is done with soil preparation in plots, where the inter-rows remain always as such, compacted and never reformed, and the row is the soil preparation site, where plots are made for cane cultivation. In this technique, cane is planted in double rows with wider spacing (1.8 m). Carr *et al.* (2008) reported increased yields by changing from the traditional soil preparation system to the permanent plot system at the Herbert River district, Australia. In this new sustainable agriculture trend, farmers in this region of Australia are replacing fertilizers such as urea and potassium chloride with calcium nitrate, ammonium nitrate, ammonium sulfate and potassium sulfate, believing that the latter are less harmful to soils. With the current high prices of fertilizers, use of alternative nutrient sources and conservative doses should become more widespread. Table 3 shows the nutrient doses used in the traditional system and in the minimal cultivation system with plots used in Australia. Cane yields, which from 1997 to 2001 never surpassed 70 $t.ha^{-1}$, have always been over 80 t/ha^{-1} since 2002, even with reduced nutrient doses. It should be noted that pests and diseases against which the variety had no tolerance also caused low yields during that period.

Cane cultivation in an organic production system

Production of cane in organic systems used to be restricted to small brown sugar, (dried sugarcane juice) or cane spirit. In the past ten years, large-scale production was the aim of several industrial units in the state of São Paulo; these units currently cultivate over 20,000 ha for these products.

TABLE 3 Nutrient management strategies in traditional and minimal cultivation strategies with plots in Australia.

	Plant cane		Ratoon cane	
	Conventional	Plots	Conventional	Plots
	$kg.ha^{-1}$			
Nitrogen	105	42	171	94
Phosphorous	30	–	–	
Potassium	56	36	77	80
Sulfur	18	22	–	48

Source: CARR *et al*. (2008).

Soil and environmental conservation is emphasized in organic sugar production, since herbicides, agrochemicals and mineral fertilizers are not allowed. In these areas, vinasse and filter cake are added to provide nutrients – especially N, P and K – and organic matter. Maintaining trash also adds organic matter, thus protecting the soil from raindrop impact and erosion. Meeting environmental regulations, conserving ecosystems, such as forest corridors and biodiversity reservations, and preserving water resources are necessary requirements for certification. Rossetto (2004) discusses the advantages and advances of environmental issues as represented by organic cultivation techniques.

Crop rotation – green fertilization

Crop rotation is one of the oldest farming practices and has gained "current airs" under the focus of sustainable farming. Rotation for sugarcane – a semi-perennial plant – is only possible when the plantation is reformed, which occurs every 5, 6 or more years. Some advantages of crop rotation are well known, such as savings when reforming the plantation because of income gained from another crop; soil conservation and major erosion control because of coverage during a heavy rainfall season; weed control; indirect pest control, such as the cane borer and the lesser cornstalk borer; increased sugarcane yield. Certain green fertilizers, such as crotalarias, may help combat nematodes. More recently, after the polemic on soil use for biomass production for fuels and the need to produce food, use of sugarcane reform sites has resulted in increased grain production in the state of São Paulo. Sertãozinho, São Paulo state, a well-known sugarcane plantation region, is one of the major peanut producing areas in this state.

Sugarcane plantations harvested from June to September that will be reformed are the best sites for rotation. Sugarcane ratoon is destroyed chemically with glyphosate. It is possible to plant early soybean, peanut crop or green fertilizers from September to March, after which the area may be prepared for a one-year and a half sugarcane plantation. Cane should be about 60 cm high to be desiccated. The ratoon root system is a source of organic matter, and may eventually help form water infiltration channels. The crop should be planted over the trash of desiccated cane.

Rotation with a leguminous crop (Fabaceas) may be more advantageous because of biological fixation of atmospheric nitrogen. Soybean, for instance, may fixate from 100 to 160 kg/ha^{-1} ofatmospheric N (Mascarenhas *et al.*, 2002).

Mascarenhas *et al.* (1994) studied the effect of soybean fertilization on the yield of a sugarcane plantation reform area. These authors found that cane only made use of the residual effect of soybean fertilization when it was higher than 0-126-90 kg.ha^{-1} of N-P_2O_5-K_2O. A mean soybean yield of 1,700 kg/ha^{-1} exported only 20 kg/ha^{-1} of P_2O_5 and 38 kg/ha^{-1} of K_2O, leaving a considerable amount of primary nutrients for cane.

Pankhurst *et al.* (2005) studied crop rotation with pastures, grains or fallow periods on soils farmed with sugarcane for over 20 years in five sites in Queensland State, Australia. Rotation remained for 30 to 42 months in four sites and for 12 months in a fifth site. Cane was cultivated again after this period. Microbial biomass increased on pastures in the first four sites and declined in the fallow site; it remained unchanged in the grain-cultivated areas compared with continuous sugarcane farming. *Pratylenchus zeae* nematode populations, which reduce cane yields, declined in sites where rotation was done longer; nematode populations, however, increased in pasture areas and decreased in fallow areas. Cane yields in areas under rotation were significantly higher compared to continuously farmed areas.

Liming and correction of deep layers

Liming is essential to form and maintain soil fertility. The cost/benefit ratio is highly positive for sugarcane crops. Calcium corrects acidity, neutralizes toxic aluminum, and stimulates root growth. In many cases, however, the effect of liming is restricted to the soil preparation layer. With the current trend for less movement in both minimal preparation and direct drill planting, subsurface acidity is not corrected. A practice often associated with increased sugarcane yield is to improve the subsurface environment by deepening the root system, thereby increasing resistance to lack of water. Thus, a measure that possibly increases yield is to incorporate lime in depth with amold board plough.

Liming is indicated whenever the aluminum saturation in soils is over 30% and/or the calcium content is below 1 $cmol_c$ dm^{-3} and the magnesium content is below 0.4 $cmol_c$ dm^{-3}. In general, by monitoring soil analysis and the liming need equation that aims to increase base saturation to 60% of the CEC, every ton of lime applied to a hectare of soil (PRNT 100) raises calcium by 1 $cmol_c$ dm^{-3} in the 0-20 cm layer. A recommendation is to add 15 to 20% more to compensate for the acidification that occurs due to fertilizer use (Rossetto *et al*., 2004). The purpose of liming is to correct the 0-20 cm layer; if preparation goes deeper, more lime should be expected. If preparation reaches 30 cm depth, the recommended value should be multiplied by 1.5.

It is important to consider that liming improves the availability of existing phosphorous and molybdenum in the soil, raises the CEC (caption exchange capacity), and increases bacterial activity. Efficient use of phosphorous provided by soluble fertilizers is increased because of liming.

Sugarcane is quite tolerant to soil acidity. This crop may grow in a wide pH range. In several cases, liming increased yields not by raising the pH, but by providing calcium. Marinho and Albuquerque (1983) reviewed liming and sugarcane and found a linear correlation between aluminum saturation and relative production. For aluminum saturation close to 100, the relative yield was estimated to be 70, which indicates strong tolerance to acidity.

Liming may raise the pH and increase the content of Ca and Mg in deeper layers of soil if long-term management is undertaken. Noble and Hurney (2000) found a significant decrease in exchangeable acidity with increased Ca and Mg content up to 1 m depth. Calcium was applied 3 times in 18 years at a dose of 5 $t.ha^{-1}$ on the surface of an acid and dystrophic soil (oxic humitropept) in Australia. As lime was applied on the surface and the pH was seen to increase up to 1 m depth, this was attributed to ionic pairs with NO_3 being formed on the surface and then leached, evidenced also by the difference in NO_3 absorption by roots at different soil depths.

Orlando F. *et al*. (1996) observed that changes in chemical attributes, such as the pH, Ca and Mg content, and base saturation in the arable layer, persist in soils as residual effects for a long time, up to 56 months after application.

Noble and Hurney (2000) found increased sugarcane yields and progressive rises in CEC and pH up to 1 m depth 18 years after a first application of lime. The dose was high, 5 $t.ha^{-1}$, in an acid and dystrophic soil (oxic humitropept) in Australia, and liming was carried out more than three times during the 18-month study period.

Application of gypsum and phosphate

Application of gypsum in soils may be advantageous when the calcium content at 40 to 60 cm depth is equal to or below 0.4 $cmol_c$ dm^{-3}; the Al^{+3} content is higher than or equal to 0.5 $cmol_c$ dm^{-3} and/or Al^{3+} (m) saturation above 30%; and sulfur content is low. Gypsum ($CaSO_4.2H_2O$) is much more water soluble than lime; when it solubilizes, the resulting SO_4^{2-} anion remains in the solution and may be leached, carrying with it calcium, aluminum, magnesium or potassium cations. Chemical complexes formed between sulfate and aluminum decreases the availability of these ions for plants, although they are not neutralized. Furthermore, a high calcium concentration displaces negative charge bonded Al^{3+} into the soil solution. Gypsum carries calcium to deeper soil layers, which results in the benefits of improving the subsurface environment, thereby promoting deep root growth.

Studies of gypsum in sugarcane have demonstrated the significantly favorable effects of this practice on yield and soil fertility, reaching deeper soil layers, compared to the improvements attained with liming only. Morelli *et al*. (1992) carried out one of the best-known experiments in this area, where increasing lime and gypsum doses (0, 2, 4 and 6 $t.ha^{-1}$) were applied to an allic dark red latosol in Lencois Paulista, São Paulo state. The subsurface layer of this soil was poor in calcium

(1.2 $mmol_c\ dm^{-3}$) and rich in Al^{+3} (6.5 $mmol_c\ dm^{-3}$), which suggested a good response to gypsum application. Liming at a dose of 6 $t.ha^{-1}$ raised the content of calcium and magnesium, and decreased the content of aluminum at 25 to 50 cm depth. Gypsum increased much further the content of these element sand its effect reached a depth of 100-125 cm. Combining lime with gypsum reduced Al^{+3} more effectively compared to such practices done separately (Table 4). Similar results were seen on yields. Looking at the 4 years of the study, lime (at a 4 $t.ha^{-1}$ dose) raised yields by 54 t, and gypsum (at a 6 $t.ha^{-1}$ dose) raised yields by 51.6 t. Both practices combined increased yields by 76.8 t.

Raij (2008) analyzed several results of studies on lime and gypsum in sugarcane, and concluded that liming and gypsum application are highly economic for sugarcane; if well applied, they may increase longevity by at least one ratoon harvest. This author also concluded that the official liming and gypsum recommendations for São Paulo state, given by Spironello *et al*. (1996), are underestimated.

Figure 2 illustrates the decreased base saturation in sandy middle texture low CEC latosol, in which soil preparation involved lime application at 2.5 $t.ha^{-1}$ and gypsum application at 1.5 $t.ha^{-1}$. The initial base saturation in the 0-20 cm layer was 15%; at 20-50 cm depth, it was 7%. Liming raised these values within the first year of farming. Subsequently, however, base saturation decreased and nearly reached the initial values at the end of the fifth harvest. Increased acidity may also result in decreased yields in subsequent harvests, since fertilizer nutrients are less utilized. These data suggest that lime should be applied again after the second harvest.

Gypsum has an important function in correcting saline and saline-sodic soils. Choudhary *et al*. (2004) aimed to investigate the effect of irrigation water with added gypsum and found that the beneficial effect of gypsum was more pronounced in sodic soils (30% increased yield) compared to saline-sodic soils (13% increased yield).

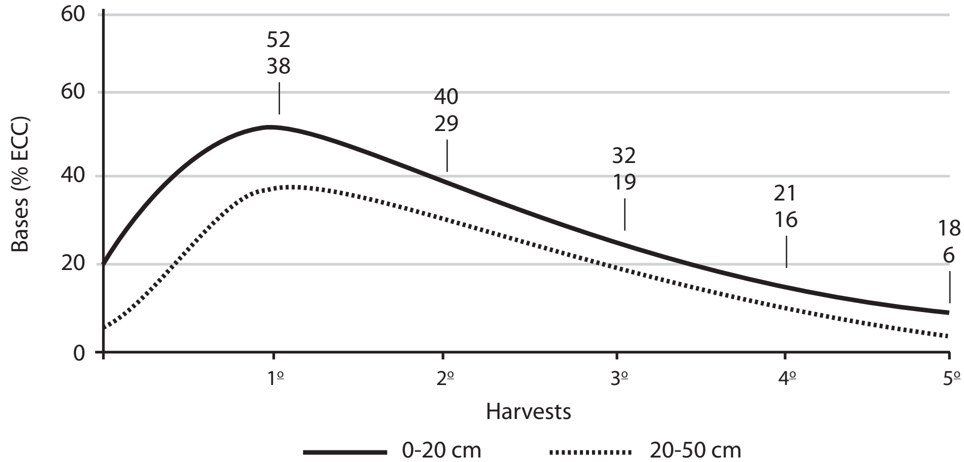
In Australia, the properties of soils with 7.9% Na to which gypsum was applied (10 $t.ha^{-1}$) followed by five irrigations, showed a significant decreased in clay dispersal and higher stability of soil aggregates. The authors of this study combined gypsum applications with molasses (10 $t.ha^{-1}$) and found a higher proportion of aggregates and lower electrical conductivity (Suriadi *et al*., 2002).

One of the main issues in soil fertility in Brazil is a low P content, especially in sugarcane expan-

TABLE 4 Chemical attributes of soil after liming and gypsum application, 27 months later.

Depth (cm)	Ca^{+2} ($mmol_c\ dm^{-3}$)		Mg^{+2} ($mmol_c\ dm^{-3}$)		SO^{4-2} ($mmol_c\ dm^{-3}$)		Al^{+3} ($mmol_c\ dm^{-3}$)	
	Gypsum (0 $t\ ha^{-1}$)	Gypsum (6 $t\ ha^{-1}$)	Gypsum (0 $t\ ha^{-1}$)	Gypsum (6 $t\ ha^{-1}$)	Gypsum (0 $t\ ha^{-1}$)	Gypsum (6 $t\ ha^{-1}$)	Gypsum (0 $t\ ha^{-1}$)	Gypsum (6 $t\ ha^{-1}$)
Lime (0 $t.ha^{-1}$)								
0-25	3.5	7.9	0.9	0.8	0.8	2.4	9.2	7.8
25-50	2.0	4.9	0.5	0.6	0.9	2.6	8.4	7.8
50-75	1.1	4.6	0.5	0.6	0.8	3.4	7.3	7.3
75-100	0.8	4.3	0.5	0.8	0.7	4.1	6.8	6.7
100-125	0.6	4.4	0.5	0.7	0.7	4.4	7.1	6.4
Lime (6 $t.ha^{-1}$)								
0-25	13.0	23.4	9.3	6.1	0.3	2.8	1.1	0.5
25-50	4.4	9.5	2.8	2.1	0.8	2.9	4.5	3.5
50-75	2.0	5.2	1.1	1.1	0.8	3.6	6.2	5.7
75-100	1.6	5.0	0.8	1.2	0.9	4.7	5.7	5.0
100-125	1.4	5.1	0.7	1.4	0.8	4.7	6.0	4.6

Source: MORELLI *et al*. (1992).



Source: MORELLI *et al*. (1987).

FIGURE 2 Bases (% of the exchangeable cation capacity) in a sandy middle texture latosol across several sugarcane harvests.

sion areas in western São Paulo. Phosphate application, which is total area application of sources of P at soil preparation time before planting cane, is a recommended practice for low and very low phosphorous content soils (below 12 $mg.dm^{-3}$) and preferably low clay content.

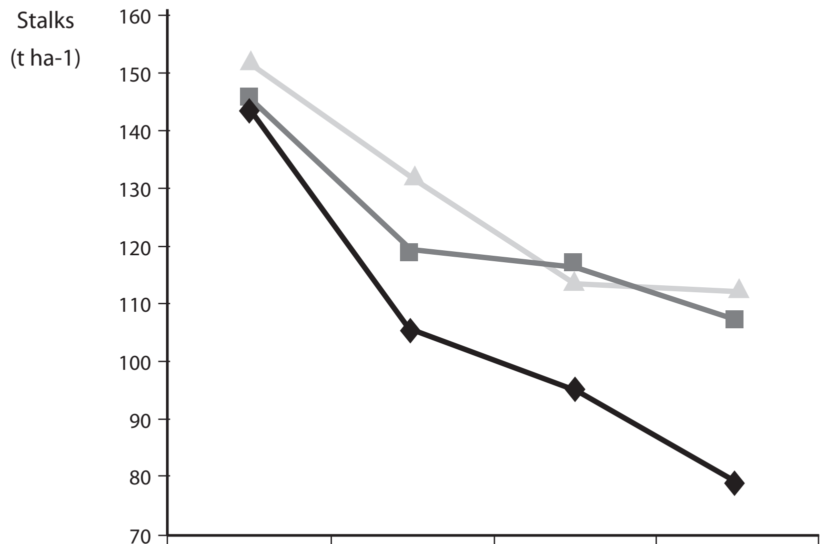
Fertilization – yield and maintenance of soil fertility

Fertilization aims to increase yields and replenish the nutrients exported by crops, to maintain and even raise the nutrient stock across the years.

In general, under favorable climatic conditions, sugarcane yields decrease gradually after each harvest, such that plant cane and first ratoon yield differences are higher than the differences found after the fifth and sixth harvests. The degree of yield decrease in subsequent harvests is a feature of the genetic potential of each variety, because much energy is used for regrowth each year, besides the soil fertility status and other production factors that need to be maintained. Adequate fertilization increased the crop yield, reduces any decrease in yields between harvests, and thereby increases the longevity of sugarcane plantations.

Figure 3 contains data gathered by Orlando Filho *et al*. (1993) and presents decreased sugarcane yields in different crop cycles, and how fertilization may reduce the impact of lower yields. In this experiment on a quartzarenic neosol, the yield reduction after the third ratoon was 45%. After NPK+S fertilization (with gypsum) the yield fell by 26% after the third ratoon. The yield reached 424 tin an unfertilized reference plantation in a sum of four harvests, which the yield reached 511 t, nearly 100 t more, in four years with the NPK+S treatment; it should be borne in mind that this was a rather sandy and low fertility soil.

Clay soils are highly able to fixate P applied as fertilizer, which reduces the efficiency of fertilization. In this case, it is convenient to limit any contact between the fertilizer and soil particles, which is why application in furrows is recommended. Since application of phosphate in plantation furrows is the only opportunity of placing phosphorous at depth, close to roots, a possible strategy would be to subdivide the recommended P_2O_5 dose into soluble phosphate in furrows and poorly soluble phosphate. This is because natural or reactive phosphorous or thermophosphate, which are slowly soluble, would have a residual effect and could provide P to ratoons. In this context, Cantarella *et al*. (2002) investigated fertilization with P_2O_5 at 120 $kg.ha^{-1}$ applied during planting of the IAC89 3396 variety in a quartzarenic neosol in Assis, São Paulo state, in the following proportions:



	Planted cane	1st ratoon	2nd ratoon	3rd ratoon
◆ Control	144	106	95	79
■ NPK	145	120	116	107
▲ NPK+G	152	132	114	113

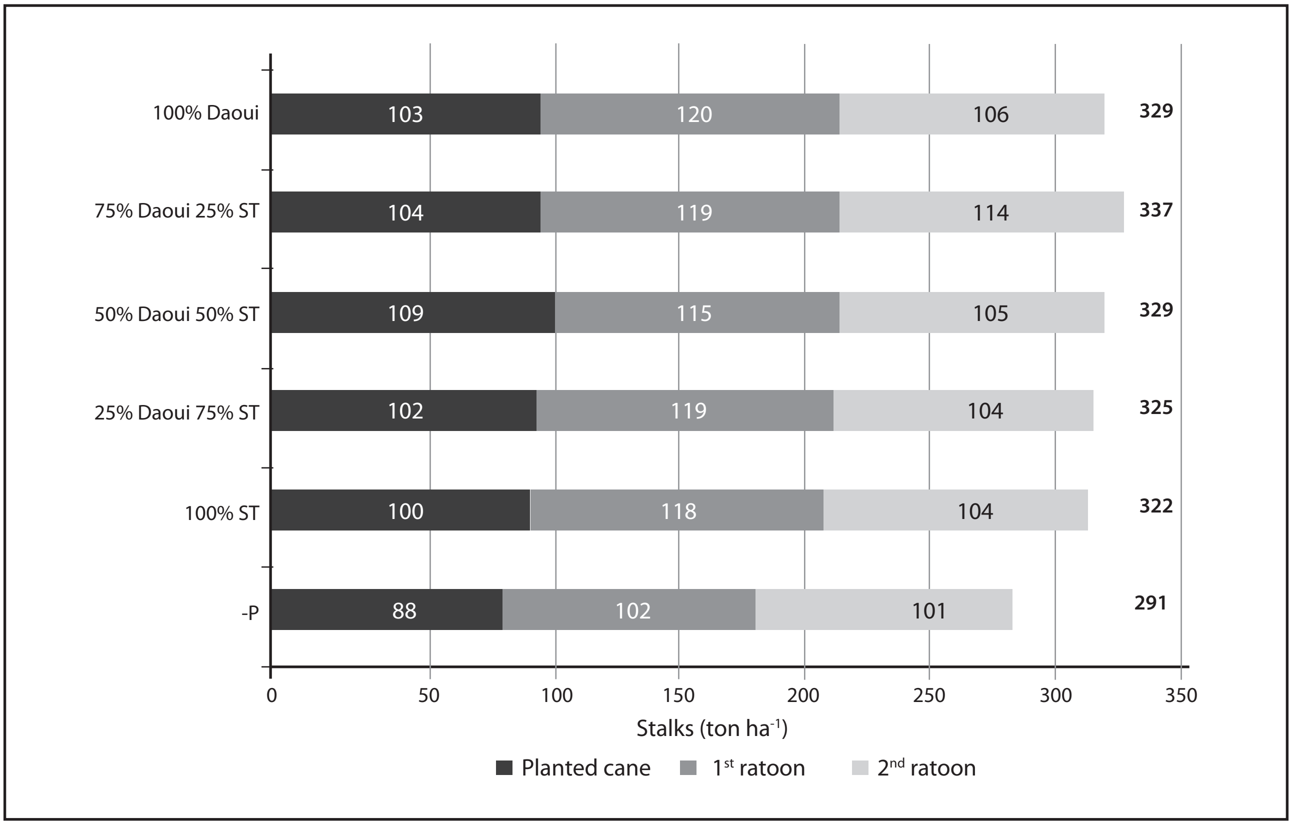
Obs.: NPK plant cane (CP) = 41-180-200 kg.ha^{-1} de N-P_2O_5-K_2O; ratoon = 80-00-200kg.ha^{-1} de N-P_2O_5-K_2O; gypsum (G) = 65 kg.ha^{-1} de S.

Source: Adapted from ORLANDO FILHO *et al.* (1994).

FIGURE 3 Variation in yields of the SP70-1143 (t/ha^{-1}) sugarcane variety in 4 years of cultivation, with fertilization and non-fertilization.

0, 25, 50, 75 and 100% of triple superphosphate (TS) or Daoui reactive phosphate. The experiment was conducted for 3 consecutive years; only N and K were applied on ratoons. Yield differences in plant cane – not favored because of lack of water – occurred only between the reference plantation without P and fertilized treatments; there were no differences in the proportions of TS and Daoui reactive phosphate. The same occurred with the first ratoon. There was a higher residual effect of treatment with Daoui reactive phosphate at 75% and TS at 25%in the second ratoon, such that the sum of yields in three years resulted in an accumulation of 46 t extra compared to the non-fertilized reference, and 15 t more than with the TS treatment (Figure 4).

Goals for sustainable management of sugarcane include increasing the efficiency of fertilizer use and reducing nutrient losses in the system. Parceling the fertilizers may be advantageous in sandy soils, although it involves an extra farming operation, especially if fertilization is done during a season with strong rain. In sandy soils, with a low CEC (cation exchange capacity), cations like potassium, are not adsorbed and may be lost by leaching. Trash also alters the management of fertilization. Urea applied over trash without being incorporated incurs in volatilization losses of N, which may reach 60% of applied N. Incorporation into soil avoids such losses, which become almost zero. However, incorporating fertilizers in the presence of trash incurs in certain operational difficulties. For this reason, the nitrogen sources ammonium nitrate and ammonium sulfate are indicated, although the cost of these fertilizers should be taken into account. There are also fertilizers with added urease inhibitors, such as the NBPT, which can delay losses and in a way increase the time after fertilizer application and the next rain that would incorporate urea into soil. Applied urea losses of 12% were reduced to 7% with a sugarcane inhibitor (Cantarella *et al.*, 2002).



Source: CANTARELLA *et al.* (2002).

FIGURE 4 Effect of mixing different solubility sources on the yields of three sugarcane cycles.

New inputs, such as micronutrient-coated fertilizers, provide more uniform and efficient application. Polymer-coated fertilizers, which release nutrients slowly and minimize losses, require further studies, but already indicate inputs with good yield and environmental quality responses. Soil fertilization in expansion areas of São Paulo state should also take into account possible micronutrient and silicon deficiencies or poor availability. Precision agriculture will be an important tool for rationalizing fertilizer use, increasing the efficiency and reducing losses, resulting in more sustainability.

Rossetto *et al.* (2008) presented a review on sugarcane mineral nutrition and fertilization, and their relation with yields and soil fertility.

Maintenance of trash on soils

Changes in the production system whereby fire is no longer used to facilitate harvesting operations result in a large quantity of trash left over the soil, which significantly alters its physical and chemical attributes. One of these modifications – of major relevance for certain production environments – is the fact that trash significantly raises water retention and infiltration in soils, which avoids surface crusts from forming. Trash significantly reduces evaporation rates. (Tominaga *et al.*, 2002; Ball Coelho *et al.*, 1993).

Ivo *et al.* (2003), in a study of a yellow argisol where the mean annual rainfall is 1,500 mm, showed that trash may contribute significantly for water conservation in Brazilian northeastern soils. When the dry season started during an atypical year (rainfall was 2,049 mm), water was not available in the 0-80 cm layer in burnt sugarcane plots. During the wet season, soil where sugarcane was harvested with no burning had available water values above those of soils where cane was burnt in 87% of the evaluations. On average, trash conserved 15.7 mm of water available during the dry season, and 19.8 mm during the wet season.

Trash over soil facilitates nutrient recycling, thus reducing fertilizer use. Wood (1991) calculated that trash in Australian productive sugarcane plantations might add to the system a mean 99 kg.ha^{-1} of N and 86 kg.ha^{-1} of K_2O every year. Most nutrients, except for K, need to be mineralized by microorganisms before being absorbed by crops. Robertson and Thorburn (2007a) studied the effect of trash on soil fertility at five sites in Australia.

The amount of trash ranged from 7 to 12 t.ha^{-1}; C ranged from 3 to 5 t.ha^{-1} and N ranged from 28 to 54 kg.ha^{-1}. The high C/N ratio (over 70) caused trash to take over a year to decompose; there were two phases to this process. The first decomposition phase took place while the C/N ratio remained high; in this case, gains or losses of N were not related with the losses of C. During the second phase, when the C/N ratio was low, losses of N were correlated and directly proportional with the losses of C. The decomposition rate of N during the first year was 1 to 5 kg per month, thus providing little of this nutrient to the crop. The offer of N in trash occurs in the middle and long-term.

McGuire (2007), in a long-term study at Mount Edgecombe (South Africa), showed that about 40 kg.ha^{-1} of N and 70 kg.ha^{-1} of K_2O return to the system annually. Altered soil fertility is not expected immediately after changing to sugarcane management under trash; it is a long-term process. Robertson and Thorburn (2007b) found that organic C and total N increased over 21% because of the presence of trash (no burning) at 10 to 25 cm depth after 3 to 6 years of management. Microbial activity was also much higher. Most of the C in trash was metabolized and lost as CO_2 to the atmosphere. Increased mineralization of N in trash does not follow stimulation of the initial microbial activity due to trash; initially, N is immobilized. Estimates by these authors of possible C and N gains in soils after long-term trash maintenance (20 to 30 years) are: 8 to 15% organic C; 9 to 24% total N, and a 37 kg.ha^{-1}.year increase in inorganic N. These authors also suggested that fertilization with N should not be decreased in the first 6 years of trash maintenance.

In the state of São Paulo, Brazil, Faroni *et al.* (2003) found that 40 to 50% of the dry matter in trash remained in soils one year later. The C/N ratio, which initially was 85, fell to 34 after one year. Oliveira *et al.* (1999) found trash decomposition rates of 20 to 70% after a year.

Oliveira *et al.* (1999), aiming to verify whether mineralization of cane trash was stimulated or not by adding urea or vinasse, undertook a study wherein 100 m^3 ha^{-1}of vinasse combined with urea was applied over trash(equivalent dose at 100 kg.ha^{-1}) or buried in the soil; also, a mixture of potassium chloride (equivalent dose at 120 kg ha^{-1} of K_2O) with urea (equivalent dose at 100 kg ha^{-1}) was applied over trash or buried in the soil. These treatments did not alter the degradation of trash lignocellulose or nutrient release; significant statistical differences were found only between the results of recently harvested cane trash and the remainders. The mass decreased by about 80% (hemicellulose and cell content), 30% (lignine), and 50% (cellulose). The mean N, P, K, Ca, Mg and S nutrient release percentages were respectively 18, 67, 93, 57, 68, and 68%relative to the total contained in recently harvested cane trash.

Franco *et al.* (2007) measured the amount of nutrients from trash in two sites in the state of São Paulo. The nutrient stock in crop waste at two sample sites had the following decreasing order of magnitude: N > K > Ca > S > Mg > P. Table 5 shows the amounts of these nutrients in both sites. The amount of N (200 kg.ha^{-1}) is nearly five times higher than what would be indicated for sugarcane fertilization in the state of São Paulo. Differently from K, N is slowly released, since it is bonded to organic molecules. The amount of N in trash that is released in the next sugarcane cycle is relatively low: 3 to 30%, as demonstrated in several studies (Oliveira *et al.*, 1999; Faroni *et al.*, 2003; Basanta *et al.*, 2002). The amount of trash N that is absorbed by the crop in the next cycle is about 5 to 10% (Ng Kee Kwong *et al.*, 1987); thus, most of this N supplies the soil stock, as evident in studies with 15 N-marked trash (Basanta *et al.*, 2002).

Maintaining trash also alters carbon dynamics and organic matter humification in soils. Busato *et al.* (2005) identified organic species of P in humic acids of an eutrophic vertic Ta haplic cambisol located in Campos dos Goytacazes, Rio de

TABLE 5 Dry matter and nutrients in two sugarcane plantations in the state of São Paulo. (Sum of results found in the root system – aerial portion of regrowth and trash.

Dry matter						
t ha^{-1}	N	K	P	Ca	Mg	S
	kg.ha^{-1}					
Site A 28.9	196.7	149.5	20.4	59.8	24.7	29.3
Site B 16.7	83.3	64.6	9	36.8	11.3	17.6

Source: FRANCO *et al.* (2007).

Janeiro state, a sugarcane cultivated area with preservation of trash with added vinasse for over 50 years. Decomposition of trash along 55 years increased the participation of labile organic forms of plant origin in humic acids, such as P in diesteric bonds. Where cane was burnt there was a higher precipitation of more stable organic forms, such as orthophosphatein monoesteric bonds. Accumulation of more labile forms of Po in humic acids in sugarcane under trash, especially in the 0-20 cm layer, may be established by the balance between the input of plant waste and its subsequent decomposition by microorganisms. Organic matter is an important reservoir of available organic P for crops. Labile forms of organic P are readily mineralized in soils. This dynamic is helped by a higher content of available P in the management of raw cone, which make it possible for organic forms of labile P to accumulate in humic acids. Canellas *et al.* (2003) studied these same areas and found that organic matter was more humidified in areas of burnt cane, compared with areas under trash for many years.

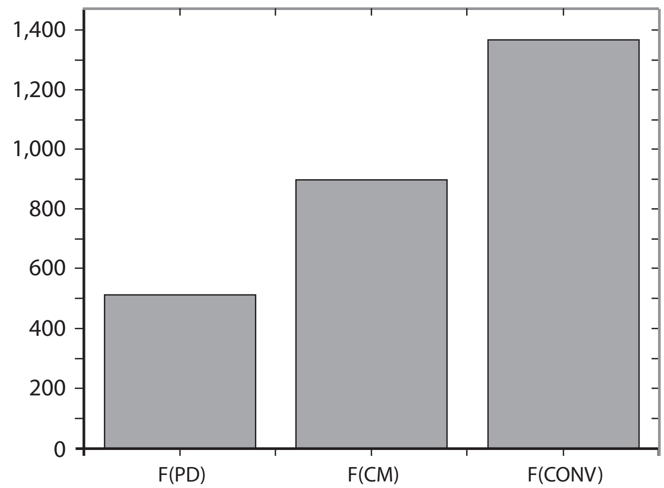
The total C and labile C contents were evaluated in three studies, two in Australia and one in Brazil (Blair *et al.*, 1998). Burning of trash resulted in higher losses of total C and labile C at 1cm soil depth compared with the unburnt system. Total C declined in one of these areas, although in this case labile C increased. In the state of Pernambuco, Brazil, management under trash for one year did not alter total C but increased labile C. The presence of trash on fields results in sequestration of 1.5 Mt C $year^{-1}$ and avoided methane emissions of 0.05 Mt C $year^{-1}$ (Cerri, 2004).

Chaves and Farias (2008) studied the spatial variation of the C stock in a dystrophic gray argisol that had been conventionally farmed with sugarcane. There was significant spatial variation of the carbon stock. In the surface layer, it was on average 33.82 Mg ha^{-1}; in other horizons, it was respectively 26.37 and 21.21 Mg ha^{-1}. Canellas *et al.* (2007) found that the carbon stock in soils of a burnt area decreased 40% compared with an unburnt trash-covered area. This study investigated a sugarcane cultivated cambisol, where the C stock at 0-20 cm depth was 36 Mg ha^{-1}, and 37.3 Mg ha^{-1} at 20-40 cm depth in the burnt area.

Bolonhezi *et al.* (2004) compared the conventional sugarcane preparation system (plowing and disking) with the direct drill and minimal cultivation system and concluded that in an unburnt sugarcane plantation, incorporation of 17 t ha^{-1} of dry matter in the conventional preparation system resulted in extra total emissions (in a 27-day period) of 3.5 t ha^{-1} of CO_2 compared to minimal cultivation and 9 t ha^{-1} of CO_2 compared with direct drill plantation (Figure 5).

Nutrient recycling – use of waste

Because of extensive farming areas, waste generated by the sugarcane industry causes an impact due to its volume. However, waste such as bagasse, filter cake, and vinasse have high added value, and are important sources for recycling soil nutrients. All waste in the sugarcane production chain is reused in the production process itself. Nutrient recycling based on this waste has contributed significantly towards the sustainability of soils and the



Source: BOLONHEZI *et al.* (2004).

FIGURE 5 Total emission of CO_2 (g CO_2 m^{-2}) in conventional (CONV), minimal cultivation (CM), and direct drill planting (PD) systems for sugarcane without burning. Twenty-seven day period after soil preparation.

sugarcane industry. Filter cake and vinasse used in soils significantly recycles nutrients and organic matter. Filter cake is a waste product of sugar production and of modern distilleries, originating from the syrup clarification process. This waste product applied to sugarcane plantations has been shown to increase yields and soil fertility, since it provides organic matter, phosphorous, calcium, and other nutrients. Filter cake is used routinely in sugarcane mill, partially or fully replacing P. In general, 50% of P from filter cake is readily available for cane. Filter cake is more efficiently used in plantation furrows, where mineralized P is close to the roots. Water in the cake also facilitates cane sprouting.

Cake filter applied in furrows stimulates root proliferation. Composting of filter cake to which gypsum, thermophosphate, reactive phosphate, and other organic sources are added, yields a highly nutritional organic fertilizer. Braga *et al.* (2003) found a strong interaction effect with 50 mm irrigation every months and application of filter cake or gypsum. In this study, cake filter associated with irrigation increased yields (Figure 6).

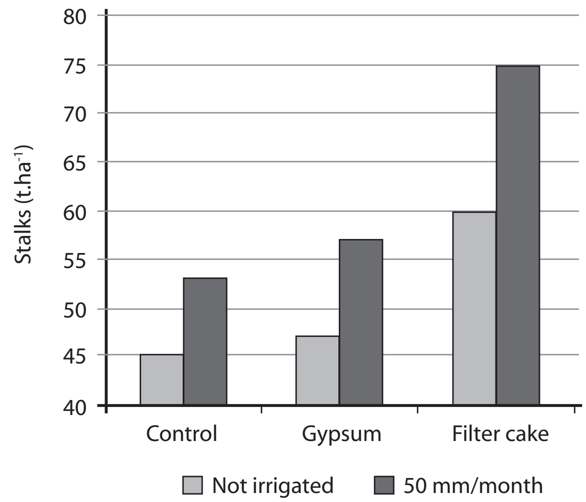
Vinasse is an organic material without metals or other contaminants that might hinder its use in farming. Characterization of vinasse, its effects after application on soils, and the potential risk of ion leaching to subsurface waters are described in Chapter 10, Part 3, of this book.

Biological fixation of N and growth-promoting bacteria in sugarcane

Sugarcane is farmed in several regions of the world; it is able to associate with endophytic bacteria, which are found inside leaves, stalks and roots, and that are able to fixate atmospheric N and produce plant hormones such as indol acetic acid and gibberellins. Practices that increase the efficiency of these associations are helping to increase the sustainability of soils and sugarcane plantations.

Doctor Johana Dobereiner, a researcher at Embrapa, in Rio de Janeiro, Brazil, discovered the association between N-fixating bacteria and sugarcane. The fixating species that may associate with sugarcane are: *Gluconacetobacter diazotrophicus* (Cavalcante and Döbereiner, 1988), *Azoarcus* spp. (Reinhold-Hurek *et al.*, 1993), *Herbaspirillum seropedicae* (Baldani *et al.*, 1986), *Herbaspirillum rubrisubalbicans* (Baldani *et al.*, 1996), and *Burkholderia* spp. (Yabuuchi *et al.*, 1992; Baldani *et al.*, 1997).

The potential of N for fixation through these associations is not clear. There are differences



Source: BRAGA *et al.* (2003).

FIGURE 6 Effect of gypsum application, filter cake, and irrigation on sugarcane yield (3rd harvest) in Goianésia, state of Goiás.

among varieties; furthermore, studies have indicated that crop management with nitrogen fertilizers may significantly affect this process. In this context, Polidoro *et al.* (2001) found that the RB72454 and SP80-1842 varieties had a high nitrogen biological fixation potential in their samples; however, managing soil fertility and plant nutrition tended to affect the degree of contribution, and monitoring of the plant nutrition status became necessary.

Controversy exists on the presence of mineral nitrogen and its possible influence on the N-fixation process. It has been suggested that high-dose application of nitrogen fertilizers are responsible for decreased populations of *Gluconacetobacter diazotrophicus* in sugarcane varieties cultivated in Mexico (Fuentes-Ramírez *et al.*, 1999), India (Muthukumarasamy *et al.*, 1999), and Brazil (Reis Junior *et al.*, 2000). Among the nutrients, limitations in molybdenum nutrition may be the most important issue because of its role in the nitrogen nutrition of sugarcane plants; this element is part of the enzymes nitrogenase and nitrate reductase, both of which are involved in N-acquisition metabolic processes (Polidoro *et al.*, 2001).

The contribution of biological fixation in sugarcane plants (18 months) inoculated in laboratories with a mixture of *Gluconacetobacter diazotrophicus* strains was 20 to 30% of the total nitrogen accumulated in plants (Oliveira *et al.*, 2003). In another study, different strains were inoculated into cane, resulting in significantly increased sprouting and plant weight compared to controls. The population concentrated in the roots and was higher after application of nitrogen at 75 $kg.ha^{-1}$, compared with 0 and 150.kg ha^{-1}, suggesting that an initial dose is needed (Moraes and Tornisielo, 1997). Bastian *et al.* (1998) showed that both *Herbaspirillum seropedicae* and *Gluconacetobacter diazotrophicus* produce gibberellins and indol acetic acid (IAA). This may explain partly the beneficial effects of these bacteria in the plants.

FINAL CONSIDERATIONS

The sugarcane crop is becoming more sustainable because of technology. Its development and support, as discussed above, demonstrate a clear change in production systems, currently allied with environmental issues. Adoption of several technologies has raised yields in sugarcane plantations, even after more than 100 years of sugarcane farming. Soil quality and function have been maintained – and even improved – across the years.

In expansion areas under old pasture soils, many of which were degraded or had low fertility soils, sugarcane farming has raised yields, which has made it possible to occupy such soils as possible farming areas.

Several technological innovations should contribute further to sustainability, such as soil recovery and continued fertility. These include precision farming, low input use production systems, new fertilizer sources, the use of improved and more efficient inputs that cause less impact to the environment, judicious mechanization, soil conservation techniques, microbiological systems for increased nutrient use efficiency, genetic breeding for higher yields in borderline soils and lower fertilizer requirements, and more adequate plans for allocation of cultivars according to production environments.

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9

FERTILIZERS FOR SUGARCANE

Heitor Cantarella and *Raffaella Rossetto*

INTRODUCTION

Sugarcane is a high-yielding crop that requires significant amount of nutrients, since mineral elements comprise about 3% to 5% of its dry matter. Sugarcane yields about 25 to 40 t ha^{-1} of dry matter in typical average Brazilian farming conditions, of which about 60% to 70% are removed from fields as stalks. Thus, sugarcane fertilization may be undertaken considering that significant amount of nutrients are exported with the harvested parts. Information gathered by several authors has shown that the above-ground portion of sugarcane contains the following nutrients for each 100 t of stalks produced: N, 100 to 154 kg, P_2O_5, 15 to 25 kg, K_2O, 77 to 232 kg, and S, 14 to 49 kg (RAIJ *et al*., 1997; FRANCO *et al*., 2008a; MOURA FILHO *et al*., 2008; ROSSETTO *et al*., 2008a).

Among Brazilian crops, sugarcane is third in fertilizer consumption, after soybean and corn. In 2007/2008, cultivation of about 8.3 x 10^6 hectares of sugarcane required about 3.4 x 10^6 t of NPK, which is 13.8% of the Brazilian use of fertilizers (ANDA, 2007). Sugarcane, however, receives a relatively small amount of fertilizers – mean 408 kg ha^{-1} of NPK (ANDA, 2007) – when the amount of plant material (mean stalk yield of 77 t ha^{-1}) and its long growth cycle are taken into account. Recommended nutrient doses for sugarcane in Brazil, especially N, are generally lower than those applied in many other countries with similar yields (HARTEMINK, 2008). The contribution of biological nitrogen fixation (BNF) is one of the probable reasons explaining why less nitrogen is used in Brazilian sugarcane. Nutrient recycling, common in the sugarcane industry, is also important for rational fertilizer use; solid and liquid residues, such as filter cake, ash, trash, and especially vinasse, are returned to fields.

Much experience from several research centers has been gained on sugarcane fertilization and nutrition for soil conditions in traditional Brazilian producing regions. Recent reviews on this theme include the publications of CANTARELLA *et al*. (2007), KORNDÖRFER (2008), MELLIS *et al*. (2008), QUAGGIO (2008), ROSSETTO *et al*. (2008a, b, c, d) and VITTI *et al*. (2008a, b). This text aims to highlight some aspects about sugarcane fertilization for which additional research is needed to face the challenges of increasing competitiveness in the biofuel sugarcane industry.

LIMING AND GYPSUM APPLICATION

Brazilian soils are generally acid, which does not favor root growth because the exchangeable aluminum content is higher and several other nutrients are less available. Limestone is used in agriculture to correct soil acidity and to provide calcium and magnesium, which are essential for plants. Limestone requirements vary according to each crop; different criteria are applied in Brazil for establishing sugarcane limestone needs. In São Paulo, SPIRONELLO *et al*. (1997) have recommended raising the base saturation (V) to 60% of the cation exchange capacity (CEC) and to use dolomitic limestone when the level of exchangeable magnesium becomes lower than 5 $mmol_c$ dm^{-3}. In the Cerrado region, the aim has been to raise V to 50% (SOUSA, 2002). Other criteria in use involve calculating the dose of limestone to neutralize exchangeable aluminum and raise the percentage of exchangeable calcium to 30 $mmol_c$ dm^3 (BENEDINI, 1988; PENATTI, 1993; KORNDÖRFER *et al*., 1999). In many sugarcane cultivated soils the exchangeable aluminum content is low, so that the calcium content is more relevant for defining the dose of limestone in this last criterion. On the other hand, several authors have suggested that sugarcane calcium requirements are met with soil contents around 7 to 8 $mmol_c$ dm^3 (ZAMBELLO JR., 1981; MARINHO, 1983).

Although many studies have been conducted on acidity correction in sugarcane, there is no consensus on this topic (QUAGGIO, 2008). Sugarcane is relatively tolerant to soil acidity and the presence of aluminum (MARINHO, 1983; ROSSETTO *et al*., 2004). QUAGGIO and RAIJ (2008) gathered data from papers published in Brazil showing that this crop responds little to liming of soils with base saturation above 25% of the CEC, which equates with a pH rate of 4.5 in calcium chloride. A point to consider is that sensitivity to soil acidity depends on the variety. Several studies have been made of rustic varieties – which are prevalent in farms – such as SP70-1143; furthermore, micronutrients were not added in most liming trials, which may have limited the response to limestone (RAIJ, 2008; QUAGGIO, 2008). In some cases, limestone need may have been underestimated.

Roots do not develop well in soils with low subsurface calcium content, because calcium is poorly mobile in plant phloem; thus, it should be made available close to the root growth area. Liming may provide calcium to subsoil layers; in this case the dose of limestone should be higher than that calculated to neutralize acidity in the superficial layer.

Gypsum has been widely employed in sugarcane farming to raise subsoil (20-60 cm) calcium content and to decrease aluminum activity in soil solution; this improves the chemical environment for root development. Gypsum is also a source of sulfur; combining limestone and gypsum may yield better results for sugarcane crops than applying each one singly (MORELLI *et al*., 1987, 1992; PERNATTI, 1993). Limestone, which is less soluble than gypsum, is more effective in the superficial layer, while gypsum acts in the subsoil because of calcium sulphate mobility in soil solutions. Therefore, gypsum requirements are based on the chemical features of the subsurface soil layer (20 to 40 cm): gypsum application should be done whenever exchangeable calcium levels become lower than 4 $mmol_c$ dm^{-3} and aluminum saturation raises above 40%. Since there is no reference sulphate adsorption index, the dose of gypsum is calculated by taking into account the clay content in the 20 to 40 cm layer: gypsum, in t ha^{-1} = 6 x clay, in g kg^{-1} (RAIJ *et al*., 1997). SOUSA and LOBATO (2002) applied a 7.5 factor instead of 6 in the Cerrado region.

Liming and gypsum application are generally done when the sugarcane plantation is reformed. Given that soils tend to acidify with time due to nitrogen fertilizers and losses by leaching, soils may become excessively acid at the end of a cycle. Although response of sugarcane to liming is small, soil reacidification may decrease the yield and lower the lifetime of ratoons. To overcome this problem, QUAGGIO and RAIJ (2008) recommend reapplying limestone and gypsum in ratoons to raise the base saturation to 60% whenever the base saturation in the surface soil layer in ratoons becomes lower than 40% and soil analysis indicates a need for gypsum. RAIJ (2008) noted that several published reports have indicated responses to gypsum at higher doses than those currently recommended. This author, therefore, has suggested that subsoil fertility should also be taken into account, and that long-term studies should be carried out to investigate higher gypsum rates than those currently employed. The effects of an improved chemical environment for subsoil root growth as a result of combining liming and gypsum application may be interesting, especially in poor soils and in areas with dry winters, to which sugarcane crops tend to move.

Calcium silicates or calcium and magnesium silicates not only provide silicon but also correct soil acidity, and may eventually replace limestone in sugarcane crops. Replacing limestone with silicates is not always economically feasible because the latter are more expensive. Furthermore, ordinary silicates contain little magnesium, which may limit the use of these materials in soils lacking this element. On the other hand, there may be advantages in using silicates for sugarcane planted in silicon-deficient soils. Although this element is not a plant nutrient, several reports in the literature have shown beneficial effects when applying it to sugarcane crops (KORNDÖRFER, 2008). Large amount of accumulated silicon in sugarcane plants increase the thickness of cell walls and alter the plant architecture, raising the tolerance to certain disease and pests, and to drought and lodging. In several countries, application of silicon is recommended based on foliar analysis (KORNDÖRFER, 2008).

FERTILIZATION OF SUGARCANE

Nitrogen

Nitrogen is the most complex nutrient to manage in sugarcane fertilization, given its many interactions with soil organic matter (SOM) and several possible routes by which nitrogen may be lost in the soil-plant system. Mineralization of SOM – the main source of nitrogen for plants – depends not only on soil and SOM characteristics, but also on the climate, in particular rain and temperature, which are hard to predict. Thus, nitrogen is one of the few nutrients for which soil analysis is not taken into account for fertilizer recommendations; this increases the degree of uncertainty when defining nitrogen doses for sugarcane (CANTARELLA, 2007).

In quantity, nitrogen is the second mineral nutrient accumulated in sugarcane plants after potassium. The above-ground portion of the plant contains from 0.7 to 1.6 kg of nitrogen per ton of stalk; the whole plant shows a nitrogen requirement of 2.1 to 2.4 kg of nitrogen per ton of stalk (ORLANDO FILHO *et al*., 1980; TRIVELIN *et al*., 2002a; CANTARELLA *et al*., 2007). These numbers suggest that sugarcane extracts over 200 kg ha^{-1} of nitrogen to yield 100 t ha^{-1} of stalks, of which about 90 to 110 kg ha^{-1} are exported upon harvesting.

Generally, sugarcane plant recovery of nitrogen applied as a fertilizer is low, around 20 to 40% as shown in most studies done with ^{15}N (CHAPMAN *et al*., 1992; TRIVELIN *et al*., 1995, 2002b; GAVA *et al*., 2003; VITTI, 2003; AMBROSANO *et al*., 2005). These numbers are lower than those seen in grain crops (FRENEY *et al*., 1992; DOBERMANN, 2005). One of the reasons is that sugarcane has a long cycle, which allows it to exploit soils longer; additionally, fertilizers are applied at the beginning of growth cycles, and are subject to immobilization by SOM and/or losses. In fact, soil becomes the destination for much of the fertilizer nitrogen (20% to 40%), where it is incorporated into the nitrogen stock of SOM, as demonstrated in studies compiled by CANTARELLA *et al*. (2007).

A small percentage of accumulated nitrogen in sugarcane derives from nitrogen fertilizers – 15% to 20% in most studies with fertilizers marked with ^{15}N (SAMPAIO *et al*., 1984; TRIVELIN *et al*., 1995; GAVA *et al*., 2001b; 2003; BASANTA *et al*., 2002; AMBROSANO *et al*., 2005), suggesting that most of the absorbed nitrogen in sugarcane originates from the soil, from BNF, and to a lesser degree, from airborne solid depositions and rain, among others.

Sugarcane cultivation in Brazil is done using relatively small amounts of nitrogen fertilizers – 30 to 60 kg ha^{-1} of nitrogen in the plant cycle, and 60 to 120 kg ha^{-1} of nitrogen in ratoon crops (SPIRONELLO *et al*., 1997; PENATTI *et al*., 1997; CANTARELLA *et al*., 2007). Nitrogen rates are generally higher than 120 kg ha^{-1} and, in some cases, may reach 200 kg ha^{-1} N or more (DONZELLI, 2005; GARCIA *et al*., 2003; RICE *et al*., 2006).

The amount of nitrogen fertilizer applied in Brazilian sugarcane crops is generally equal to or lower than the amount exported with stalk harvesting and trash burning. Nevertheless, sugarcane has been cultivated continuously for decades – or even for over a century in certain regions – without yield loss, apparent soil degradation, or marked SOM depletion (BODDEY, 1995). In Brazil, this has been seen as indirect evidence that BNF has a relevant role in sugarcane nitrogen nutrition (URQUIAGA *et al*., 1992; BODDEY *et al*., 2003).

Since DOBEREINER'S (1961) pioneering work, isolating N_2-fixating bacteria in sugarcane roots, several diazotrophic bacteria have been associated with this crop, particularly those of the *Glucanoacetobacter*, *Herbaspirillum*, and *Burkholderia* genuses, which have been detected in sugarcane stalks, leaves, roots, and vascular system (BALDANI *et al*., 1997; REIS *et al*., 2004; CABALLERO-MELLADO *et al*., 2004; PERIN *et al*., 2006).

Diazotrophic bacteria may promote plant growth not necessarily associated with BNF, but with phytohormone production, increased plant enzyme activity, and pathogen control (JAMES, 1997; SEVILLA *et al*., 2001; PINON *et al*., 2002; MARQUES Jr. *et al*., 2008). URQUIAGA *et al*., (1992), however, using ^{15}N to measure nitrogen balance in long-term studies of sugarcane, have shown that 60% to 70% of accumulated nitrogen originated from BNF in some varieties. The amount of fixated nitrogen reached 170 to 210 kg ha^{-1} of nitrogen. However, the contribution of BNF in the majority of published studies has been below 30% of absorbed nitrogen, sometimes associated with specific sugarcane varieties (OLIVEIRA *et al*., 2002, 2003, and 2006). Surveys using the $\delta^{15}N$ technique in several countries have shown a BNF contribution ranging from 0% to 70%, with 30% as the mean value (YONEYAMA *et al*., 1992; POLIDORO *et al*., 2001).

Practical implications of BNF for sugarcane plant nutrition are controversial. It is thought that BNF contribution is relevant, albeit not constant, under Brazilian conditions. However, studies in Australia, South Africa, and Spain have suggested that BNF is not a significant source of nitrogen for sugarcane in those countries (BIGGS *et al*., 2002; THORBURN *et al*., 2003; HOEFSLOOT *et al*., 2005; TEJEDA *et al*., 2005), although nitrogen fixating bacteria have been found in fields (BIGGS *et al*., 2002; HOEFSLOOT *et al*., 2005).

There are several reasons why BNF may not work properly. Application of nitrogen fertilizers can cause a reduction in microorganism numbers and in the fixating capability of diazotrophic bacteria (FUENTES RAMIREZ *et al*., 1999; REIS *et al*., 2000; KENNEDY *et al*., 2004). BNF also decreases in the dry season (BODDEY *et al*., 2003), which usually occurs when most of the ratoons start growing in Southwest Brazil. Furthermore, interaction between diazotrophic bacteria and genotypes is relevant for successful BNF (URQUIAGA *et al*., 2003; MUNOZ-ROJAS, 2003; OLIVEIRA *et al*., 2006).

Inoculating diazotrophic bacteria in sugarcane plants has not been proven effective to raise BNF in field conditions because there already is an established diazotrophic bacteria community in sugarcane plantations. Furthermore, the production of an inoculant with diazotrophic bacteria for sugarcane has been hindered by the fact the several species and strains can fix N_2 from the atmosphere and it is not clear which one is the main contributor to NBF (BODDEY *et al*., 2003). Recent promising results have been obtained by inoculating a combination of five diazotrophic species rather than single species (OLIVEIRA *et al*., 2002, 2003, 2006; REIS *et al*., 2008), which opens the possibility of raising BNF in sugarcane. Additional studies are still required before recommending diazotrophic bacteria inoculation in field conditions. Partial replacement of nitrogen fertilizers may result in economic gains and an improved energy balance for producing ethanol from sugarcane.

The traditional sugarcane manual harvesting method after burning of trash is gradually being replaced by mechanical harvesting without setting fire to the crop (known as green cane) in order to reduce harvesting costs and to meet regulatory restrictions against plantation burning. Soils, therefore, now remain covered by a thick layer of trash containing from 6 to 18 t ha^{-1} of dry matter (mean 14 t ha^{-1} in the Central-Southern region). Trashing increases nutrient recycling, especially for nutrients that are volatized during burning, such as nitrogen and sulfur. The presence of trash implies in changing fertilizing practices, in particular for nitrogen. Trash makes it difficult to incorporate fertilizers into soil, a common practice for fertilizing ratoons after harvesting and burning. Nitrogen fertilizers applied over trash increases the risk of temporary nitrogen immobilization by microorganisms that decompose plant residues (HAYSON *et al*., 1990), and may result in significant nitrogen losses due to volatilization of NH_3 if urea – which represents 60% of nitrogen sources in the market – is employed. Losses of NH_3 may reach from 20% to 40% or more for nitrogen applied over sugarcane trash, according to some Brazilian studies (CANTARELLA *et al.*, 1999; VITTI *et al.*, 2002, COSTA *et al.*, 2003) and studies in other sugarcane producing countries (PRAMMANEE *et al.*, 1989; DENMEAD *et al.*, 1990; FRENEY *et al.*, 1992). Adding urease inhibitors to urea may decrease NH_3 losses, but the degree of loss depends also on factors such as the temperature, soil moisture, and rainfall (CANTARELLA *et al.*, 2008). CANTARELLA *et al.* (2007) and VITTI *et al.* (2008b) have described other possibilities for reducing NH_3 losses in sugarcane fertilization.

The need for altering nitrogen rates for sugarcane according to the presence of trash is not clear. Increased nitrogen recycling with trash may raise the stock of organic nitrogen in soils in the long term; however, studies in Brazil, Australia and South Africa have suggested that such changes are slow and usually restricted to soil depths of up to 10 cm (GRAHAM *et al.*, 1999, 2000, 2002; THORBURN *et al.*, 2000; LUCA, 2002). On the other hand, sugarcane takes up only 5% to 10% of the nitrogen present in the trash (40 to 80 kg ha^{-1} of nitrogen) in the season following trash deposition (NG KEE KWONG *et al.*, 1987; CHAPMAN *et al.*, 1992; GAVA *et al.*, 2003; VITTI *et al.*, 2008c).

In the short term, fertilizing nitrogen doses in unburnt harvested areas may be higher than in burnt areas because of nitrogen demand by microorganisms for breaking down trash, as well as higher stalk production due to increased water availability (OLIVEIRA *et al.*, 1994), although stalk yield may not always be higher in green cane areas (THORBURN *et al.*, 1999; GAVA *et al.*, 2001a; BASANTA *et al.*, 2003). Nitrogen in a soil-plant system must reach a new equilibrium in areas managed with surface trash, after which fertilizing nitrogen doses may decrease because of an increased stock and cycling of this nutrient in soil (MEIER *et al.*, 2002). THORBURN *et al.* (2002) used a simulation model and estimated that the sugarcane nitrogen response in Australia would only stabilize after 30 to 40 years. However, rainfall in the study area (950 mm a year) was lower than that in most sugarcane cultivated areas in Brazil.

As in Australia, there is no consensus in Brazil on nitrogen rate changes in green cane. However, nitrogen rates applied in areas not burnt during eight to ten years in several sugar mills in São Paulo state have decreased 20% or more. Detailed studies are required for calculating nitrogen fertilization in unburnt areas, given its economic and environmental implications.

Phosphorus, Potassium and Sulfur

Phosphorus takes part in complex physical-chemical soil reactions. It is strongly retained by iron and aluminum oxides in acid soils, and precipitates as calcium phosphate in alkaline soils. Therefore, the concentration of phosphorus in soil solutions is usually very low. The efficiency of phosphate fertilization is usually small in that generally 10% to 30% of applied phosphorus is absorbed by plants during their growth cycle; the remaining phosphorus is immobilized in soil, part of which may be used in subsequent cycles.

Most Brazilian soils are originally poor in phosphorus. Thus, sugarcane responses to applications of this element are high, especially in the plant cane cycle. The plant requirement ranges from 10 to 40 kg ha^{-1} of P_2O_5 for each 100 tons of cane, as compiled by ROSSETTO *et al.* (2008a). Phosphorus fertilizer is used in larger amount in Brazil compared to most of the other cane producers. The mean doses are 120 and 30 kg ha^{-1} of P_2O_5 for cane plant and cane ratoon crops, respectively (DONZELLI, 2007; ROSSETTO *et al.*, 2008a). Corresponding rates of P_2O_5, in kg ha^{-1} for plant and ratoon crop values are 58 and 57 in Australia(DONZELLI, 2007, HARTEMINK, 2008); 60 and 60 in Mexico, and 150 and 75 in Costa Rica, respectively (ROSSETTO *et al.*, 2008a).

Phosphate fertilization is recommended based on available P content in the soil. Phosphorus doses for plant cane range from 40 (for soils with a high phosphorus content) to 180 kg ha^{-1} of P_2O_5 for very low P soils (SPIRONELLO *et al.*, 1997) in São Paulo state. Research results show that in many cases, phosphorus applied at planting supplies P for the full cycle; little or no response is seen when this nutrient is applied to ratoons (BOLSANELLO *et al.*, 1993, KORNDÖRFER, 2004). Nevertheless, phosphorus fertilization of ratoons may increase the stalk yield in poorly or non-fertilized areas in the plant crop cycle (WEBER *et al.*, 2002) in soils with low levels of available phosphorus (VITTI, 2002) or when soil acidity increases across the years and decreases phosphorus availability (DEMATTÊ, 2005).

Recommended doses of phosphorus for ratoons in São Paulo state are much lower than those for plant crops: 30 kg ha^{-1} of P_2O_5 for soils with low or very low phosphorus content. Phosphate fertilizers are not indicated for soils with medium or high phosphorus content (SPIRONELLO *et al.*, 1997). Lower doses of phosphorus applied to ratoons reflect experimental data showing limited responses to phosphate fertilization after the first harvest. However, removal of 0.25 to 0.40 kg of P_2O_5 per ton of dry matter harvested may impoverish the soil across the crop cycle, as DEMATTÊ (2005) has shown, which underlines the importance of replacing at least part of the P exported in ratoons.

Highly water-soluble sources are indicated for applying phosphorus in planting furrows, as demonstrated in pioneer studies of ALVAREZ *et al.* (1965). Reactive phosphates and thermophosphates may partially or fully replace these sources of soluble phosphates in medium or high phosphorus content soils (CANTARELLA *et al.*, 2002; ROSSETTO *et al.*, 2002). These options may be advantageous in specific situations because reactive natural phosphates are inexpensive, and thermophosphates contain magnesium and micronutrients, besides silicon, which sugarcane absorbs in significant amounts.

In soils with low or very low phosphorus, which limit sugarcane production, high P fertilizer rates broadcast and incorporated into the soil (phosphatation) is an option for totally or partially substitute for the usual furrow application in order to rapidly raise soil fertility and increase yields (ROSSETTO *et al.*, 2002, VITTI, 2002). Low water-soluble phosphates are appropriate for phosphatation because the thorough mixture and increased contact with soil facilitate the solubility of these P sources (KORNDÖRFER, 2004).

Significant amounts of phosphorus may be recycled in sugarcane crops by using organic waste, which reduces the need for mineral fertilizers. Filter cake is produced in an average of 30 kg per ton of crushed cane and contains 1% to 3% phosphorus. Practically the entire cake filter produced in sugar mills is reused in agricultural areas in its natural state or by composting (COLETI *et al.*, 1986). For calculation purposes, 50% of phosphorus in filter cake is available for plants in the short term (SPIRONELLO *et al.*, 1997).

Potassium is the nutrient extracted in the highest amounts by sugarcane plants; therefore, significant responses to potassium fertilization are expected, especially in low K soils, as has been demonstrated in recent reviews by KORNDÖRFER and OLIVEIRA (2005) and ROSSETTO *et al.* (2008c).

Managing potassium fertilization is relatively easy compared to nitrogen and phosphate because potassium interacts less with soil mineral and organic components. Exchangeable potassium content in soil is a good indicator of potassium needs, and may be used as a parameter for fertilizer requirements together with expected yield, which is relevant for nutrients that accumulate significantly in plants (RAIJ, 1974; ORLANDO FILHO *et al.*, 1980, RAIJ *et al.*, 1997; KORNDÖRFER *et al.*, 1999, ROSSETTO *et al.*, 2004; 2008c). Recommended doses for the plant cane cycle for soils with very low potassium content (< 0.8 $mmol_c$ dm^{-3}) in São Paulo state range from 100 to 200 kg ha^{-1} of K_2O, depending on expected yield. Corresponding doses for soils with medium potassium content (1.6 to 3.0 $mmol_c$ dm^{-3}) are 40 to 80 kg ha^{-1}. Potassium fertilization is not recommended for soils containing over 6 $mmol_c$ dm^{-3}. Doses range from 30 to 150 kg ha^{-1} of K_2O in ratoon cycles as a function of nutrient availability in soils and yield goals (SPIRONELLO *et al.*, 1997). Medium potassium doses applied in sugarcane (plant cane and ratoons, respectively) in some countries are: 120 and 145 kg ha^{-1} of K_2O in Australia; 175 and 150 kg ha^{-1} of K_2O in Costa Rica (ROSSETTO *et al.*, 2008c). In Florida (US), doses range from 0 to 280 kg ha^{-1} of K_2O in plant crops to 0 to 170 kg ha^{-1} of K_2O in ratoons (RICE *et al.*, 2006); in Louisiana

(US), doses are lower, at 55 and 67 kg ha^{-1} of K_2O for plant and ratoon crops respectively (LEGENDRE, 2001), which reflects potassium supplies in different soils.

Potassium is usually applied once in the plant furrow or soon after harvesting, over ratoons, during the agricultural year. However, leaching losses may occur in low CEC sandy soils, especially in the plant cane cycle because of initial slow crop growth. Potassium fertilization may be split under such conditions. A further benefit of K splitting in soils with a sandy texture is to avoid damage to sprouting due to excess salt in the plantation furrow (KORNDÖRFER, 2005).

Potassium chloride is the most commonly used potassium source in sugarcane; its cost is lower compared to other potassium fertilizers, it is water-soluble, and the nutrient is readily available for plants. Vinasse is also an important source of potassium in ethanol-producing companies; significant amounts of nutrients may be recycled and mineral fertilizers can be replaced in parts of the area (see MUTTON *et al*, in this book). Vinasse is a byproduct of ethanol or cachaça fermentation and is generated in large amounts (between 800 and 199 L per ton of cane when ethanol is produced from cane juice or from molasses, respectively); it contains 0.8 to 3.8 g L^{-1} of K_2O (mean – 2.0 g L^{-1}), depending on the material used for fermentation (ROSSETTO *et al.*, 2008c). An application of 100 m^3 ha^{-1} yields from 80 to 380 kg ha^{-1} of K_2O generally more than enough to provide crop needs.

In São Paulo state, the State Environmental Agency (Companhia Tecnológica de Saneamento Ambiental or CETESB) defined the Technical Standard P4231 (2005) to regulate the dose of vinasse that can be applied to the fields. This is calculated such that the amount of exchangeable potassium in the 0 to 80 cm soil layer does not exceed 5% of the soil cation exchange capacity (CEC). In soils with this CEC saturation level, potassium provided by vinasse should be restricted to replacing the only the amount of K that the sugarcane plant has extracted, which is estimated at 185 kg ha^{-1} of K_2O (KORNDÖRFER, 2005).

Luxury potassium consumption – absorption of nutrients beyond the necessary amount for plant function – may occur in fertile soils or those fertilized with high doses of potassium or vinasse. In this case, accumulated potassium in sugarcane plants may reach values well beyond the mean values mentioned above: 0.77 to 2.32 kg of K_2O per ton of stalk. For example, FRANCO *et al.* (2008a,c) measured K uptake in plant cane grown in a high available K Dystrophic Red Latosol in Jabotiacabal, and found 589 kg ha^{-1} of K_2O in the above-ground parts and 659 kg ha^{-1} of K_2O in the whole plant – including its underground portion – at harvesting time, with a stalk yield of about de 146 t ha^{-1}.

High vinasse rates generally delay cane maturity by stimulating vegetative growth, which decreases the sucrose content in stalks (SILVA *et al.*, 1976; ORLANDO FILHO *et al.*, 1995), thus affecting raw material quality for industrialization. However, this effect appears not to be associated with excess potassium, but rather with excessive amount of other nutrients, such as nitrogen, or with organic matter in vinasse, since luxury potassium consumption generally does not affect sugar or sucrose concentration in syrup when provided as a mineral fertilizer (ORLANDO FILHO *et al.*, 1980; CHALITA, 1991). Luxury potassium absorption increases ash content, which negatively affects sugar crystallization, thus decreasing the industrial yield. On the other hand, ash may favorably affect ethanol production by serving as a source of nutrients for yeast (KORNDÖRFER, 2005).

Some distilleries have areas for occasionally dumping vinasse ("sacrifice" areas) when field application is not possible and that may accumulate high amounts of K. Excess soil potassium in such areas may be removed by cultivating sugarcane as long as the soil has not become saline or the extremely high K does not affect plant growth due to imbalances with other nutrients. Because of luxury potassium consumption, large amounts are absorbed from the soil and may be removed in cane stalks, which generally contain over half of the potassium content in the above-ground portion of plants, as the crop is harvested and K exported from the fields (ROSSETTO *et al.*, 2008c).

The amount of sulfur extracted by sugarcane is relatively small (0.2 to 0.5 kg per ton of stalk), depending on the variety, soil type and fertilization (RAIJ and CANTARELLA, 1997; COLETI *et al*., 2002; RAIJ *et al*., 2006; TASSO Jr. *et al*., 2007; ViTti *et al*., 2008a). Sulfur has been neglected in studies of sugarcane in Brazil. The effect of sulfur on sugarcane yield is often indirectly inferred in works aimed at investigating gypsum or fertilizing sources of nitrogen and phosphorus that contain sulfur (CANTARELLA *et al*., 2007). Several authors have suggested that sugarcane responses attributed to other elements in fertilizers, may be due to sulfur (VITTI *et al*., 1992). For example, VITTI *et al*. (1988), citing MALAVOLTA *et al*. (1982), have considered that part of stalk production variations from different sources of phosphorus were due to the presence or absence of sulfur in the fertilizer. Similarly, VITTI *et al*. (2005) have noted that sulfur-containing nitrogen sources (ammonium sulfate, liquid fertilizer containing vinasse) resulted in higher stalk yields compared to sulfur-free nitrogen sources (urea, ammonium nitrate), although the advantage of ammonium sulfate over urea may also have been due to lower NH_3 losses by volatilization. There may also be synergy between nitrogen and sulfur in plants. BOLOGNA-CAMPBELL (2007), in a study using ^{34}S, noted that nitrogen fertilization increased sulfur uptake by sugarcane. The opposite has also been observed. VITTI *et al*. (2005), in a study using ^{15}N, showed that nitrogen was used more efficiently in treatments containing ammonium sulfate compared with those containing urea, although the effect may be partially attributed to NH_3 losses, as mentioned above.

ESPIRONELLO *et al*. (1987) observed small responses to sulfur as a nutrient in 2- to 4-year long studies in four sites. Differences were significant in only one site, but there was a trend toward S response in all of them, which suggested that experimental errors may make small yield increments unnoticed when using sulfur.

Recommended sulfur rates for sugarcane are low. VITTI *et al*. (1992) suggest applying 30 kg ha^{-1} of sulfur for the cane plant crop and 15 kg ha^{-1} of sulfur per year for ratoons. For the whole cane cycle between 50 and 60 kg ha^{-1} of sulfur should suffice (VITTI, 2002; DEMATTÊ, 2005).

The frequent application of gypsum and residues of sugar and ethanol production, common in the southwest region in Brazil, probably can supply the S requirements of most sugarcane plantations. Nevertheless, S deficiencies may occur where gypsum is not applied or where organic residues are not returned to the fields, such as in areas distant from the mill or belonging to independent cane suppliers to the industry, or in sites fertilized with concentrated NPK formulations, especially in sugarcane plantations harvested after burning, in which part of the plant sulfur is lost to the atmosphere rather than recycled in the field (CANTARELLA *et al*., 2007; VITTI *et al*., 2008a).

Micronutrients

Micronutrient extraction by the sugarcane plant is relatively small, notwithstanding the large volume of plant material produced. The above-ground portion of the crop accumulates about 50 g of molybdenum, 500 g of boron, copper or zinc, from 1,000 to 4,000 g of manganese, and from 4,000 and 10,000 g of iron (ORLANDO FILHO, 1983; FRANCO *et al*., 2008c; MOURA FILHO *et al*., 2008) to yield 100 t of stalks.

Few studies on micronutrients in sugarcane have been published in Brazil. Responses to micronutrients in sugarcane have been infrequent, as shown in the pioneering work of ALVAREZ and WUTKE (1963), ESPIRONELO (1972), ALVAREZ *et al*. (1979), and others. Sugarcane is in fact thought to respond poorly to micronutrients, especially in the Southwest region, as demonstrated in reviews by ORLANDO FILHO *et al*. (2001) and MELLIS *et al*. (2008). It is also likely that many studies in which micronutrients had no effect on plants may not have been published.

Part of the reason for poor sugarcane responses to micronutrients is that for many years this crop was planted in the best soils of the Southwest region. Furthermore, organic residues from sugar mills and distilleries were recycled. Thus, micronutrient fertilization of sugarcane in this region has been infrequent. On the other hand, micronutrient deficiencies are known, especially of copper, zinc and boron in low-fertility soils on the coastal flat lands of the Northeastern region (MARINHO, 1981).

Increased stalk yields due to micronutrient applications have been reported sporadically in specific sites. Responses to boron were seen in studies by ALVAREZ and WUTKE (1963), Alvarez (1984), and in unpublished work cited by ORLANDO FILHO *et al*. (2001). MARINHO and ALBUQUERQUE (1981) and other authors have described responses to copper in São Paulo (ALVAREZ, 1984) and in sandy soils in the Northern area of Rio de Janeiro, São Paulo and Mato Grosso do Sul states (ORLANDO FILHO *et al*., 2001). AZEREDO and BOLSANELLO (1981) obtained increased stalk yields by adding 5 kg ha^{-1} of manganese in field trials in Rio de Janeiro, Espirito Santo, and Minas Gerais states. Other studies reporting responses to manganese have been conducted in the state of Pernambuco (ORLANDO FILHO *et al*., 2001). Zinc is the micronutrient for which favorable responses of sugarcane have been most frequently reported. MARINHO and ALBUQUERQUE (1981) found increased stalk yields in Northeastern Brazil, and ALVAREZ (1984), CAMBRIA *et al*. (1989) and ORLANDO FILHO *et al*. (2001) reported such increases in São Paulo and Mato Grosso do Sul. Recent studies showing responses to zinc applied in sugarcane plantations in the state of São Paulo include those by FRANCO *et al*. (2008c) and MELLIS.[1]

Molybdenum is the nutrient extracted in the smallest amounts by sugarcane and few studies with this element are available. ALVARES and WUTKE (1963) and ALVAREZ *et al*. (1979) found responses to molybdenum in trials carried in São Paulo many decades ago. MELLIS and ALVES[2] have recently shown increased cane yields by adding molybdenum. Soil depletion of Mo, increased yields obtained with new varieties and improved crop management and the larger nitrogen requirements associated it may explain these last results.

Favorable responses to iron are improbable in the acid Brazilian soils. Chloride is applied in large quantities with potassium and, thus, there are no reports of chloride deficiencies in sugarcane.

Many authors have associated sugarcane response to micronutrients with diagnosis of micronutrient by soil analysis. Critical, albeit preliminary, levels of micronutrient availability in soils have been suggested. Responses to copper fertilization are expected in soils with copper levels below 0.6 mg dm^{-3} (SANTOS, 1980) or 0.25 mg dm^{-3} (MARINHO, 1981) in soils (copper extracted by the Mehlich-1 solution). Copper in sugarcane is recommended in São Paulo with soil copper concentration below 0.2 mg dm^{-3} in DTPA extract (SPIRONELLO *et al*., 1997). MARINHO and ALBUQUERQUE (1981) have suggested a 0.5 mg dm^{-3} limit for zinc (Mehlich-1); this same limit is used in the state of São Paulo in DTPA extracts (SPIRONELLO *et al*., 1997). MALAVOLTA (1990), cited by ORLANDO FILHO *et al*. (2001), has suggested concentration limits for several sugarcane soil nutrients, defined in studies of various crops.

ORLANDO FILHO *et al*. (2001) compiled data in the literature about critical and adequate foliar concentration ranges for sugarcane micronutrients, although foliar analysis is little used in Brazilian sugarcane plantations because results vary widely.

Several experiments that reported low responses to micronutrients were conducted a long time ago; thus, micronutrient requirements for high yields needs to be reassessed. Long-term sugarcane extraction and export of these elements has impoverished soils in cultivated areas. On the other hand, new more productive and demanding sugarcane varieties have been introduced; furthermore this crop is being grown in poorer soils, where nutrient deficiencies are more likely to occur.

Small yield increases are not always considered as statistically significant; if consistent, however, they deserve attention. Thus the need for networked trials to establish more clearly the critical micronutrient levels in soils and leaves. Short-term or single crop studies may not be sufficient. FRANCO *et al*. (2008b), for example, ap-

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[1] MELLIS, E. V. **Instituto Agronômico**, Campinas, SP. Personal communication. Data from the ongoing micronutrient trial. Network in São Paulo state.

[2] ALVES, Bruno Rodrigues. **Embrapa Agrobiologia, Seropédica**, RJ, Personal communication.

plied zinc to plant cane and found increased yields only in the ratoons.

Recent results have suggested that molybdenum deserves further attention. Molybdenum has an important role in biological nitrogen fixation, and may be relevant for nitrogen fixing endophytic microorganisms in sugarcane.

ENVIRONMENTAL ASPECTS OF FERTILIZATION

Nitrogen and other nutrient losses to the environment

Volatilization of NH_3 may result in significant loss of fertilizer nitrogen – especially urea – as discussed above.

Contamination of underground and surface water by nitrates from nitrogen fertilizers has become an environmental issue in a few regions of the world; nitrates may compromise the quality of drinking water or result in eutrophication of lakes, estuaries and vast areas in seas (LAGREID *et al*., 1999; HOWARTH, 2006; SCAVIA, 2006). Available data has suggested that NO_3^- losses by leaching in sugarcane are negligible with current management practices (CANTARELLA *et al*., 2007); these losses may be relevant in other parts of the world where higher nitrogen doses are employed (PRASERTSAK *et al*., 2002).

Losses by denitrification produce mainly N_2 and N_2O. The assessment of such losses is done with great uncertainties because of methodological limitations. Losses due to denitrification are generally regarded as responsible for the non-accounted portion of N in ^{15}N-marked nitrogen balance studies of soil-plant systems, including experimental errors. These missing N values attributed to denitrification range from 10% to 30% of the fertilizer-applied N in sugarcane (CANTARELLA *et al*., 2007), but may be overestimated. Increased amount of trash in green cane areas may result in higher losses by denitrification.

From the environmental point of view, emissions of N_2O are the focus of global carbon balance regarding fertilizers because this gas destroys stratospheric ozone and its greenhouse effect is 296 times that of CO_2. Current IPCC estimates (2006) suggest that 1% of fertilizer nitrogen used in agriculture is converted into N_2O.

Ammonia and other nitrogen-containing gases may also be lost when biomass is burned; in addition, plants with excess ammonia nitrogen or senescing plants may lose NH_3 to the atmosphere (FARQUHAR *et al*., 1980; SCHJOERRING *et al*., 1998; TRIVELIN *et al*., 2002b).

Phosphorus is also often associated with surface water eutrophication. However, there have been few reports of excess phosphorus in sugarcane crops in Brazil, because tropical soils generally lack this nutrient and show great capacity to adsorb and retain it. Surface water contamination in these soils is mainly due to runoff erosion, since phosphorus does not move in depth. Phosphorus transportation resulting in runoff loss is uncommon because it P is mostly applied in plantation furrows, and little phosphorus is used on ratoons, where it is most likely to be surface-applied. Furthermore, soil conservation practices generally used in sugarcane plantations are relatively efficient for avoiding laminar flow. However, in lowlands and flood plain in Florida, US, eutrophication has been associated with P applied to sugarcane fields (HARTEMINK, 2008).

MUTTON *et al*. (in this book) discuss environmental issues due to vinasse.

Energy costs of fertilization are relevant when sugarcane is used for producing biofuels. Some authors have criticized the use of agriculture – including sugarcane – for producing biofuels, arguing that added environmental costs due to greenhouse gas emissions are higher than those resulting from burning gasoline (FIELD *et al*., 2007; SCHARLEMANN, 2008). CRUTZEN *et al*. (2008) have recently stated that N_2O released from soils and nitrogen fertilizers for the production of biofuels could offset the benefits derived from the reduction of CO_2 emissions by replacing fossil fuels with biofuels, although in the case of sugarcane, the authors concluded that there could be a small environmental gain. However, other studies indicate that the energy balance sugarcane ethanol produced in Brazil is positive because 8 to 9 energy units are made available for each unit of fossil fuel used for producing ethanol; this ratio could increase as agricultural and industrial processes are improved (MACEDO *et al*., 2008; BODDEY *et al*., 2008).

Nitrogen fertilizers made of natural gas or other oil feedstock require much energy: about 53.8 MJ per kilogram of nitrogen, or about 1,400 m^3 of natural gas per ton of nitrogen. BODDEY *et al*. (2008) calculated that about 25% of the energy cost of field operations for producing sugarcane – including inputs, labor, machines and transportation – are due to the use of nitrogen fertilizers, notwithstanding the low dose of nitrogen: 56.7 kg ha^{-1} nitrogen. This suggests that the reduction or the rational use of nitrogen could improve the energy balance in ethanol production.

Sugarcane residues recycling

An important point is that part of the fertilizers used for sugarcane may be replaced by agricultural residues generated in the sugar and alcohol industry. Exported products – especially sucrose and ethanol – consist of carbon, hydrogen, and oxygen, so that the mineral nutrients for producing sugarcane can be at least partially recovered and recycled in agriculture. Improved means of recovering and recycling of vinasse, ash, boiler ash and filter cake, added to practices that avoid burning of sugarcane plantations, may improve the efficiency of the system for managing nutrients, with evident economic and environmental benefits.

Research challenges and needs

Topics that require further study in the context of sugarcane fertilization for ethanol production include:

a) Improving the subsoil chemical environment, especially in areas with prolonged dry seasons.
b) Long term management of sugarcane nitrogen fertilization in the presence of trash.
c) The potential of BNF for sugarcane.
d) Assessing the energy-environment balance in sugarcane fertilization, especially in the release of greenhouse gases.
e) Improving nutrient recycling in the sugar and ethanol industry.

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10

AGRICULTURAL USE OF STILLAGE

Miguel Angelo Mutton, Raffaella Rossetto and
Márcia Justino Rossini Mutton

INTRODUCTION

Stillage is a liquid residue from the distillation of wine, resulting from alcoholic fermentation of cane juice, molasses, or a mix of both, to obtain alcohol. It has a high biochemical oxygen demand (BOD), and includes several soil borne chemical elements absorbed by sugarcane. Among them, stillage is rich in potassium and sulfur, containing sizeable amounts of phosphorus, nitrogen, calcium, magnesium, and micronutrients. Each liter of alcohol generates about 10 to 15 liters of stillage.

Due to its high polluting power, its disposal was a problem for industries. Concern about its environmental impact is ancient. There are reports of high fish mortality when stillage was directly dumped in rivers, in the 1950s. Due to its organic nature, and the absence of contaminants, metals, or other undesirable compounds, it lead to the idea of using it on soil, however its pH being extremely acid, some care had to be taken. The first studies on applying stillage on soil were carried out by Professor Jaime Rocha de Almeida's team in the 1950s, at Esalq/USP, in Piracicaba, São Paulo. However, the concern regarding environmental impacts and continuous high fish mortality resulting from stillage disposal in rivers led to Decree-Law n. 303, of February 28th, 1967, which definitively ban on the discharge of such residue to rivers, lakes and water courses.

After this Decree was passed, the first solution found was to apply stillage on the so-called *sacrifice areas*, adjacent to distilleries, which suffered from receiving large quantities of this residue for several years in a row. These areas were rendered useless for agriculture, mostly due to the high salinity of the soil, turning it barren and difficult to remedy.

As Proalcool came up, with the consequent expansion of the sugar-alcohol industry in Brazil, there was a significant increase in the production of alcohol, and consequently of stillage, which in the 2008/2009 harvest season reached about 350 billion liters of stillage. Figure 1 shows the evolution of alcohol production and stillage generation over the years.

Currently applying stillage on sugarcane plantations, like fertiirrigation, is a widespread practice among Brazilian mills and distilleries. However, the technology for the agricultural use of stillage as a fertilizer in growing sugarcane was wholly developed in Brazil, as no other country generates such a huge volume of this kind of residue.

Generally stillage promotes improvements in the agricultural yield of sugarcane, as well as chemical, biological, and physical benefits to the soil, in addition to savings in fertilizer costs.

On the other hand, if overused, it can cause serious changes to the quality of the industrial raw material, such as lower technical quality of the juice.

Though significant technical breakthroughs have been documented advocating the use of this residue, several issues are still being discussed, particularly those related to the environment, as well as other potential uses.

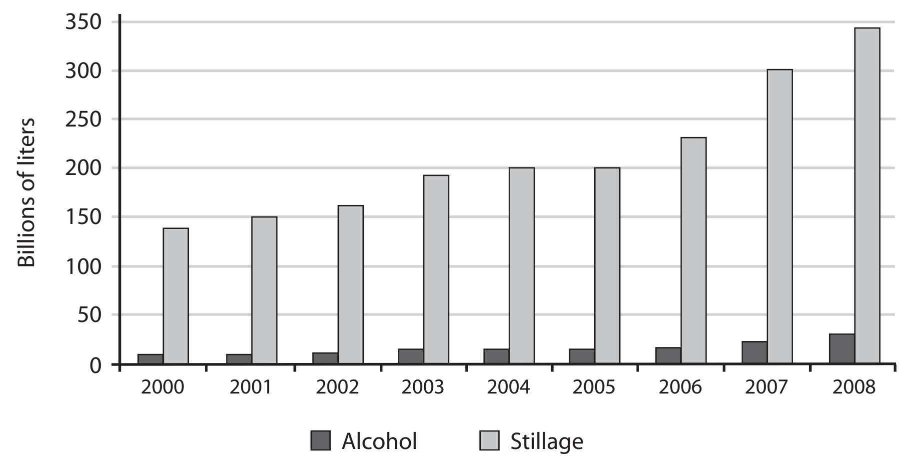

FIGURE 1 Evolution of ethanol and stillage production over the years.

COMPOSITION OF STILLAGE

Stillage composition varies considerably with several factors, among them the type of mash used in fermentation. When sugarcane juice mash is used, the resulting stillage is always less concentrated than the one resulting from molasses or mixed mash (Table 1). Furthermore, the stillage concentration varies from one mill to another, and in one same mill there are variations over the harvest period, resulting from milling different varieties, maturation, soils, yields, among other parameters. Table 2 shows maximum, average, and minimum data for the physicochemical characterization of stillage, as determined by ELIA NETO and NAKAHODO (1995), in São Paulo state production units.

Stillage is an effluent rich in organic matter (mostly as organic acids) and, in lesser quantities, in minerals, featuring high potassium content and significant levels of calcium, magnesium, and sulfur. Being a suspension of mineral and organic solids, stillage has high chemical oxygen demand (COD) and biochemical oxygen demand (BOD), from which its high polluting potential stems from, in addition to low pH and high corrosivety.

The occurrence of heavy metals in stillage results from the sugarcane's own composition, as these are essential nutrients for the plant; they may come from corrosion or abrasive wear of metallic equipments; or entry may also take place via inputs such as lime and sulfur. Table 3 shows the results obtained by BARBOSA (2007), regarding heavy metals content in stillage from Companhia Energética Santa Elisa (Sertãozinho, São Paulo). Reference levels used were taken from the Environmental Protection Agency – EPA (USA), whose regulations dated 1982 (CARVALHO, 2001). Considering the normal yearly intake of the residue, it can be ascertained that all elements are within acceptable limits, hence in quantities supposedly not sufficient to reach hazard levels.

EFFECTS OF STILLAGE IN THE PLANT AND ON THE SOIL

According to MAGRO (2007), until the early 1970s, some production units did the distribution by gravity, on grooves, sometimes flooding the areas.

High doses, around 500 to 2,000 m^3/ha^{-1}, were initially prescribed. GLÓRIA (1975) and GLÓRIA and MAGRO (1976) in innovative papers developed at Usina da Pedra, São Paulo, studied closely stillage composition over two harvests. They discussed more rational ways for its use, considering its chemical composition, and application as a fertilizer, in addition to soil and cultivation conditions.

TABLE 1 Chemical composition of stillage from molasses mash, mixed mash, and juice mash, according to different authors.

Element	Molasses mash			Mixed mash			Juice mash		
	Concentrations			Concentrations			Concentrations		
	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
N (kg/m^3)	0.57	0.77	1.18	0.33	0.46	0.70	0.25	0.28	0.35
P_2O_5 (kg/m^3)	0.10	0.19	0.34	0.09	0.24	0.61	0.09	0.20	0.49
K_2O (kg/m^3)	5.08	6.00	7.87	2.18	3.06	4.59	1.15	1.47	1.94
CaO(kg/m^3)	1.85	2.45	3.64	0.57	1.18	1.72	0.13	0.46	0.76
MgO(kg/m^3)	0.98	1.04	1.40	0.33	0.53	0.66	0.21	0.29	0.41
SO_4 (kg/m^3)	1.05	3.73	6.40	1.60	2.67	3.74	0.61	1.32	2.03
Mat. org. (kg/m^3)	37.30	52.04	63.94	19.10	32.63	45.10	15.30	23.44	34.70
Fe (ppm)	52	80	120	47	78	130	45	69	110
Cu (ppm)	3	5	9	2	21	57	1	7	18
Zn (ppm)	3	3	4	3	19	50	2	2	3
Mn (ppm)	6	8	11	5	6	6	5	7	10
pH	4.2	4.4	4.9	3.6	4.1	4.6	3.5	3.7	4.3

Source: GLÓRIA and ORLANDO FILHO (1983).

These studies were conclusive by using low volume stillage of up to 35 m^3/ha, totaling 300 kg K_2O/ha^{-1}, revolutionizing the prevailing thought, and prescribing up to 1,000 m^3/ha^{-1}.

In those places deemed sacrifice areas, receiving large quantities of stillage, as much as 10,000 m^3/ha^{-1} or more, there was a heavy salts concentration, easily noticeable by the sugarcane having low resistance to hydric deficits, when planting it in these areas was attempted. FERREIRA (1980) evaluated incremental stillage doses (0, 200, 400, 800, 1200, and 1,600 m^3/ha^{-1}) applied to samples of three soils: Alluvial (51% clay), red-yellow Podsol (38% clay), and hydromorphic (5.5% clay). Using electric conductivity tests, the author ascertained that the hydromorphic soil reached 4.0 mmhos. cm^{-1}, above which the soil is considered saline with doses between 400 and 800 m^3/ha^{-1} of stillage; Podsol required 1,200 m^3/ha^{-1} to reach the saline level, and alluvial – due to its higher clay content – failed to reach that level with any of the doses. For the average stillage doses normally used by mills, around 150 m^3/ha^{-1} with 2 to 3 kg K_2O/m^{-3} content, such saline effect was not observed.

Being a strongly acid liquid residue, it was believed that, when applied to soil, its effect would be to raise acidity; however, ALMEIDA *et al.* (1950) demonstrated precisely otherwise. Results obtained revealed that during the 15 days immediately after applying stillage there was indeed an increase in soil acidity, which tapered off gradually, due to the intense bacterial activity resulting from the addition of organic matter present in stillage.

Studies carried out by LEAL *et al.* (1983) confirmed that after stillage was applied, the soil pH indicated acidification as a result of the addition of organic matter to the soil, which, under aerobic conditions promotes oxidation of the organic carbon, which gives electrons to O_2, generating the O^{2-} ion. This ion, either for its strong alkaline character or due to the presence of the H+ ion, consumes the acidity-generating ions. Another

TABLE 2 Physicochemical characteristics of stillage (average of 64 samples from 28 mills in the São Paulo state).

Stillage character	Concentrations			Standard
	Min.	Avg.	Max.	g or ml L^{-1} álcohol
pH	3.50	4.15	4.9	
Temperature (ºC)	65	89.16	110.5	
Biochemical Oxygen Demand – BOD_5 (mg L^{-1})	6,680	16,949.76	75,330	175.13 g
Chemical Oxygen Demand – COD (mg L^{-1})	9,200	28,450	97,400	297.6 g
Total solids – TS (mg L^{-1})	10,780	25,154.61	38,680	268.9 g
Total suspended solids – TSS (mg L^{-1})	260	3,966.84	9,500	45.71 g
Fixed suspended solids – FSS (mg L^{-1})	40	294.38	1,500	2.69 g
Volatile suspended solids – VSS (mg L^{-1})	40	3,632.16	9,070	43.02 g
Total dissolved solids – TDS (mg L^{-1})	1509	18,420.06	33,680	223.19 g
Volatile dissolved solids – VDS (mg L^{-1})	588	6,579.58	15,000	77.98 g
Fixed dissolved solids – FDS (mg L^{-1})	921	11,872.36	24,020	145.21 g
Sedimentable residues – SR – 1 hora (mg L^{-1})	0.2	2.29	20	24.81 ml
Calcium (mg L^{-1} CaO)	71	515.25	1,096	5.38 g
Chloride (mg L^{-1} Cl)	480	1,218.91	2,300	12.91 g
Copper (mg L^{-1} CuO)	0.5	1.2	3	0.01 g
Iron (mg L^{-1} Fe_2O_3)	2	25.17	200	0.27 g
Total phosphorus (mg L^{-1} P_2O_5)	18	60.41	188	0.65 g
Magnesium (mg L^{-1} MgO)	97	225.64	456	2.39 g
Manganese (mg L^{-1} MnO)	1	4.82	12	0.05 g
Nitrogen (mg L^{-1} N)	90	356.63	885	3.84 g
Ammoniacal nitrogen (mg L^{-1} N)	1	10.94	65	0.12 g
Total potassium (mg L^{-1} K_2O)	814	2,034.89	3,852	21.21 g
Sodium (mg L^{-1} Na)	8	51.55	220	0.56 g
Sulfate (mg L^{-1} SO_4)	790	1,537.66	2,800	16.17 g
Sulfite (mg L^{-1} SO_4)	5	35.9	153	0.37 g
Zinc (mg L^{-1} ZnO)	0.7	1.7	4.6	0.02 g
Ethanol-CG (ml L^{-1})	0.1	0.88	119	9.1 ml
Glycerol (ml L^{-1})	2.6	5.89	25	62.1 ml
Yeast (dry base) (ml L^{-1})	114.01	403.56	1,500.15	44.1 g

Source: ELIA NETO and NAKAHODO (1995).

possible reaction is the compounding of Al^{+3} and organic anions present in stillage. With the multiplication of microorganisms and organic matter transformation, mostly the N, with the reduction of nitrate to nitrite, consumption of H^+ ions is observed and, consequently, pH rises. According to RODELLA *et al*. (1983), effects of rising pH in the soil may be temporary, as there is a trend to resume original values after a certain time.

By the colloidal character of the organic matter contained in stillage, its addition to the soil confers to it a larger quantity of negative charges, reducing cation lixiviation, and consequently increasing cationic exchange capacity – CEC

(GLÓRIA, 1983). CEC increases due to the large input of organic matter represented by the addition of stillage.

Application of stillage increases K content of the soil by successive applications (ROSSETTO *et al.*, 2008). PENATTI (1999a) evaluated the application of increasing doses of stillage (0, 100, 200, and 300 $m^3.ha^{-1}$) on clayous soil (red latosol) during 4 harvests with dose reapplications on the same place, and ascertained that potassium content in the soil increased as a result of applying the stillage doses, mainly in the most superficial layers at 0-250 mm and 250-500 mm depth. K content increased up to 0.10 m depth with the largest stillage studied doses (200 and 300 $m^3.ha^{-1}$).

As a result, the economic benefits derived from complete or partial replacement of chemical fertilization became evident. Organic matter content in stillage also contributed in improving the physicochemical characteristics of soils, increasing its fertility and the productivity threshold in many sugarcane cultivated soils.

Several authors studied the effect of stillage on soils and, over time, concluded that: stillage increases pH in soils (MATIAZZO, 1985); increases CEC; supplies and increases availability of some nutrients; improves soil structure; increases water retention; enhances biologic activity, promoting a large number of small animals (earthworms, beetles etc.), bacteria, and fungi.

Stillage, when applied in proper doses for sugarcane nutrition, using the potassium fertilization recommendation, does not cause any salinization or ion lixiviation problems that may compromise the environment. Soil enrichment occurs in the 0-200 mm (soil surface) and 200-400 mm (soil sub-surface) layers. Occasional negative effects caused to soils or plants resulted from overdoses, according to FERREIRA and MONTEIRO (1987); LEME *et al.* (1987), CAMARGO *et al.* (1983), and GLÓRIA and ORLANDO FILHO (1983).

It should be pointed out that stillage used in fertiirrigation promotes considerable gains in sugarcane productivity, saving money, as most of the potassium-bearing fertilizers are imported. Furthermore, using this residue in agriculture represents a significant contribution for recycling nutrients, with a consequent environmental gain.

Stillage, in addition to improving the soil chemical properties, also improves the soil's physical conditions, as it brings in organic matter. Therefore it contributes to a better soil aggregation, improved water holding, as well as soil conservation. From this standpoint, it offers more environmental gains than losses. Nevertheless, care should be taken so that overdoses on very sandy soils, with waterbeds close to the surface, don not incur in environmental pollution risks, considering especially nitrates and chlorides that may be carried with potassium which, after lixiviation, may reach the water bed. In the state of São Paulo, Cetesb directive (P. 4231/2005), that regulates the use of stillage and sets maximum doses to be applied, represents a significant step towards its safe use within environmental standards; however, it should be constantly reevaluated and improved.

It is important to remember the organic character of this residue, for example, organic agriculture agencies certify that stillage is a wholly accepted in organic and green-seal sugar (ROSSETTO, 2008).

TABLE 3 Quantities of heavy metals found in stillage, application rates used, and a conformity sign relative to annual limits recommended by Usepa – U. S. Environmental Protection Agency.

Element	Annual limit (USEPA $kg.ha^{-1}.year^{-1}$	Stillage 200 $m^3.ha^{-1}$		
		Content $mg.dm^{-3}$	Dose $kg.ha^{-1}$	Signal
Arsenic	2.000	0.001	0.000	Yes
Cadmium	1.900	0.010	0.002	Yes
Chromium	150.000	0.010	0.002	Yes
Copper	75.000	0.530	0.106	Yes
Lead	15.000	0.010	0.002	Yes
Mercury	0.850	0.003	0.001	Yes
Molybdenum	0.900	n/a	n/a	–
Nickel	21.000	0.212	0.042	Yes
Selenium	5.000	n/a	n/a	–
Zinc	140.000	0.050	0.010	Yes

n/a = not ascertained.

The positive effect of stillage in sugarcane productivity has been reported by many researchers in practically all varieties, in most different soil and climate conditions, and it is visible in business areas (PENATTI, 2000). Stillage has raised the productivity threshold in many soils, either by the addition of organic matter or by the nutrients it bears. According to PENATTI (2007), continuous use of stillage has increased productivity in cultivation, and in comparison with areas using mineral fertilization, as much as 10 tons of stalks per hectare in each harvest. Positive effects on the sugarcane fields should also be considered. In some dryer regions, the water contained in this residue promotes ratoon sprouting, and thus may be considered as rescuing fertirrigation.

Stillage is obviously not a complete fertilizer, providing all sugarcane needs, so many researchers studied how, when, and with what type of stillage should be supplemented. For example, ratoons need stillage supplemented with nitrogen.

In spite of its high agricultural value, reflected in the increased sugarcane productivity, the negative effect of high stillage doses on the raw material for producing sugar was evidenced. SILVA *et al.* (1976) researched 16 sugarcane varieties planted with and without stillage irrigation, using a dose of 100 m^3/ha^{-1}, about 590 kg/ha^{-1} of K_2O. Their findings showed that the addition of stillage to the soil, especially with high potassium content, delayed maturation, lowered sucrose and fiber content, and promoted ash accumulation in the juice, impairing raw material quality. It should be observed that potassium in excess is absorbed by the plant (luxury absorption), settling mainly in the core and the leaves, interfering with the industrial juice cleansing process, especially when sugar production is intended.

REGULATIONS ON STILLAGE DISPOSAL

For a long time agriculture has been using the most varied kinds of residue from human activities and, due to its intensive use and the quantities employed, like in the case of stillage, environmental safety concerns have been increasing (ABREU JR. *et al.*, 2005). In Brazil, there are no specific laws on using agro-industrial residue in agriculture; however, compliance is required to several laws and decrees, such as:

- Decree n. 24 643, of 07/10/1934, Code of Waters, protecting all water bodies from pollutant discharge.
- Law n. 4 771, of 09/15/1965, Forestal (Forestry) Code, that sets the minimum tree coverage and strip width for riparian forests.
- Decree-Law n. 1 413, of 08/14/1975, rules on control of the environmental pollution caused by industrial activities.
- Decree n. 8 468, of 09/8/1976, approved the regulation of Law n. 997, of 5/31/1976, which established the pollution control in waters, air, residue, standards, requirements, licensing, penalties.
- Law n. 997, of 5/31/1976, ruling on environmental pollution control.
- Ministry of Internal Affairs Directive n. 323, of 11/29/1978, forbidding direct or indirect release of stillage to surface water springs, and demands submission of projects for treating and/or using stillage.
- Ministry of Internal Affairs Directive n. 124, of 8/20/1980, established standards relative to water pollution prevention, industry locations, potentially polluting buildings or structures, and protection devices.
- Ministry of Internal Affairs Directive n. 158, of 11/3/1980, extending the previous directive to encompass residual waters and other distillery liquid effluents.
- Conama Resolution n. 0002, of 06/5/1984, determining the execution of studies and projects to control pollution from effluents of alcohol distilleries.
- Conama Resolution n. 0001, of 01/23/1986, which made Environmental Impact Assessment, and Environmental Impact Report mandatory for any new units or expansion of the existing ones.
- Law n. 6 134, of 06/2/1988, determining that "liquid, solid, or gaseous residue from agricultural, industrial, commercial or any

other activities may only be conveyed or disposed of in a way that will not pollute underground waters".

- Law n. 6 171, of 07/4/1988, ruling on the use, conservation, and preservation of agricultural soil.
- Law n. 7 641/91 allowed the irrigation or fertiirrigation of the soil using organic origin industrial effluents, as long as it is evidenced that its chemical characteristics confer high biodegradability to the soil, not having the presence of metallic organic compounds.
- Decree n. 32 955, of 06/7/1991, regulated Law n. 6 134, of 06/2/1988, ruling on the preservation of natural underground water beds.
- Decree n. 41 719, of 04/16/1997, regulating Law n. 6 171, of 07/4/1988, ruling on the use, conservation, and preservation of agricultural soil.
- Law n. 9 605, of 02/12/1998, determining administrative and penal sanctions for actions and activities that are harmful to the environment.
- Cetesb Decision n. 023/00/C/E, of 06/15/2000, approving the procedure for action in contaminated areas, based on the document titled "Procedure for Contaminated Areas Management".
- Resolution CNRH n. 15, of 06/1/2001, setting guidelines for integrated management of surface, underground, and rain waters.
- Cetesb Management Decision n. 014/01/E, of 07/26/2001, approving the Report on Reference Values for Soils and Underground Waters in the São Paulo state, and the implementation of reference values by Cetesb.
- Resolution Conama n. 357, of 03/17/2005, establishing, among other guidelines, conditions and patterns for effluents disposal.
- In 2005, Cetesb, by means of Technical Norm P4.231, imposed further control on the use of stillage on agricultural soil in the São Paulo state.

STILLAGE DOSE TO BE APPLIED

The dose to be used considers a sufficient supply of potassium for the ratoon cycle. As sugarcane takes in luxury amounts of potassium, it is possible that, in many areas, stillage will add surplus potassium.

Stillage is prescribed in accordance to soil analysis for K and its contents in stillage, just as if it were a chemical fertilizer. For the São Paulo state, Cetesb directive P.4231/2005 determines that the dose of stillage to be applied to soils be calculated according to the equation:

$$\text{m}^3 \text{ of stillage.ha}^{-1} = [(0.05 \text{ x CEC} - \text{ks}) \text{ x } 3744 + 185] / \text{kvi}$$

Where:

0.05 = 5% of CEC

CEC = cationic exchange capacity, expressed in $\text{cmol}_c.\text{dm}^3$ at pH 7.0, given by the soil fertility analysis, carried out by a soil analysis laboratory using the methodology from the Soil Analysis department of the Campinas Institute of Agronomy, duly signed by a technical expert.

ks = concentration of potassium in the soil, expressed in $\text{cmol}_c.\text{dm}^3$, at 0,80 meters deep, given by the soil fertility analysis of the Campinas Institute of Agronomy, duly signed by a technical expert.

3744 = constant to convert the fertility analysis results expressed in $\text{cmol}_c.\text{dm}^3$ or meq.100cm^3 into kg of potassium in a volume of one hectare at 0.80 meters depth.

185 = kg of K_2O extracted by the culture per ha, per harvest.

kvi = potassium concentration in the stillage, expressed in kg of $K_2O.m^3$, as shown on an analytic test report, signed by a technical expert.

Despite the formula, it should be considered that scientific research will indicate the need for adjusting the calculation of the maximum dose to be recommended as restrictive for some soils, mostly those in the Western region of the São Paulo state, the main expansion area of the agribusiness. Some situations may become overly permissive, surpassing by far the doses deemed ideal for adequate plantation nutrition and fertilization.

Stillage provides a remarkable contribution in replacing potassium fertilizer. Considering that currently mineral fertilization in sugarcane is about 120 kg of $K_2O.ha^{-1}$, and that approximately 40% of the cultivated area receives stillage as potassium fertilization, more than 500,000 tons of potassium chloride (KCl) are saved. This procedure represents a sizeable contribution to recycling and using potassium.

STILLAGE HANDLING FOR OPTIMIZED PRODUCTION

Despite being a nutrient-rich organic material, stillage is not a complete or balanced fertilizer. For this reason, several studies focused on the need of supplementing it with other important nutrients for sugarcane productivity, mostly nitrogen. PENATTI *et al*. (1988), upon evaluating the application of stillage in the doses of 0, 50, 100, and 150 $m^3.ha^{-1}$ and nitrogen in the doses of 0, 50, 100, and 150 $kg.ha^{-1}$ on sandy soil (red-yellow latosol) and clayous soil (red latosol), ascertained that stillage caused productivity increases up to the dose of 150 $m^3.ha^{-1}$ for both soils, response having been higher in the sandy soil. Response for nitrogenated supplement occurred for doses up to 100 $m^3.ha^{-1}$ of stillage. As sugarcane response was linear up to the dose of 150 $m^3.ha^{-1}$, PENATTI and FORTI (1997) assessed the effects of applying higher stillage doses: 0, 100, 200, and 300 $m^3.ha^{-1}$ of stillage and/or 0, 50, 100, and 150 $kg.ha^{-1}$ of nitrogen on ratoons harvested with and without burning straw. Average potassium (K_2O) content in stillage was 2.4 kg m^3. There was significant response for stillage and/or nitrogen. With reapplication of stillage in later ratoons, PENATTI (1999b) ascertained that in red-yellow, sandy, and low-fertility latosol, application of stillage promoted an increase in sugarcane productivity ($t.ha^{-1}$) up to the 300 $m^3.ha^{-1}$ dose, if compared to mineral fertilization. There was further increase in productivity when stillage was supplemented with nitrogen. The average results of three harvests from the four experiments also indicate a productivity increase up to 300 $m^3.ha^{-1}$ of stillage. Nitrogen supplementation promoted a productivity increase up to the 200 $m^3.ha^{-1}$ dose of stillage. The need for supplementing stillage with N and P was also studied by MAGRO and GLÓRIA (1977).

Nitrogen supplementation of stillage is still an issue to be studied further. Many mills do not do it in the belief that the response in productivity from nitrogen supplementing is not rewarding. Nitrogen complementation effects also have to be studied further regarding environmental concerns, as nitrates and other anions may be lost in the profile and reach the water bed.

CONCENTRATED AND BIODIGESTED STILLAGE

In addition to natural stillage as a fertilizer, several other options were predicted, such as those suggested by CAMHI (1979): (a) stillage concentration by evaporation, or (b) drying for animal feeding; (c) aerobic fermentation by microorganisms to produce unicellular protein; (d) anaerobic fermentation using methanogenic bacteria to produce methane (biogas). Furthermore, stillage may also be used to produce the so-called stillage soil to make bricks (ROLIM, 1996). It may also be used for burning to recover potassium salts and produce energy (FREIRE, 2000).

Recovery of the organic compounds present in stillage may be done by the concentration process, through multiple effect evaporators, to obtain by-products that may be used as fertilizers (40% ds), animal feed (60% ds) or 60% ds for boiler fuel. In this case, the product has concentration levels that may vary from 35° to 60° Brix.

The first works related to concentration date back to 1950. Among the evaporators used, the falling film type was the most frequently prescribed for liquids having a high content of incrusting salts, to save electric power. They can withstand stillage up to 25° Brix, requiring hydrocyclones for sludge removal and more frequent cleaning.

According to ALBERS (2007), in 1978 Usina Santa Elisa bought a stillage concentrator with Vogelbusch technology, which is still in operation, and that was designed to partially concentrate the stillage produced, to make feasible transporting it to more remote locations. Due to its high energy cost, it started operating regularly after the implementation of an electricity co-generation system; in 2005/2006 it produced about 3.3 $m^3.h^{-1}$ of concentrated stillage. To apply the concentrated stillage, a tanker truck was developed with a pressure pump and an arm large enough for application to 7 sugarcane rows. It applied concentrated stillage in the 2005/2006 harvest over approximately 5,000 ha (BARBOSA, 2006).

According to ALBERS (2007), another technology available for concentrating stillage (Vogelbusch in partnership with Dedini S.A. Indústria de Base) is stillage concentration energy-wise integrated with the distillery. In this case, the alcohol vapor from the top of the rectification column will condense in the body of the first effect of stillage evaporation, and return to the normal distillation process to ensure the qualities of the hydrated ethanol produced.

Using this solution, will avoid an additional vapor consumption to concentrate about 55% of the stillage produced. As a large quantity of water is removed from stillage, when the evaporation is performed, the condensed liquid may be reused in other mill processes, such as return to fermentation to dilute the honey, to drench the mill, among others, reducing water intake from rivers and contributing to recycle water in the system.

Stillage water may also be recovered for industrial re-use. Recent technologies strive to transform up to 80% of the liquid part of stillage in distilled water, reducing water treatment costs, and promoting its reuse. At the same time, it would make it possible to produce pelletized or granulated potassium fertilizer (JORNAL CANA, 2004).

In the next few years it is expected to attain higher efficiency in the ethanol production process from the development of new technologies and/or equipment. It is worth noting the search for osmophlic yeasts, able to consume substrates with higher sugar content, producing wines with higher alcoholic grade, leading to lower stillage production per liter of alcohol, and thus reducing the impact from generating this residue. In order to have a proper fermentation process, temperature control has to be improved in a lower range than usual, to minimize the toxic effect alcohol has on yeasts. Care should also be taken to get more stability in honey/juice proportions in composing mash for fermentation, resulting from stable milling, stable juice quality, i.e. a better raw materials in the process.

Another important point to be considered, according to ALBERS (2007), is to indirectly heat the exhaust column, which receives the wine from fermentation, in addition to exhausting the phlegmass. In indirect heating, the steam used to heat the column is generated by its own base, with the heat from the external steam source, not incorporating this condensed steam to the stillage. In this sense, the falling film (Vogelbusch) system, which accepts smaller temperature gaps, is a more recent option, using the exhaust steam and vegetal steam, recovering condensed liquid to route it back to the boiler. Using such procedure, stillage volume is reduced to 2 to 4 liters per liter of ethanol. Likewise, to reduce the quantity of stillage, it is common to separate phlegmass; this is done when there is a column to exhaust it, in order to prevent the loss of ethanol at the rectification column base. Using this additional column, the partially exhausted phlegm is not returned to the wine exhausting column. There are different uses for the phlegmass removed from this column, as it is basically composed of clean hot water, which can be used to wash fermenters (or fermentation tanks) and heat exchangers. Using such technology, stillage volume is reduced to 2 to 2.5 liters per liter of ethanol.

There are other processes for concentrating stillage, like the one used by the Indian company Praj, which adopts the fluidized bed drying process. The high energetic cost in electricity to concentrate stillage, regardless of the process, is still its major objection.

According to BARBOSA *et al.* (2006), currently, due to the high cost of transportation, areas located close to industrial plants receive high stillage application doses, which represents fertilizer waste, in addition to the risk of contaminating soil and waters. In this scenario, concentrated stillage, due to its reduced volume, becomes a way to make viable its transportation and use in places farther away from industries. A test carried out using combinations of three doses of ammonium nitrate (0, 45, and 90 kg.ha^{-1} of nitrogen), with three doses of potassium chloride (0, 90, 180, kg.ha^{-1} of K_2O), and three doses of concentrated stillage (0, 180, and 270 kg.ha^{-1} of K_2O), whose composition is shown on Table 4, indicated that the use of this product resulted in increased sugarcane and sugar productivity per harvested area unit. Authors ascertained that it is possible to replace, with gain, the use of mineral fertilizers with equivalent doses of NK, or with nitrogen supplementation. Analyzing chemical alterations in an incubated soil with doses of 300 and 750 kg.ha^{-1} of K_2O, using natural, concentrated and dry stillage, CAMARGO *et al*. (1984) observed a rise in pH after 60 days, soil electric conductivity having failed to reach levels hazardous to plants.

Stillage biodigestion is a process that achieves BDO load reduction to a level between 70% and 90%, producing around 0.3 to 0.5 m^3.kg^{-1} of methane gas, using anaerobic reactors, while according to FREIRE and CORTEZ (2000), it is still a little studied and utilized alternative. The resulting stillage, duly normalized, presents the desired physicochemical balance (Table 5), so it can be distributed to agriculture.

This process allows a more efficient use of mineral elements of the soil, by adding or supplementing nutrients such as: nitrogen, phosphorus, and potassium, calcium, and magnesium; on top of contributing to the correction of soil acidity. PERES (2007) pointed out that biodigested stillage is a good fertilizer for sugarcane culture, still including a portion of organic matter, in addition to preserving potassium content. Treated stillage provides better environmental quality by reducing organic matter, thus eliminating its peculiar odor, in addition to avoiding insect population that occur in such environment.

It should be pointed out that new environmental and energetic issues will arise from mills/distilleries that will process sugarcane juice fermentation with hydrolyzed cellulose (bagasse, trash). Likewise, it should also be considered that stillage produced in this process will have different characteristics, observing the possible differentiation aspects. In this case, plants that will adopt bagasse hydrolysis will need additional energy input, which may be obtained from biogas, as part of the bagasse will be routed to ethanol production.

TABLE 4 Composition of natural stillage and concentrated stillage produced by Cia. Energética Santa Elisa.

Components	Natural stillage	Concentrated stillage
	kg.m^{-3}	
Soluble solids	45.00	416.00
Total N	0.64	5.85
P_2O_5	0.37	3.47
K_2O	4.50	40.75
CaO	0.72	6.69
MgO	0.24	2.21
SO_4	0.25	2.43

Source: BARBOSA *et al.* (2006).

TECHNOLOGY FOR STILLAGE APPLICATION

According to MAGRO (2007), until the early 1970s, some mills distributed stillage by gravity on grooves, which could be considered as irrigation by flood, or by infiltration grooves. One main line carried stillage to distribution channels, and from these it went to the planting grooves either by flooding or using PVC pipes with outlets to

TABLE 5 Physicochemical characteristics of natural and biodigested stillage.

Components	Natural stillage	Biodigested stillage
pH	4.0	6.9
COD (g/L)	29	9
Total N (mg/L)	550	600
N ammoniacal N (mg/L)	40	220
Total P (mg/L)	17	32
Sulfate (mg/L)	450	32
Potassium (mg/L)	1,400	1,400

each groove. This required a slope between 0.2% and 0.5%. Grooves were dug on the sugarcane interlines (ROSSETTO, 1987). This system was very difficult and inefficient, as stillage application resulted very irregular.

In the early 1970s, pioneer research carried out at Usina da Pedra (Serrana, São Paulo), under the coordination of Prof. Dr. Nadir Almeida da Glória, evaluated stillage composition over 2 harvests and the recommended dose, which was up to 1,000 $m^3.ha^{-1}$. They contributed to the prescription of using low volumes, which made possible the distribution via tanker trucks taking up to 8,000 liters each, being the tanks made of wood and distribution by shower.

Using higher power trucks, tank capacity was increased to 15,000 liters, made of stainless steel, carbon steel, marine carbon steel. Later, tanks were made of fiberglass.

By late 1970s, conventional semi-fixed (low-range) sprinklers began to be replaced with hydraulic cannon systems mounted directly on motor-pump assemblies, drawing water directly from the channels. Next, stillage distribution using this system had some improvements, placing the sprayer cannon on pipe extensions. These systems allowed for better control on the doses applied.

According to MAGRO (2007), since the 1990s tank capacity was increased up to 40,000 liters, for trucks fitted with very high power. Distribution on the field began to be made with take-up reels, a breakthrough for applying stillage. Spraying was carried out by a self-propelled unit with medium-density polyethylene piping, which allowed more automation, better operating efficiency, more efficiency, lower labor demand, and a smaller number of equipment changes and transportation (LEME *et al.*, 1987). It is worth noting that the tanker truck had restrictions, mostly in terms of soil compaction, difficult application in rainy days, and application over large distances, which did not happen with application by spraying with the hydraulic cannon, which became the most widely used system.

Considering that the leading system is still spraying, according to SOUSA (2007), in certain cases trucks have been adapted to the self-propelled system with two tanks and bottom-loading. The advantage of this system is in the transportation to smaller and segmented areas, as well as when it is necessary to go through third-party properties, which cannot be done with channels. The downside of this system is transportation during rainy seasons, as well as the higher operating cost, especially for distances over 35 km from the mill.

Then, pressurized main lines with removable pipes began to be used, to reduce the quantity of channels, or the truck circulation in the area. Some recent proposals consider distribution by spraying from a central pivot, a towable linear pivot, and surface dripping. The first would result in improved irrigation-borne fertilization quality, as compared to self-propelled and directly mounted systems, however it involves higher implementation costs and requires equipment resistant to stillage corrosion. For fertiirrigation, the most adequate option seems to be the towable pivot, though technical and economical feasibility must be assessed. Surface dripping also has a high implementation cost.

There are also two situations that remain, as of today: natural or water-diluted stillage application with other effluents from mills (sugarcane washing water, condensation water, barimetric column water, floor washing water etc., generally known as wastewater).

Stillage, initially stored in decantation ponds or sacrifice areas, began to be stored in buffer tanks, using large storage facilities, up to 4-6 milling days. These tanks became source of undesirable odor. After Cetesb Directive P4231/2005, those tanks became buffers for storing milling hours, no longer days, minimizing odor release, which is highly desirable for the communities close to the milling areas (CARVALHO, 2007).

Among all alternatives introduced for using stillage, the one offering highest economical benefits and efficiency from the agricultural standpoint, and that therefore became widespread and adopted by most mills, was sugarcane plantation fertiirrigation. Though widely used in the industry, the expression fertiirrigation is not proper, since it fails to comprise irrigation in the sense of controlling water beds and the frequency this would be required. In the case of stillage, it refers to applying liquid residue, which also wets the soil (FREIRE, 2000).

Spraying with a winding spool, according to HERNANDEZ (2006), in spite of requiring less initial investment – if compared to other irrigation systems, is the one presenting highest operating costs.

In a survey among 54 mills, 25 of them in the São Paulo state, representing 22.5% of the sugarcane milled in Brazil, NUNES JR. *et al.* (2005) determined that stillage is preferably distributed by channels and applied by spraying with a take-up spool system (Tables 6 and 7).

Share analysis of the various stillage application systems in the São Paulo state, carried out by SOUSA (2007), showed that conventional tanker truck still represent 6%, other spray systems 94%; 10% of still being the directly-mounted cannon; 53% with self-propelled plus groove; and 31% with truck plus self-propelled (spool). According to LUZ (2007), the transportation and distribution system may comprise: tank, channel, pipe network, and truck, employing these methods for application: spraying, direct mount, take-up spool, irrigation rod, towable pivot, in addition to local application by dripping.

According to CARVALHO (2007), there are still other application models using fixed input lines and distribution channels, or a system comprising tanker trucks for transporting and movable input pipe, which may be considered adequate and economically viable, since the cost of the trucks system is approximately 50% higher.

TABLE 6 Distribution of stillage in various Brazilian regions during the 2003/2004 harvest seasons.

Region	Distribution of stillage (%)	
	Channels	Truck
São Paulo	76.6	23.4
Center-South	80.9	19.1
Northeast/East	100	0
Brazil	82.5	17.5

Source: NUNES JR. *et al.* (2005).

The application of concentrated stillage, with 40% solids content, is feasible at distances of 100-120 km, according to research by BARBOSA (2006), at Usina Santa Elisa (Sertãozinho, São Paulo).

Stillage-conducting channels coating is required by Cetesb Directive n. 4231/2005-Cetesb, and it may be done with asphalt lining, or HDPE (high density polyethylene) lining or pipes. Among these, CARVALHO (2007) pointed out channel piping, with 350 mm diameter PVC pipes, and with 1:1000 slope, which provides flow rates of 250 to 270 $m^3.h^{-1}$. In this case, though the initial investment may be somewhat higher than HDPE lining, there are operational and environmental advantages, such as less odor, insect propagation, and weed control, as well as lower risk of wild animals falling into channels, and vandalism in puncturing liners. On the short term, by subscribing to the agro-environmental agreement with the São Paulo state government, 100% of the cultivated sugarcane will be harvested without burning. In this case, the open channel, even if lined, will become a collector of trash, resulting in a clogged system. In this context, attention must be paid to the predefined changes.

Another important issue refers to stillage feed piping automation, regarding both security and operational safety. According to CARVALHO (2007), there are systems monitored by radio-frequency systems, placed at strategic points, such as pumping stations, waterways crossings, and end of lines. These systems provide leak detection, and information and control on stillage line pressure, temperature and flow rate. This automation aspect is important, as it allows full flow control on the network, making it possible to distribute stillage directly from the mill's integrated operation control center.

USE OF STILLAGE AND ENVIRONMENTAL ISSUES

The continuous use of stillage on the same soil, even with small doses, one year after another, may cause cation saturation, mostly potassium in soil CEC, resulting in problems from lixiviation of its components to underground waters.

TABLE 7 Ways of applying stillage in various Brazilian regions during the 2003/2004 harvest season.

	Spray		Truck	
	Direct mount	Take-up spool	On the field	With spool
São Paulo	6.7	69.9	9.9	13.5
Center-South	24.0	56.9	9.2	9.9
Northeast/East	100	0	0	0
Brazil	30.3	52.2	8.4	9.1

Source: NUNES JR. *et al.* (2005).

Potassium lixiviation to the sub-surface is not an environmental issue, as this element is not a water pollutant. Nevertheless, its high concentration favors the formation of chemical compounds which, having neutral charge, are easily lixiviated. The (K)+ and (NO_3)complex formed is a specific concern from the environmental stance, as nitrate is a major water pollutant.

In the São Paulo state, Directive P4.231/2005 (Cetesb) regulated criteria and procedures for applying stillage, implementing standards for its storage, transportation, and disposal on the soil. That norm being effective, many areas will undergo restrictions, as industry is preparing to transport stillage over longer distances, and/or making other uses viable, such as its concentration.

Though there are some signals of ions from stillage in water beds, such as Cl^{-1}, $SO4^{-2}$, water bed contamination from the use of stillage in doses currently employed on fertiirrigation over sugarcane trash may be a remote possibility, limited to certain conditions, such as marginal, sandy, or shallow soils. If it occurs, it is likely that the contamination process will take too long to be detected. However the simple potential of this possibility justifies caution.

For deep clayous soils, there is a thick layer for adsorbing potassium. CUNHA *et al.* (1987) studied lixiviates from a soil where 800 $m^3.ha^{-1}$ of stillage had been applied. Assessments detected no K+ movement below 40 cm depth in the soil. As sugarcane, especially ratoons, has a very deep root system, K intake may occur even if it is lixiviated to deeper layers. ORLANDO FILHO *et al.* (1995) studied NO_3- and NH_4+ in sandy soil, applying mineral nitrogen (60 $kg.ha^{-1}$) and doses of stillage (0, 150, 300, and 600 $m^3.ha^{-1}$). Results from four sampling periods and at three soil depths (up to 2 m) showed that there was no nitrogen lixiviation up to 25 weeks after application.

CRUZ *et al.* (1990) reported results from a long-term study on the influence of stillage applied at a dose of 300 $m^3.ha^{-1}.year^{-1}$ on soil properties (up to 1.5 m deep) and subsurface waters. The experiment assessed periods comprising 0, 5, 10, and up to 15 years, ascertaining an improvement on soil fertility properties over the years. Increments in organic matter and P contents were observed in the superficial layer, while for Ca, Mg, and S it was detected both in superficial and deeper layers. Nitrate was found in sub-surface waters, however in concentration levels below those hazardous to human health.

GLOEDEN *et al.* (1990) evaluated the influence of applying stillage at 150 and 300 m^3/ha doses on low CEC sandy soils, on soil fertility and ion lixiviation to water beds. They ascertained that the water had an increase of ions: chloride, ammonia, organic carbon, and forms of organic nitrogen. K remained seized in the soil and was absorbed by sugarcane, not reaching waterbeds during the study period. However the authors alert to the fact that organic forms of N were actually found, and that these might have generated nitrates, very detrimental to human health.

It is important to keep in mind that stillage is an organic source material, free from metals or other contaminants that could prevent its use in agriculture. From this standpoint, it is perfectly accepted by organic agriculture, and there are no restrictions to its use as a source of nutrients, according to certifying agencies. Stillage will represent an important source of K to be considered in organic agriculture. For producing organic sugar, stillage may provide all N, and all K sugarcane requires (ROSSETTO, 2008).

STILLAGE AND AGRIBUSINESS SUSTAINABILITY

ALTIERI (1989) notes that traditional agriculture simplifies agroecosystems, decomposition is altered, since the plant is harvested, and fertility is preserved, not by recycling but through fertilizers instead, depending on continuous human intervention; and recommends using production methods that restore homeostatic devices, optimize the return rate, and recycle organic matter and nutrients. On the other hand, it is worth observing that the use of fertilizers is important to increase fertility, and, hence, the production of biomass.

According to GOMES *et al*. (2000), the principle of ecosystems' sustainability is in ODUM's (1971) statement: "The longer elements can be maintained within an area, and used by successive generations of microorganisms, the smaller the losses will be, therefore the need to replace these elements from external sources will be lower." The operation of ecosystems is based on circulating nutrients between the different compartments, the cycle of these elements spanning over several generations, made up of phases with live organisms (bio) and lifeless phases (geo). This statement serves as grounds for harvesting trash without burning, and using agribusiness residue in agriculture, from the biogeochemical cycle management standpoint for the sustainability of sugarcane production. Burning causes the release of elements to the atmosphere, either by volatilization or by carrying away non-volatile particles; yet, the ashes laid on the ground, in the absence of trash, will be easily carried away by water and lost from the ecosystem. On the other hand, the return of residues from industrial processing of sugarcane to agriculture is absolutely necessary, to minimize the use of external sources for fertilizers.

According to SIQUEIRA and FRANCO (1988), organic residues are important components of natural ecosystems and agro-ecosystems. They represent a large quantity of reduced carbon, an immense repository of mineral nutrients, important for heterotrophic organisms that live in the soil, as well as mineral nutrients for plants. The biologic activity of soils, which is dominated by decomposing organisms, transforms them into a huge biologic incinerator; a decomposing machine driven by the microorganisms proliferating within itself, and that, through their various activities, control the carbon and essential nourishing elements' flow and cycling.

The growth of sugarcane cultivation, driven by global demand for renewable energy, is causing sustainability concern. Witnin this context, BARBOSA (2007) developed a research showing a systemic view of the sugarcane agro-industrial process, from the biogeochemical cycles stance, with the recycling of residues and effluents. It comprised models of the ways and strategies for using residues and effluents for N, P, K, Ca, Mg, and S, in the various compartments of the production process. The author set and discussed certain indicators (fertilization index, return index, and emission index), that allowed for analyses of nutrients flow in the agro-industrial system. In the scenario analyzed, it was found that the quantities of potassium, calcium, and magnesium in circulation were sufficient for fertilizing the culture with adequate quantities, while nitrogen, phosphorus, and sulfur were insufficient, requiring external supplementation. Therefore, the conclusion was that modern sugarcane agro-industry is conceptually very favorable to sustainability, being the use of residues and effluents, especially stillage, extremely important to reach such condition.

TECHNOLOGICAL BOTTLENECKS AND REQUIREMENTS

Technological bottlenecks are restrictions that limit activities related to new products and processes, as well as improvements to existing products and processes, on top of aspects such as management, information, and logistics; they can be understood as a current, potential, or future inhibitor, preventing a more proper development of the production system. These are critical points that, if overcome, will significantly contribute to the industry development.

Considering the agricultural use of stillage, the following technological bottlenecks stand out:

- Weaknesses in the development and/or adaptation of industrial processes aiming to reduce the volume of stillage.
- Weaknesses in the development of new products related to storage, distribution, and application of stillage produced, or that may be produced such as concentrated or biodigested stillage.
- Gaps in characterization and on the effects of stillage to be produced by new cellulosic materials fermentation processes.
- Gaps in the knowledge and needs of altering/adapting facilities and production processes.
- Gaps resulting from governmental regulation.
- Gaps in environmental management.
- Weaknesses in monitoring stillage handling systems in different soil/climate conditions.
- Gaps in institutional support and in strengthening basic research.
- Gaps in human resources training and development.
- Weaknesses in alternative possibilities for using stillage.
- Gaps in the participative involvement of the production industry, and in research for design, planning, and implementation of public policies.
- Circumstantial gaps.

Requirements are represented by the need for new knowledge, research and technology development, aiming to reduce the impact of the restrictions identified in the generation and use of stillage in the various parts of the sugarcane agro-industrial production system, aiming to improve the quality of its processes and products, production efficiency, competitiveness, and sustainability.

FINAL CONSIDERATIONS

Reports from the 1970s by the present Companhia de Tecnologia de Saneamento Ambiental (Cetesb-SP) pointed out at the sugar-alcohol industry as a major source of environmental pollution, both qualitative and quantitatively, because of its liquid residues, especially stillage, which were poured directly to rivers.

Ever since, the techno-scientific knowledge amassed has been used to guide towards a more rational and economical use of stillage, as well as less aggressive to the environment, seeking sustainability for the sugar-alcohol industry. However it is known that a lot has yet to be researched and developed to attain such objectives more completely.

The agricultural use of stillage produced by the sugarcane industry has undergone several changes over the years. Together with the concern for higher agronomical efficiency and the optimization in using this residue, a worldwide heightened environmental awareness – developed after the 1990s – should be highlighted. This reality behooved the industry to get organized before the new problems arising from the use of large quantities of this residue on soils, capable of causing problems, such as lixiviation of chemical elements, and their consequent conveyance to underground waters and aquifer pollution.

The use of stillage over decades represented productivity gains in the culture, in improving physical and chemical properties of soils, promoted recycling of nutrients and savings in inputs and money for the country, representing environmental gains for the production chain. Under this scope, Cetesb Directive P. 4231/2005 represented some considerable progress by establishing parameters that shall guide technical procedures for handling this residue, aiming to minimize the impact on the environment.

Brazil is the country that holds the technology for using stillage in agriculture, based on techno-scientific knowledge developed over the past 30 years. Nevertheless, basic research and technical, economic, social, and environmental viability studies are still missing to characterize impacts and/or guide other ways of using stillage, such as concentrated stillage, biodigestion, incineration etc. There are many parameters to be considered to understand what takes place in the soil and in the plant when concentrated/biodigested stillage is applied. A similar situation occurs regarding reutilization of water evaporated in the industrial process, reducing external sourcing. There is also a lack of information that validate the production and use of dry or pelletized stillage as animal food and fertilizer.

In this context, it is noticeable that current procedures for handling and monitoring stillage – from technical, economic, social and environmental stances – are partially adequate, requiring more detailed and extended studies, under different edaphic-climatic conditions that are sufficient to determine its distribution and application systems, and its use under even lower risks.

On the other hand, the ethanol production technology development from cellulosic materials, surplus bagasse, or trash remaining from sugarcane harvesting without burning, or even from whole sugarcane (stalks and leaves), will produce stillage that may have physicochemical characteristics different from the current one. This should determine additional research to ascertain the possible impacts caused on the soil, culture, and environment. Consequently, distilleries adopting this process will need additional energy inputs, which may be obtained from biogas and/or burning residue, as part of the bagasse will be led to ethanol production.

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11

BIOLOGICAL CONTROL OF PESTS AS A KEY COMPONENT FOR SUSTAINABLE SUGARCANE PRODUCTION

José Roberto Postali Parra, Paulo Sérgio Machado Botelho and *Alexandre de Sene Pinto*

INTRODUCTION

Although Brazil is the leading producer of sugar and alcohol in the world, with a production of 31.3 mm tons of sugar and 27.7 mm cubic meters of ethanol in 2008/2009 (MAPA, 2009), these values could be still higher if it wasn't for insect pest attack on different parts of the cane plant, including seed pieces or setts, roots, stalk base, stalk and leaves, causing significant losses in yield.

Various cane pests are dealt with in books (GUAGLIUMI, 1972/1973; MENDONÇA, 1996), with GALLO *et al*. (2002) describing 24 of the most important species in Brazil.

It is interesting to point out that although there are regional peculiarities, the main pests are controlled by biological alternatives, whether by insects or pathogens (ALVES; LOPES, 2008; PARRA *et al*., 2002). Therefore, sugarcane is one of the few crops in Brazil where sustainability has been practiced since the 1970s (GALLO, 1980).

Biological control (BC) is intensively used to control the main pests, including the sugarcane borer, *Diatraea saccharalis*, principally in the Southeast and the froghopper, *Mahanarva posticata*, in Northeast Brazil. In the case of the sugarcane borer, an imported parasitoid, *Cotesia flavipes,* is used, which is currently liberated in around 1,700,000 hectares through one of the most unique BC programs in the world (POTTING, 1996) due to its efficiency and the area covered (PARRA, 2008, personal communication).

Similarly, biological control has been used for the control of froghoppers for many years, including the leaf froghopper, *M. posticata,* in the Northeast. Today in Brazil, the green muscardine fungus, *Metarhizium anisopliae*, is applied on around 1 million hectares to control the root froghopper, *M. fimbriolata*, a recent problem in sugarcane in the Southeast (ALVES; LOPES, 2008).

Therefore, with the perspectives of a doubling of the area planted with sugarcane in the near future, there is a worry that with the opening up of new areas, sustainable crop production will not be respected and chemical products (particularly by aerial spraying) will be applied indiscriminately. This may cause disastrous secondary outbreaks and the appearance of "new pests" which would make the maintenance of those measures adopted almost 50 years ago more difficult.

The objective of the present paper is to show the perspectives for using BC to control the main pests in modern sugarcane production; and what research needs to be done so that alternative control measures become a key component for producing sustainable sugarcane.

FACTORS WHICH CAN ALTER THE SUGARCANE ENTOMOFAUNA

Harvesting

The "raw cane", that is, cane harvested mechanically without being burnt beforehand, is a reality today, but despite the environmental advantages of this practice it does alter the plant micro-climate and favor certain pests. This is the case of the root froghopper, *M. frimbriolata*, which, together with the sugarcane borer, *D.*

saccharalis, are the most important pests in São Paulo state (MENDONÇA, 2005; GARCIA *et al*., 2006; 2007a, b). The same thing occurs with the sugarcane weevil, *Sphenophorus levis*, studied since the 1980s (DEGASPARI *et al*., 1987) and which had been restricted to the Piracicaba region until a short time ago, but currently can be found in a 100 towns in São Paulo and even extends into Minas Gerais state.

The problem caused by *S. levis* increases in areas which are harvested mechanically due to the increase in cane trash deposited on the soil, increasing the availability of shelter for the insect and making its control difficult. On the other hand, such conditions can favor microbial control. However, in the light of present knowledge, control of this pest is very difficult (PINTO *et al*., 2006). Nests of leaf-cutting ants are also more difficult to locate where cane trash is deposited on the soil surface.

Quarantine problems

The exchange of seedlings can result in the appearance of new problems. This occurred recently with the registration of *Telchin licus* in São Paulo. This insect, known as the giant sugarcane borer, was restricted to the Northeastern states and limited by the river São Francisco. Observed in June-July 2007 in São Paulo, it will probably become a significant problem due to its size, long life cycle, the damage it causes and by the absence of any control measures.

Secondary outbreaks

The systematic application of certain chemical products to control leaf-cutting ants (*Atta* spp.) and even other foliage pests, has killed off predators, especially ants, so that pests which were not a problem have become one. An example is *Hyponeuma taltula*, the hairy borer, which is already considered the main pest in some regions of Brazil. The population levels of other common caterpillars in sugarcane, such as *Spodoptera frugiperda*, *Pseudaletia sequax* etc., are able to increase and cause considerable damage in such secondary outbreaks.

Cultivation systems

In no-till situations, the burrower bug, *Scaptocoris* spp., has increased its importance, aggravated by the fact that there are no efficient control methods for this subterranean pest (FERNANDES *et al*., 2004).

Soil characteristics

Pests such as subterranean termites (especially *Heterotermes tenuis*), the lesser cornstalk borer, *Elasmopalpus lignosellus* (VIANA, 2004) and *Migdolus fryanus* (BENTO *et al*., 1995) occur more in sandy soils.

The problems with subterranean termites increased after the prohibition of organochlorine products, which were applied together with fertilizers at planting, and today, these termites are controlled almost exclusively with modern synthetic chemicals whose residues are still little studied.

E. lignosellus is more important in areas with sandy soils and in the savannah regions (“cerrados”), occurring mainly in dry-climate years or when there are summer droughts. It occurs less in areas of “raw cane”.

M. fryanus, which is present in 100,000 hectares in São Paulo state, has a unique biology and is principally controlled with insecticides, which means the application of a quantity of agrochemicals which is incompatible with environmental conservation and sustainability. This situation should drive the development of research for changes in control.

DAMAGE CAUSED

The damage caused has only been quantified for some pests. Many of them, such as *T. licus*, *S. levis*, and *M. fryanus*, can, when they occur, cause significant damage although such damage has, in general, not been quantified up to now.

Sugarcane borer, *D. saccharalis*

The sugarcane borer is the pest for which there is most bioecological information in sugarcane (PARRA *et al*., 1988; MÉLO; PARRA, 1988;

PARRA; MIHSFELDT, 1992; PARRA, 1993; PARRA *et al.*, 1999).

Since the 1950s, there has been an exhaustive series of similar types of studies on the damage caused and it was concluded that, on average, the sugarcane borer caused considerable damage: each 1% infestation resulted in losses of 0.42% of sugar or 0.21% of alcohol and a 1.14% weight loss.

The damage is greater in plant cane, which grows more vigorously, independent of the variety. The soil preparation for plant cane also eliminates the natural enemies which maintain the pest population in equilibrium (BOTELHO; MACEDO, 2002).

Damage can be direct (dead vascular tissue, aerial rooting, lateral shoots, weight loss, stem breakage) and indirect (caused by the fungi *Colletotrichum falcatum* and *Fusarium moniliforme*). The red-rot, in the case of indirect damage, inverts the sucrose level thereby lowering sugar production and the fungi and other microorganisms compete with the yeasts in the fermentation of the alcohol.

There have been times, such as in the 1980s, when infestations reached 10% in São Paulo state, with yearly losses of US$ 100 mm due to pest attack.Today, with new varieties which are richer in sucrose, an increase in planted area and an inadequate control of the pest, the mean infestation level may reach higher levels than those registered in the 1980s, if there is no investment in the production of beneficial and the training of labor to implement the correct field control measures.

Froghopper

Leaf froghopper, Mahanarva posticata

The adults suck sap from those cells on the periphery of the parenchyma and reduce photosynthesis. As a consequence of this constant sucking, maturation is delayed, the internodes are atrophied and there is a reduction in stem sucrose which affects the quality of the juice and agricultural and industrial yields.

The adults are toxigenic and on introducing the toxins, formed by a complex of enzymes and oxidizing amino acids, cause alterations in the cellular tissue of the area affected. The extent of the chlorosis causing the leaf "burning" depends on the number of "bites" and the physiological state of the sugarcane. The nymphs perforate and contaminate the roots, which stops water and nutrient uptake and causes the plant to produce new roots. They cause plant malnutrition and dehydration during the rainy period (when froghoppers occur). This continuous sucking by nymphs can result in the same damage caused by the adults. The damage caused by nymphs and adults in big infestations can cause yield losses of 17% in sugar production in the Brazil's Northeastern region.

Root froghopper, Mahanarva fimbriolata

Research on this pest has been facilitated by recent studies on its biology, fertility life table and breeding techniques by GARCIA *et al.* (2006) and GARCIA *et al.* (2007b).

The adults cause a "burning" of the sugarcane on injecting the toxins into the leaves and also reduce plant photosynthesis. The nymphs cause a "physiological disturbance" due to the bites which affect the root tracheae, resulting in their deterioration and making the water and nutrient flow more difficult due to the dehydration of the phloem and xylem. They insert the stylets into the epidermis, which pass through the cortex and reach the vascular cylinder, feeding on the contents of the perforated tube of the primary phloem. The adults of *M. fimbriolata*, introduce their stylets through the stomata, pass through the cells of the chlorophyllous parenchyma and reach the metaxylem in the vascular bundles (GARCIA *et al.*, 2007a). Also, similar to that which occurs with *M. posticata*, as a consequence of the constant sucking of sap, there is a reduction in sucrose levels in the stalk which affects juice quality and industrial and agricultural yields (MADALENO *et al.*, 2008).

The dehydration of the phloem and xylem can result in a hollow stem, with the appearance of external wrinkles. Tillers can die and lateral shoots may appear which changes the plant architecture so it looks like a palm tree.

The damage in areas of raw cane where the pest is a problem can be as high as 11% of the agricultural productivity with a 1.5% reduction in sugar levels.

Damage is greater in ratoon cane and the second generation of the pest (there are two or three generations) can reduce productivity by up to 26% (GARCIA *et al*., 2006). General aspects, including the effect of varieties and of harvest timing on infestation levels, have been discussed by DINARDO-MIRANDA *et al*. (2001).

Termites

There are various genera of subterranean termites which attack sugarcane (*Heterotermes*, *Procornitermes*, *Neocapritermes* and *Syntermes*). However, the most important genus is *Heterotermes* with *H. tenuis* causing the most damage. This species has a tapering body, is milky white, with a yellowish cephalic capsule, a thorax with rounded sides and long mandibles. It does not take back any soil to the galleries it builds inside the stalks like other species, such as *Procornitermes*, do. Its nests are subterranean, concentrated and underground, shaped like cylinders, about 10 cm high and 6cm in diameter, completely closed except for the two extremities which communicate through galleries. In order to feed (cellulose), the termites attack plants growing near their nests.

The termites attack seed pieces, damaging the buds and affecting germination, causing gaps in the stand which often have to be replanted. Yearly losses can reach 10 tons/ha and the termites are more commonly found in sandy soils (VALÉRIO *et al*., 2004).

Other pests

There are other less common pests whose attacks can cause a total loss although there are no evaluations (studies) on this for São Paulo state or for Brazil. This is the case for *M. fryanus*, *T. licus*, *S. levis*, *Scaptocoris* spp. and *H. taltula*. However, their occurrence is more restricted, except for *T. licus*, whose distribution and damage potential are still unknown due to its recent introduction into São Paulo state. This pest may cause losses similar to those of the sugarcane borer, *D. saccharalis*, in the Northeast, although the caterpillar's much larger size could result in greater damage. In areas infested by *S. levis*, 50% to 60% of the tillers are attacked, resulting in losses of 20 to 30 tons per hectare (PINTO *et al*., 2006).

Other pests, such as the aphids *Rhopalosiphum maidis* and *Melanaphis sacchari* associated with sugarcane mosaic virus and sugarcane yellow leaf virus respectively, have been controlled by using resistant varieties. White grubs are controlled at the same time as the termites.

CONTROL ALTERNATIVES

Diatraea saccharalis

The sugarcane borer has been controlled since the 1970s by the imported parasitoid, *Cotesia flavipes*. This parasitoid has been studied extensively together with the sugarcane borer (BOTELHO; MACEDO, 2002; PÁDUA *et al*., 1994).

Around 6,000 parasitoids are liberated per hectare at a cost of US$ 7/ha. At the present time, with the appearance of private companies selling such agents (there are about 20 firms selling this parasitoid in Brazil) and with the reactivation of laboratories in the mills with large scale production, parasitoids are liberated on around 1.7 mm hectares (PARRA, 2008, personal communication). The success of this program, one of the biggest in the world due to the area treated, is demonstrated by the reduction in losses caused by the borer: these used to reach US$ 100 mm a year in São Paulo state in the 1980s, and are now US$ 20mm in areas where liberations have been made. General aspects of the production and liberation of the parasitoid are described in MACEDO and BOTELHO (2002).

A new alternative exists today for controlling this pest in sugarcane: the egg parasitoid, *Trichogramma galloi*, produced by two firms in Brazil (PARRA, 2008, personal communication).

Since the key factor in the population growth of *D. saccharalis* is the egg stage (BOTELHO, 1985), it is expected that this parasitoid will efficiently control this pest. Research results have shown that when around 200,000 *T. galloi* parasitoids are liberated per hectare, at weekly intervals, in three liberations, and associated at the same time with *C. flavipes*, infestation intensity was reduced by up to 60% (BOTELHO *et al*., 1999).

The parasitoid *T. galloi*, which has already been liberated on 150,000 hectares, should be liberated in preference to *C. flavipes* where the latter is inefficient or in areas where egg predation is low.

Biological control of *D. saccharalis* by *C. flavipes* is efficient as long as the pest infestation level is not greater than 3% and by *T. galloi,* when the first *Diatraea* eggs appear in the crop, generally 50 to 60 days after planting of the sugarcane (LOPES, 1988). There have been many studies over the last few years on the parasitoid (PARRA; SALES JR., 1994; BOTELHO *et al*., 1995a, b; 1999; CÔNSOLI *et al*., 2001; PINTO *et al*., 2003; PARRA; ZUCCHI, 2004).

Froghoppers

Although there are varietal differences, with some varieties, such as SP 79-1011, suffering less attack by the root froghopper in São Paulo state, plant resistance is still not a viable control alternative. The total elimination of cane trash by mills, which could reduce future froghopper populations, is also not economically viable.

Other biological agents such as egg parasitoids (*Anagrus urichi* and *Acmopolynema hervali*) and predators such as *Salpingogaster nigra,* occur naturally but are difficult to handle in the laboratory, which makes their manipulation difficult. They should be preserved by avoiding agrochemical applications in the crop.

The economic threshold level for the root froghopper is two nymphs per linear meter of row. The sampling is done at five points per hectare, with each point represented by a linear meter of row. The sampling should be done with the first pest generation when the rains begin.

The green muscadine fungus, *M. anisopliae*, currently produced and sold by ten firms, has been used to control both species in the Northeast since the 1970s and is presently applied on about 1 mm hectares.

The quality of the fungus, its dosage and formulation (wettable powder, granules or oil-based) are the key to successful control. It should be applied at high volumes (300 liters of water) at a concentration of 5×10^{12} viable conidia per hectare, the equivalent of 225 g of pure conidia or five kilos of fungus plus culture medium (rice). Since this pathogen needs certain temperature and humidity conditions, efficiency will be greater if applications are made at dusk since, besides avoiding the action of UV light, which degrades the fungus, it permits the germination of the conidia under these same environmental conditions.

Since there is a close correlation between froghopper populations and excess soil water, the time when the pest occurs also favours fungal development.

Termites

Although termites are controlled chemically, their control should not be over the total area in order to avoid greater outbreaks.

In reformed areas, examine 20 rootstocks per hectare to evaluate the presence of termites. Another option is the use of corrugated cardboard baits (Termitrap®), using 20 baits per hectare. The economic threshold level is 25% infestation.

In ratoon cane, use Termitrap® type baits which contain the active ingredient, imidacloprid, together with *Beauveria bassiana* fungus, using 40 baits per hectare per year. This treatment aims nests elimination (ALMEIDA; ALVES, 1996; ALMEIDA; ALVES, 1999).

Migdolus fryanus

There is a sex pheromone of the amide group for this pest, which is restricted to certain areas of Brazil (DIAS FILHO, 1984), and it is sold as one milligram pellets. It can be used for monitoring, with one trap per area of 10 to 20 hectares between October and March, with substitution of the pellets every three or four weeks (BENTO *et al*., 1992; BENTO *et al*., 1993; LEAL *et al*., 1994; BENTO *et al*., 2004). However, the control of this pest is mainly with insecticides. Mechanical control during plantation reform, to reduce larval populations which are feeding at the rootstock base, is extremely efficient when done at the right time.

Photos: Negri.

FIGURE 1 Most common biological agents used to control sugarcane pests. A. *Cotesia flavipes* parasitizing a caterpillar of *Diatraea saccharalis*; B. *Trichogramma galloi* on eggs of *D. saccharalis*, where b_1 is a normal oviposition of the sugarcane borer and b_2, one parasitized by the microhymenopteran; C. Nymph of *Mahanarva fimbriolata* infected by the green muscardine fungus *Metarhizium anisopliae*, also showing healthy adults of *M. posticata* (c_1) and *M. fimbriolata* (c_2).

PROPOSALS FOR DEVELOPING SUSTAINABILITY IN SUGARCANE

Although sugarcane is one of the crops where biological control is most practiced in Brazil, based on the “Technological Workshop on Sugarcane Pests” held in Piracicaba, São Paulo state, in August 2007, it is possible to define actions to develop control alternatives, especially pest biological control, as a key component for sustainable sugarcane production.

These actions may be summarized as follows:

- In general terms, it can be concluded that critical mass is desperately lacking in the area of sugarcane pests and this calls for training, whether it be of researchers or technicians.
- On the other hand, there is a lack of equipment and better-organized laboratories, to enable Brazil to be on an equal footing with laboratories in the developed countries where the synthesis of semio-chemicals, or even volatile plant substances, are routine activities. Only through training and equipping such laboratories will Brazil be able to reduce its dependence on outside help.
- Another aspect discussed, and which merits reflection, is that the projects (or research) are isolated, as is usually the case in our work, with no inter or multi-disciplinary actions to produce global results instead of just local ones.
- The giant sugarcane borer, *T. licus*, recently introduced into São Paulo state, should merit special attention due to the damage it causes and what it could represent for the sugarcane crop with the large predicted expansion in planted area. Bioecological studies of the pest, monitoring methods and control alternatives should be extensively researched since the control methods presently in use are empirical and inefficient.

Soil pests

- Studies should be made relating the effect of cane trash and decomposing species on the new agroecosystem resulting from mechanical harvesting and also the effects on soil pests, beneficials and entomopathogens;
- Alternatives for the control of *E. lignosellus*, *S. levis*, *H. taltula* etc.;
- Environmental impact of chemical control on important soil species;
- Relationship between population density and the damage caused (with emphasis on the root froghopper, *M. fimbriolata*);
- Evaluation of the efficiency of biological control on pests (biological and microbial control should be favored by mechanical harvesting);
- Bioecological studies of traditional and secondary pests (which could become primary pests);
- Monitoring and sampling techniques for soil pests.

Biological and chemical control

- Pest monitoring studies (including geoprocessing) to sample them adequately and control them rationally, whether it be through biological or chemical options.
- Determination of the economic threshold levels of the more important pests (for different control options).
- Environmental impact studies of agrochemicals and control alternatives in the agroecosystem (selectivity, niche occupation, biological outbreaks, pest resurgence, resistance management).
- Bioecological studies of primary and secondary pests.
- Production methods for parasitoids, predators and entomopathogens.
- Quality control of beneficials and pathogens produced in the laboratory.
- Search and identification of new biological control agents, involving studies on disease epizootiology, pest population dynamics, strain selection and of biological control agents.

Transgenic plants and pest control in sugarcane

- Although it is known that transgenic plants will be available to farmers only in the medium and long terms, support should be given to transgenic research currently being done, whether it be with *Bacillus thuringiensis* (Bt) for *D. saccharalis*, or Bt allied to proteinase inhibitors for Coleoptera (*M. fryanus* and *S. levis*) and other possible techniques, aiming at other pests in the crop.
- Studies on the regulation of transgenic plants compatible with Brazil's reality as well as matters linked to intellectual property rights.

Pheromones

- Studies (explanatory campaigns) demonstrating the viability to the farmer of using synthetic pheromones for monitoring and control (*M. fryanus*) and others which might eventually be synthesized and which can substitute the agrochemicals presently in use.
- Research in the short term to synthesize pheromones for *S. levis* and *D. saccharalis*.
- Research in the medium and long terms to develop and synthesize pheromones [for *T. licus*, *E. lignosellus* and white grubs (*Scarabaeidae*)].
- Incentive of entrepreneurship – formation of firms with a technological base for the commercialization of semiochemicals as well as beneficials and entomopathogens.
- As already mentioned, multi – and interdisciplinary programs which would need the development of human resources, the acquisition and maintenance of equipment and facility in buying solvents.

Measures need to be urgently taken because the volume of entomological problems in Brazil will probably increase with the occupation of new areas with sugarcane, having different climatic conditions, as well as the use of new cultivation systems in different soil types and different ecosystems. All these variables together will certainly result in increased entomological problems to be added to those that already exist.

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12

TECHNOLOGICAL EVALUATION OF SUGARCANE MECHANIZATION

Oscar A. Braunbeck and *Paulo Sérgio Graziano Magalhães*

The expectations of expansion of the cultivated area with sugarcane, from 7 million hectares in 2008 up to 14 million hectares in 2030, will demand significant alterations in the whole mechanization system, in order to place the activity in less vulnerable levels of sustainability. The sugarcane is a semi perennial crop typically grown in cycles of four–seven years, producing on average 81 ton/ha^{-1}-year (CONAB, 2008). About 1.4 million hectares are replanted every year, and in only 30% of them mechanical planters are used, in the remaining of the area planting is semi mechanized. The method is totally manual and restricted to areas of little significance with high steepness, predominantly in the northeast part of Brazil. Sugarcane is usually planted in the rainy period, between January and March, to be harvested in the following crop season, causing a productive system deficit of one year. During the period between the harvest of the last cycle and the planting of the new one, some mills do crop rotation with legume species. Cane harvesting use to be traditionally done manually, but it has witnessed a rapid transformation in the last decade due to mechanical harvesting, , mainly as a response to environmental legislation that restricts the use of field burning.

The increase of ethanol production certainly passes through changes in both: the agricultural and the industrial process so as to make possible the integral use of the sugarcane produced. According to Dourado Neto (2007) the current production model needs to be reformulated to increase productivity, from an economic, social and environmental sustainability point of view; it is necessary to define agriculture strategies for a better use of resources. The technology of agricultural production should be improved with focus not only in yield and the reduction in demand for new areas, but mainly to improve environmental impacts for which mechanization has significant contribution to make.

MECHANIZATION

Considering mechanization as equipment that replaces or aids manual and animal work, it can be said that it is necessary in most phases of sugarcane production cycle to provide competitive and sustainable conditions for plant growth e.g. erradication of the stooll, physical and chemical conditioning of the seedbed, soil moisture control, planting and agrochemical applications all the way up to cane harvesting and delivery. Mechanization is particularly important in harvesting and transport operations from the field to the mill, as a consequence of the high amount of biomass that needs to be handled.

Currently grains production is the most highly mechanised. The grains dominate the equipments market in function of its production area far higher than for sugarcane, as illustrated in Table 1. The model of grains mechanization, with more than a century of evolution, was extended to sugarcane although its characteristics are different, mainly because it is a semi perennial crop, with a volume of annual biomass much higher than grains. For example, Table 1 shows that the globally planted and harvested area with cereals is close to 32 times

TABLE 1 Production and world productivity of grain and sugarcane

Product	Harvested area (ha x 10^6)	Productivity (t . ha^{-1})
Sugarcane	21.9	70.8
Cereals	700	3.3
Soy bean	94.9	2.3
Wheat	217.4	2.8

Source: FAO – Faostat (2008).

higher than sugarcane area; this justifies why the mechanization profile is defined by the cereal sector. The table also shows mass volume per hectare harvested annually is about 21 times higher in the case of the sugarcane. Considering the annual cycle for cereals and for sugarcane, the amount of mass removed by hectare between two consecutives seedbed preparations is 105 times superior in the case of sugarcane. The process of biomass removal is associated with intense machinery movements (all kind of equipment) with different wheel track mismatching crop row spacing, which varies between 1 and 1.5 m; the result of this poor combination of equipment wheel track is a high percentage of area being trafficked.

There are some characteristics of the current mechanization system that damages the stalks, the soil and increase the operational costs and therefore requires new research to find ways to reduce their effects.

Tractors, harvesters and wagon have not standardized narrow track width, it frequently mismatching the crop row spacing practiced in sugarcane. The outcome is traffic passing too close to crop rows, and sometimes directly running over them, damaging the stalks. These equipments do not allow taking advantage of the controlled traffic technique.

Harvesters are primarily designed for single row and pass twice for each inter-row with the side wagon. The harvested cane is transported inside the field by wagons pulled by tractors where the traction capacity depends on the tractor own weight rather than on the transported load. The system uses approximately 50 t of equipments to remove 80 t of biomass per hectare.

The most widespread configuration is a tractor with two wagons characterized for being a long composition that demands space for maneuver, usually quite superior to the available at the in field roads.

The agricultural tractor and sugarcane harvesters define or influence row spacing, the area geometric lay out, the pattern of traffic in the field as well as the size and the design of most of implement. The problems posed by mechanization are not unique to Brazil; the world sugar industry suffers a great mismatching of row spacing and equipments track width, according to Cox (2006). Equipment movements and soil compaction are much more severe for sugarcane than for cereals. It seems valid, from an economical and environmental point of view, to consider specific mechanization solutions for sugarcane, focus in solving this specific problem.

The conventional mechanization of sugarcane in Brazil has gone through an improvement process from 1975 to 2005, based in operation standardization, adaptation of the tractors power to demand, with larger work capacity, maintenance programming and control, operator training, incorporation of new equipments for planting, application of filter cake and stalks elimination, among others. That evolution contributed to reduce production costs, which is the lowest worldwide. It can be affirmed that the principal responsible for that evolution were the technicians in the cane mills, with the support of regional manufacturers and research institutions that shared the common objective of reducing costs and simplicity and quality of operations.

That evolution seems to have reached a plateau with very little gains, since conceptual bottlenecks of conventional mechanization have been reached e.g. excessive traffic, low quality of the raw material, harvesting losses, heterogeneous billet distribution in the planting furrow, as well as the low quality and the high cost of the trash recovered.

The technological evolution of the mechanization in order to turn sugarcane production more sustainable within the next 30 years, could be much more effective if restrictions imposed by tractors and harvesters could be eliminated. Such improvement will allow to create new opportunities, and open the door to many technicians, users and suppliers of farm equipment with extensive experience in sugarcane.

A brief analysis of the historical and the basic functions and physical principles involved in the design of tractors, can contribute to the formulation of proposals which can reduce the negative impacts of t mechanization, as it is the case of the controlled traffic concept.

The agricultural tractor concept has not changed since its introduction at the end of the XIX century. Analyzing the three generations of tractors presented in Figure 1 it can be observed that there was a technological evolution within of the same concept based in a power unit, steam or internal combustion engines, surrounded by four wheels, with narrows track width, less than 2 m, with traction capacity generated through its own weight, with no transportation capacity and with implements coupled at the rear hindering the operator monitoring and control. In reality the concept suffers little changes from the previous stage that is the animal traction.

The tractor concept, as its name indicates, has its origin in the need of generating forces for implementing traction used in the intense soil tillage. That pulling force is generated based in the tractor own weight, through over dimensioned iron structures, iron ballasts added to the back and front wheels as well as water inside the traction wheels. The agricultural tractor is part of the agricultural mechanization profile that requires investments and energy to act in a vicious circle of soil compaction and loosening with negative consequences on sustainability.

The mechanical concept of soil physical conditioning through intense and deep tillage is being substituted by the concept of minimum or zero tillage where the biological activity, the incorporation of organic matter from crop residues mulch, crop rotation, the permanence of roots from previous cycles and traffic reduction are capable to maintain adequate the soil condition for the development of a new crop. This system promotes drastic reductions in soil erosion, mechanization costs and water losses. It is also much more aligned with the emphatic demand of environmental preservation.

In conventional mechanization, the inputs and harvested products are frequently transported by wagons pulled by tractors. The wheel paths of those equipments usually follow the planting rows, but they are not selective in terms of concentrating the traffic in specific rows. The wagons, vehicles and tractors track width are not standardized to the point of allowing concentration of the traffic on specific lines.

Besides the fact that the tractor conception remained static, its technological evolution has been slowing down over time. In the period of 50 years between 1880 and 1930 an important technological evolution appeared with the substitution of the steam engine by the internal combustion engine with the Otto cycle. The next period of 20 years, between 1930 and 1950, the Otto cycle

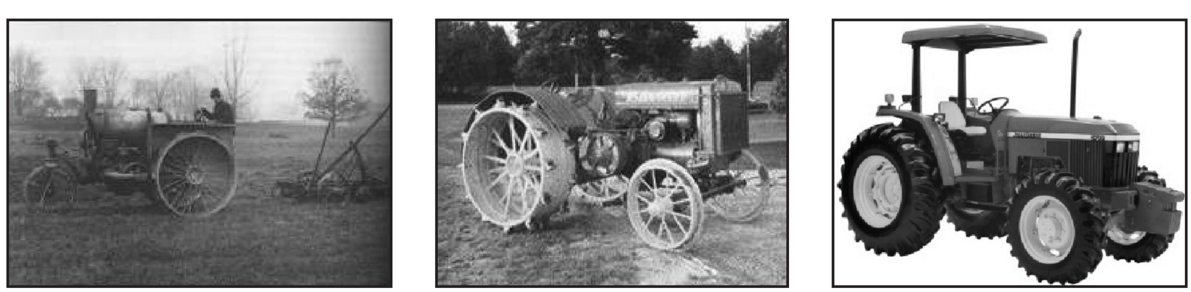


FIGURE 1 Evolution of the agricultural tractor over 130 years.

engine was substituted by the diesel cycle engine and the steel wheels by pneumatic tires. The following years, until present, the evolution has been in terms of power increase and components such as hydraulic transmissions and electronic controls, but conserving the original concept of narrow track width, own weigh for traction generation, inadequate positioning of the implements and lack of load capacity.

The production cycle of sugarcane involves operations that demand energy for deep soil tillage, seedbed preparation, seed billets and fertilizers transport as well as harvesting and removal of approximately 100 t/ha^{-1} of biomass, including the trash. In that cycle, seedbed preparation is meant to create favorable atmosphere for the development of the plant allowing the infiltration and storage of water, the circulation of gases and the propagation of the roots, within fragile structure. However the wheels or crawler tracks of the equipments promote a re-accommodation of the particles creating a strong structural arrangement required to support the weight of the equipments. The tractors and the harvesters apply good part of their power source and fuel consumption to promote soil compaction.

Plants and wheels need to withstand different soil conditions. That conflict has been promoting research in the last decades to reduce soil pressure. Large tyres, with radial structure have been developed, to generate larger contact area and reduced soil pressure; in parallel to the weight of equipments such as transport vehicles, harvesters and tractors has been increased. The consequence is that the benefits of the introduction of high flotation tyres have been total or partially eliminated by the increase of the equipment weight. The effect of the tyres on the soil compaction, in terms of resistance to penetration, varies with soil type and moisture content. It can be observed in Figure 2, that there is some compaction reduction with the use of radial tyres, however the compaction provoked by both types of tyres, radial and diagonal, is superior to the of the soil without traffic.

On the other hand, the narrow track width of the tractors and harvesters together with the wider tyres increases the percentage of the soil surface trafficked. This percentage overcomes 50%, in

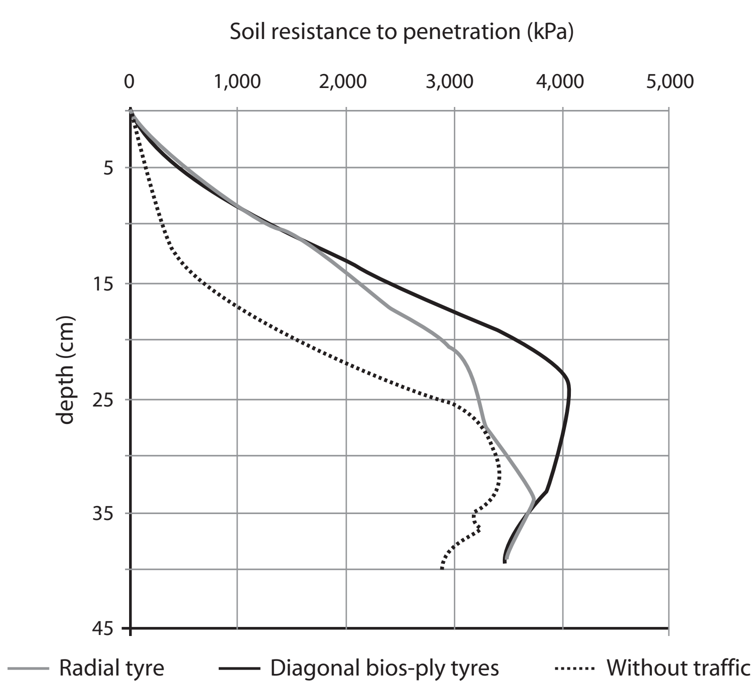


FIGURE 2 Soil resistance to penetration when submitted to different traffic conditions.

the case of sugarcane. Everything indicates that new developments focused on reduction of soil compaction should be directed more to increase the track width of the equipments than to the increase of tire width.

The impact of the traffic on the soil and the plant is recognized by several authors e.g. Grange *et al*. (2004), Garside *et al*. (2005), Mari *et al*. (2006), Mari and Changying (2008), Mc Phee (1995), Naseri (2007) and Chamen *et al*. (1994). Today there is still potential to reduce those impacts using alternative mechanization that reduces the percentage of machinery movements in relation to the planted area. The noxious effect of the traffic on the soil structure is evident when the soil is well structured, in favorable conditions for the development of the crop and with good resistance to hydro erosion. If the soil is more compacted and dry the effect of the tyres becomes less perceptible, the development of the crop is difficult and there is a potential for soil erosion. Even if the effects of the traffic are less significant in the winter when the soil is dry, they are much more severe at the beginning and ending of the harvesting season when precipitations are more intense.

Considering the problems described between the wheel and the crop, it seems appropriate to separate the space dedicated to the development of the plant from the space dedicated to the traffic of wheels or crawlers which will reduce the impacts on the soil, Braunack and Garry (2006). This separation allows to improve both spaces and maximum development of the plant and maximum traction efficiency for the wheel. São Martinho mill, in Pradópolis region, has been practicing this philosophy using modified conventional equipments, with good results in terms of yield recovery. In the past the reduced yield was consequence of the intense and uncontrolled movements of harvesters and wagons; even using narrow track width harvesters (1.6 m) and 3 m for the tractors and wagons such dimensions allow to maintain a 0.7 m strip dedicated exclusively to the plant and a 0.8 m strip dedicated exclusively to the wheels.

Manor (1995) analyzes alternative mechanization based on controlled traffic of elevated, self-propelled wide frame structures, to execute all the operations of the agricultural cycle with drastic reduction in the soil trafficked areas. It presents a potential for costs reduction and productivity increase. The author highlights other potential advantages of these equipments such as the agro chemical pulverization in closed cameras with reduction of drift, and the possibility of transporting the harvested product in the wide frame, thus avoiding the traffic of container wagons in the area.

The demand that encouraged the development of conventional mechanization dates back to the end of the XIX century. This mechanization model improved during the XX century, focusing primarily on costs reduction through the use of higher power required by the heavy soil tillage operations as well as seedbed preparation and harvesting, for which animal power was insufficient. It was also concerned to replace the scarce labor as a result of migration to the urban centers. It is observed that demand changed in the present century with relationship to the soil tillage and seedbed preparation where sustainability demands are added. That can be materialized through changes in the agricultural practices, as it is the case of the controlled traffic, the zero tillage and precision agriculture.

Considering that conservative agriculture (CA) technologies are being tested in approximately 88 million hectares all over the world, and has seen an increment of more than 50 times in South America in the last 20 years alone, it is questionable why the Brazilian sugarcane industry does not use this technology as a strategy to reduce costs, to conserve the soil and the water, and improve sustainability of agricultural production. The potential advantages of the zero-tillage, in the case of the sugarcane, do not differ much from other crops in which the result has been well demonstrated.

The sugarcane industry can also benefit from mechanization technologies that promote the reduction of investment, operational costs, reduce harvesting losses, and reduce fossil fuels use and their emissions, and the optmize operational efficiency of the complex cycles of mechanized operations involving several interacting equipments.

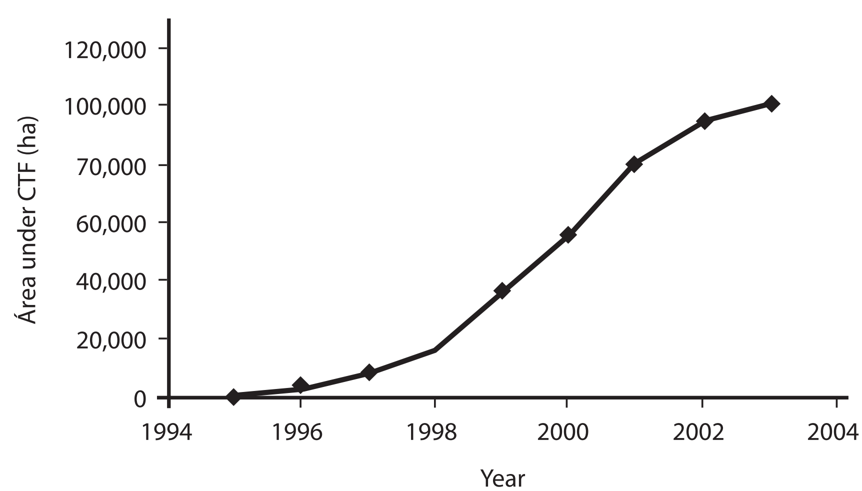
The evolution of agronomic technologies emphasizes the need for mechanization more adapted to agronomic conditions, without imposing limitations to evolution as it is the case of that limits the planting row space of sugarcane equipments track width.

In the last decade environmental legislation has been forcing to reduce sugarcane burning to minimum levels, forcing an increase of mechanical green harvesting that leaves on the soil about 15 $t.ha^{-1}$ of trash (d.b.), forming a mulch 100 to 200 mm thick. Cane planting can be done directly over this mulch, and it is done by some mills, or the remaining straw of other crops used in the rotation cycle. The mulch covering conditions of the soil for implantation of the zero-tillage in sugarcane are favorable.

The technique of controlled traffic (CT) has demonstrated to be a successful innovation in Australia. Figure 3 shows the evolution of the areas in CT, in that country. According to Yule and Radford (2003) the controlled traffic leads to productivity earnings, reduction of operational costs and of investments; and reduces runoff and erosion, increases steady infiltration rate, as well as improvement in the soil physical condition and fertility.

Controlled traffic maintains compacted tracks permanently, avoiding the cost associated to the vicious cycle of soil compaction and loosening practiced in conventional planting system. When controlled traffic is applied to sugarcane, using conventional mechanization, strips approximately 0.8 m wide, spaced of 1.5 m, are traffic dedicated. It means that close to 50% of the area is used by tires or crawlers of the harvester, tractors and self tipping wagons. The narrow track of the tractors and harvester promotes the traffic condition as illustrated in Figure 4 where each small rectangle represents the passage of two wheels. Wheel traffic is much higher on the top eight lines of the figure that corresponds to the harvesting operation including harvester, tractor and self tipping wagons. The illustration considers mechanized operations involved in an 18 month cycle of sugarcane. It can be observed that 32 tires pass in some inter-rows suggesting that some alternative mechanization system would be required to be able to move into no tillage farming.

Braunack and Garry (2006) compared the effects of controlled and random traffic as well as the effect of conventional intensive soil cultivation and reduced tillage on seedbed and crop growth as well as the effect on soil physical parameters and soil macro-fauna. The results indicated that the controlled traffic and reduced tillage would benefit the crop system minimizing soil degradation and maintaining productivity in a sustainable manner.



Source: YULE (2003).

FIGURE 3 Evolution o controlled traffic in Australia.

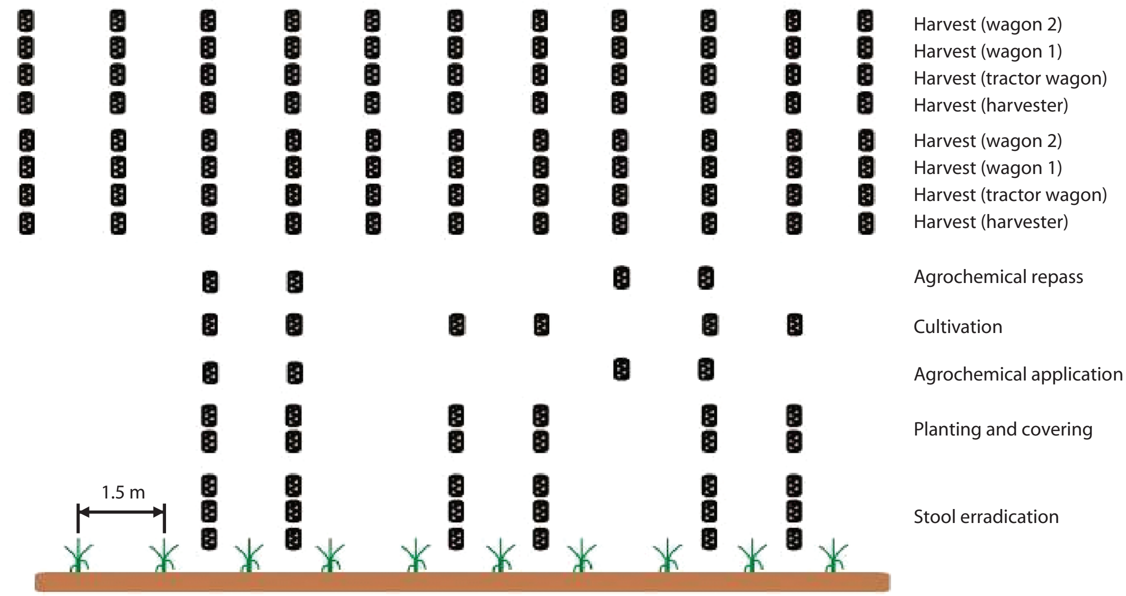


FIGURE 4 Number of double tire passes at plant cane inter-rows during an 18 month cycle.

The alternative equipment described by Manor (1995) apply the concept of controlled traffic, can contribute to break the paradigm of conventional mechanization progressively and open a new range of development opportunities for research and production sector. As the number of simultaneous rows harvested is increased the percentage of trafficked area is proportionally reduced.

SEEDBED PREPARATION

Land preparation for planting sugarcane takes place at four to six years intervals, or even up to ten years, depending on several factors such as soil type, irrigation or fertigation, climatic conditions and type of cultivation, or cultivation techniques applied in the previous years. Soil tillage can follow different approaches, often includes one or two heavy passes of offset disc harrow to eliminate the previous stool, or it can be done chemically by spraying glyphosate over the emerging ratoon. Due to the intense traffic of machines during the crop cycle, subsoiling operations are required as well as additional harrowing or ploughing operation, followed by disk leveling operation with the objective of reducing the size of soil aggregates. Detected the need of limestone application for base saturation elevation up to 60%, this should be done, as uniform as possible, in the period between the beginning of soil tillage and before the last harrowing.

According to Ide (2007) little research is being conducted on soil tillage for sugarcane and many reports do not present scientific background on the dynamics of soil biotypes, physicochemical modifications as well as water and nutrient dynamics, mainly in green cane plantations. There are bottlenecks in relatioon to the effectiveness of implements used for tillage and the efficient and correct methods to conduct this operation. The author concludes that the main challenges in this process are: 1 – to evaluate the environmental impacts of the current tillage process; 2 – develop smaller and more versatile equipments for liming and herbicide applications.

According to Braunbeck (2008) a conservative agriculture, such as zero tillage, is a promising route to mitigate the negative effects of conventional tillage on water and soil conservation in the sugarcane industry. Direct seedling is a planting method without soil tillage. Just a narrow strip of soil is tilled in the row where the seeds or billets are deposited, maintaining crop residues on the soil surface. In early 1960's, this technique was first used in England, in an experimental way, and later improved in the United States, where around 23 million hectares using this method are cultivated today. In Brazil, the system of direct seedling began to be implanted at the beginning of the seventies, in the north of the state of Paraná, with the objective of reducing soil erosion. In the 1990's, the system began to be used extensively in the state of Rio Grande do Sul and to a less extend in the "Cerrados" (GO, MG and DF). Currently the cultivated area with zero tillage in Brazil is over 25 million hectares.

Nowadays, in Brazil zero tillage is accepted as irreversible; it is used mainly in soya bean but is also to a large extend in corn, wheat and beans farming, which is increasing rapidly, Smiderle (2005).

Studies done by the Fundação Agrisus – Sustainable Agriculture, focused on the state of the art of zero-tillage, verified that in 77%, or 22 Mha of soya beans, use zero-tillage, and approximately 65% of the framers have been using zero tillage for more than 10 years. The study considered four climatic areas with differentiated conditions in the winter (1 – cold and rainy – Rio Grande do Sul, Santa Catarina and south of Paraná, 2 – unpredictable rainfall – remaining of Paraná, south of Mato Gross do Sul and Southwest of São Paulo, 3 – warm with little rain – north of Mato Grosso do Sul, Mato Grosso, Rorâima, remaining of São Paulo, Southwest of Goiás, Minas Gerais triangle; 4 – hot and dry – remaining of Goiás, Tocantins, south of Pará, west of Bahia, southwest of Piauí and Maranhão). Cardoso (2006).

Straw and Soil Protection

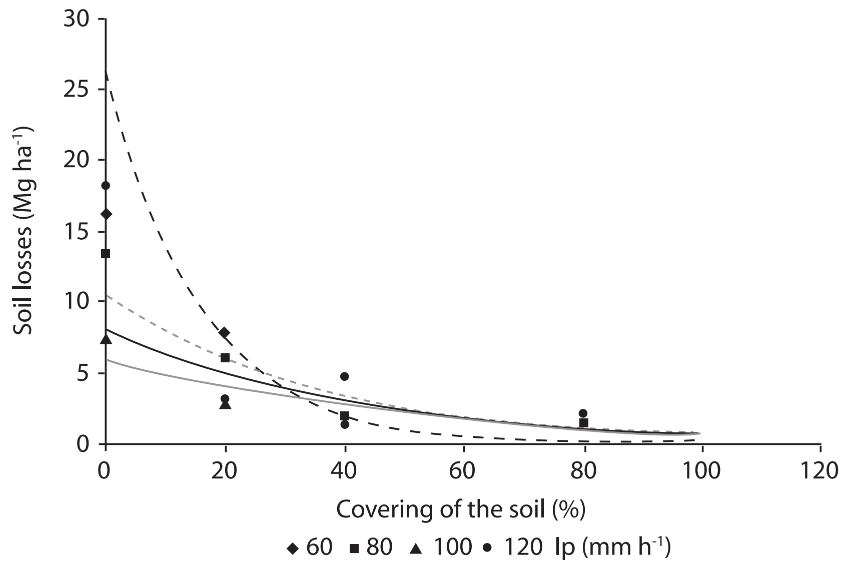
Although the main motivation of the sugarcane growers to adopt zero-tillage is costs, soil conservation is equally important for environmental protection. Soil degradation can be considered as one of the most important environmental problems, as it is very harmful e.g. it has a direct impact on productivity, and causes silting up and pollution of water sources. The constant crop improvement, together with greater use of chemical fertilizers and more efficient pest control, tend to hide erosion impacts and thus little priority is given to its control.

The process of water erosion of the soil particles happens in three sequential phases: loosening, drag and deposition. In the initial phase the loosening of aggregated soil particles results from the impact of water drops and the action of superficial water run-off. In a second phase, the loosened particles can stay close to the aggregate or be transported be the running water. The straw mulch protects the soil in both phases of the erosive process, in the first phase the straw absorbs the kinetic energy of the rain drops and in the second phase it reduces the speed of the superficial run-off and it holds back the displacement of particles.

Silva (2005) used a rain simulator on red-yellow argisoil, with 9.5% slope to analyze the effect on of soil cover losses using four precipitation intensities (60; 80; 100 and 120 mm.h^{-1}) on different percentages of soil covering (0; 20; 40; 60; 80 and 100%). The effect of the soil covering percentage on the soil losses accumulated at the end of the six rain events, for the different precipitation intensities studied is shown in Figure 5. The authors verified that, independently of the precipitation intensity, the increment of the covering percentage caused accentuated reduction in the soil losses, becoming very small when covering approaches 100% of the soil surface.

The amount of available vegetable material for soil covering is critical in some cultures, mainly in areas with higher temperatures. In the case of the sugarcane there is a fraction of approximately one third of the biomass produced that can be used for soil protection. Burning the cane before harvesting limits the biomass available for soil protection, but with the intensification of the green cane harvesting there will be enough material for soil covering.

Conventional soil tillage promotes, in a mechanical way, vertical movement of nutrients with low mobility. In zero-tillage that movement can be obtained through crop rotation during plantation renewal. Tanimoto (2008) in experiments done in



Source: SILVA (2005).

FIGURE 5 Soil losses as function of the percentage of covering of the soil and precipitation intensity.

north and northeast areas of the State of São Paulo verified that growing soya bean or crotalaria in the sugarcane trash, as crop rotation, makes possible the mechanical sugarcane planting after harvesting of the legume, with little movement of the soil. According to the author with relationship to the soil-borne diseases when they happen, their effects can be minimized, keeping the population of those pests at the acceptable level with crop rotation.

Soil protection obtained with surface trash has a secondary equally positive effect related to water retention. Water has significant effect on sugarcane productivity, because when restrained, reduces yield significantly even in fertile soils and, when appropriate, it increases the production even in the soils with less potential. Sustainable use of natural resources means reduced water run-off, and increased efficiency of water and nutrients use.

Soil covering with crop residues is a decisive factor in the process of water infiltration. Trash covering the soil increases water retention, since it reduces the evapotranspiration and reduces, or even eliminates the superficial run-off. Studies indicate a reduction in water loss of approximately 70% with the use of the zero-tillage, as shown in Figure 6, Domingues (2006).

Trash Decomposition and Soil Fertility

Similar to water, soil fertility also occupies a prominent place in sugarcane cultivation. The level of soil fertility, when involving biological, physical and chemical aspects, is determined basically by its structure. Besides the favourable effects of the presence of trash not decomposed on the soil surface, the material already decomposed is also beneficial. In the long run, trash decom-

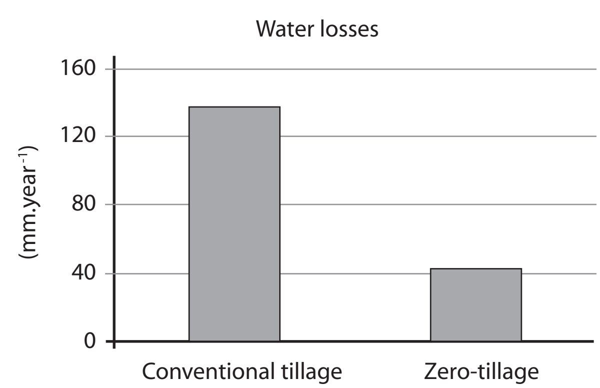


FIGURE 6 Water losses in conventional soil tillage and zero-tillage.

position increases soil organic matter content, which has a conditioning effect on soil, because it aggregates the particles, improving its physical structure, what reduces or eliminates the need of harrowing or ploughing operations for soil physical conditioning.

One of the most significant effects of the increase of soil organic matter content, it is the increase in Cation Exchange Capacity (CEC). CEC is the capacity of a soil for ion exchange of cations between the soil and the soil solution. CEC is used as a measure of fertility, nutrient retention capacity, and the capacity to protect groundwater from cation contamination. Most of the Brazilian soils have low fertility and are poor in organic matter; one of the main forms of increasing nutrient storage capacity is by increasing the organic matter content. Studies done by Souza (2005) indicated yield increase when using trash on the soil surface, but mainly when trash was incorporated into the soil, however, the soil mobilization to homogenize crop and residues oxygenates the soil and stimulates the microorganisms decomposition effect that accelerate the rate of organic matter losses. Conventional tillage can duplicate the rate of organic matter mineralization in relation to zero-tillage. The mineralization of the soil stable organic matter changes its structure and degrades fertility.

The increase of the organic matter content in the soil increases carbon stock, collaborating for greenhouse gas effect reduction. The potential of carbon sequestration, through zero-tillage, is also related to a reduction of fossil fuels use, to the erosion control, and to a reduced use of fertilizers.

Summarizing, the main advantages of zero tillage are the improvement of the soil structure; the increase of the biological activity; the increase of the organic matter content; the increase in crop yield; the reduction of the operational costs and investments in mechanization; time saving because there is a reduction in the number of operations; the fertilizer long run economy and a differentiated handling of the trash which results in more efficient energy use of sugarcane biomass.

The implantation of zero-tillage in sugarcane requires significant changes in cultivation method and corresponding investments in research and development to eliminate the problems associated to those changes. Some of the difficulties are: break the conventional tillage paradigm; the need to eliminate cane burning; weed control; the potential for increase in soil pests that are beneficiary of the non soil movement, as well as the need to fertilize and lime through the trash layer.

Considering the gains and challenges described and the successful experience of grains, zero-tillage can be considered an agricultural practice with great potential contribution to turn the sugarcane agriculture more sustainable, and it opens horizons for a new cycle for technological evolution of the mechanization, as it happened with the conventional mechanization in the last thirty years, since the beginning of the Proálcool program.

PLANTING

Sugarcane is traditionally planted through vegetative propagation. Billet planting is becoming common and each billet usually has from 2 to 3 buds. Cutting of the stems into billets is required in order to break of the effect of the apical dominance existent among the buds distributed along the stem. Newer buds, located closer to the top, sprout more quickly and they delay the development of inferior bud. According to Gheller (1995), mentioned by Jamini (2007), the division of the stems in billets of 3 buds is applied traditionally in Brazil and other countries. The billets are an energy storage for bud nutrition during its emergency and until the development of the root system.

Sugarcane planting involves four main stages. Billet harvesting, billet transport to the planting area, the furrow opening, billet distribution in the bottom of the furrow, fertilizer application and furrow reclose.

The planting process can be partially or totally mechanized. In the semi-mechanized system “seed cane” harvesting and distribution in the furrow is done manually, being the main advantage of the semi-mechanized system the good uniformity of seed spacing in the furrow; the loading, unloading, transport, covering and the spraying operations are done mechanically. In the mechanized system the planting operations are executed in two phases, in the first the seed cane are billet harvested mechanically and transport to the target field where they are loaded into the planters, and in the second phase all the remaining operations are executed in only one pass of the planter. The mechanical system has significant reduction of labor and operational costs, but it requires more seed to overcome the lower quality of the seed spacing in the furrow.

Chopping the stems into billets presents restrictions in both manual and machine cut, cost and labor availability in the first case and damage to the buds in the second case. In the semi-mechanized system 4 to 8 $t.ha^{-1}$ of seed cane are used, depending on the variety, the planting period, as well as the soil and climatic conditions of the area. Mechanical planting requires almost 50% more seed cane, from 8 to 12 $t.ha^{-1}$, Janini (2008).

The technology of billets distribution used by the available planters in the market results in a quite inferior distribution quality compared with manual planting. The lack of spacing uniformity among billets forces to use larger number of buds per lineal meter of furrow. So that after completing the sprouting processes and elimination by natural competition results a population of compatible stems with competitive levels of productivity and longevity.

Ide (2007) considers that success of mechanized planting is dependent on the solution of existing problems such as furrow opening, uniformity of seed distribution and billet recovering, as well as pesticide application. Some of these factors depend on development of implement technology, such as row parallelism, quantity and quality of buds and covering efficiency. The author points out that these factors deserve attention on the part of the researchers to improve effectiveness of sugarcane planting. The author also considers that it is still necessary to discover the ideal system for sugarcane planting, capable to minimize environmental problems and to improve agricultural productivity.

It is possible to get sugarcane vegetative propagation starting from one bud instead of three. This bud is embed in a small billet treated to avoid pests and diseases and having enough energy to hold the development until the root system takes over. The small billet has a more homogeneous geometry to allow for a more precise metering process. That way planting cost is reduced due to the lower volume of seed to be handled by the planter.

As mechanical harvesting grows, labor moves away from the cane fields during the harvesting season. That way the labor cycle is interrupted during the months of April to November, reducing the man power available for sugarcane manual planting. In general the conventional operations involved in sugarcane production involve work conditions and energy demand progressively less compatible with the amount and profile of rural workers available. The accelerated process of cane expansion turns this labor shortage even more critical.

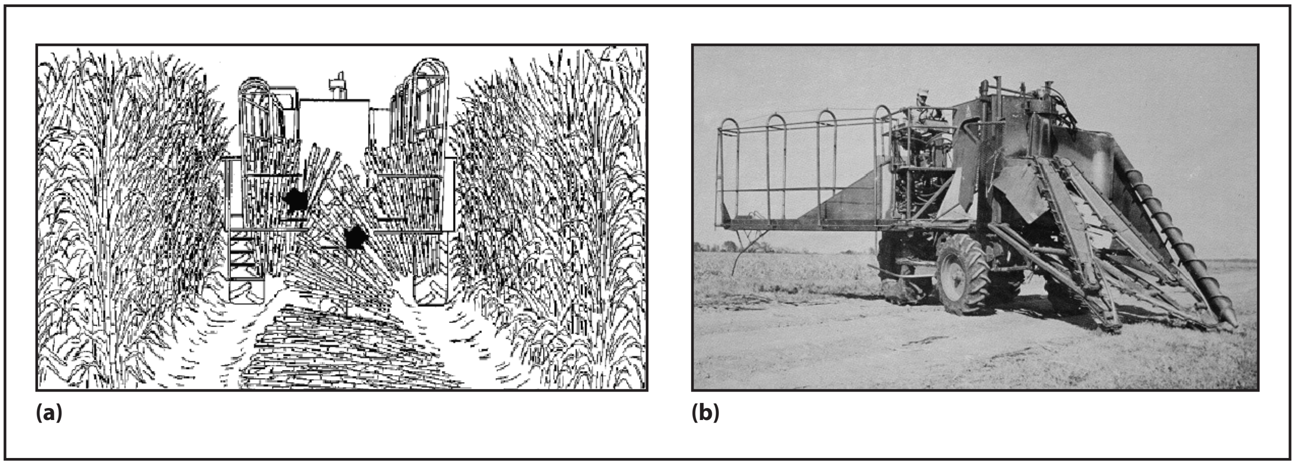
The labor shortage for manual planting and the deficiencies of the available commercial planters turn particularly critical the need for research and development of mechanical processes with equivalent quality to manual planting.

HARVEST

Sugarcane harvest began in a manual way and it stayed like this for five centuries. Social, economical and technological changes in Australia, in the USA and in Cuba created mechanization proposals in the half of the XX century. In all the cases the proposals just required the recovery of the stalk and the straw was eliminated in the most possible economical way, usually through fire, or it was maintained if necessary, for soil moisture content conservation.

Analyzing the existent crop technologies can be concluded that they are not adequate for present requirements in terms of environmental legislation, efficient recovery of the biomass, sustainable use of the soil and capacity to operate in steeper expansion areas.

The sugarcane harvesting process involves the following six main operations: cut of the stalks at the base and at the top; removal of the stalks from an erect or entangled plantation; parallel ordering of stalks; detrashing; and chopping into



Source: CTC.

FIGURE 7 Harvesters that use the "soldier" harvesting principle (Louisiana); (a): two rows; (b): one row

billets or whole stalk orderly piling. Today there is no mechanical device able to execute those operations efficiently, either for chopped or for whole stalk cane.

Three harvesting principles, tested along the last 50 years and with characteristics quite differentiated, reached commercial relevance. One is the process called "soldier ", that picks up the whole stalk, erect or little tilted, not entangled, and maintain them ordered parallel; this system executes the cut at the base and tops efficiently with subsequent ordered conduction of the stalk to a pile formed on the soil. Figure 7 illustrates two models of "soldier harvesters" with capacity to cut one or two rows. The "soldier" process presents important restrictions for the present scenario of the sugarcane industry; they are: the impossibility to remove and order stalks of a tangled plantations; the lack of detrashing function, and the intense trampling resulting from the traffic of harvest, loaders and transport vehicles.

A second commercially tested principles it is the process denominated "push-rake ", developed in Hawaii. It is a whole stalk handling process that has been discontinued for several reasons: cane stalks are disorderly removed from the plantation, inexistent or inadequate base and top cut, low load density in transport vehicles, high mineral contamination, use of fire for detrashing and stool destruction during harvesting.

An intermediate harvest principle, among the previous two, is the billet harvesting that appeared almost simultaneously in Cuba and Australia; this system had as initial objective the substitution of scarce labor and the elimination of the whole stalk grab loading operation by introducing bulk handling of billet cane, in the way it is done for grains. The billet or chopped cane harvesting process executes eleven basic operations on the stalks: cut at the tops; rising and alignment; knockdown; base cut; rising of the bottom end; parallel arrangement; chopping; primary ventilation; transport with side elevator; secondary ventilation and dumping into a side wagon.

FINAL CONSIDERATION

The restrictions of the available technologies for mechanized planting and harvesting of sugarcane are severe, mainly from the stand point of sustainability. They demand research and development of new operational principles as well as exploration and adaptation of scientific and technological solutions available in industrial, military and urban areas. New technologies should be focused specifically on sugarcane instead of just adapting existing mechanization developed for the much larger market of grain crops. The agricultural machinery market is much more attractive and better developed for grain crops, even though the potential environmental impacts of mechanization are much higher in the case of sugarcane. The mass handled per hectare at harvesting is over 20 times higher for sugarcane than it is for grains, while the planted area worldwide is the opposite, about 35 times larger for grains than it is for sugarcane. Breaking this paradigm is a significant challenge.

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SUGARCANE AND STRAW HARVESTING FOR ETHANOL PRODUCTION

Paulo Sérgio Graziano Magalhães and *Oscar A. Braunbeck*

INTRODUCTION

Brazil is currently confronted with the perspective of significant increase on ethanol fuel demand. This forecast is based on three main points: i) the success of flexible-fuel vehicles that can run on any proportion of gasoline (E20-E25 blend) and hydrous ethanol (E100), together with the mandatory E25 blend throughout the country which allowed ethanol fuel consumption to achieve more than 50% market share of the gasoline-powered fleet; ii) Brazilian exports of ethanol (the world's largest exporter) as function of the growing worldwide interest for blending ethanol-gasoline For example, in 2008 Brazil exported 4.85 billion liters, representing 18% of the production, and almost 50% of the global exports; iii) Brazilian option for biodiesel production using ethanol in the transesterification of vegetable oils.

A detailed analysis of the Brazilian ethanol production potential carried out by the Interdisciplinary Center for Energy Planning-NIPE, UNICAMP, shows that Brazil can produce 102 billion liters by 2025 to meet 5% of the projected world gasoline demand if an aggressive research agenda is conducted (CERQUEIRA LEITE *et al*., 2009). This important production expansion can become a reality through the implementation of new plants, opening new sugarcane areas, but will demand, in parallel, a concentrated effort to increase overall productivity e.g. liters of ethanol/ha/year of planted sugarcane. This increase can be achieved primarily through two technological routes. The first route is by improvements in the agricultural phase e.g. introduction of new sugarcane varieties, through the intensification of the current genetic research programs, to increase overall productivity in tons of sugarcane/ha/year. The second route should focus on industrial technologies to allow the integral use of sugar ethanol production, or other renewable fuels e.g. through the development of the biorefinery concept which can add value to whole sugarcane chain by developing new products.

In a new paradigm of "energy cane" sugarcane would be collected (by optimization of the whole harvesting process), optimizing also the energy balance to increase the amount of the overall volume of biomass. In this context, billet sugarcane harvesting, now available, which does not use straw which is burned or left on the soil, depending on the harvesting system, would have to be replaced. One of the principal challenges to make possible the use of this material is the development of an automated harvesting system that contemplates the recovery of straw, at least partially, with acceptable cost and quality of this material as an energy source.

Processes tested up to now for straw recovery involve natural drying, followed by windrowing, baling, loading and transport. The windrowing process is responsible for high amount of mineral material incorporated to the sugarcane trash, which varies between 5 and 10%. The cost of recovery of the trash is over 20 R$/ton. Besides, the harvesting system presently available in the world market does not contemplate mechanical harvesting in areas with slopes superior to 12%, and thus is unviable in small areas, and is not justified economically for farmers that produce less than 100,000 tons of sugarcane annually.

Based in this scenario, in November of 2006 a second Workshop of the series on "Guidelines for Public Policy for Scientific and Technological Research on Bioenergy in the State of São Paulo" was accomplished. The objective of this specific workshop was to discuss the current technological apprenticeship of the of sugarcane and straw harvesting system, bottlenecks, challenges for the next few years and the new paradigms needed to allow the sustainable expansion of the sector.

Four fundamental subjects were discussed:

- Sugarcane harvesting by mills.
- Sugarcane harvesting by independent growers.
- Straw Recovery for energy purposes.
- Break of paradigms in sugarcane harvesting.

Bering in mind the specificities of the theme and shortage of research aimed at solving these issues, the organizer of this event invited speakers and panelists, in addition to researchers, specialists of the productive sector with recognized competence, that could contribute in an effective way to the debate, discussing new ideas and experiences.

SUGARCANE HARVESTING BY MILLS

Unburned green sugarcane harvesting, including stalk tops and transport of the cane to the mills for processing, should receive special attention because of the associated costs and technological development. Until recently sugarcane was burned and harvested manually in Brazil, today this scenario is being changed rapidly without adopting the most suitable solutions to the technical reality (topography, industry, or manual labor). Therefore it is necessary to develop local solutions for harvesting systems and transport that consider local technical, social, economical and environmental conditions.

Even the sugarcane production cycle, today with around five cuts (ratoons) before replanting, initially idealized to maximize the sucrose content, should be reviewed within this new paradigm, seeking to maximize the production of biomass and also to minimize the negative environmental impacts. A prolongation of the cycle associated with a reduction of agricultural operations can reduce substantially the production cost.

Key questions in this area of development:

- How should sugarcane be harvested within 5 years or 10 years?
- Can the current model of harvesting be altered?
- How can harvest losses be reduced while increasing efficiency?
- Why two-row harvesters are not available since they could be use as a strategy to reduce traffic and harvesting cost?
- Is 12% slope the real limit for sugarcane land use when it is mechanically harvested? Is not there engineering technology for off road vehicles to increase this limit up to 30%?

Sugarcane harvesting in the current, and new expansion areas, will became eventually totally mechanized, leaving just semi-mechanization in areas of difficult access for the harvesters; burning prior to harvest should be completely eliminated within the next few years. This forecast is based on restrictions imposed by the legislation which is restricting the areas allowed to be burnt, difficulties with cane cutters, cost reduction in relation to the semi-mechanized harvesting and to the expansion of the sector.

One of the principal challenges to be overcome by the harvester is its operational limit of 12% slope. The support equipment such as tractors and wagons, do not have that limitation, due to the adjustment allowed to the equipment track width. To be able to implement 100% of mechanization in sugarcane, it will be necessary to have equipments capable to work in fields of greater slopes. The development of harvesters capable to operate in more accentuated slopes has some advantages. One of them is associated with the possibility of the machine to harvest two simultaneous rows, requiring an increase of the track width, improving the stability and making harvesting possible in areas currently restricted.

With two rows, it is possible to increases the harvester field capacity and to reduce the traffic in the field, bringing benefits in relationship to soil compaction and subsequent crop yield. However, difficulties do remain and need to be overcome e.g. increasing the harvester cutting and processing capacity (sugarcane mass for unit of time), associated to losses, visible and invisible, and the quality of the raw material.

Although considerable efforts have been made in the last few years to reduce losses and extraneous matter (vegetable and mineral) presents in the load received at the mill, progresses has been slow and not very significant, with affect raw material quality. Data from the Center of Sugarcane Technology (CTC) in Piracicaba, SP, indicate that the visible and invisible losses during sugarcane harvesting can be as high 10%, while for other crops, such as soya bean, these values are in the order of 1%.

The harvesters currently available in the market are technically old and require a lot of new investment to increase their efficiency e.g. a more efficient system for base cut height control, as a monitoring system to control sugarcane losses, or impurities. Currently the control of these parameters depends upon the communication capacity between the sugarcane reception area at the mill and the operator.

A further improvement is the correct control of furrow opening to receive the cane stalks for billet planting. These can help to improve the mechanical harvesting quality, contributing to the reduction of sugarcane losses, ratoon damage; and extraneous matter incorporation. The adoption of the precision agriculture in the sugarcane planting, cut and loading system can contribute in a significant way to the efficiency of the production system.

Energy cane requires that harvesters are adapted to harvesting varieties with different characteristics from the current ones. In order to recover trash for energy generation some mills are collecting stalks and trash, and transport to the mill where a dry cleaning station separates the sugarcane from the trash. If that tendency is maintained the project of the harvester should be revalued. The reduction of the engine power, due to lower demand of the cleaning mechanism, is also one of the alternatives.

From the environmental and economic point of view it is necessary to reduce the soil compaction during harvesting. The harvesting equipment consists of a single row harvester, with a 350cv engine weighing up to 20 ton, which cuts the stalks at ground level and delivers cane billets into an infield wagon unit alongside the harvester, weighing up to 30 ton when fully loaded, pulled by a 180cv tractor weighing 10 ton. The result is that each inter-row is trafficked twice by the harvester and at least twice by each wagon (usually there are two wagons connected) and a tractor. The result is poorly matched equipment with crop row spacing and single row harvesting with considerable potential for soil compaction, adverse effects on crop yield, reducing the longevity of the sugarcane filed and forcing to accomplish the subsoiling operations during replanting. Traffic control is one of the possible solutions to overcome this problem; other alternatives include re-design of harvesters or the development of a totally new sugarcane harvesting system.

Improvements of the harvesting process should also include new and improved genetic varieties more suitable for mechanical harvesting. The development of semi mechanized systems to facilitate manual cutting could also be an option in areas in which the harvester is not the appropriate solution. This will contribute to minimize the social problem originating from of the rapid mechanization of sugarcane. Within the next 10 to 15 years technological progress should make possible to harvest mechanically even in today restricted areas.

HARVESTING BY SUGARCANE INDEPENDENT SUPPLIERS

Mechanization represents the best option for sugarcane harvesting, from an ergonomic, economical and environmental point of view, since it makes feasible green sugarcane harvesting, including trash use for energy purposes.

Today concept of sugarcane harvesters were originally developed in Australia by Austoft, and later widely copied by other companies. The machine cuts the cane at the base of the stalk, chop it in billets, remove the leaves blowing the thrash back onto the field and transfer the cane into a transporter that runs aside. There are small variations depending on the manufacturer e.g. feeding system or transport of the material inside the harvester.

For about 20 years the evolution of mechanical harvesting in Brazil was slow, it suggests that this is a quite restricted and uncompetitive market. For example, the original high price and maintenance cost, makes this option unfeasible for the small and medium growers.

Key questions in area of development:

- Should sugarcane independent suppliers continue to exist in the future?
- Which are technological requirements to harvest unburned sugarcane?
- Do smaller harvesters based on existent technology solve the problem?
- Are sugarcane mechanical harvester contractors a feasible solution?

Data from the 2008/2009 sugarcane crop season (Ministério da Agricultura, 2009) shows that 61.8% of all sugarcane processed in Brazil comes from areas managed by agro industry units (mills) (even if part of these production areas belong to partners), 39.2% of the processed cane are produced by independent suppliers. The size of the area cultivated by the suppliers varies from 20 ha up to 4,000 ha.

Orplana represents 26 associations of sugarcane growers in SP, MG and MT, with 16,406 producers, and 125.5 million tons of sugarcane produced in the 2008/2009 season, or 24.9% of the sugarcane produced in the Center-South region. The farmers from Piracicaba-SP region are an example of difficult area for sugarcane mechanization. They have a predominant Kandiuldult and Lithic Hapludoll soils with high slope. It is a traditional sugarcane production area, with 3,072 independent suppliers producing in an average area of 39 ha.

Recognizing the importance of the sugarcane suppliers CTC has been contemplating the support and technology transfer to this group and counted in 2006 with 13 growers associations as members of the CTC. Those entities answer for 400,000 ha of sugarcane distributed among 12 thousand growers.

Under the present scenario sugarcane expansion it can be concluded that growers should continue to exist, because:

- there is an interest of the mills for the sugarcane produced by independent suppliers (relationship cost-benefit);
- the sugarcane supplied by independent farmers presents quality at lower costs;
- there is a predisposition from the mill to increase the amount of sugarcane supplied by independent farmers;
- the independent farmers create more jobs and improve income distribution.

Most of the suppliers have low investment capacity besides having difficulties in creating a production cooperative or harvesting cluster. On the other hand the contractors are usually more capitalized and have operational involvement with the mills, what facilitates the logistic planning and usually employ more specialized labor to operate tractors and harvesters. The cooperatives and associations that until now have been focusing in political-social issues, begin now to discussions technical aspects, relative to harvesting mechanization. These cooperatives of suppliers could be potentials contractors.

The green harvest technology to be made available to the growers should consider environmental issues, labor availability, cost and efficiency of green sugarcane manual harvesting as well as the handling of the straw. The current harvesting equipments are large and designed to fit large areas. Smaller harvesters, (i.e of smaller field capacity) do not solve the problem, because some technological problems, such as the harvester efficiency, soil compaction and need of systematized areas remain.

Sugarcane growers are reluctant to new technologies, but mechanical harvesting will be adopted for economical reasons, independently of the pressures for the maintenance of job.

STRAW RECOVERY FOR ENERGY PURPOSES

The present processes of manual or mechanical harvesting seeks the use of the stalk only. The harvesting process includes a sequence of simple operations; the cut of the base, and the top of the stalk; piling up of the stalk (manual harvesting) or cutting it in billets (mechanical harvesting). In both cases the use of the straw is not part of the harvesting process.

The harvesting process is suffering modifications as function of legal and environmental restrictions, associated with the increasing interest in the use of the straw for other applications, such as cogeneration and vegetable mulch for conventional or organic horticulture. A new concept of sugarcane harvesting process, that seeks the integral use of the plant, involving additional operations for separation and compaction of the straw is being developed.

This approach has other implications such as lower cane losses, and less mineral contamination of the straw when compared to the conventional process of manual and mechanical harvesting. It is important to highlight the efforts accomplished by users and equipments manufacturers to adapt the sugarcane harvester the new reality, the success has been partially and everything indicates that principle of those equipments need to be reformulated to face the new demands of integral harvesting of the plant.

With that perspective becomes pertinent to discuss the new propose that turns the green sugarcane harvesting more attractive than the burned sugarcane harvesting, as a form of consolidating its implementation without the pressure of the law or of the environmentalists. It is important to reminding that the current process inefficiencies will increase as the sugarcane production growth.

Key questions for development:

- How to harvest the sugarcane and the straw in an efficient way? Whole? Billeted? At what cost? With what level of mineral and vegetation impurities?
- Does the harvesting of integral sugarcane demand the construction of dry cleaning stations? Are these stations efficient? Are they economically viable? The transportation cost is justified?
- How to make feasible the straw transportation for large distance?
- Are the current levels of soil compaction generated by the traffic of harvesters, tractors and wagons compatible with no tillage farming?

Sugarcane trash is composed of the material left in the field after harvesting, which includes the straw (green and dray), soil, weeds, tops and roots. In a study done by CTC, Tufaile Neto (2005) shows that moisture content of trash varies between 13.5 and 82.3% depending on its composition; the ash content, carbon free and volatile materials do not vary a lot among its components; and the higher heating value (HHV) does not vary significantly as function of the sugarcane variety or age.

According to Ripoli *et al*. (2000) a ton of trash is equivalent to something between 1.2 and 2.8 barrel of oil equivalent (BOE), and the yield per hectare is around four to nine tons of dry matter. Consequently the non use of trash means energy waste.

Manechini (2005) evaluated the problems and the benefit of maintaining the soil covered with the mulch originating from sugarcane trash. Among the benefits they detach the protection to the soil against erosion; reduction in soil temperature variation and protection against direct radiation; increase of the biological activities; better water infiltration; better water availability due to smaller evaporation; and better control of the weeds. Some disadvantages mentioned by the authors are: fire risk; difficulties of doing mechanical cultivation during or between seasons; delay in ratoon sprouting and consequent decrease of the productivity; and increase in the population of pests that benefit from mulch for protection and reproduction. The authors attempted also to define which would be the minimum amount of residue that should stay on the soil to obtain the maximum agronomical benefits from mulching. They led experiments during a three to five years period, in three different plots in the state of São Paulo, analyzing the effect of different trash percentages (100%, 66% 33% and 0%) left in the field after mechanical harvesting. They analyzed the population of weeds with different initial degrees of infestation. The authors concluded that with 66% (about 7.5 t/ha/year, d.b.) the probability of getting similar effect of chemical herbicides is high. In relationship to the sugarcane yield, the authors did not come to a final conclusion. They observed that with the increase of trash in some cases there was a pol per hectare reduction, but this variation probably is more related to sugarcane variety, climate, degree of pest' infestation, among other, suggesting that futures works should be conducted.

Trash represents an option to increase the biomass availability for cogeneration at the mills. Most of the Brazilian mills already began a process of optimization of the thermal balance of their plants, with the objective of marketing the cogenerated energy surplus. Today, the installed potential for power cogeneration using bagasse is 90 kWh/tc. This potential is not entirely utilized as function of the energy sale price. The remuneration system now used by the mills for payment of the sugarcane to suppliers is not encouraging integral harvesting, necessary to produce surplus material for cogeneration. To help reaching the benefits longed for the "energy cane" it is necessary to use the fiber content and not only the sucrose content in the formula for producers' remuneration.

The potential cogeneration capacity of the sugar-ethanol industry sector is 30 million MWh/year, which represents 9% of the energy generated in Brazil in 2006. The sector can increase even more its cogeneration capacity, with no need for additional investments in new plants by making available, at relatively low cost, the straw resulting from green cane harvesting.

The use of the straw for energy proposes is not a simple system ready to be used; it demands financial and technological solutions. A great current difficulty is related to conditioning, handling and transporting this material from the field to the thermo electrical plant.

Some well succeeded initiatives already exist in the way of handling straw for energy purposes. Several systems to remove trash from the field were already tested such as bulk transport of straw and billets, round, square and cottom bales of trash. Studies developed by Esalq in partnership with Cosan Industries indicate that bulk handling of straw and billet, also called the integral system, offers the lowest recovery cost. This results were confirmed by Michelazzo (2005) that accomplished a cost sensibility analyzes for several methods of straw and trash recovery. An important aspect to be considered when doing straw or trash recovery analysis is the level of contamination with mineral residues.

The tendency is the introduction of specific equipment for trash recovery, other than the current sugarcane harvester. The cane harvester configuration could be simpler if the cleaning blowers were eliminated by adopting the integral system of billet and straw handling. Stationary dry cleaning station would be used at the mill to separate the straw from the billets.

The companies specialized in cogeneration solutions are already making available projects for mills interested in taking advantage of the straw cogeneration. The system considers that the thermo electrical plant should work during almost the whole year, and not just during the harvesting season. This implies in the production of safe and reliable equipments for steam generation condensation.

It is probable that in the near future some mills will make investments for the integral use of the sugarcane (sucrose, bagasse and straw) to produce exclusively energy, opting for no sugar production. The new technologies in study for ethanol production through hydrolyze of bagasse have fundamental impact on the speed at which these changes take place.

BREAKING THE PARADIGMS OF SUGARCANE MECHANIZATION

To overcome some barriers existing in sugarcane agricultural some technological changes should be tried. The straw should be considered a product to be harvested with similar priority as cane stalks. Sugarcane planting should move to no-till farming in order to become more sustainable in terms of protecting the soil as well as the social and economical investments that are being done in this sector.

Currently sugarcane is planted in rows spaced about 1.5 m. Harvesting is conducted with a single row harvester, which delivers cane billets into in-field double wagons pulled by a tractor that runs alongside the harvester. The result is an intense traffic on the inter-rows that are trafficked twice by the harvester and at least twice by the tractor and the wagons. The traffic condition becomes more severe as a result of the existing miss-match between crop row spacing and the equipment, each having different track width (~1.8 m), mostly wider than the crop. About 60% of the soil surface is heavily trafficked yearly. These conditions promote low operational performance and higher operational cost besides a strong potential for soil compaction which contributes to force replanting every 5 years.

Reducing the traffic most likely would reduce the need for ploughing, subsoiling or disking operations allowing a gradual implementation of no-till farming. Well succeeded long term commercial results in grain production as well as field trials of sugarcane under minimum tillage done by CTC in the eighties showed that this agricultural practice could bring sustainable cost reduction, soil conservation and yield increase. The controlled traffic approach based on permanent traffic lines combined with wide track width equipments (above 8 m) would allow to have higher traction efficiency for the wheels combined with non compacted soil for the crop. This combination is particularly important specifically for sugarcane where approximately 400 ton are produced and handled over a 5 year cycle, from plant to plant, different from grains where about 3 ton are harvested and transported in a cycle. This concept has great potential to be applied on the less steep uniform fields of the sugarcane expansion areas in Brazil.

This concept was successfully tested with in the USA, Israel and Canada, but it did not reach a commercial stage mainly as a result of the sugarcane small market size as compared to grains. The main driving force for investments in mechanization technologies comes from the agribusiness related to grain production. About 700 million hectares are devoted to grains worldwide, but just 22 million to sugarcane.

Key questions in mechanization development for sugarcane:

- Is it possible to break the paradigm of traditional sugarcane mechanization?
- What benefits an alternative mechanization could bring to the sector?
- What is the land size of a sugarcane that would benefit from this technology?
- What companies could be interested in manufacturing this equipment and what would be the cost?

The present technology for sugarcane harvesting is based on the social, economical and technological conditions existing in Australia, USA and Cuba in the middle of the 20th century. In all those cases the harvesting principle was focused on the recovery the stalks, eliminating the straw in the most economical way, usually through burning, or in the case of green sugarcane, the straw was maintained for soil conservation.

The main principles tested for sugarcane harvesting along the last 50 years are:

- **Soldier or Louisiana system** that harvests the whole stalk, windrowing them on the soil, parallel to each other. It executes the base cut and the topping efficiently and can only cut green sugarcane as leaves assist the chains to grab the stalk. There are no straw removing devices in this machines and the green cane is pilled in windrow to be burned on the ground before it is grab loaded into wagons or trucks for transportation.
- **Push-Rake system** that cuts and grab loads whole stalks totally disordered, without cutting the tops, with low load density and with destruction of the stool during the harvesting operation.

- **Billet system** can be considered a more resourceful solution as compared to the previous two. It became available more or less simultaneously in Cuba and in Australia with the intention of replacing scarce labour and to eliminate the grab loading operation, necessary in the systems that handle whole stalks.

Five important reasons turn the present scenario significantly different from the existing one in the historical moments described above:

1. The product to be harvested is not only the stalk but the straw as well.
2. The socio economic conditions of the sugarcane areas turned labor limited.
3. There exists a good knowledge on the characteristics and performance of the several harvesting systems already tested.
4. Risk and development cost are nowadays lower. Several engineering tools are available which are capable of modeling, simulating and optimizing the phenomena involved in the development of new harvesting prototypes as well as in the process of taking them into commercial products.
5. Genetic engineering should accelerate the development of new sugarcanes varieties with grater yield, consequently taller and more difficult to be harvested using the current technology.

Present harvesting technology does not seem to be adequate when analyzed from the stand point of the following factors:

- environmental legislation;
- efficiency of biomass recovery from the stand point of quality and losses of both straw and stalks;
- sustainable use of the soil;
- capacity to operate on expansion areas considered topographically inadequate.

Some paradigms about mechanical harvesting prevail among the technicians, users, manufacturers and machine dealers as described below; they must be broken if better harvesting approaches are to be introduced.

- **The base cutter must be attached to the harvester feeding system (main frame)**

The double disk base cutter used by chopper harvesters performs two functions simultaneously: base cut and stalk feeding. This combination makes difficult to improve each function without affecting the other. This mechanism is wide and heavy, with slow dynamic answer in the process of following the soil surface; it has a cutting profile inadequate for the furrow profile; it promotes movement of large volume of soil and demands proportional hydraulic power to drive the disks. It is desirable that the base cutter performs only the cutting function, using just one disk, similar to the configuration used by the Louisiana soldier harvester. This simple alteration would sharply reduce the energy demand, will have better adaptation to the soil profile, will have less mass and consequently better flotation capacity on the soil surface and will be able to discharge soil particles laterally instead of feeding them on to the incoming stalks. The single disk base cutter allows harvesting multiple rows at narrower row spacing conserving the advantages described above, just installing an independent disk for each row.

From the above considerations it can be conclude that the problems usually allocated to the base cutter are in reality problems associated with the stalk feeding process, i.e. difficulties to extract the stalk from the plantation and to place them inside the harvester.

- **One row harvest**

Even if the base cut can be solved satisfactorily through the use of an individual floating disk for each row, it remains to develop an appropriate solution to feed the stalk into the harvester after the base cut is completed. In present chopper harvesters the base cutter with double disk participates in the feeding process facilitating the entrance of the base of the stalks into the first pair of feeding rollers. It can be anticipated that the single row harvester paradigm could be broken if a feeding system was developed able to remove the stalks from the plantation after the base cut is done that would leads them to a parallel arrangement before entering the chopper or a storage container in the case of harvesting whole stalks.

- **Maximum land slope is 12%**

The restrictions that hold back the operation in steeper areas are associated with the harvester stability to the overthrow and lack of directional control. The restriction of stability can be solved increasing the width of the harvester by harvesting a larger number of rows. The restriction of directional stability can be solved through the use of four-wheel drive and steering. This resource allows for compensation of the lateral drift or slip angle resulting from soil and tire deformation caused by the side weight of the machine running on a steep terrain. Hydraulic or electric transmissions can be used to facilitate individual steering of each wheel. With relationship to the capacity of a tire to generate traverse forces as a function of the wheel angle is verified that angles in the order of 5 degrees are enough to generate traverse forces of the order of 50% of the weight, in other words, enough to balance the weight components, for steepness of up to 30%.

- **Separation of stalks and extraneous matter should be pneumatic**

The pneumatic cleaning system used by billet harvesters depends on the cut of the stalk and leaves and subsequent separation using the differential terminal velocity principle. This system presents restrictions that make the separation of leaves just partial, always remain 5 to 6% of vegetable extraneous matter (EM) among the billets to be delivered to the mill.

A promising way to break this paradigm is to harvest integral sugarcane. A partial cleaning in the harvester associated with a stationary dry cleaning station at the mill seems to be the most appropriate combination; this reduces biomass losses in the harvester and allows to adjust the amount of straw recovered for energy proposes, leaving in the field only the amount of straw necessary for weeds control as well as conservation of soil and water.

- **Trash should stay on the soil**

The straw, the stems and good part of the tops are processed simultaneously in the harvester. At the pneumatic separation chamber the trash is thrown onto the soil and the billets are transferred to the infield wagon. In the current concept of "energy cane", where large expansion of the planted areas is foreseen, the need to reformulate this paradigm will arise so that the straw, that represents approximately one third of the cane energy, could be recovered with cost and quality adequate for energy use.

Three important changes can be pointed in the processes of straw recovery that would contribute to accelerate its energy use: the increase of straw density for transportation, a reduction of the handling cost and a reduction of soil contamination.

- **There is no alternative to reduced the intense traffic of machines in the inter rows**

The necessary traffic to make possible the current system of sugarcane and straw harvesting demands soil tillage at replanting. This traditional soil management approach opposes the principles of no-till farming that has showed positive results for other extensive crops such as soybean, corn and wheat with cost reduction and increase of sustainability. Billet harvesting and hauling processes represent the principal impediment for implementation of the no-till or minimum tillage approaches. The elimination of the traffic in the cultivated areas would allow a progressive reduction of soil tillage to finally reach the no-till stage.

The paradigm of intense traffic in the inter row can be appeased through the use of multiple row harvesters and standardized track width for all the equipment used for in field operations. A more radical traffic decrease could be obtained by introducing specific mechanization for sugarcane based on controlled traffic and wide track width machines.

The six paradigms discussed above block the technological development of sugarcane harvesting and hauling in the following aspects:

- reduce cane losses and extraneous matter content;

- harvesting green sugarcane with no economical difference in relationship to the burned harvesting;
- reduce mechanization cost;
- reduce investment for harvested ton of sugarcane;
- reduce topographical restrictions;
- reduce costs for straw recovered;
- increase sustainability of the sugarcane production.

The paradigm of traditional mechanization can be broken through new investments for research and development in some fundamental points such as: cane stalk cutting and feeding processes, reduction of biomass losses; new approaches for straw recovery; field traffic reduction; yield maps generation and analysis; soil property maps on fine GPS grid; new varieties fitted for low traffic and new demands of quality for integral energy cane.

The solutions here proposed are different for each productive sector. Feeding and detrashing processes, simple and efficient, operating with whole stalk cane can assist growers with areas smaller to 1,000 ha. Multiple rows harvesters mounted on wide frame structures operating under controlled traffic can be used, with the advantages described above, in units with areas over 10,000 ha.

The multiple row harvesters or even the wide frame structures have a potential market in the order of 5,000 machines. In Brazil there is a large number of sugarcane producers, planting and harvesting more than 10,000 ha. The wide frame structures are simple machines, primarily composed of steel structural pieces and of machines elements such as engines, tires, hydraulic, electric and electronic components. This size market and type of equipment may not be interesting for the traditional tractor and harvesters manufacturers, but they can be produced by other manufacturers of agricultural machines.

FINAL CONSIDERATIONS

On the subject of “Sugarcane and straw harvesting for Ethanol production” the following conclusions can be withdraw.

- There is no disagreement on the need of investments to improve mechanization of green sugarcane harvesting, for both, large and smaller producers, and that available technology does not attend the user’s expectations in several aspects:

1. lower operational cost;
2. capable to operate on steeper land;
3. capable to harvest more than one row at a time;
4. less soil compaction;
5. capable to harvest stalks and straw for energy uses.

- The sugarcane independent suppliers, which are usually less capitalized, need lower cost equipments for mechanization.
- To consider straw as a co-product of “energy cane” an adequate technology for recovery should be made available.
- Several technologies available in other areas of engineering could be used to improve the performance of harvesting and hauling process, reducing the operational costs and improving sustainability aspects of the ethanol production.
- The creation of a consortium among the private and public sectors could help to joint research and development resources required to create innovative technology for this sector.
- Government investments are required for the development of new high risk technologies.

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14

INSTRUMENTATION AND AUTOMATION IN THE SUGARCANE-ETHANOL CHAIN:

SOME OPPORTUNITIES FOR AGRICULTURAL MANAGEMENT

Ricardo Yassushi Inamasu and *Ladislau Martin Neto*

PRECISION AGRICULTURE

General aspects

Agriculture is a highly complex production system when one includes the production of a live system in a live medium, interacting with the environment and society. Capacity and technology are fundamental for the effective planning, management and operation of all the aspects of agriculture. The viability and sustainability of the chain depend on the efficiency of the entire system.

Mechanization has been an essential tool in the process of expansion and large scale production. Due to the intrinsic characteristics of Brazil's sugarcane cultivation, as well as the absence of importable solutions, the country's sugarcane sector has made exceptional efforts to adapt and innovate its operations using planters and harvesters.

Precision Agriculture – PA was considered a step forward and even a refinement of the conventional process. The first phase of PA focused on machines equipped with GPS – Global Positioning Systems, and productivity maps. The world today has advanced on the theme beyond the cultivation of grains, and the concept is also applicable to crops that display spatial variability. The objective of PA is to manage spatial variability and maximize economic return while minimizing the effects on the environment. Therefore, PA can be considered a management strategy that uses information technologies to compile data from multiple sources and support decisions about vegetal production.

The application of Precision Agriculture is founded on three steps: reading, interpretation and action, which closes the circle. Reading is characterized by the indexation of the parameter of interest in a geographic position, i.e., the data contain additional parameters such as geographic coordinates (latitude and longitude), as well as other information such as historical data (time).

Geographically indexed data can be interpreted and analyzed by means of maps and supported by geostatistical tools. Studies of the spatial dependence of information and correlations with other parameters require thematic maps and a huge amount of data. Therefore, Geographic Information System – GIS, tools are part of the arsenal integrated to Information Technology – IT.

The first data that impressed everyone were productivity maps. The instantaneous productivity-related information stored with its respective geographic coordinates (latitude and longitude) enabled production maps to be drawn up. The initial interpretation of these maps was intuitive. Areas of low productivity were easily recognized and delimited. The impact on the results of the property was immediate if the cause of low productivity was easy to solve. The first machines equipped with harvest monitors were grain combines, favoring advances in the PA of corn, soybean and wheat cultivation. These were followed by efforts to devise productivity maps for other crops, since this was believed to be the most important parameter for guiding crop management actions. Current efforts are focusing on understanding quality-related parameters. Although higher economic returns are sought by increasing quality or production, it is also possible to strive for the rational use of inputs such as fertilizers and agrochemicals in general. The process of identifying subareas with their respective input needs has advanced substantially, as in the case of soil fertility and weed infestations.

Advances in the use of PA in sugarcane cultivation have been more modest that in corn cultivation, despite the technological advantage of sugarcane for ethanol production. The market availability of harvest monitors for combines is recent (MOLIN and MENEGATTI, 2004) (MAGALHÃES and CERRI, 2007) and a commercial response is not yet available, since the number of machines operating in the field is still insufficient.

Very likely due to the difficulty of obtaining tools and support to aid in measuring spatial variability in crop performance, the use of PA in sugarcane has been limited predominantly to soil correction. This involves recommending the application of inputs at varied rates based on a sample composed of two or more hectares, which has reported resulted in significant savings in fertilizers (MENEGATTI *et al.*, 2008; BARBIERI *et al.*, 2008; SANCHEZ *et al.*, 2008). PEZETO *et al.* (2008) and BARBIERI *et al.* (2008) report the successful use of topography as the basis for determining management zones and for guiding sampling and recommendations for soil correction.

The role and potential of automation in the agricultural process

The role of automation has been to replace human labor in the quest for greater efficiency and competitiveness. Despite the ongoing search for innovative technologies to maintain the competitiveness of sugarcane cultivation, there is still much room for conventional mechanization to advance in the stages of cultivation, planting and harvesting, as discussed even before automation arrives on the scene.

However, with Precision Agriculture, errors that were considered negligible in view of magnitudes in the field become significant. Overlapping applications of inputs and gaps left by machines begin to be registered. Operational quality becomes economically measurable. Field monitoring and measuring processes tend to intensify, which requires qualified labor that is scarce in the Brazilian work market. Thus, there is a potential for automated sensing.

In our reality, automation tends to involve the search for quality and minimization of errors. Another important role of Precision Agriculture is in inputs savings. Inputs can be applied at varying rates provided there are automated machines that can apply them according to a recommendation map or the indications of an on-the-go sensor.

Challenges of instrumentation and automation for the sector

Precision Agriculture has required the development of a substantial number of instruments for automation, as reported by AUERNHAMMER and SPECKMAN (2006). Remote sensing techniques, soil sampling strategies, GPS and GIS, among many others, are being adapted and developed for agricultural use. More recently, the use of reflectance sensors to observe some light spectra has proved feasible for identifying nitrogen levels (SCHARF and LORY, 2000), organic matter (ANOM *et al.*, 2000), insects (MICHELS *et al.*, 2000), and invader plants (BILLER and SCHICKE, 2000), among other correlatable factors, by means of light scattering spectroscopy. In addition, new instruments such as Veris[1] for measuring and mapping soil electrical conductivity have appeared on the market.

The use of on-the-go sensors is one of the major targets of industry and research in this area. The technique is employed during farming activities to inspect or monitor the crop, aiming to avoid additional operational costs. However, it is not always applicable, and cases such as monitoring pests, diseases, nitrogen levels in plants, and other variables of the cultivated area require the use of ground-based instruments in the plantation, which greatly hampers efficient sampling. For example, to build a soil property map with a resolution of 20 meters in an area of 200 hectares requires collecting 5 thousand samples, making the process unfeasible if carried out by hand.

[1] Available at: <http://www.veristech.com>.

Allied to this reality are other factors such as the high cost of labor, aging rural populations without prospects of renewal, the need to minimize the exposure of workers to unhealthy activities, and concerns about the conservation of environmental balance. All these factors have motivated and justified research on mobile agricultural robots by several groups such as KEICHER and SEUFERT (2000), REID *et al*. (2000) and TORII (2000). The need for environmental preservation and recovery, in particular, has led to a growing number of researches in this area. Works such as those of HAGUE *et al*. (2000) and BLACKMORE and GRIEPENTROG (2006) have proposed viable solutions for the development of semi-autonomous or autonomous agricultural machinery that allows for more precise operations to reduce costs and minimize the environmental impact of farming tasks such as the application of agrochemicals. Moreover, mobile agricultural robots can dispense with elements of "comfort and ergonomics" and the costs of the electronics required for the construction of such vehicles are becoming increasingly accessible. These electronics include microprocessors, video cameras, digital communication, and GNSS receivers, among others.

For the aforementioned reasons, companies such as AGCO and John Deere have searched for solutions to render viable the technologies of mobile agricultural robots. Moreover, the international standard ISO 11 783 for electronics in agricultural machinery and implements includes characteristics for the use of navigation devices (AUERNHAMMER and SPECKMANN, 2006). In his conclusions about electronic trends in Precision Agriculture, AUERNHAMMER (2004) cites the potential of robotics in farming machinery and implements for agricultural operations in the search for efficiency.

Photographic services by satellite and aircraft have also emerged on the market, including the recent appearance of unmanned aerial vehicles – UAVs, for photographic services for the construction engineering sector. Significant advances have been made in the last few decades. The various studies and contributions to remote sensing methods have made it possible today to gain a better understanding of how the reflectance and emittance of leaves change in response to the leaf's thickness and age, the plant species, the shape of the crown, and the plant's nutritional and moisture status. The presence of chlorophyll and its preferential absorption at different wavelengths provides the basis for the use of satellite broadband radiometric platforms or hyperspectral sensors that measure narrow-band reflectance. Understanding the reflectance of leaves leads to different vegetative indices to quantify a variety of agronomic parameters of plantations, e.g., foliar area, vegetative cover, biomass, type of crop, nutritional status, and yield. Canopy emittance is a measure of foliar temperature and infrared thermometers have enabled the creation of crop stress indices currently used to quantify water needs. In the case of sugarcane, there is still a lack of studies and of a methodology to determine spatial variability.

Communication networks have proliferated in digital electronic systems embedded in a variety of vehicles and installations. Nevertheless, despite the existence of accepted and adopted solutions, the recent development of wireless sensor networks may further expand the presence of electronic technology in the field. The use of radio or infrared data transmission instruments in the agricultural environment became widespread several decades ago. Today the market offers several options of climate stations and automated irrigation systems that use these means of communication. The obvious advantage is the extremely easy installation and maintenance of wireless systems operating in the field. However, in face of the possible applications of what has been dubbed pervasive or ubiquitous computing established by means of wireless sensor networks distributed in the field and crossing borders, the benefits will be uncountable (WANG *et al*., 2006). The practice of PA in the current models allows for potential savings of inputs and less environmental contamination, but this positive impact can be even more significant if the control of processes such as spraying is aided by an ample grid of wireless sensors monitoring plants, soil and environment with real-time spatial information.

The adoption of Precision Agriculture requires a change in management attitudes and a shift to observing variability as one of the elements to be considered and managed. This attitude is considered by many as a natural paradigm shift, but this change requires commitment and heavy investments. An investment is not made if the return is considered uncertain or if the moment is not the right one. Opportunities and the return potential for this crop are still being explored, and further research is still needed in order to propose creative and applicable solutions.

The sugarcane sector faces an additional challenge due to the historical and conservative nature of the production system. Despite the evident change in management with the advent of modern and nontraditional companies in the sector, the field is still managed in a way that can be considered traditional and fearful of a too radical change. Therefore, the large majority of companies only absorb well-known and economically proven technologies. The sector's participation in breaking paradigms or developing long term knowledge is scanty, but it is the role and challenge of Science and Technology to involve the sector so that it increases its innovation potential through knowledge.

The advent of PA brought into play a relatively large number of electronic instruments for aiding navigation and for the application of inputs. Electronic technology embedded in agricultural machinery has evolved very intensively in the wake of other sectors. The computational power available for the new machines allows for integration of agricultural operations with the company's Information System. Interchangeable electronic connections and automatic recognition of active functions in tractors and implements may become common mass-produced instruments. However, what one sees is the manufacturer's proprietary solution resulting from his efforts to meet the demand. This leads to the creation of incompatible equipment and file formats.

Online connections in the field with machines produced by different manufacturers would make it possible to carry out coordinated operations in real time, reducing unproductive time, eliminating unnecessary costs, and increasing efficiency. This would only be possible if there were a single standard of communication. The ISO-11783 protocol is being drawn up with this approach. The potential for use of the standard is real, since it is of interest to the entire chain.

Standardization of embedded electronics

Worldwide efforts have focused on standardizing electronics embedded in agricultural machinery. Since the advent of Precision Agriculture, the standardization of information and communication system data between electronic devices has been pinpointed as a challenge to be overcome so that the technology can be widely adopted (INFORMATION, 1997). Groups composed predominantly by manufacturers of agricultural machinery in Europe and the U.S. have dedicated their efforts to drawing up the ISO-1178 code (also known as the ISOBUS). The objective of this standard is to promote a standard interconnection of electronic devices embedded in agricultural machines and implements through a serial control and communication network. In 2009, eleven of the fourteen parts foreseen for the standard had already been published. Each part specifies important topics for the interconnection and covers not only the specification of connectors and electric values but also the communication between intelligent elements, composing them into a multipoint digital network.

Although the protocol has resulted in complex and voluminous details with specifications ranging from the motor to file formats, the network will work transparently for the user. All the user will have to do is switch on the agricultural machine, connect it, and insert the file without worrying about possible incompatibilities between manufacturer models. The immediate implication this protocol brings to automation in the sugarcane chain is the reduction of its implementation cost and the possibility of installing a more up-to-date technological system. Therefore, standardization precludes the possibility of the sector being obliged to accept an obsolete and outdated technology. As with any protocol of this nature, this one is also not closed and the committees are prepared to receive contributions. The sector has the opportunity to point out the peculiarities of sugarcane cultivation

FIGURE 1 Comparative images of a tractor with proprietary solutions – left, and with ISOBUS – right, presented by Hans Jürgen Nissen of John Deere AMS Europe in 2007.

and to dictate an international standard for sugarcane production. Figure 1 illustrates the interior of two tractor cabins presented by Hans Jürgen Nissen of John Deere AMS Europe at the ISOBUS Workshop 2007 in Brazil[2]. The image on the left is of a cabin with panel installations of various implements. Because it is a proprietary solution, a display/command is installed for each implement. The cabin on the right shows an ISOBUS solution in which both the display and commands are reconfigured for a new compatible implement. The solution tends to involve a lower final cost.

Agricultural robotics

Lastly, robotics is one of the emerging technologies in Precision Agriculture, with a strong potential for application in all the stages of sugarcane production.

The areas under development, such as autopilots, embedded electronics (standardization) and information systems, channel and potentiate robotics technology toward the search for greater precision in agricultural operations, operator safety and higher quality in the field and of the material delivered to the mill.

The autopilot system is expected to evolve rapidly to automation of headland maneuvers and to synchronization of the harvester with the transshipment. Robotics technology can be employed to improve the harvesting process, rendering it more selective using less power. Efficient mechanisms, sensors and actuators for removing stalks during harvesting and planting are a challenge to be overcome with a great deal of creativeness. Robotics may help handle these elements productively.

Consonant with the development of soil and plant moisture sensors, remote sensing and image interpretation technology, applications are being developed for aerial robots (Unmanned Aerial Vehicles – UAVs) or even land robots (Autonomous Agricultural Vehicles – AAVs). In other crops and other countries, factors such as the extremely high cost of labor, aging rural populations without prospects for renewal, the need to minimize the exposure of workers to unhealthy activities, and concerns about the conservation of environmental balance have driven and justified research into robotics. The need for environmental preservation and recovery, in particular, has led to a growing number of researches in this area. Authors such as

[2] ISOBUS Workshop 2007 in Brazil, http://www.isobus.org.br/workshop2007.

HAGUE *et al*. (2000) and ÅSTRAND and BAERVELDT (1999) have presented viable solutions for the development of semi-autonomous or autonomous agricultural machines that allow for more precise operations to reduce costs and minimize the environmental impact of farming tasks such as the application of agrochemicals. One should also keep in mind that a robot can dispense with elements of "comfort and ergonomics" and that the costs of the electronics required for the construction of an autonomous vehicle are becoming increasingly accessible. These electronics include microprocessors, video cameras, digital communication, and GNSS receivers, among others.

As mentioned earlier, large tractor manufacturers such as AGCO, John Deere and Yanmar have pursued solutions to render AAV technologies feasible. The ISOBUS standard for farming machines and implements foresees requirements for the use of guidance devices and autonomous navigation systems (JAHNS, 1997). In their conclusions about electronic trends in Precision Agriculture, AUERNHAMMER (2001), PEDERSEN *et al*. (2005) and BLACKMORE *et al*. (2008) cite the potential of robotics in farming machines and implements for agricultural operations aimed at efficiency and quality. Figure 2 shows a conception of AGCO presented by BLACKMORE *et al*. (2008), which was also featured on the cover of the October 2008 edition of the journal *Crop, Soil, Agronomy News* under the teaser "the future of Precision Agriculture". The article cites features such as agility, nocturnal activities and the ability to perform a large number of repetitive operations accurately. The reality in the sugarcane sector is no different. Monitoring crop quality (soil and plant status, insect and invader plant populations) to identify the need for interventional actions is a potential.

Source: BLACKMORE, 2008.

FIGURA 2 Artistic conception of an agricultural robot.

UAVs and AAVs are low-impact tools since they are light and can perform tasks that would involve high costs if carried out by manned vehicles.

OPPORTUNITIES FOR RESEARCH INTO INSTRUMENTATION FOR HANDLING STRAW

Issues of global climate change are of great interest and represent major challenges for life on Earth. In general, these issues have been decisively influenced by the consumption of nonrenewable fossil fuels, which have contributed to increase the concentration of carbon gas in the atmosphere and augment the greenhouse effect. Therefore, the sugarcane-ethanol theme is directly connected to the issue, since it represents a feasible alternative, especially in Brazil, for the production of renewable fuel such as bioethanol. However, it is vital for the productive system to use conservation farming practices in tune with sustainable development. One of the relevant changes taking place in agricultural management is the extinction of burning during sugarcane harvesting, which is advancing with the use of machines, and which is commonly known as raw sugarcane harvesting.

In mechanized harvesting, a considerable amount of sugarcane straw is now left on the field and the destiny of this material is a current and relevant issue in the improved management of sugarcane production as well as with regard to the complete use of the biomass produced. There is intention and interest in making use of sugarcane straw in the near future by generating bioethanol through lignocellulose conversion, which is an item on the renewable energy agenda of several countries. However, the economic cost of this conversion is still an obstacle to its use. Therefore, the current destination of straw at Brazilian sugar and alcohol mills has been to leave it in the field instead of burning it to generate steam and electrical power at industrial plants. The recovery and transportation of straw still presents challenges due to the large volumes of low-density material that are produced. However, it should be pointed out that leaving sugarcane straw on the field may have an extremely positive effect on the soil and on management, since this material can keep the soil covered, minimizing the impact of raindrops and hence of erosion. Moreover, upon decomposing, part of the straw biomass may remain in the soil and become incorporated as organic matter, recycling part of the nutrients and improving the soil structure. Nevertheless, evidences of potential benefits such as increased soil organic matter (which could represent soil carbon sequestration) and the ideal quantity of straw to be left in the field, among other aspects, are current challenges for research. In this context, several Brazilian groups and institutions already use equipment and techniques to monitor organic matter and changes in soil and its properties in field conditions, such as aspects of fertility, including increased cation exchange capacity and nutrient availability, soil compaction, water retention and infiltration etc. (MARTIN-NETO *et al*., 1998; VAZ *et al*., 2001, 2005).

With regard to issues related to soil organic matter, a series of researches have been conducted using advanced instrumentation such as elemental analyzers (CHNS), chemical and physical fractionation of soils, spectroscopic methods such as electron paramagnetic resonance, nuclear magnetic resonance, UV-Vis fluorescence, and laser-induced fluorescence etc. These researches have provided fresh information in studies about soil organic matter content and quality under different types of management, including no-till farming, application of sludge and effluents from sewage treatment plants, crop rotation, reactions with pesticides and heavy metals, effects of precipitation on the humification of organic matter etc. (MARTIN-NETO *et al*., 1994, 1998; BAYER *et al*., 2000, 2004, 2006; MILORI *et al*., 2002, 2006; PEREZ *et al*., 2004, 2006). More recently, SEGNINI (2007) and MARTIN-NETO *et al*. (2008) have reported an increase in soil carbon content in areas of pastureland and sugarcane in comparison with reference areas, demonstrating the potential for soil carbon sequestration. This is an indicator that points to the high sustainability of production systems, especially as they relate to issues of augmented greenhouse effects. Thus, future researches on the agenda of the development of the production system of the sugarcane-ethanol chain, instrumentation and automation tools will be used more systematically and will be able to bring to light new information about the behavior of soil and its key constituents, such as organic matter under different types of management with different quantities of straw left on the field, crop rotation, especially in the replanting of sugarcane, among other relevant aspects.

INDICATIONS OF OPPORTUNITIES FOR RESEARCH INTO PRECISION AGRICULTURE, AUTOMATION AND INSTRUMENTATION

In summary, there are numerous opportunities for the application of precision agriculture, automation and instrumentation in the sugarcane-ethanol chain, such as:

- soil and plant sampling and monitoring;
- imaging techniques;
- harvest monitoring using sugarcane quantity and quality monitors;
- cultivation interventions, such as the application of solid and liquid agricultural inputs;
- cultivation, which includes the design of new machines;
- the use of course-planning autopilots;
- mathematical and computational resources to use all the information;
- environmental assessments;
- use and application of agricultural and agro-industrial by-products;
- development of tracking sensors and tools for traceability;
- development of the ISOBUS as a fundamental aspect to expand versatility in the use of equipment from different manufacturers;
- automation of sugarcane irrigation, which is needed in several regions in Brazil;
- more efficient Brix analyzers;
- planter sensors;
- the use of advanced instrumentation methods for studies of the dynamics and reactivity of organic matter and soil properties as a function of straw handling in areas of raw sugarcane harvesting, and in crop rotation.

This is a set of actions with the potential to expand and capitalize the sector, and the channeling of public and private investments is expected to increase the number of opportunities in instrumentation and automation.

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15

TRANSPORT LOGISTICS OF RAW MATERIAL AND WASTE OF SUGARCANE

Oscar A. Braunbeck and *Efraim Albrecht Neto*

STALKS

The transportation of sugarcane basically involves transport of stalks from the field to the industrial plant where they will be processed. In Brazil, cane transportation is done predominantly by road. Trucks used in the transportation of cane carry wholestalk sugarcane or billeted cane, depending on the harvesting system used. Silva (2008) states that the transportation of cane is integrated along with the harvesting and loading operations forming what is called the harvest, load and transport system "CCT", responsible for the continuity of the milling rate.

Logistic operations

The CCT logistics is considered as the management of equipment, human resources and information necessary to deliver cane from the field to the mill's cane discharge zone, at a uniform mass flow rate using the available cane transportation fleet, operating the closest possible to full milling capacity, with varying crop yield and transportation distances along diferent production areas. According to Chiarinelli (2008) the challenge of CCT logistics, is to keep the mill in constant operation, in a condition that could be considered as just in time, working with very low machinery idle time, a cane stock close to zero, and each operation fully depending of the activities before and after it. It is common, in some plants, occurrences of discontinuity between the delivery of cane to the mill and the milling operation throughout the day due to miss-control of timing, resulting in traffic queues at the cane discharge zone. In other words, accumulation of excessive cane stok in the discharge zone and increase of the idle time of the cane transportation fleet, with corresponding reduction in transportation capacity.

Transport logistics involve both agricultural and industrial variables of the company, in addition to those inherent variables of transportation itself. Harvesting planning and the sugarcane reception system at the mill, are part of the dynamics of transport management.

Agricultural area

During the harvesting season sugarcane mills operate in a continuous process where the cane is supplied from several production areas known as "harvesting fronts". Regardless of the harvesting system used, manual or mechanized, these units are responsible for harvesting and loading the stalks in trucks and trailers for transportation to the mill. The "harvesting fronts" are strategically located so as to have an average weighted transport distance compatible with the fleet capacity.

Manual harvesting

In the manual harvesting process, cane cutters generally select and grab 4 or 5 stalks at a time and cut them at the base with a machete. Stalks are then gathered in piles aligned perpendicularly to the harvested lines, with a roughly parallel configuration among the stalks.

FIGURE 1 Loading of whole stalk harvested sugarcane.

This phase of the harvesting process has strong influence over the sugarcane transportation fleet performance as the parallel configuration of stacked stalks enables to reach higher cargo densities thereby enhancing performance of the transport operation. To reduce machine traffic on the cane stools the stacked stalks are positioned over the center line of a five row strip.

After the sugarcane stacks are formed the hydraulic grab loaders pick-up the piles and load them into a truck or wagon that follows by side of the loader (Figure 1). The loading operation is an important part of the transport logistics due to the significant amount of time dedicated to this operation as well as the delays associated with truck queues at the loading zone and time spent by loader in positioning maneuvers in the field. Lately the use of combined cargo vehicles (CVC) is becoming increasingly frequent in loading operations, these combinations require additional auxiliary operations and machinery such as coupling and uncoupling of trailers, extra tractors and trucks which demand extra time and also contribute with additional delays inherent to these operations that also should be considered as part of transport logistics.

It is important to remind that manual harvesting can also be carried out on green cane, but the performance of the workers drops dramatically, increasing the cost of both harvesting and loading operations as a consequence to the lower tonnage harvested and the low density of the cane grabbed by the loaders.

Mechanical harvesting

Mechanical harvesting of sugarcane can be accomplished by both whole stalk cane harvesters and chopped cane harvesters which are able to harvest both burnt and green cane when compared to whole stalk harvesters that can only harvest standing burnt cane. While whole stalk harvesters leave the harvested stalks in the field to be picked-up during subsequent loading operation, chopper harvesters simultaneously load the billets into the accompanying transport vehicle.

Today chopper harvesters are responsible for all the mechanically harvested cane in Brazil. Loading of billet cane has been consolidated through an internal transportation system of intermediate self tipping wagons which are loaded by the harvester on-the-go and then moved to a transfer zone outside the harvested areas where the load is transferred to the transportation trucks as shown in Figure 2.

FIGURE 2 (a) Self tipping wagon getting the cane from the harvester; (b) side dumping to the truck.

Mechanical harvesting significantly changes the logistics of cane transportation since the beginning of harvest planning, frequently there is no burning of sugarcane and transportation follows simultaneously the harvesting operation. In this case logistics should consider the interactions of harvester with wagons and road trucks (CVC). Interactions between these equipments involve loading and unloading time, waiting time and maintenance delays.

Industrial sector

The main task in the mill's industrial sector relative to cane transport logistics consists in unloading the cane loads brought by the trucks. This procedure is pretty much the same among most sugar mills. According to Silva and Alves (2003) when the trucks enter the mill they go through a scale to measure the loaded gross weight and about 30% of them follow to a procedure for load inspection called Technological Analysis, where a probe takes samples of the loads to determine its quality. Trucks are chosen randomly for this procedure, only exception being the loads from external cane suppliers that have all loads analised for payment procedures. After weighting and quality analysis the trucks head for discharge procedures, in this phase loads may be discharged directly into the mill feeding conveyor or left in the yard for storage. After unloading, billet trucks head directly to the weighting scale to measure the trucks empty weight. Wholestalk trucks go through a cleaning process of soil and cane stalks form the bottom of the body before they head to the weighting scale. After the empty weighting the trucks return to the field to begin a new cycle.

Delays of trucks standing idle in the cane discharge zone could be a consequence of an over sized transportation fleet or an error of logistics planning with negative impacts over investment and labor costs. If the fleet is optimally sized, the line up of trucks in the discharge zone implies in their absence in the field which causes a harvesting interruption followed by a later lack of cane at the mill.

Evolution of the sugarcane transportation

According to Chiarinelli (2008) factors such as low density loads, bad operational conditions and excessive return time of the trucks to the field contribute to increase the cost of cane transportation. Another issue concerning transport efficiency is the field average displacement to the mill. According to Macedo *et al.* (2008) recently the average field distance is estimated in about 20 km it will grow to around 30 km. The average displacement of the transportation trucks is directly related to the overall efficiency of the transport operation, in other words, when trucks operate in short distances the cycle time involves a larger number of

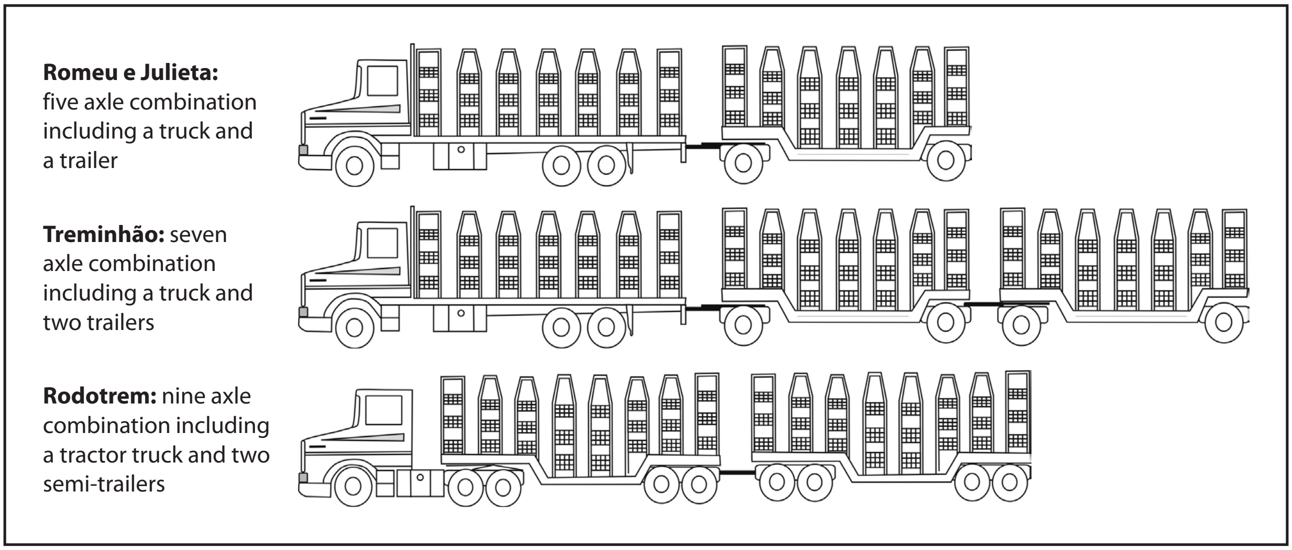

FIGURE 3 Transport combinations of track and trailer used for cane transport.

loading and unloading times during the day which makes it a critical point to the transport logistic management model.

The bulk density of the truck loads is another variable that significantly impacts transport efficiency. As it frequently happens, it is the volume and not the weight the legal limiting factor to truck load capacity. The chopper harvester can affect significantly bulk density of loads through the billet length the chopper is adjusted.

Combination Vehicle Load – CVC

The ethanol industry has evolved considerably in recent decades regarding cane transport equipment. Cane transportation was formerly done with two axles trucks carrying a load close to 10 tons per trip. Today tractor trucks using trailer combinations are used to transport a load of about 60 tonnes per trip working with up to nine axles. The transport combination to be used depends on factors such as the distances from the fields to the industrial plant and the conditions of trafficability over the roadway network. Currently there are three configurations or of track and trailer combinations : they are the "Romeu e Julieta", the "Treminhão" and the "Rodotrem" (Figure 3) with load capacities of approximately 30, 45 and 60 tonnes respectively.

According to Silva (2008) the greatest advantage of "Rodotrem" is the high load capacity and the operation versatility of the "bate volta[1]" system, which maximizes the use of the tractor truck. Moreover, the advantage of the "Treminhão" is related to the larger number of hitch joints, which allows it to operate in areas with restricted space and smaller turning radius. An additional advantage of "Treminhão" is that in regions where there are restrictions for the use of long compositions during the night, when releasing the second trailer, 66% of the cargo is still transported, against only 50% of the load in the case of "Rodotrem", when releasing the second semi-trailer.

On internal roads of the agricultural area, out of state or federal highways, some mills use track-trailer combinations where the truck pulls simultaneously more than two trailers, going up to 10 trailers in some cases. These combinations are used only on roads that do not have sharp turns or steep slopes. Besides the technological evolution of CVC's significant advances related to truck bodies have also ocurred, such as weight reduction and body desin focused on reduced cane losses during the trip.

Considering the limitations imposed by the Brazilian legislation over transport vehicles, both

[1] No stop tractor truck.

restricting the allowed load per axle and the over all dimensions, it seems unlikely to achieve significant gains of transport performance through research and development in the near future, especially when comparing this sector to those less developed and with greater earning potential, such as harvesting and planting.

Logistics operation

Considerig that the auxiliary time spent for loading and unloading trucks diminishes the performance of the transportat fleet, the mills adopted the system known as "Bate e volta" to reduce auxiliary times and increase the performance mainly of the tractor tracks. In this system the trailers are detached from the trucks and pulled by agricultural tractors during the loading and unloading operations, remaining only the accountable time of coupling and uncoupling at the field and at the mill, in the transport cycle of the truck. In this case, once the truck arrives at the harvest front, the trailers are unleashed and the truck passes ahead of the other equipment to be loaded, when this process is completed the truck moves to where the loaded trailers are coupled to it. In the case of mechanical harvesting tractors pull the self tipping wagons that take the cane from the harvesters to the trailers parked at the load transfer area. This logistic operation is particularly effective for shorter transport distances where the auxiliary time represents a larger fraction of the total cycle time.

The data associated with transport, harvesting, plantation and mill unloading are part of the database used for the optimization of transport logistics, helping to choose the location of the harvesting fronts so that the average distance of transport is compatible with the available capacity of the fleet and the average distance of the sugarcane remaining in the field is still compatible with the available fleet, even at the end of the season when the harvesting and transport capacity are reduced. The maturation of the sugarcane and crop yield are also involved in the design process and logistics management.

Diesel oil consumption

According to Macedo *et al*. (2008) the fuel consumption for operations involving the production of one ton of sugarcane during the season 2005/2006, was 2.64 l/t (diesel oil). The same author also points out that the consumption corresponding to transport, for a distance of 23 km, was 0.87 l/t. It thus appears that transport accounts for about 30% of the diesel used throughout the agricultural cycle.

With the growth in production of sugarcane the average distances of transport will increase gradually and the fuel consumption per ton of produced sugarcane will do the same. However, with the introduction of the CVC´s with large capacity, and increased efficiency the fuel consumption becomes less pronounced. This trend can be seen in Table 1 which shows the evolution of the distances and energy efficiency of trucks in two seasons, and a scenario for 2020.

The fuel consumption of diesel engines used for sugarcane transport is optimized within the standards of last generation of engines commercially available. In this line of evolution a possible improvement would be the replacement of diesel oil by ethanol. This alternative was implemented in the 1980s in several mills, mainly using additivated ethanol in conventional diesel engines or bi-fuel

TABLE 1 Evolution of the distance and energy efficiency of trucks.

Parameter	Units	2002	2005/2006	2020
Distance	km	20	23	30
Efficiency	$t/km/L^{-1}$	49.0	52.4	62.0

Source: Macedo *et al*. (2008).

engines with pure ethanol and a smaller fraction of diesel fed through a second injection pump for ignition. However, due to the lower cost of diesel oil these changes were interrupted. Presently, price trends are just the opposite so the new scenario opens again the possibility of using ethanol, even if only for the fleets owned by the mills. This would require engine development to make the necessary adaptations and ajustments.

Another option to reduce fossil fuel consumption would be the use of electrical transmissions in local roads with high traffic density, within the mill agricultural area and using co-genetated electricity.

Management operations

The management of sugarcane transportation is subject to interactions of several variables such as weather conditions, load density, fleet size and maintenance program, conditions of the roadway network, location of the harvest fronts; average distance from the mill and the harvesting areas, among others (Chiarinelli, 2008). New information technologies are essential to integrate efficiently the management of the harvesting, loading and transportation operations, with a systemic view of the process. Traditional methods treat each subsystem separately, or use average equipment performance values to manage the systems.

Transport logistics involves the synchronization of operations between the various areas of agriculture and industry. New technologies involving the automation of decision support processes, for example, the dynamic allocation of the trucks destination at the exit of the weighting scale, depending on the variables described above, contributes to achieve the objective of supplying sugarcane to the mills with lower cost and environmental impact.

Dynamic management

The technologies focused on agricultural remote sensing are in the process of adjustment and consolidation in the agricultural market, showing more reliability and efficiency. Telecommunication technologies allow monitoring the machine position in the field, making it possible the management processes in real time. The satellite technology and GPRS for real time monitoring of machines and vehicles is becoming progressively more accessible, both for equipment and services.

Obtained information is analyzed through accurate processing resources (GIS) and specific mathematical models that are linked to the corporate databases facilitating consultations through time and space to generate reports including complex relational information.

The new mobile communication technologies and long-range field agricultural systems process real-time information that traditionally would take days to become available.

An example of that is the proposition for monitoring and control of CCT by Cerri *et al.* (2008). The proposition is a simulation model for monitoring historical parameters of the area and events of the harvesters, trucks, and industry operation to perform the automatic dispatch of trucks with feedback in real time, using mathematical models based on spatial-temporal data. According to the authors, in addition to continuous monitoring, the proposed system allows the integration of agricultural and industrial information with logistics.

Need for research and development

Despite the limitations imposed by legislation on the size and configuration of transport compositions to increase load capacity of sugarcane transportation vehicles, research can still be focused on other types of vehicle, lighther structural materials and higher load densities to obtain reduction of cost and environmental impacts.

Most available systems for on-line data transmission prioritize the use of the communication by phone instead of via satellite due to the lower cost of transmission by phone lines. However, the satellites network (Iridium) ensures full coverage in remote areas where cellular communications does not. Therefore public policies focused on preferential tariffs for traffic information in the agricultural sector as well as funding for installation of towers GSM/GPRS in agricultural areas and creation of technical courses for training and retraining of personnel are desirable for the sector.

The large number of agricultural and industrial variables involved in establishing and operating the complex logistical process of sugarcane transportation demands a great deal of research and the development of algorithms and methodologies for collecting and analyzing data of the various parts involved in the process. These data are related to the transportation fleet, the structure for sugarcane reception at the mill, the sugarcane age and maturation curves, the climate and soil data as well as the conditions for of sugar and ethanol marketing throughout the harvesting season, among others.

According to the discussions presented in this article it can be stated that performance of sugarcane transportation has significantly improved as a result of contributions of intermediate transportation of sugarcane, mainly by reducing idle time of the equipment involved in the process. It is also possible to state that there still is a great potential for performance improvements in transport logistics through development and application of information technology resources.

CANE TRASH

The trash of sugarcane can be used as soil cover or fuel for power generation. Given the evolution of no-till farming for grains and the increasing demand for renewable energy it is suitable to think that in the near future, the use of trash should pass through both these paths. The fraction of trash agronomically used that are left on the field during harvest, does not require logistical arrangements for their handling. The rest of the trash must be separated from the stalks, transported and stored so that finally, during the period between harvest seasons, be loaded, transported and unloaded at the mill boiler or used in processes of fuel production.

Currently there are a few alternatives to the logistics of trash recovery that are an adaptation from the handling of livestock forage, considering that the trash volumes processed in this activity are much lower than those involved in the energy utilization of trash. This contributes to a high cost of trash recovery operation in large-scale mainly as a result of the low efficiency in the processes of collection, separation, compaction, size reduction and storage concerning this technology. Only the transport of the trash is made with high capacity vehicles, with load volume within the limits prescribed by law and for that so leaves the density as the resource to be optimized.

The recovery of trash has been practiced by two ways, first releasing them through the harvester over the soil forming a layer exposed to the sun. In the second path, the stalks, trash and some of the pointers are launched by the harvester to the transport vehicles, without contact with the soil, which is called an integral harvest, and later the stalks are separated at the plant, using a dry cleaning station. The option of leaving the trash over the soil keeps them in a natural process of drying for about 10 days, which reduces the moisture to about 20% (Ripoli, 2002). After this period the trash is concentrated in piles of higher density, with about 10 kg/m^{-1}*. This operation, called Windrow, has a negative effect on the quality of the material due to the large amount of mineral impurities that incorporates the raking over the soil. According to some authors the content of land incorporated into the trash reach up to 10% in extreme situations. The stacks left on the soil are collected through the processes of gathering and baling or gathering and chopping. In the first case the trash undergoes compactation and the second case a size reduction is performed to increase density of transportation load.

Trash density

The compaction of trash has limitations related to the low density achieved from recovered materials and low operating capacity of the equipment used. It can be consider that the cost of trash transportation decreases inversely to the proportion of the increase in density. There is a need to improve the compactation technologies focused on handling the large volumes of energetic biomass, such as trash. The density of the trash also has a direct relation to the storage costs, a process that is necessary for generating power through the whole year. There are currently several cases of compaction resulting in different densities, with different capacities, and different operational costs and investment demand. In the study conducted by Michelazzo (2005) principles of compaction ranging from zero or spontaneous compaction, and high pressure compaction as used in Briquetting Pellets were considered.

Trash recovery Systems

Among the most tested systems that were used in experiments of trash recovery are the full harvest, baling and chopping the bulk of which only uses the baling process of mechanical compaction.

Integrated harvesting

In this system, the machine harvests with the extractors turned off gathering stalks, trash and pointers all together. The mixture of stalks and trash are transfered to transporting wagons which then transfer them to the transportation trucks. The trash is then transported to the Mill where the stalks and trash are separated by a dry cleaning unit, through pneumatic and mechanical separation performed by polygonal rotating disks. One of the problems of this system is still the lack of processes and equipment to do the cleaning efficiently with acceptable sugar losses. Sotelo and Correa (1999) observed in a dry cleaning facility that the amount of trash separated was about 50 kg per tonne of processed cane. The dry cleaning facility is a Center of cane reception and cleaning used in Cuba, where the trash is reduced in size and separated by strong air currents. The composition of trash found by the authors was: tips, green leaves and shoots (59%), straw (28%), fragments of sugarcane (9%) and others (4%).

Baling

The trash left on the soil by the harvester is gathered and collected by the baler, which performs the compression of low pressure, with lashing, using a rod-crank or roller mechanism. The bales are released by the baler and remain in the field to be loaded later on and transported to the storage location. The bales can be lightweight, allowing the manual handling as traditionally practiced in the treatment of animals, or may be greater burdens that require mechanical handling. The CTC (1999) conducted studies which indicated that the use of large, prismatic bales (density of 170 kg/m^3), generates the best economic results in the recovery of trash. This results from the greater baling operational capacity and better volumetric occupation in the truck during transportation. In general, baling of the trash has the disadvantage of requiring a chopping process when the trash is intended for burning to improve the uniformity of feeding conditions for combustion in the boiler.

Chopped bulk

The trash left on the soil by the harvester is gathered and later on collected by the forage chopper, which reduces the size to pieces about 1 cm length, launching it to the transportation truck directly by its own inertia. This process of fine chopping with inertial loading does not involve the compaction thus resulting in a low load density of 85 kg/m^{-3} (Ripoli and Ripoli, 2004, Franco, 2003 and Ideanews, 2002). Carriers load the trucks that transport the chopped trash to the storage location.

The two alternatives described above for trash recovery, leaving trash on the soil or directly loading it in a carrier results in products with different qualities in terms of mineral impurities content. Logistics of trash recovery should consider whether the use will be the direct combustion or fuel production. Both options have different quality requirements associated with the impurities and microbiological processes developed during storage.

Performance of recovery systems

Considering that there are no consolidated logistical arrangements for handling trash, technically and economically defined, results of two techno-economic studies which address the main options that could be used for the trash recovery with the available technologies will be presented and analyzed. In the first study, the Sugarcane Technology Center (CTC), in a Project called Report BRA/96/G31, considered three alternatives listed below for mechanical harvesting of sugarcane:

Alternative 1: in this system the harvester keeps the extractor fans operating and the trash is left over the soil. Then, the spread trash is gathered and later on collected by baler that will leave the bales along the harvested areas. These bales are loaded in a truck using a hydraulic grab loader and then transported to the mill where they are shredded and fed to the boiler furnace.

Alternative 2: in this system, the harvester keeps the extractor fans off, so that the trash and sugarcane stalks are harvested together. Both are transported by transportation trucks to the mill's dry cleaning facility.

Alternative 3: the process of trash recovery is very similar to Alternative 2, however, the harvester works with the secondary extractor off and the primary operating at reduced speed. This configuration allows only part of the trash to be left in the field, thus performing only a partial cleanup.

The alternatives described above present quite different costs of trash recovery. Table 2 shows the cost of recovery about the three alternatives studied, one can observe that the cost of alternative 2 is superior to the others. This comes as a result of two factors, first the lower density of stalks and trash mixture results in higher transportation costs and secondly, the criterion of cost allocation that was adopted in the study by which any increase in transportation costs resulting from lower density is allocated to the trash, since it is a part of the load with a tonnage far below the stalks.

In the second study Michelazzo (2005) simulated the recovery of trash through a simulation model involving cost efficiencies and operational capabilities of each recovery system through the concept of maximum efficiency of the equipment according to the trend that followed mechanization of sugarcane cropping in the last decade. The study uses machines for windrow, collecting, consolidating, loading, transporting and reducing size of trash. The author considered the six systems listed below:

System 1 (bundling): in this system the trash is gathered and collected by the baler, through which it performs a low pressure compression, with lashing, using engine belts and rollers instead of the baler plunger. The bales are released by the baler and remain in the field to be loaded later on and transported to the storage zone, next to the boiler. At the time of burning, the bales are shredded to enhance combustion efficiency in the boiler.

System 2 (chopped bulk): in this system the trash is gathered and collected by the forage harvester, reducing the size of the trash and then by inertia loads the carrier until it reaches capacity so they can then load the transport trucks.

System 3 (briquetting): in this system, the process of windrow, chopping and internally transporting system is similar to the bulk chopped handling. After being raised and chopped by the forage harvester, trash is transferred to the carriers, transported through a short distance, and fed directly in the field into a briquetting press, which

TABLE 2 Cost of recovery of trash a (US$/t).

	Alternative 1	Alternative 2	Alternative 3
Trash put the plant*	9.61	23.23	2.74
Separation of trash and sugarcane	–	2.79	3.69
Processing trash	0.89	0.85	1.14
Total cost	10.50	26.87	7.57

* For alternative 1 is included the following: Windrow, baling, loading and unloading and transport. For alternatives 2 and 3 operations are: internal transport (bus) and transport to the plant (trucks).

Source: Report BRA/96/G31.

performs a high pressure compression, without lashing it with robes, using a rod-crank mechanism. Once hardening, the trash in the form of briquettes is transported to the mill by trucks.

System 4 (Pelletizing): this recovery system is equivalent to the trash briquetting, described above, only changing the configuration of the press to a continuous compression process, with the aid of helical coils that compress and force the material through a matrix perforated with enough compaction pressure to maintain the cohesion of the trash fibers making it unnecessary to use lashing to tie the trash blocks formed in the process.

System 5 (cotton bale): this recovery system is also equivalent to the trash briquetting, described before, only changing the configuration of the compression process. The piles are raised and the chopped by forage chopper and then transfers the material to carriers which then transfer the trash to a cotton stuffing machine in the field, in this case the carrier uses a feeding conveyor to uniformly transfer the trash to the Cotton Stuffing Machine. This machine operates in an intermittent process of low pressure compression by means of hydraulic pistons. The burden's own weight, due to its large size, ensures the maintenance of the higher density, thus not requiring lashing. The burden is transported to the mill by a self loading truck also called "roll on – roll off".

System 6 (integral harvesting): in this system, the harvester is harvesting the cane stalks together with the trash, keeping the extractor fans off. The mixed stalks and trash are transferred to carriers which then transfers to the transportation truck that takes the mixed material back to the mill where it is separated in a dry cleaning station.

This study adopted a trash yield of 20 t/ha with a withdrawal rate of 50%, so the amount of trash collected was 10 t/ha. The characteristics of compacted trash through the different systems are presented in Table 3.

The costs of recovery of trash obtained by Michelazzo (2005) for the six systems operating at a transport distance of 15 km are listed in Table 4.

Comparing the Project BRA/96/G31 and the study of Michelazzo (2005) it is possible to verify that there are 02 systems that were analyzed by both of which are condensed in Table 5. This table compares the cost of baling systems and integral harvesting. The bundling has a lower cost of $ 4.37 at Project BRA/96/G31 as a result of having used a prismatic baler producing larger and greater density of the bale. In addition, the prismatic bales allow better accommodation in the back of the truck and thus the load transported is much higher lowering transportation costs. The difference in cost is then attributed over baler performance and transportation efficiency.

However the study of Michelazzo (2005) presents a complete cost of the integral harvest system less than $ 20.00 to that obtained by the Project BRA/96/G31, this difference arises from the fact that the cost of transporting the whole system was divided among the stalks and trash

TABLE 3 Characteristics of dense trash by different processes.

Features	Round bale	Cotton bale	Briquette	Pellet
Density (*kg m*$^{-3}$)	170	160	1,000	1,200
Weight (*kg*)	231	10,000	2.4	0.01
Volume (*m*^{3})	1.36	62.5	0.002	0.00001
Height (*m*)	–	2.5	–	–
Width (*m*)	–	2.5	–	–
Length (*m*)	1.2	10	0.30	0.035
Diameter (*m*)	1.2	–	0.10	0.01

Source: Michelazzo (2005).

TABLE 4 Cost recovery of trash.

Recovery system	Cost (US$/t)
Baling	14.87
Stuck bulk	13.74
Briquetting	49.02
Pelletizing	28.67
Cotton bale	18.41
Integrated harvesting	6.87

Source: Michelazzo (2005).

in proportion to the tonnage of each component, in other words, 20% of the cost of transportation refers to the trash and 80% refers to the stalks. In the methodology adopted by the Project BRA/96/G31, the trash is penalized with all the extra cost of lower efficiency of transportation caused by the presence of trash.

Regardless of the criteria adopted for the calculation of costs is evident that the presence of trash affects the load density and that efforts should be focused on developing innovative technologies for the logistics of trash recovery to make this energy source more attractive and capable of winning economic space in a near future. The trash is still considered only as an impurity with no potential to generate economic benefits. The advances in technologies for production of a second generation of bio-fuels and valorization of renewable electric energy should also contribute to the economic feasibility of trash recovery.

Storage of cane trash

Trash conversion to energy, either in direct combustion processes or production of other fuels, requires storage to enable energy production out of the harvesting season.

Storage of trash for burning at boilers must consider properties such as density, moisture and impurity contents. Trash stored for hydrolysis must retain the chemical composition of fiber: lignin, cellulose and hemicellulose. The higher the amount of cellulose and hemicelluloses preserved in storage the higher will be the amount of ethanol produced. There are some technologies used for storage of agricultural forages that can be used in the case of cane trash. The most common options are stacking in the open, silo-bags, trench silos and inflatable canvas structures. Each alternative has different characteristics in terms of demand of labor and handling equipment, investments, land surveying and final product quality.

The storage of trash in the open is similar to what is currently done for bagasse. The silo-bag is widely used for agricultural storage of grains and forages in temperate climates. It may become a viable alternative for trash. The canvas inflatable structure is used by sugar mills for storage of sugar.

Some alternatives for trash storage were analyzed in a study done by CGEE (2007). This work considered 6 scenarios in order to identify those having the best cost effectiveness. The analysis contemplated the productivity, demand for investment and operating costs of a model distillery, using data provided by manufacturers of agricultural implements and machinery and the results presented in report BRA/96/G31.

Three storage conditions were studied by CGEE: trash stacked in the open; stored in canvas inflatable structures and stored in silos-bag. Two harvesting systems were considered for trash recovery: integrated harvesting and transportation of cane-trash mixture later separated by a dry cleaning station at the mill and conventional baling of trash recovered from the ground surface.

To determine the final costs of trash the CGEE study took into consideration the cost of trash operations used for collection and transportation from the field to the mill, obtained in the BRA/96/G31 report. The costs of storage and transportation from storage to the mill were simulated together with the cost of the storage structures.

TABLE 5 Comparison between the cost of trash in the studies presented (US$/t).

System recovery	Michelazzo (2005)	Report BRA/96/G31
Baling	14.87	10.50
Integral harvesting	6.87	26.87

The total cost of trash recovery for all scenarios is presented in Table 6.

The study concludes that trash density is the factor that most influence the final cost of storage and handling. Operational cost of storage in conjunction with capital cost of structures also contributes significantly to the cost of trash. The simulation study did not considered trash losses occurring during storage. Open storage has cost significantly lower than covered storage. Specific studies on mass losses and quality of trash for alternative systems of storage is needed. It will assist in choosing the appropriate type of handling and storage system for direct combustion or fuel production.

Closing remarks

The equipment available for the logistics cycle of cane trash was designed for production volumes much lower than those required to produce biomass energy. There is a high number of operations and related equipment participating of the logistics cycle. High-capacity equipment, operating in continuous processes for recovery, compaction, loading, transport and storage, in many cases involving new operating principles, are necessary to make the cost of trash recovery compatible with the market prices of electricity or bio-fuels. It should be noted that even if the trash allocated to the practice of no-till farming does not involve logistics processes there is usually trash in excess to be used for bio-energy and it requires logistics improvements.

Integral harvesting of trash and cane is currently the system with the lowest total cost available. However, further studies are needed to examine properly the increase of cane transportation costs incurred as a result of the lower load density resulting from trash mixed with cane. Separation of trash in the field, with appropriate density and without soil contact appears as a route of development with good potential to reduce transportation costs of both, stalks and trash. It also eliminates the contamination caused by mineral impurities introduced by the raking operation involved in the baling process.

Recovery processes involving trash disposal on the soil surface for natural drying and adaptation of the trash logistics to existing equipment, such as balers or forage choppers generate high cost and levels of soil contamination. Current technologies

TABLE 6 Total cost of trash recovery and storage for six scenarios (R$/t trash).

Recovery and storage system	Operational Cost (R$/t)		Cost storage structure (R$/t) (simulated)	Total (R$/t)
	Recovery * (Report BRA/96/G31)	Storage (simulated)		
Integral harvesting; Open storage (ρ = 100 kg.m^{-3})	27.67	15.82	0.00	43.5
Integral harvesting; Inflatable canvas (ρ = 100 kg.m^{-3})	27.67	15.82	51.84	95.3
Integral harvesting; Silo-bag (ρ = 200 kg.m^{-3})	27.67	15.23	22.14	65
Baled trash; Open storage (ρ = 200 kg.m^{-3})	37.34	15.03	0.00	52.4
Baled trash; Inflatable canvas (ρ = 200 kg.m^{-3})	37.34	15.03	25.92	78.3
Baled and chopped trash; Silo-bag (ρ = 200 kg.m^{-3})	37.34	20.43	22.14	79.9

* Exchange rate: 2.02 R$/US$; ρ: specific gravity.

Source: CGEE.

for trash recovery must be reviewed looking for improvements in the natural drying process and a reduction in the number of operations involved.

AGRO-INDUSTRIAL RESIDUES

Sugarcane industrialization produces waste materials such as vinasse, filter cake and boiler ashes that require handing operations with varying importance according to the quantities produced. According to the composition of the waste different field applications systems were developed in the form of solid or liquid fertilizer, always focused on reducing costs and environmental impacts. Filter cake and vinasse have high water content so any reduction of moisture content has a positive impact on the cost of transportation and distribution. In both cases the moisture content plays also an important role in deciding what distribution system to use.

Vinasse

Vinasse is a liquid residue of the ethanol distillation process. It is produced at a rate of about 11 liters per liter of ethanol, is the most important liquid effluent of the sugarcane industry. Some positive factors, such as the recovery of potassium, organic matter and water, together with the negative pollutant effect of vinasse make the logistics of distribution on ratoon cane a matter of high economic and environmental importance. The use of vinasse in fertigation requires transport, storage and distribution systems with acceptable environmental impact together with feasible operating cost and investment, at distant areas from the industrial plant. Choosing sugarcane fields eligible for fertigation depends on the topography, the distribution system and the field management strategies adopted. Currently there are companies applying vinasse on up to 70% of the cane fields (Nogueira *et al.*, 2008).

The distribution of vinasse on the soil involves four quite distinct stages: the primary transport from industry to the storage tanks, storage, the secondary transport from the tanks to the fertigated fields and finally the distribution on the sugarcane field. Each phase involves equipment, infrastructure, manpower and management techniques focused on economic and environmental goals that are the essence of logistics for vinasse distribution. The primary and secondary transport can be made by road transport or pipeline, using fossil fuel or electric co-generation. These are systems using different physical operating principles which in turn have different energy efficiencies and require different investments according to the nature of the equipment involved. Storage of vinasse is done in strategic locations according to the areas scheduled for fertigation and considering primary and secondary transport infrastructure available together with the application infrastructure and the harvesting schedule, always keeping in focus the increase of the fertigated area.

Transport and distribution of vinasse

Vinasse transportation to the fields can be done by tank trucks, pipelines or a combination of both. Different energy consumption per unit of transport can be achieved depending on the transport principle involved. According to Menezes *et al.* (1984) the energy consumed by tank trucks is mainly associated with the rolling resistance of tires on the road. In the case of the pipelines, energy consumption is mainly associated to the friction between the particles along the pipe.

Transport by tanker trucks

The transport tanks attached to trucks or trailers have been used since first began the vinasse fertigation process at the mills. Tanks mounted on trailed or semi-trailer carts can operate in the mode “bate e volta” (non stop) allowing only for the trailers to remain parked in the field during the application with travelling irrigator reels or during discharge into storage tanks. The tanks currently available in the market can have different configurations with volume capacity in the range of 16 to 45 m^3, built in fiberglass with high resistance to corrosion, Figure 4. The rapid spread of the tanker trucks transportation system in the mills and distilleries throughout the country can be explained by the simplicity and versatility of the system. The truck is able to execute all the operations involved in the logistic of the vinasse distribution cycle, all the way from the collection at industry to the application on the fields.

The logistics of vinasse distribution performed entirely by truck has some limitations related to operating costs and soil compaction caused by vehicle traffic on ratoon crops. According to the characteristics of the areas of each company there is a maximum distance economically feasible for vinasse fertilization.

Pipeline transport

Pipelines may be buried or set apparent on the ground surface, or even elevated for crossing roads or waterways. Closed underground ducts allow large amounts of fluids to be transported safely, reducing surface traffic, and facilitating the movement of farm machinery and transport vehicles for sugarcane, inputs and residues.

According to Luz (2005) pipelines are operated by pumps using electric motors or diesel engines, plus a set of accessory components such as valves and bends. The author also highlights the concept of movable pipelines to work for fluid elevation and also to operate as sidelines for final application of vinasse on the soil. It avoids the need for perennial pipelines.

Fluid transportation using open channels still requires pipeline networks to raise the vinasse to higher elevation reservoirs, strategically located, from which it flows gravitationally through master channels to truck loading stations, or flows to secondary networks for application via travelling irrigator reels. Since each company has specific conditions, both topographical and operational, there is great variability in the patterns of the duct type distribution systems.

According to Luz (2005) vinasse transportation using open ducts is more economical than pipelines or road transport. Ditches or open ducts prevent the contact of vinasse with the pipe and hydraulic equipment, preventing wear and corrosion. On the other hand open ducts can have significant vinasse losses when operating in very permeable soils, reducing the potential for fertigation and generating environmental impact. This system may also result in loss of acreage if the road layout is not adequately designed to keep roads parallel to the channels. The use of ditches requires a specific study for the local conditions in order to have adequate implementation and operational conditions.

Coating channel walls improves performance in terms of vinasse losses and reduction of flow friction as surface roughness is improved. Regulations including criteria and procedures for application of vinasse on agricultural soils (Technical

(a) (b)

FIGURE 4 Tank truck (a) transferring the load to a storage tank (b).

Standard P4.231 CETESB) were published in the state of São Paulo. They require that master or primary channels of distribution be sealed with waterproof geomembrane or other form of equal or greater effect.

Conjugate transportation

Transportation cost of vinasse by tanker trucks can be reduced using a conjugate system where part of the road is replaced by ditches. So, instead of a single truck loading station located near the plant, ditches are used to feed multiple stations strategically distributed in the field. This reduces the number of trucks and part of the fossil fuel is replaced by co-generated electricity.

Integrated transport of vinasse and sugarcane

Considering that empty trucks return to the cane fields flexible tanks can be used for vinasse transportation in the way back of the truck from industry to the field. Flexible tanks are pillow shaped and foldable on the bottom of the truck body when cane is being transported. After unloading the vinasse the flexible tank is wound at one end of the truck body leaving the whole volume free to receive whole or chopped sugarcane. Similarly, after unloading the cane at the mill the flexible tank is extended on the bottom of the truck body and is ready to receive the load of vinasse. That way the combined cost of transporting cane and vinasse is lower. The integrated transport of sugarcane and vinasse had successful experience in commercial applications, but it requires more complex logistics planning in order to reduce the impact of loading and unloading time on the transportation cost. The use of tractor trucks pushing trailed or semi-trailed tanks, operating in the "bate e volta" mode, with efficient teams and infrastructure makes vinasse economically feasible at longer application distances.

Storage tanks

The logistics of vinasse distribution demands temporary storage using tanks as illustrated in Figure 4b. The tanks allow for changes in the rate of field application or even some interruption for repositioning of equipment in the field or during periods of high precipitation or interruptions required to perform repair and maintenance of equipment. Current law requires the sealing of the reservoirs with geomembrane or other techniques of equal or greater effect and also inspection wells to monitor infiltration.

Application of vinasse

The main systems for vinasse application are infiltration furrows, tank trucks and spraying. The use of infiltration furrows is restricted by the need of areas with suitable topography, Silva (1992). Tanker trucks using gravitational or pumped unloading was the distribution system most widely used in the past. It is versatile and simple, with adequate uniformity of distribution; however, there is a limit to the maximum distance from the loading station to the application areas where it can economically operate.

Sprinkler distribution became a commercial option as the irrigation methods were improved. That is the case of the semi-fixed sprinkler that captures vinasse from ditches and pumps it into main or secondary pipelines on which sprinklers are attached. In the 1980s the hydraulic cannon become popular, called the direct assembly. It comprises a pump attached to a cannon type sprinkler that moves along the ditches pulled by tractor, (Orlando Filho *et al*., 1993; Luz 2005). Currently, in the State of São Paulo, a conjugate system comprising a ditch, a diesel engine pump and a reel spool become popular.

FILTER CAKE

Filter cake is a residue coming out of the process of sugar clarification. It is produced at the rate of 30 to 40 kg per ton of cane processed. It is an organic compound in 85% of its composition, rich in calcium, nitrogen, potassium and phosphorus which vary according to the cane being processed. The cake is used as a complement for mineral or fluid fertilizers. It can be applied in the form of wet cake in dosages ranging from 15 to 35 $t.ha^{-1}$, when applied into the planting furrows, or may be applied on cane ratoons in dosages ranging from 80 to 100 $t.ha^{-1}$ when broadcasted over the soil surface or at a rate of 40 to 60 $t.ha^{-1}$ when distributed in between the ratoon rows (Cortez *et al.*, 1992). The high biochemical oxygen demand of filter cake may turn it into a polluting source, so adequate controls are required during the processes of storage and application. Optimization of the planning and logistics of storage and distribution of filter cake allow to extend its benefits to areas located further away from the plant and may also avoid increasing levels of heavy metals that are not absorbed by the plant and tend to percolate at risk of groundwater contamination, Ramalho and Amaral (2001).

The agricultural use of filter cake involves operations of storage, mixing, drying, loading, unloading, transporting and distribution. These operations take place between the mill hopper and the final deposition on the ground. dump trucks or self loadable "roll on – roll off" buckets are used to receive the cake at the mill hopper and damp it down at a nearby area. Transportation cost of filter cake with high moisture content, using dump trucks with low capacity, force to locate storage areas close to the mill. The material stored in the area undergoes processes of fermentation and drying that can be natural or boosted using a mixer as illustrated in Figure 5. Composting organic material undergoes microbial action under aerobic conditions, leading to a stabilized product in which

Source: Centro de Tecnologia Canavieira.

FIGURE 5 Self propelled mixer composting filter cake.

the compounds have undergone mineralization with reduction of the C/N ratio to around 10.

Composting filter cake with poultry litter, gypsum, boiler ashes and cane trash improves concentration of nutrients and reduces the moisture content, which economically enables transportation over longer distances.

Filter cake remains in storage areas until the planting season. Bucket loaders transfer the cake to dump trucks for transport to the planting areas. Trucks tip down the cake into sized piles at specific locations to cover the planting areas in accordance with the quantities to be applied. Fertilizing with filter cake in more remote areas requires higher capacity trucks most likely the movable floor type instead of dump trucks.

During the planting operation the cake is loaded into distributor wagons using front loaders. The cake wagons are specifically designed to distribute the cake at the bottom of two furrows simultaneously. The mass to be handled in the case of fertilization with filter cake is about 40 times higher than conventional chemical fertilizers; intense traffic of wagon and tractor wheels takes place at the planting furrows. Conventional planting procedure includes soil tillage, furrowing, cake distribution and seed distribution to finally perform the seed coverage and application of pre-emergence herbicides.

Although filter cake fertilization is economically feasible with present application technology, especially for planting, logistics of filter cake distribution still offers a good potential for a sustainability increase by reducing costs, soil compaction and environmental risks.

Cost reduction of agricultural handling for filter cake can also be obtained if the mass to be handled is reduced without changing the nutritional value of the cake. Natural drying in the field or moisture reduction in the manufacturing process as well as reduction in the amount of mineral impurities incorporated to the cane during harvesting are some of the potential actions to be taken to reduce the mass to be handled.

The composting process complements the cake with nutrients and promotes moisture reduction; in addition it produces a homogeneous composite material adequate for a more precise metering process when precision agriculture is being practiced.

The renewal of the sugarcane plantations takes place in different plots spread all over the fields of the mill. These areas have different soil type, soil fertility, application records of filter cake and vinasse, distance to the plant and amount of chemicals with pollution potential stored in the soil. The number of variables involved and the complexity of the interrelations between them demand models and criteria to make optimal decisions both economically and environmentally on where and how much cake or compost should be applied. It is worth noting that the areas closest to the plant allow for greater productivity through higher cost of fertilizer and cultivation due to lower transportation costs of the production.

FINAL CONSIDERATIONS

The logistics of vinasse distribution and filter cake varies greatly from case to case. Field topography determines a set of operations and equipment with varied performance, operating costs and investment costs that lead to specific management. The criteria involved in both the design and management stages require the use of modeling and computer simulation to make decisions that lead to results close to the optimum economical and environmental.

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16

AGRICULTURAL MANAGEMENT TECHNOLOGY IN THE SUGARCANE ETHANOL INDUSTRY

Nilson Antonio Miguel Arraes, Paulo Sérgio Graziano Magalhães and *Jorge Luis Donzelli*

INTRODUCTION

Agricultural management is understood as the execution of administrative functions (organization, planning, leading and control) by an administrative team, under the lead of a manager, usually appointed in the mills by the Agricultural Manager, with the purpose to produce and transport sugarcane to the mills/distilleries.

Agricultural management may be part of the overall flowchart of the sugarcane producer, mills or distillery or even a group of mills. In any of the three cases, agricultural management, given its specific function[1] of production and transportation, is located at a tactical/operational level within hierarchy of the company.

For technology management it is understood as information technologies or telematics (computation – hardware and software – and telecommunications) applied to management. However, given the strong correlation between technological and organizational innovations (RAUPP, 2001), practical organizational procedures should also be considered as management technology. These procedures derive from management theories or models, which can be divided into: i) functional and ii) process (or quality).

This main purpose of this chapter is to synthesize the Terms of Reference from the Workshop entitled "Agricultural Management in the Sugarcane Ethanol Industry"[2], and the workshop contributions. This chapter is divided into six parts. The first part characterizes the diversity of situations in which agricultural management occurs. Starting from situations where the management model and technology management are more developed the other four parts examine organizational innovations (process management and ERP) and technological innovations (software, SIG and telecommunications). The final consideration, based on the Workshop outcome, looks at ways to promote technological advances in agricultural management in the sugarcane and ethanol industry.

Organizational practices and technology management in the sugarcane alcohol industry are distributed in various institutions. Public research institutions are highlighted, particularly individuals or research groups in universities such as ESALQ/USP, DEP/UFSCAR, FEAGRI/UNICAMP, FCA/UNESP Jaboticabal, or research institutes such as INPE; private research institutions, particularly

[1] In addition to functional analysis – production and commercialization, human resources, finances –,management analysis can be strategic, comprising the company and its environment, and sectorial, comprising the actors of the sugarcane alcohol chain (equipment industry and inputs, suppliers, distilleries and mills, distributors and intermediary consumers) and its associations (ORPLANA, UNICA, …) with the State, the market and the society.

[2] This Workshop integrated the research project "Guidelines of Public Policies for the scientific and technological research in bioenergy in the State of São Paulo", financed by FAPESP. Further information about the project can be obtained in: <www.apta.sp.gov.br/cana>.

TABLE 1 Grouping of 281 C-S mills, 2006/2007 mills, by quartile interval.

Quartile interval	Annual milling, average 2006/2007 (thousand ton.)	% of the total milled sugarcane 2006/2007
< 3^{th}	3,243	53
< 2^{nd} and > 3^{th}	1,608	26
< 1^{st} and > 2^{nd}	968	16
> 1^{st}	340	6

Source: UNICA website (available at: <www.unica.com.br>).

the CTC. Consultancies specialized on sugarcane and ethanol management, on ERP; experts in hardware and software; geotechnologies (e.g. sensors, images, and gps) and telecommunications (e.g. PDAs and cell phones), (KUBOTA, 2006). It also includes mills/distilleries, technology and practices users.

Some professionals that work in management consultancies and agricultural management are university graduate and postgraduate students; others have attended leading private research centers such as the Centro de Tecnologia Copersucar (Copersucar Technology Center), currently Centro de Tecnologia Canavieira (Sugarcane Technology Center). Some companies and mills have also partnerships with research institutions, to train their personnel in R&D or in specific courses for the industry – e.g. CEPEGE/ESALQ: Investment and Management in the Sugarcane Alcohol Agro-industry), or the GVPEC/FGV, EAESP and IDE (Agrobusiness: Economy and Management of the Sugarcane Alcohol Industry).

ORGANIZATIONAL CONTEXT WITHIN WHICH SUGARCANE MANAGEMENT TAKES PLACE

From suppliers to industrial groups

When thinking on sugarcane production, one generally imagines a mill producing sugar and ethanol), or a distillery (producing ethanol only); and/or the integration of the agro-industrial and ethanol chain. This image, is in fact true because 61.8%[3] of all sugarcane processed in the country comes from integrated agro industrial units (even if some production components are carried out by partners). There is a considerable diversity among the 281[4] mills of the Center-South, as shown in Table 1; the milling data shown in the table corresponds to the 2006/2007 harvest season, totaling 431 million tons of cane, grouped in quartiles

The rest, 39.2% (even if partly owned by the mills' shareholders) of the sugarcane crashed is produced by third parties or independent suppliers. Among these suppliers there is also great variety of producers, ranging from 250 ha to 20 ha. ORPLANA which represents 26 suppliers' associations in SP, MG and MT, with a total of 14,222 producers, and 73 million tons of milled sugarcane in the 2006/2007 harvest, (20% of milled sugarcane in C-S region); 13,980 producers responsible for 68.6 million tons (26% of the milled sugarcane), are based in the Sate of SP, as illustrated in Table 2.

The diversity of companies in the agricultural and agro-industrial sectors means that management production systems very considerably. For example, small suppliers can manage their own production without formalizing any techno-economic management agreement, though indirectly they benefit from it. On the other extreme, large

[3] For the 2006/2007 season, according to the Balanço Nacional de Cana-de-açúcar e Agroenergia 2007 (National Balance of Sugarcane and Agroenergy 2007)

[4] In the milling ranking available in the UNICA website in the 2006/2007 and 2007/2008 season are 281 mills in C-S, being 169 in SP. In the record of mills available in the MAPA website, up to 07.11.2008, are 315 mills in C-S, being 184 in SP.

TABLE 2 Profile of sugarcane producers of the State of São Paulo – 2006/07 harvest season. Data calculated from the "Pagamento de Cana pela Qualidade" (Payment by Sugarcane Quality).

Production (in tons)	Number of growers	% of Growers	Average areas (ha)	Productions (t)	% of Production
< 200	1,582	11.3	1	190,051	0.3
201 to 800	3,758	26.9	6	1,754,667	2.6
801 to 4.000	5,455	39	22	10,324,399	15
4.000 to 10.000	1,788	12.8	74	11,257,936	16.4
> 10.000	1,397	10	381	45,121,937	65.7
Total	13,980	100	58	68,648,990	100

Source: ORPLANA (available at: <www.orplana.com.br>).

mills have already professionalized management, supported by computing systems that can provide the shareholders with greater transparency of management actions while at the same time providing instruments to assess the performance of the managers themselves.

More recently, two opposite movements have brought greater interest to the management of sugarcane production. The first refers to the formation of industrial groups, a horizontal integration, comprising several industrial units and farms. According to CARVALHO (2007)[5], in 2006/2007 harvest in Center-South (C-S) region, 154 mills (or 58% of the C-S mills), were controlled by 67 groups responsible for 73% of sugarcane. The largest group is COSAN with 18 mills and 14% of the crashed sugarcane in the state of São Paulo in the 2006/2007 harvest season. The pressure on management, especially fiscal, is intense. This is because a driver of unit A, driving a truck of unit B, and carrying sugarcane of a farm of unit C, could be taking the cane to a mill in unit D. Simulations on the optimization of transport logistics of sugarcane, after the administrative integration between two mills, have shown a 30% reduction in the overall transportation costs.

The second movement refers to third parties or outsourcing (ALVES, 1998). In the mills, besides "outsourcing" by sugarcane suppliers, several units [transport of personnel, cultivation of ratoon cane, application of herbicides, mechanical harvesting, sugarcane transport (shipment & transshipment), and equipment rental (i.e. sugarcane trucks and crawler dozers), is currently used extensively in service management. For example, RIOS (2007) quotes a company with 180 buses that provides transport for the personnel of 5 mills in the region of Presidente Prudente. According to Agricultural Indicators of 2003/2004 season of the IDEA Group, based on data of 42 mills and distilleries in the C-S, 29% and 79% of shipment and transportation, respectively, of sugarcane in these mills was carried out by third parties; 65% of work related to biological control was also outsourced. In addition, the most labor intensive agricultural activities e.g. planting, chemical control, sugarcane cutters and tractor driver[6] /operators, are also outsourced, as shown in Table 3.

Despite the fact that sugarcane production areas are quite heterogeneous, if considered

[5] VI Conferência Internacional Datagro (Datagro International Conference), Eduardo Pereira de Carvalho (Unica).

[6] The Agrop, that belongs to the Junqueira family, traditional sugarcane business, noticed the lack of good quality manpower and started outsourcing in farms and mills. Its 550 workers are submitted to health control, learn how to use safety equipment and the correct handling of working tools. The company provides also legal, tributary, work safety and engineering advice.. Founded on 1995, after a low start, the company has expanded rapidly in recent years Roberto Junqueira, of 29 years old, agriculture director of Agrop. (**Exame**, Os inovadores da cana – The sugarcane innovators, 24.08.2006)

TABLE 3 Degree of outsourcing and relative importance of the roles of direct agricultural labor.

Roles of the direct agricultural labor	Degree of outsourcing and the role of direct labor force (%)							
	Daily crash capacity (t.day^{-1})							
	< 3,000		3,000-6,000		6,000-9,000		> 9,000	
Rural area: planting	79	16.0	80	15.9	76	19.4	90	17.6
Rural area: weeding	70	6.4	35	4.7	38	3.1	57	8.1
Rural area: Chemical control	47	5.6	89	4.4	56	5.2	49	5.0
Rural area: General services	44	6.5	39	11.2	28	7.3	40	3.3
Operator/tractor driver	34	6.4	39	8.3	35	8.1	37	14.5
Driver	37	5.5	40	6.1	32	6.7	38	10.6
Sugarcane burner	13	0.9	11	0.6	3	1.1	28	0.5
Sugarcane cutter	5	49.4	12	44.2	5	45.9	14	35.9
Coupler (Julieta)	2	0.9	6	0.6	0	0.7	22	1.7
Load trimmer	0	0.2	0	0.2	0	0.2	0	0.4
Suga rcane picker	7	2.4	1	3.7	0	2.4	11	2.4
Total	**42**	**100**	**32**	**100**	**33**	**100**	**40**	**100**

Source: Data from IDEA.

within the agricultural business, mills and similar groups, the state regulation kept until the end of the 1980's, was very favorable and less restringing when compared to any other business. Early in 1990's, thanks to deregulation, greater competition started between the agro-industrial companies, promoting a race that intensified the rationalization of productive processes, in search of greater technical efficiency and resulting in a significant cost reduction, including management, and thus allowing preserving or expanding their market share.

This race created a demand for advisory/consultancy companies, offering management solutions already been adopted by other branches of activities, as already indicated, to improve the financial performance; such activities inspired technological innovations in management, stimulating the entry of new companies into this market. There was also Sate support by means of a financing program for the adoption of information technology, through the MCT Ordinance MCT n. 200, of November 18th, 1994.

These changes incorporated new management models – from functional to processes – demanding a new cultural attitude and improved organizational practices; the adoption of IT tools, new and better data also enriched and facilitated decision making. These changes e.g. new and processing of data, and the speed of operations, allowed to increase the time frequency and the number of variables to be considered in the models for supporting the decision making process. More recently, geo-technologies have increase time frequency, physical scales and the wave bands of aerial images, incorporating spatial dimensions to support decision making, enriching the possibilities of management tools, from precision agriculture to the prevision of crop yield. Precision agriculture is a direct reflection of management technologies e.g. technological advances in remote sensors, Geographic Information System – GIS, and on-board electronics.

The incorporation of new management models and technologies did not occur in a uniform manner within the industry; the largest mills/

distilleries are most active in this area. In 1998, the essay "Competitivity of the Sugarcane agroindustry System", carried out by PENSA/FIA/FEA/USP, warned that the mills that avoid government subsidies, as strategy for government support, also were conducting their strategies for technological improvement of commercial relations, in addition to integrating partnerships and syndicates; while mills that kept high dependence of government support did not adopted them. The Essay about the "Competitivity of the Sugarcane Agroindustry System and Sourcing of New Ventures", authored by the Evaldo Loi Institute and SEBRAE in 2005, grouped mills according to their survival perspective within current deregulation, into two sets: i) those mills that benefit from state support during the most interventionist period, and ii) mills that did not benefit much from state support, facing serious difficulties to survive in the current environment.

More recently, a study "Productive Chain of Agroenergy" (2007), coordinated by Batalha and Buainain, with technical support from Paulilo and Mello, Freitas Vian and Belik, emphasizes the need for good management and technological development if Brazil is to keep its competitive position. The main innovation initiatives observed in the most competitive units are: (a) Professionalization of mills by hiring management executives, (b) Internal networking for the flow of information ,with the adoption of Enterprise Resources Planning – ERP; systems for integrating management processes, and use of Electronic Data Interchange – EDI, with business partners; (c) Harvest planning and planting with use of expert software (optimization through non linear equations), (d) Integrated Geoprocessing software with remote sensing and satellite images (Georeferenced Information System – GIS), with the purpose of monitoring the development of sugarcane plantations, (e) Digital control for use of equipment (bar codes, radiofrequency), monitoring of tractors by satellite, and (f) Adoption of precision agriculture by hiring service providers for agricultural operations.

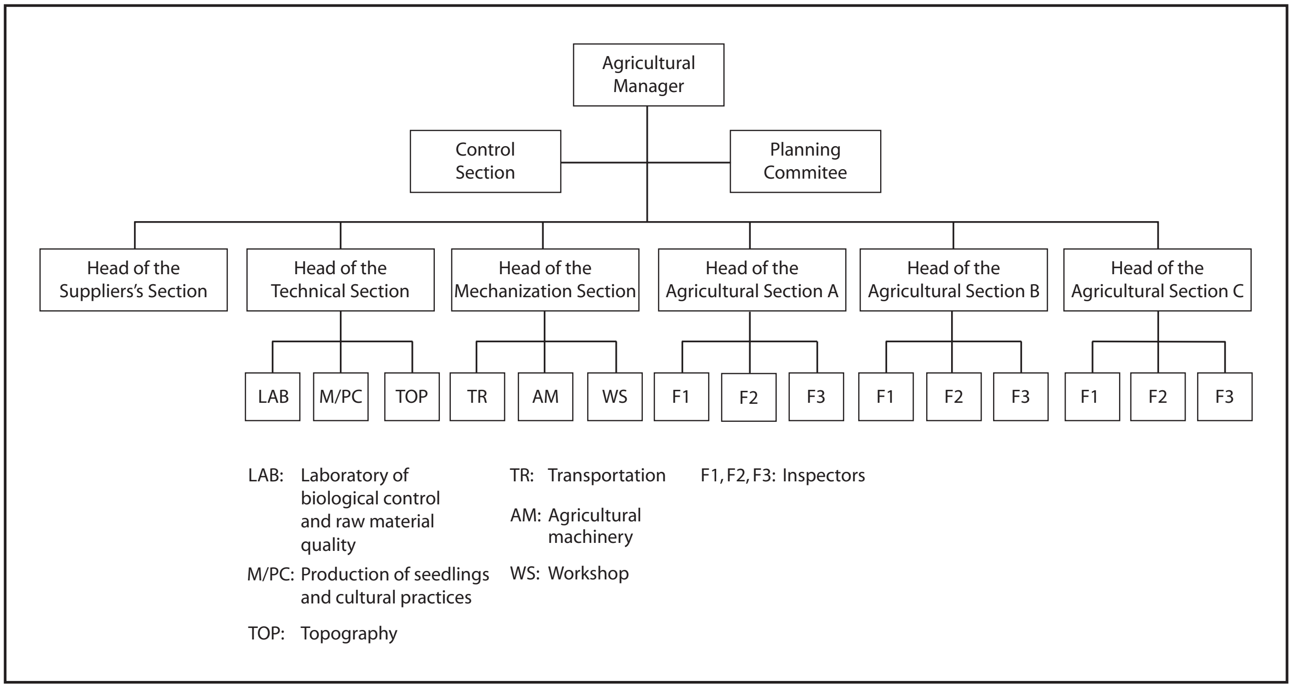
These innovations promoted the transition between functional and procedural management models, with increasing degrees of IT adoption, comprising data collection and transmission systems, and data analysis systems to support decision making, – from the sensors (and actuators) to software. Thus, the more recent innovation in management models are of a crosswise kind (or non disruptive), allowing transition processes with gradual incorporation of the new model.

PROCESS AND ERP MANAGEMENT

From functional to processes models

BRUGNARO *et al*. (1981) book is the only one in Brazil that deals exclusively with the theme of sugarcane agriculture management. The book was at the vanguard of conceptions and management models and helped to consolidate company management over the productive economy. Also, when focusing in production management of a single culture, it helped to advance techno-economic aspects of planning and organizational structures in agricultural management. In addition, it enhanced the role of leadership and the specialization of teams, and so many other aspects of agricultural management hardly known before. At a time when the use of IT in mills was still very restricted, the book led to a new phase on functional models in sugarcane and ethanol management. In this book prevailed the vertically hierarchical relations of employees, functionally grouped, focusing on good performance. Figure 1 shows the functional model of these authors and Figure 2 the difficulties of interdepartmental relations in vertical functional structures – one of the biggest criticisms of the functional model.

The deregulation of the industry and the search by the mills to improve business performance opened up new possibilities for consultancy and management advisers to influence old behavior and practices, especially in areas of management of information/knowledge and the relation with clients/suppliers that were critical. These "new" models favored horizontal relations, promoting a business vision like a (macro) process, in which work and resources flows integrate, aggregating value, conditioned by relations with



Obs.: 1) The number of Agricultural Heads, as the number of inspectors per section can vary from case to case.
2) The Agricultural Sections will be mentioned in the text only as "Sections" in most cases.

Source: BRUGNARO *et al*. (1981).

FIGURE 1 Functional flowchart of agricultural management.

clients and suppliers (internal and external). Employers requested that employees performed their functional role in multidisciplinary teams, controlling the results and assessing, criticizing and improving their activities continuously. The reductions of managers, improved performance, greater motivation and flexible teams have been the main benefits of process management[7].

A representation of an organizational structure of agricultural management of a sugarcane ethanol plant in the process model is depicted in Figure 3. As can be observed, the main process – (business) is supported by other support processes (integration and management), valuing the production area in relation to the other functional areas of the company. When compared to Figure 1, it can also be observed that several "Head of Sections", responsible for the management of several activities and operations carried out in agro-industry, are replaced by "Head of Activities", responsible for the same activity, performed in several sections.

This new culture of processes management is gradually being disseminated/implemented and does not overlaps, completely, the functional models, as highlighted by DAVENPORT (1994), TACHIZAWA and SCAICO (1997). GONÇALVES (2002) depicts 5 stages in the evolution of a company toward process organization (Table 4). Company management advisers provide support to this transitional phase of management models, minimizing negative impacts while accelerating the positive impacts.

The implementation and operation of the principles of process management and the adoption of information systems that incorporated these principles were initially consolidated in department of industrial production of the company. The information systems were developed with environmental management databases, giving support to

[7] The ISO 9000 and 14000 family, on the quality and environmental management, respectively, the experience of production management of TOYOTA lean management and total quality management – TQM, were considered as having the same basis for process management models.

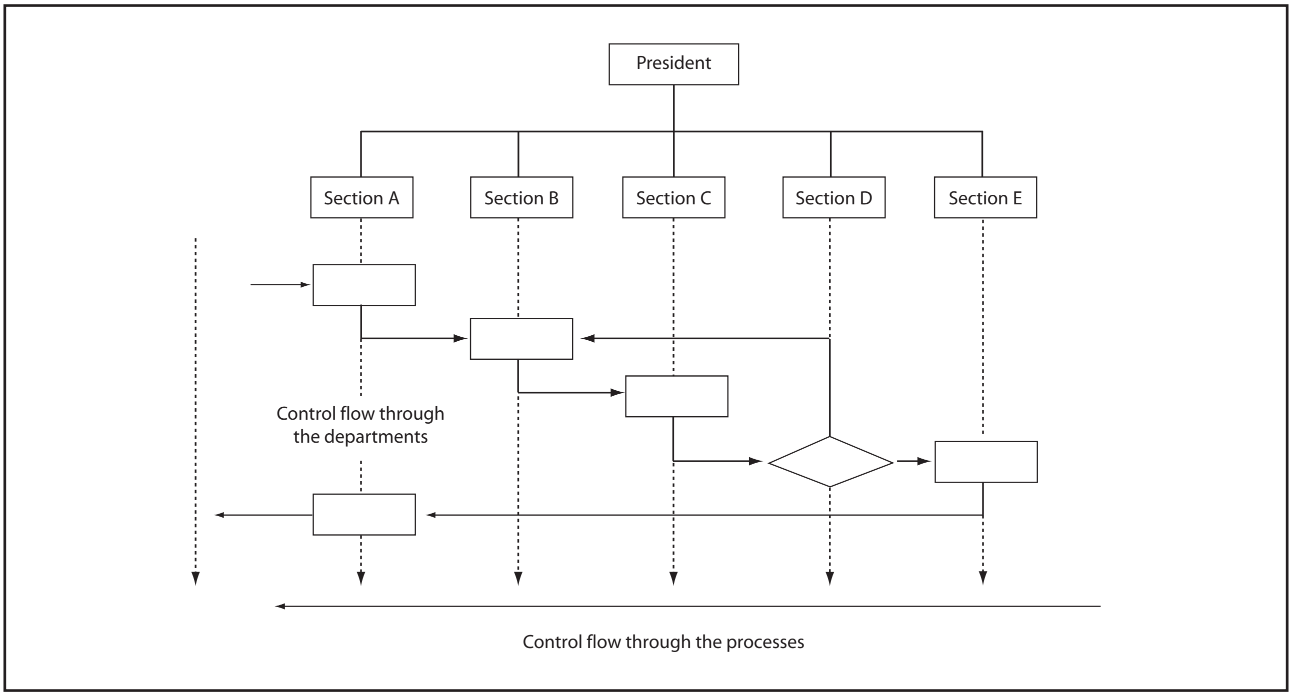


FIGURE 2 Control flow in functional structures and in structures for process.

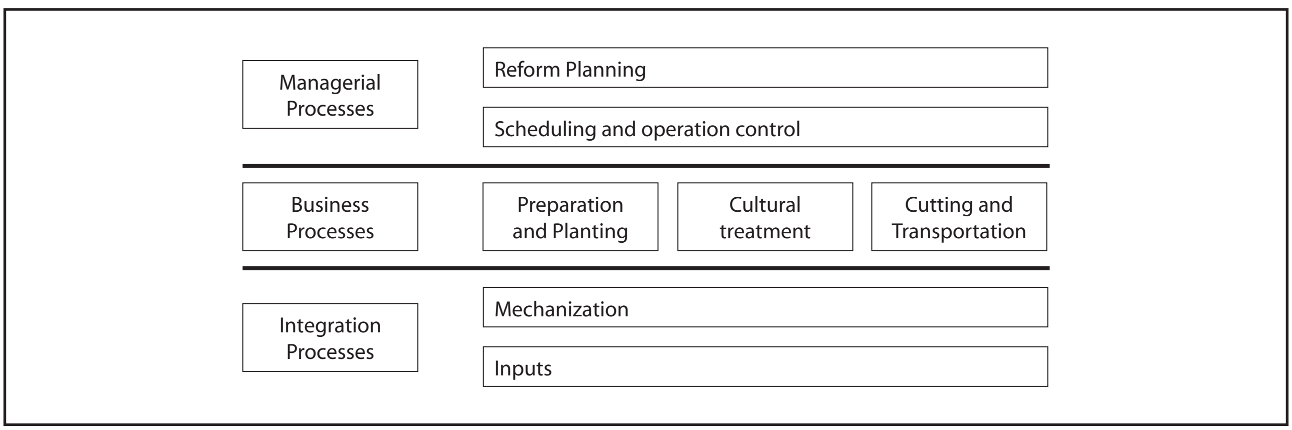


FIGURE 3 Processes in the agricultural management.

the *Manufacturing Resource Planning* – MRP. These systems extended their inputs to control activities (purchase, storage, sales, marketing), including work and equipment – MRP to MRP II (SLACK *et al.*, 1997; GAITHER and FRAZIER, 2002; CORRÊA and CORRÊA, 2004). And since the 1990s started to expand to the whole organization, integrating all functions e.g. industrial production, human resources, finances and relations with suppliers and clients – the ERP's – Enterprise Resource Planning (Figure 4).

In Brazil, the market of these integrated packages are controlled by two large foreign companies – **SAP** (+ TriversityDiversity), whose clients include Cosan, São Martinho, Zilor, Dreyfus, Itamarati, Batatais, Santa Cruz; and **Oracle** (+Peoplesoft+J D Edwards), whose clients include Nova América, Farias); and a Brazilian company – **TOTVS** (Microsiga + Logocenter + RM + Datasul + Meya + Informenge). Some mills use ERP's developed internally, as the case of Santa Elisa (Linux platform). Others involve other companies as the

TABLE 4 Steps of the transition for process management models.

	Step A	Step B	Step C	Step D	Step E
Situation	Process/es, what process/es?	The organization identifies its processes.	The organization improve its processes.	The organization defines responsible for processes and use them as basis for allocation of resources.	The organization was designed by the logic of its essential processes.
Main characteristics	• The organization did not pay attention to the idea of process and its potential. • There is only perception of the manufacture process.	• The focus of improvement effort is still in the functions. • The processes are fit in the functional structure.	• The organization still rationalizes by functions, even if knows well its processes. • The authority still resides in the vertical units.	• The organizations begin to obtain results of emphasis in processes. • There is a level of disagreement between the functional structure and the processes.	• Functional areas practically do not exist. • The goals and metrics are defined for the processes.
Possibilities of improvements and gains	Limited and related to production process.	Correlate to the treatment of bottlenecks in punctual aspects.	Correlate to the rationalization of activities in the essential processes.	Improve the isolated process management and the integration with the support processes.	Correlate to the integrated management of the essential processes.

Source: GONÇALVES (2002).

FIGURE 4 Functions Integration and processes of the company.

case of IFS, with clients *such as* Grupo Naoun, Agrovale, and Corona.

The CIO of Grupo São Martinho, Joaquim Paulo, in the Forum SAP 2006, presented an investment of R$ 12 million for implementation a SAP which led to a cost reduction of R$ 23 million.year[1]. He also highlighted that the number of positions fell from 800 to 90, suppliers from 1,500 to 900, product purchase cycle from 22 days to 4 and closing accountant from 20 days to 5.

According to data from International Data Corporation, the Brazilian IT agroindustry Market was estimated in US$ 180 million in 2006; its main deficiency includes adoption of management software (ERP) focusing on logistics, finance, purchase and storage management, soil mapping system and decision-making support in planting and harvesting processes. In the article "The second age of ERP" (Computerworld), the editors state that ERP companies will seek to "verticalize their systems", specializing in some sectors – agribusiness, for instance. In addition, the ERP's will seek to "communicate in a transparent manner with tools like Customer Relationship Management – CRM, and Business Intelligence – BI, besides, of course, being ready to support applications and new business models in the web".

MANAGEMENT APPLICATIONS IN AGRICULTURE

Agricultural management consultancies and applications aimed at sugarcane production

Although large management consultancies and IT integrated solutions are specializing, each department they verticalize e.g. agribusiness, the service they provide is normally complemented by other specialized consultancies with more experience, be it by mergers, partnerships or independent service providers, also appealing to the mills.

Some of these specialized consultancies do not have IT solutions, concentrating instead in carrying out studies (i.e. business plans for expansion or new mills, *benchmark*); in the creation and implementation of working methods (i.e. organization of production processes, structuring of special units of crop management, programming routines, budget control of operations), and in supporting teams. Some of them include IDEA (<www.ideaonline.com.br>), and Chaves Planejamento e Consultoria (<www.chavesconsultoria.com.br>), both based in Ribeirão Preto and the CANAPLAN (<www.canaplan.com.br>) in Piracicaba.

Adopting the same principle of process management of integrated packages (ERP) but with specialized modules of management support in sugarcane production, domestic companies have also produced and commercialized their own systems. Among them, is **Próxima** (www.proxima.agr.br) of Assis, which according its website has 115 clients in the sugarcane industry, with 5,000 users of its software, representing 45% of Brazilian sugarcane production. Próxima charges the mill customers between 0.5% and 1.8% of annual revenue for IT support.

Others include, **GATec** (<www.gatec.com.br>), based in Piracicaba, with more than 60 major clients (mills and distilleries); **UniSoma** (<www.unisoma.com>), based in Campinas; **SoftFacil** (<www.softfacil.com.br>) in Ribeirão Preto; **CHB** (<www.chb.com.br>) of Franca; or **PROCENGE** (<www.procenge.com.br>), based in Recife. As large multinational companies are entering this IT market, their applications need to be compatible with the Brazilian market, and thus some of them have established partnerships, or even in some cases taken over as the case of Próxima, by Data Sul, facilitating the verticalization. Other groups e.g. **Agrisoft** (<www.agrisoft.com.br>) of Curitiba, focuses mostly on suppliers, adopting a functional structure for its modules.

Specialized agricultural modules help to support tactical management in harvesting and logistics of sugarcane transportation, in addition to operational schedule support and control of activities, resources and costs of several operations (preparation, planting, harvesting, loading and hauling). Mechanized resources have a specific module, given its economic importance, combining machinery and maintenances activities e.g. *Assiste* – <www.assiste.com.br>, based in Piracicaba, focuses specifically on these modules.

Most of tactical management modules incorporate numeric techniques to optimize activities, using linear, integer, non-linear, dynamic or by restrictions programming, combinatorial algorithms, metaheuristic and intelligent systems (CALIARI, 2001; CALIARI *et al.*; 2004, MARQUES, 2006; HAHN, 1994; GRISOTTO, 1995; BANCHI, 1989; IANNONI, 2000; LOPES, 1995; BARATA, 1992; FLORENTINO, 2005). The difficulty in adapting these techniques has stimulated the creation of companies that deal specifically with such techniques of which a good example is iLab (<www.ilab.com.br>), based in Ribeirão Preto, or (Guarani) and GAPSO (<www.gapso.com.br>), located in Rio de Janeiro.

GEO-TECHNOLOGY APPLICATIONS

Remote Sensing (RS), Geographic Information System (SIG), and Global Positioning System (GPS)

New possibilities are emerging as a result of technology advances in digital images of the Earth surface with space resolutions, time frequencies and spectral bands for agricultural use – the satellite and optical sensors – and technologies for handling these images, integrated to the database – the geographical information systems – SIG. Among the most widely used in Brazil ArcGIS of the North American ERSI, the Idrisi of North American Clark Labs, and Spring of Brazilian INPE.

Although aerial pictures (photos), obtained by flying over the interested areas, generate appropriate images for agricultural applications, high costs prevent their utilization in small scale or to generate weekly or monthly time series.

The satellite registers image pixels; the most common used today in agriculture is measured in an area of 30 per 30 meters, the lowest information unit that the satellite captures. There are now more advanced models, not used yet in this activity, which register up to 60 per 60 centimeters (*Revista AlCOOLbras*, n. 95, 2005). In 2000 an image of the Landsat satellite cost up to R$ 2,000 but today it can be freely available.

Data can be both sold and disclosed via internet. The National Institute for Space Research – INPE, recently implemented free distribution of images obtained by the Sino-Brazilian (Brazil-China) satellite – the CBERS. This was offered to Brazil as the country is an important user of this technology (*Revista ALCOOLbras* n. 104, 2006).

Perhaps the biggest initial impact of this technology has been to view its own images and generate detailed maps with information of different sugarcane production areas (sections, farms, sectors, blocks etc.), which up to now were exclusively stored in big tables consisting of thousands of records and fields databases.

However, the most innovative applications are on sugarcane crop management, by means of time series of these images. With a frequent interpretation of the images, monitoring identifies any problem much easer (i.e. incidence of pests and diseases, failure in preparation and planting). Data from these images allow to identify more precisely yield estimates (i.e. errors dropped by 15% to 20%), providing the best support for harvesting, loading and hauling logistics (MACHADO *et al.*, 2002; RUDORFF, 1985; PICOLI, 2006).

Another application of this technology is pre-mapping of soils, which allows a better space distribution in greater detailed of soil sampling. For example with satellite images it is possible to differentiate soil classes and quantify some of its components – clay, iron, silt, organic matter (DEMATTÊ *et al.*, 2004; DEMATTÊ *et al.*, 2005).

The incorporation of SIG modules occurs, both in IT and large companies, by integrating generic ERP + generic SIG, as example of the SIG or ERSI + ERP of SAP of PIMS-SIG of Próxima (Datasul), using the TerraLib of INPE.

Later, the integration of these technologies with GPS, which allow to locate mobile resources (tractors, harvesting machines, sugarcane transporting trucks and peoples), opened up other management possibilities for management applications to precision agriculture.

FieldStar (AGCO) and AMS (John Deere) are example of the use of precision agriculture in machines, integrating SIG and GPS. The first provides georeferenced maps of the area to be worked by the machinery and the second reports periodically the machine position in this map, orienting, for example, route corrections (navigations systems

– light bars and DGPS) for planting or application of fertilizers with variable taxes (flow controller with GPS incorporated).

With the advent of automation of tractors and sugarcane harvesters, the GPS' signal needed be corrected. This correction is also made by remote control, prevailing the RTK standard (Real Time Kinematics). The plant needs to distribute this signal through radio or some other form of wireless that generate signals in a station with a stationary antenna. What is hoped is that in the near future signals can be generated and make more widely available. The IBGE already works with this option, although in an experimental scale, distributing differential correction RTK standard through the internet. The wireless communication at field level, with good data transfer rates is a necessity and should be available in internationally standard form.

APPLICATIONS IN TELECOMMUNICATIONS

From field records to mobile phones

Communication has always been an important aspect for tactical-operational level of agricultural management. The more difficult part was "bidirectional" (decision maker-operator) with the purpose to increase efficiency (i.e. avoiding time-wasting) to increase the effectiveness, mainly readjusting scheduling activity and operations in a timely manner.

Traditionally, the operations were reported in field spreadsheets by machine operators or by keepers (field work inspectors), and then sent for typing and validation, and later on for processing and management reporting, and consisting basically of average performance for comparison at the end of the harvest. The whole process would normally take 5 to 7 days.

Two changes brought together operational and tactical levels. The first were the sensors attached to machines (integrated to PDA's – Personal Digital Assistant) that allowed controlling the equipment conditions (oil temperature, and speed) or operational results (worked area, or volume of cane harvested), operational time's e.g. "reasons for stopping". This information was later "downloaded" into computers (IrDA, BlueTooth), which allows to bypass typing, and thus minimizing errors and shortening the time to generate information to support decision-making.

The second change was the communication systems, initially through radio frequency – RF, and more recently also through GPRS – General Packet Radio Service[8], via mobile phones. In the first case it was possible to accelerate the use of field data, inserted in the PDAs which became available as it was generated; and the second case made possible the dissemination of bidirectional communication, improving and extending radios, thus allowing direct access to information on activities directly managed or performed by means of Web applications. Advances in communication, the PDAs (or handhelds, palmtops), evolved rapidly, acquiring new features e.g. use of mobile phones, wireless internet access, (or handhelds, palmtops) and supports Web applications, besides the possibility to incorporate GPS.

Broadband technologies (GSM and CDMA) of the current generation of mobile networks have a low range in areas with low number or scattered population, a common feature in many rural regions, and this results in poor signal quality or none at all. As stated by MOLIN (1985), to overcome these limitations, some companies have developed data collection systems that use radiofrequency to transfer between components e.g. between field equipment and the trucks. The data typed by operators, or collected by sensors, in machines are transferred to trucks that, when reaching the plant, perform a new transfer by radiofrequency, downloading this data to the central database. This represents a relatively simple solution that generates useful information on CCT with just a few hours of delay. New generation of broadband technologies (WCDMA/3G e WiMax) promise to overcome current limitations.

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[8] The GPRS technology reaches velocities of up to 115 kpbs, making it viable the high speed internet access and other communication systems, besides supporting a wide range of bands.

These developments, providing greater communication agility, allows decision makers to prepare reports with just a few hours "delay" after carrying out operations, while at the same time operators and inspectors can receive frequent information related to their operations more frequently, thus minimizing stopping time and better redirecting of operations in case of unexpected events.

An example of company specialization in development and implementation of portable devices, one could mention Simova e-Logicon (<www.simova.com.br>), based in São José dos Campos. The BoB – Boletins on Board – is an automatic system of agricultural records, fed by cell phone that allows monitoring in real time, through the internet, of all machines in operation and to interact with the operators[9]. The system is being implemented in the mills of the *Grupo Equipav*, with has close to 450 cell phones, covering an area of 100,000 ha of sugarcane crop and generated an economy of R$ 1 million to the group, according to its IT manager[10].

The *SIG Logística* of Enalta (<www.enalta.com.br>), located in São Carlos, specializes in sugarcane hauling logistics from the field to the mill. Fed by information, in real time, of the fleet location, harvesting and milling conditions of the plant, the trucks receive guidance on what to do, both at the exit of the plant, after unloading or during this operation, if some unforeseen event happens.

FINAL CONSIDERATIONS

The Workshop, mentioned at the beginning, had four panels, each one dealing with one of the organizational and technological innovations presented in this chapter. Each panel was made up of representatives from research institutions, service providers and mills.

Generally, research institutions approved the "state of art" practices and the technology management stated in the Terms of Reference; service providers put forward their solutions while mill representatives described the current situation. Despite the Terms of Reference, nothing was said with regard to the medium to long terms technological situation or the bottlenecks needed to overcome to further its development. In the short term, it was expected that service providers will draw attention to the "necessity of adopting modern management solutions", be it on organizational practices or in management technological terms.

Management models based on processes are relatively new and the electronics embedded in computers, sensors, actuators, networks, telephones, GPSR etc., are continuously improving and becoming cheaper, allowing the development and the integration of support systems in decision-making. In some cases, access to data with frequency and reliability is not a technical problem; the question is to what extent it is possible to transform data into useful information for the decision maker and what kind of rewards will be available for investment in management systems.

It should be emphasized that the use of an information system is closely tied up to the business culture. Thus, information and support systems in decision-making that fail to meet the "managerial spirit of the organization", even if technically qualified, can result in a serious failure.

Technological production is prolific but the mills and suppliers need to have access to it (specialy the samall ones), and reliable information from producers/sellers of this thechnology, regarding investment return, should be available.

As a way of promoting and adopting technology management, the sugarcane chain seems to need information that assesses the cost-benefit relation of these solutions. Such assessment need to be carried out taking into account the diversified profile of potential users, so that it can provide appropriate solutions to each plant or supplier. Lack of assessment creates a vicious circle where innovative organizations do not show interest in disclosing their results for fear of competition. This makes it harder for new users to join the market and compete with established companies in this area on the same basis.

[9] *Revista Fator, agronegócios,* 09.20.2007.

[10] Google News. Cellular Networks increase profit in sugarcane farms. 27.03.2008.

It should also be recognized that the lack of technology assessment may be interpreted as a consequence of the sugarcane industry cultural characteristic, once the industry has sufficient organization by means of it associations to mobilize efforts for an activity such as this. An alternative is the benchmark carried out by the IDEA group and, more recently, by CTC, besides management quality awards, which exemplifies "good management practices."

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17

OTHER RAW MATERIALS FOR PRODUCING ETHANOL

Manoel Regis Lima Verde Leal, Teresa Losada Valle, José Carlos Feltan and *Cássia Regina Limonta Carvalho*

INTRODUCTION

Ethanol may be produced from a wide variety of raw materials, both fossil and renewable. Current commercial fossil sources for ethanol are natural gas, petroleum, and coal, which will not be discussed here. Most of the ethanol is produced from renewable raw materials, which are essentially sources of carbohydrates as sugars (sugarcane, beet, sweet sorghum, Jerusalem artichoke, fruits), starch (corn, wheat, cassava, sweet potato), and lignocellulosic materials. Ethanol production technologies from materials rich in sugars or starches (these are sugar polymers) are called first generation, while ethanol and other biofuels production processes from lignocellulosic materials are named second generation. While first generation technologies are in an advanced degree of commercial maturity, the second generation will still require several years, maybe decades, to become competitive. However, the expectation is that when this happens, they will supersede and replace the first generation processes, for using abundant, varied and cheaper raw materials than those used now. It is important to mention that this expectation is not certain and there is a chance for both technologies to coexist and get pooled together, rendering the production of renewable ethanol even more competitive in comparison to fuels derived from petroleum.

In spite of the large variety of possible raw materials for producing first generation ethanol, over 90% of the current world production is from corn or sugarcane. The interest in cassava (Thailand, Colombia, African countries) and beet (Europe, Egypt, Pakistan, Colombia) is growing and indicates that these raw materials will take a significant role in the future, so they deserve more attention. Sweet potato, in spite of its great potential, lacks some additional technology development in the agricultural end, and also lacks developed varieties to maximize the fermentable material content; this is the reason why it now faces problems with high production costs. Other less-known products, though having a reasonable potential in terms of productivity and production costs, are sweet sorghum and Jerusalem artichoke. These will be the raw materials covered in this chapter, the approach considering two groups, one made up of cultures using developed agricultural production technology, i.e., having the possibility of growing in considerable scale like corn, sorghum, cassava, and sweet potato; and another comprising species that have demonstrated potential for high biological yield at laboratory level, but lacking agricultural production technology adequate to Brazilian conditions.

IMPORTANT RAW MATERIALS

Corn

Corn is nowadays the most utilized raw material, being the US the largest ethanol producer in the world, using almost exclusively this cereal. China, the third largest ethanol producer, after the US and Brazil, also uses mostly corn for the production. Other countries that are large corn producers like Argentina, Australia, and South Africa have seriously considered starting large-scale ethanol production from this cereal. It is important to mention that corn is one of the most cultivated cereals in the world, using an area of 158 million hectares (FAO, 2008), and it is a *commodity* with a strong international market.

DOSON (2001) compares corn with various other raw material options for producing ethanol in the US and the key indexes are shown on Table 1.

These values look rather underrated, as we will see later, but they are interesting as comparison.

Average values of the typical corn composition are shown on Table 2.

Table 2 shows that the content in protein, fatty material and carbohydrates gives corn a high nutritional value, both for human beings and animals. The above 70% content of carbohydrates makes transportation and storage easier and cheaper, allowing its processing into alcohol throughout the whole year.

TABLE 1 Ethanol yield from different raw materials.

Raw material	Fermentable material %	Ethanol yield ($l.t^{-1}$)
Wheat	58.6	356
Corn	57.8	348
Beet	16	92
Sugarcane	11	63
Sweet potato	23.3	129
Potato	15.6	94
Jerusalem artichoke	15.2	82
Pure sugar	100	577

Source: Adapted from DOSON (2001).

TABLE 2 Typical composition of corn.

Component	Content (% m/m)
Moisture	10.93
Protein	9.88
Fatty material	4.17
Carbohydrates	71.95
Fibers	1.71
Ashes	1.36

Source: DOSON (2001).

The great popularity of corn as such a widespread international culture explains its being now the leading raw material for producing ethanol. Nevertheless, its expansion does not seem to be sustainable due to the unattractive energy balance, mediocre productivity and high production costs. On top of requiring subsidies for corn and industrial production, corn ethanol still depends on the sale of its by-products (*Distillers Dried Grain with Solubles* – DDGS in the case of *dry milling*; oil, bran, germ, HFCS in the case of *wet milling*) to be economically feasible. The market for these by-products is limited, and its saturation point doesn't seem too far to be reached.

From the standpoint of area required, corn does not seem to be a good option. Only the US and Argentina have productivity levels that could justify using corn to produce ethanol, as shown on Table 3. The value of 400 $l.t^{-1}$ of corn was used in this table for being a more updated figure than the one presented on Table 1.

From Table 3 it is possible to observe that only the US and Argentina have a productivity level compatible with ethanol production, however much lower than sugarcane.

The technology for converting corn into ethanol is very well developed in the US, which is today the largest ethanol producer in the world. Two processes are used, with relative advantages: *wet milling* and *dry milling* (DOSON, 2001).

The *dry milling* technology is the older and more traditional to produce ethanol from corn. It comprises well characterized steps: grinding, cooking, saccharification (hydrolysis), fermentation, and distillation. Several plants use the simultaneous saccharification and fermentation process – SSF, reducing investment costs and making operation easier.

Grinding is done in mechanical mills, achieving an adequate granulometry for saccharification. The cooking stage's purpose is to gelatinize starch, to allow hydrolysis by enzymes, converting it into

TABLE 3 Corn production in some countries.

Country	Area (1,000 ha)	Production (1,000 tons)	Productivity (t,ha^{-1})	(l,ha^{-1})
US	35,022	332,092	9.48	3,800
Brazil	13,827	51,590	3.73	1,500
India	7,770	16,780	2.16	860
China	28,074	151,970	5.41	2,160
Argentina	2,838	21,755	7,66	3,000

Source: FAO (2008).

sugar. The corn bran that leaves the mills is mixed with water and stillage to reach a solids concentration of 35% before being sent to the pre-cooker, which operates at 60 °C, and with mechanical shaking; the maximum precooking time is 5 minutes. Next, the moist dough is taken to the continuous cooker, which operates under an 11 bar pressure, and 180 °C temperature, where it will stay for approximately 2minutes. The cooked gum is unloaded, by pressure, on the saccharificator, where part of the water evaporates (*flashing*), bringing the temperature down to about 60 °C, when enzyme alpha 1,4-D-glucan hydrolase added in a ratio of 0.025% to 0.050% relative to the starch dry base will act. The pH should be kept between 3 and 5 and the temperature between 30 °C and 65 °C.

Fermentation and distillation processes are similar to those used for sugarcane, discussed in other chapters in this book, except in the SSF process. In this case, the whole process is done in about 40 hours. The main sub-product of the *dry milling* process is called *Distillers Dried Grain with Solubles* – DDGS, which is used as cattle food.

The *wet milling* process is more recent, having been introduced to large scale in the late 1970s, with the accelerated growth of corn ethanol in the US. It was originally designed to produce pure starch, used to produce dishwashing detergent and corn fructose syrup (high fructose corn syrup – HFCS). Its use for producing ethanol was made popular by *Archer Daniels Midland* – ADM, the largest ethanol producer in the US.

The greatest advantage in this technology is the generation of a large number of co-products (HFCS, corn oil, corn germ, dextrose, gluten, and other types of food products for human beings and animals), which contributes to improving the economic viability of ethanol.

Before grinding, corn is immersed in water (*stripping*) to remove the soluble portions and recover the germ, fiber and gluten. After this process, the corn is ground, saccharified, fermented, and the alcohol is distilled in a very similar way to the one used in the *dry milling* process.

Cassava

Cassava is a species that was domesticated by the pre-Columbian populations, with the objective of storing starch in the roots, and being multiplied on its own since 6 to 7 thousand years ago. The selection process was so efficient that cassava became the basic food for various indigenous populations and a supplement to others. Yet nowadays it plays an important socioeconomic role in several tropical countries, mainly in America and Africa. Brazil is the second largest producer in the world, accounting for 10% of the production, after Nigeria (FAO, 2008). Historically, the production of roots in Brazil oscillates between 20 and 25 million tons of roots per year, being the fourth product in volume among the yearly cultures, after sugarcane, soybean and corn.

Cassava in Brazil is typically intended for human nutrition, as starch or its derivates, cassava

TABLE 4 Quantity and value of some selected yearly cultures over three years.

Culture	Production (tons)			Value of the production (thousand R$)		
	2003	2004	2005	2003	2004	2005
Sugarcane	396,012,158	415,205,835	422,956,646	12,288,334	12,149,902	13,148,658
Soybeans (grains)	51,919,440	49,549,941	51,182,074	28,584,866	32,627,677	21,750,332
Corn (grains)	48,327,323	41,787,558	35,113,312	13,522,976	11,595,513	9,459,161
Cassava	*21,961,082*	*23,926,553*	*25,872,015*	*4,372,646*	*4,954,660*	*4,081,973*
Rice (with husk)	10,334,603	13,277,008	13,192,863	5,894,739	7,750,355	5,014,251
Wheat (grains)	6,153,500	5,818,846	4,658,790	2,459,688	2,102,426	1,413,409
Potato	3,089,016	3,047,083	3,130,174	1,594,161	1,719,657	1,879,496
Beans (grains)	3,302,038	2,967,007	3,021,641	4,008,884	3,082,348	3,475,946

Source: IBGE (2007).

flour and to a lesser scale, for animal feeding. Throughout Brazil there is a predominance of survival cultures and small-scale production for one's own consumption, and small local and regional markets. In parallel, using 100% Brazilian technology, in the states of Paraná, Mato Grosso do Sul and São Paulo, with some branches in the Santa Catarina state, a vibrant agribusiness developed, connected to the cassava production chain, its technological development being a global benchmark. It produces and processes about five to six million tons of roots per year, apparently half for starch and half for flour. The competitiveness of the cassava in this region is based on the good agricultural performance in comparison to other Brazilian regions: high productivity (Table 5), modern industrial facilities and economy-driven administration throughout the supply chain. Therefore, it is a model region to analyze the feasibility of producing ethanol from cassava. Even in this region, cassava is mostly cultivated by small farmers, though some of them have areas beyond 2,000 ha, in the least fertile soils in the region, rotating with soybean, corn and pasture.

Production of roots

Cassava is a long cycle plant that begins storing starch in the roots 40-60 days after planting, and continues doing so during all the time it is cultivated, as long as there are environmental conditions for photosynthesis. To optimize cost/benefit, cultures intended for flour and starch industries are harvested after 2 cycles (18-24 months); how-

TABLE 5 Production, area and productivity of cassava in Brazil and selected Brazilian states in 2005.

State/Brazil	Production (tons)	Area (ha)	Productivity ($t.ha^{-1}$)
São Paulo	1,144,880	48,643	23.54
Paraná	3,308,000	165,970	19.93
Santa Catarina	589,998	32,165	18.34
Mato Grosso do Sul	538,754	32,492	16.58
Brazil	25,872,015	1,901,535	13.61

Source: IBGE (2007).

ever, there is no technical reason preventing to do it either earlier or later than this period. Harvesting takes place all year round, with a slight reduction in starch content during summer.

Cassava is a species with high yield for producing biomass. The maximum estimated potential under optimum conditions, by means of mathematic growth models, predicts that good genotypes may produce up to 90 $t/ha^{-1/}year^{1}$ of roots, or 30 $t/ha^{-1}.year^{1}$ of dry matter. In small plots, 28 $t/ha^{-1}/year^{1}$ of dry matter were obtained at the International Tropical Agriculture Center in Cali, Colombia (COOK, 1985, p. 78). However, it is in stressful conditions that cassava offers advantages in comparison to other cultures by its tolerance to biotic and abiotic factors. Even in regions where performance is better, if analyzed in detail, there are quite different productivity levels, as shown on Table 6.

Overground part production

Cassava is cultivated only to exploit the roots and a small part of the stems as propagation material. About half of the green mass produced is left on the field. This residue may be used to feed animals, as input for power generation or, when abandoned on the field, it has a high nutrient recycling capability. There is consistent information in scientific literature demonstrating the quality and the viability of using it to feed animals, particularly ruminants (CARVALHO, 1983 *et al.*). There is quality and volume to feed a considerable quantity of animals, e.g., 10 ha of cassava produces an overground part sufficient to feed 100 bovines for three months on a fattening program, with minor nutritional supplements. Considering the productivity of 45 t/ha^{-1}, for 18 to 24 months plantations, and the bromatologic compound, it is possible to feed 1,500 bovines per day/ha^{-1} on a fattening program.

Regarding it as an input for power generation, cassava vine is not different from the pattern of other biomasses. The heating value of dry vine was considered as 15.76 $MJ.kg^{-1}$ by CERQUEIRA LEITE (2005) and SILVA, *et al.* (2007). BOOG *et. al.* (2007) estimated that a cassava plantation with approximately 300 days of cultivation in Assis-SP, produces 2.86 $t.ha^{-1}$ of dry mass usable as input for power generation with Higher Heating Value – HHV of 15.1 $MJ.kg^{-1}$ and considering 40% moisture, results in 4.76 $t.ha^{-1}$ of material for combustion with Low Heating Value – LHV of 7.65 $MJ.kg^{-1}$. Simulations of the power generating potential at various productivity levels observed in the São Paulo state are shown on Table 7. Considering that the energy consumption (industrial + agronomical) of producing ethanol is approximately 82,400 $MJ.ha^{-1}$, estimating a production of 33 $t.ha^{-1}$ (SALLAS, 2008), using the vine may be decisive for the energy balance of cassava. These figures are simulations obtained from estimated parameters in laboratories and on the field, so they do not comprise transportation costs and other logistic aspects required to the use of the overground part of cassava, because no actual studies were found on this issue.

TABLE 6 Production of roots, dry matter, starch and ethanol from cassava in two regions and some selected producers in the São Paulo state.

Reference	Productivity $t.ha^{-1}$	Dry Matter %	Starch $t.ha^{-1}$	Ethanol (99,5° GL)[4] $L.ha^{-1}$
Mogi-Mirim area[1]	38	38	13	8,000
Assis area[2]	28	38	10	5,900
Selected producers[3]	55	42	18	12,800

[1] Mogi-Mirim (harvested area 2,200 $ha.year^{-1}$; production 84,000 $t.year^{-1}$; average 2001-2006).
[2] Assis (harvested area 8,300 ha/year; production 231,000 ton/year; average 2001-2006).
[1,2] Source Cati/IEA, 2007.
[3] Variety IAC 14, 2-cycle harvest (18 to 24 months).
[4] Utilizing parameters obtained by SALLA (2008) (1 ton roots with 330 kg starch + 50 kg fermentable sugars, yielding 210.6 liters of ethanol 99.5° GL).

TABLE 7 Heating value of residues from a cassava plantation (vine + variety) in two regions and some selected producers in the São Paulo state.

Reference	Productivity		Energetic value[4]			
	Roots	Overground part	Based on heating value	Base on LHV	Equivalent in	
	$t.ha^{-1}$	$t.ha^{-1}$	$MJ.ha^{-1}$	$MJ.ha^{-1}$	kWh[5]	Liters of ethanol
Mogi-mirim[1]	38	25	98,150	82,875	69,063	4,421
Assis[2]	28	20	78,520	66,300	55,250	3,537
Selected producers[3]	55	45	176,670	149,175	124,313	7,958

[1] Mogi-Mirim (harvested area 2,200 $ha.year^{-1}$; production 84,000 $t.year^{-1}$; average 2001-2006).
[2] Assis (harvested area 8,300 $ha.year^{-1}$; production 231,000 $t.year^{-1}$; average 2001-2006).
[3] Variety IAC 14, 2-cycle harvest (18 to 24 months).
[4] HHV above 15.1 $MJ.kg^{-1}$ and LHV below 7>65 $MJ.kg^{-1}$ at 40% moisture.
[5] An average low-income home uses 250 $kWh.month^{-1}$, in average.

Source: Cati/IEA (2007); developed by VALLE (IAC) and BIZZO (Unicamp).

The overground part of cassava has a mineral composition similar to other species. Due to the large volume of biomass produced, it is a great nutrients extractor (Table 7). However, in the roots that are extracted from the field, the major components are water and starch. The overground part is richer in diversity and minerals concentration, so cassava is an excellent recycler of nutrients. Cassava extracts more nutrients than sugarcane, however it exports much less (Table 8), which gives it a more favorable profile for environments handled in a sustainable way. Another differentiating feature is the quantity of N required. Though cassava needs more N during the cycle, it exports only 69 kg/ha^{-1}, while sugarcane exports 96 kg/ha^{-1}. Surprisingly, cassava has extremely low needs for nitrogenated fertilization, while sugarcane is very responsive to this fertilizer. The nutrients cycling profile favors producing cassava in self-sustainable handling as well as the energy balance. Nitrogenated fertilizers require great supplies of energy during production, being an unbalancing factor in the energy balance.

Improvement, germplasm, and genetic resources

Cassava is a species about which little techno-scientific knowledge is available, in comparison to other cultivated species. Nevertheless, as it is a native species from Brazil, plenty of empirical

TABLE 8 Nitrogen and other macronutrients extracted, exported and recycled by sugarcane and cassava.

Mode	Sugarcane		Cassava	
	Nitrogen	Other nutrients[1]	Nitrogen	Other nutrients
	$kg.ha^{-1}$			
Extraction	163 (100%)	383 (100%)	232 (100%)	434 (100%)
Export	96 (59%)	199 (52%)	69 (30%)	150 (35%)
Recycling	67 (41%)	184 (48%)	163 (70%)	284 (65%)

[1] Other macronutrients: P+K+Ca+Mg+S.

Source: SALLA (2008).

knowledge is available, as well as techno-scientific knowledge aimed at the production of cassava flour and starch, which may be used as *input* for energy generation.

Brazil is the largest holder of genetic resources for cassava in the world. This species is cultivated, and has native varieties in all Brazilian ecosystems, from the Amazon, semiarid, down to the sub-tropical region, with mild temperatures. Genetic improvement programs developed in Brazil are few, but having good results. Table 9 shows the progress in productivity and dry matter content obtained in the Agronomic Institute with new more productive varieties, resistant to epidemic diseases and tolerant to low-fertility soils. So far, improvement efforts have focused only in improvements for root production and resistance to diseases; only recently the dry matter content began to be considered an important attribute in trading.

Regarding biotechnology techniques, molecular tracers, sequencing, and structural and functional analysis of the genoma, recently made available for improvement, in cassava, they are practically absent or focused on other objectives, distant from the assisted improvement aimed at starch production or sugars biosynthesis. For ethanol production, theoretically, it is interesting to develop varieties that accumulate directly fermentable sugars in the root, so that the saccharification process will not be necessary. A germplasm with this feature is already known, however there is a need to develop varieties compatible with large-scale production.

Nutrition

Cassava has good performance in fertile soil, however, its performance is also quite satisfactory in poor soil, even with little fertilization, where other cultures would be unviable. Therefore, it is an excellent instrument for exploiting marginal soils without having to resort to oil-based fertilizers. This behavior is explained by the efficient association with mycorrhiza and/or association with other non-Rhizobia nitrogen-setting microorganisms, a mostly unstudied subject, nevertheless proven efficient. (COOK, 1985). The aptitude of cassava for sharing land with other cultures without loss in productivity may be used in conjunction with nitrogen-setting leguminous plants, mostly peanuts. Therefore, it is a species that may collaborate to mitigate nitrifying pollution.

Tolerance to hydric deficit

Cassava seeds have their mass between 30 and 130 g per unit, which gives it good resistance to rainless periods during planting. When the plant is installed, short mini-summers in the winter season may reduce the potential yield, however, in no way it will jeopardize production, as it happens with cereals. Therefore, it is a low-risk culture. This adaptability makes cassava a species very

TABLE 9 Comparison of productive performance and dry matter content of different cassava varieties.

Variety	Production		Dry matter content
	$t.ha^{-1}$	%	%
White from Santa Catarina	20.8	100	39
Fiber	20.8	100	35
Roxinha	21.2	102	36
IAC 12	21.8	105	41
IAC 13	22.6	105	40
IAC 14	26.1	125	43

15 to 22 assessments with one cycle (10 to 14 months).

Source: LORENZI and MONTEIRO (1996).

well adapted to tropical climates where rains are not frequent. This feature is a consequence of the deep root system that exploits a large volume of the soil and physiological mechanisms of rational use of water (COOK, 1985). Therefore, cassava may occupy areas not recommended for sugarcane due to their hydric deficit.

Mechanization

Mechanization of the cassava cultivation has evolved significantly from the 1990s on, and many tasks became fully mechanized, like planting, or partially mechanized, like harvesting. This evolution, associated to the use of herbicides, allowed the increase of cultivated areas in the states of São Paulo, Paraná and Mato Grosso do Sul and is spreading to other states where large projects are being implemented. However, cassava still requires considerable labor, which may limit its cultivation. Machinery for cultivating cassava is typically low cost, in comparison to what is used for cereals and sugarcane, making it affordable for small farmers.

Technology directed to family agriculture

Cassava is a culture whose technological profile matches family agriculture and that in parallel with, or complementary to, sugarcane, may continue to develop technically for large agribusinesses, as well as to integrate family agriculture in energy generation in a way to integrate – and not exclude – social benefits. Therefore, exploiting the features below may be useful in the formulation of public policies, aiming at improving the productive system and minimizing negative socioeconomic impacts.

a) *Low capital demand.* Cassava is a low-risk, low-cost culture. The major disbursement is in harvesting, i.e., close to the income period. Therefore, even producers on a small capital budget can cultivate cassava with low credit needs, with their own capital or even in collaboration with the agro industry receiving the raw material.
b) *Constant cash flow.* Cassava roots are marketed throughout the year, so positive cash flow is constant, making finance management similar to a non-seasonal business, with easy and rational administration for small producers and agro industries.
c) *Business model for small producers.* Currently available techniques allow small producers to obtain a good income, becoming a profitable business model. In the past years, the average cultivated area has increased as a result of the development of agricultural machinery, however, these are expected to remain affordable to small producers.
d) *New varieties.* The most important instruments for obtaining a good profit with cassava are either free or low cost. They are good varieties, good seeds and planting at the right time. Cassava is a vegetative propagation species and the varieties are in the public domain, so it is important that the development of new varieties is not protected, requiring the payment of royalties.
e) *Equipment developed by small producers.* Since the 1990s, there was considerable development in machinery for planting and harvesting, which made working in small areas easier and allowed the expansion of cultivated areas, as they increased the income from the cultivated area. These machines were and are still being developed by technicians with empirical and academic background in the Center-South of Brazil and are manufactured by small and mid-size industries specialized in agricultural machinery. It is a very dynamic industry, and the more professional companies are also developing machines for large projects. In this mix, there are a large number of farmers interacting with small jig and fixture shops that develop, manufacture and improve agricultural machinery for cassava. This employs local talent, adds dynamism to the local and regional economy and to the whole production chain. Though there are many technical innovations, the industry works informally without requesting patents and deserves governmental support to continue the informal innovation process.
f) *Marketing agreements.* The price conflict between farmers and agro industries was

a negative factor in the production chain, but with the introduction of agreements and the publication of trading prices (available at: <www.cetea.esalq.usp.br/mandioca/> and others), the sector became more professional and several problems were mitigated regarding prices and delivery of the agreements. Various conflicts still persist, requiring technical formulations to be equated, mostly by publishing information widely, aiming at reducing unbalanced prices.

g) ***Development of jobs, competencies and income.*** Since production technologies for cassava are developed locally or regionally by small entrepreneurs and public institutions, this makes local and regional economy stronger and more dynamic. Obviously, the industry will develop faster, more efficiently, and with more innovation if it is supported by public policies made for the industry with this intent.

Summarizing, one can state that cassava has a large utilization potential for ethanol production due to biological features that may significantly contribute to mitigate social and environmental impacts derived from the production of this commodity. However, this potential is scarcely explored because its technological development has undergone slow improvements, and to a much lesser extent than needed. Its current status may be considered as resembling sugarcane in the 1970s. Its natural potential will only be exploited if there is intense governmental support to qualify human resources, develop technology and transfer it to the production sector.

Sweet potato

Sweet potato is originated from the tropical regions of the Central and South America. It is a species with high economic and nutritional value (Table 10), being one of the sources of food safety of countless populations, mostly those located in poor regions. It is a rustic culture, adapted to tropical and sub-tropical conditions, with great potential for technology development.

Currently China stands out as the world's largest producer, having over 4.7 million hectares cultivated with sweet potato, and reaching an average productivity level of 21.3 $t.ha^{-1}$ of roots (FAO, 2008). The African continent is second, however with low average root productivity (4.4 tons/ha). Still in Africa, the leading producer is Nigeria, with over 1 million hectares cultivated with sweet potato, however, presenting only 3.4 t/ha^{-1} in average root productivity (Table 11).

Among developed countries, Japan stands out with the highest average root productivity (24.2 $t.ha^{-1}$), above the level achieved in the US (21.0 $t.ha^{-1}$). Still considering Japan, historically, sweet potato was used as raw material for producing ethanol during Word War II, as reported by Mr. Ryoichi Nakagawa, which was used as fuel for aircrafts and other vehicles (NEELY, 1997), (AKIHIKO ANDO, personal communication)[1].

In Brazil, sweet potato is cultivated practically everywhere, and mostly as a culture to guarantee food in small rustic properties. In 2006, IBGE data showed the Northeast (19,381 ha), the South (18,768 ha) and the Southeast (5,635 ha) as the regions having the largest areas producing sweet potato (Table 12).

In the Southeast region, the São Paulo state stands out with the largest cultivated area with this tuber (3,114 ha) which is scattered all over the state (Figure 1). Three large production areas, however, should be highlighted, represented by the cities of Sorocaba, Dracena and Presidente Prudente, where areas larger than 250, 300 and 2,000 hectares, respectively, are cultivated (Figure 2).

Processing of amylaceous raw materials for ethanol

The starch present in the roots, tubers and cereals has to be converted into sugar, to be fermented by yeasts. Hydrolysis or saccharification of starch may be done by acid or enzymatic way

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[1] ANDO, Akihiko. Personal comunication (2007). Escola Superior de Agricultura Luiz de Queiroz – Esalq/USP – Centro de Energia Nuclear na Agricultura (Cena); Piracicaba-SP.

TABLE 10 Average nutritional composition of sweet potato *(Ipomoea batatas)*, taro *(Colocasia esculenta)* and yam *(Dioscorea alata)*.

Composition	Sweet potato	Taro	Yam
	Ipomoea batatas	***Colocasia esculenta***	***Dioscorea alata***
Moisture (%)	71.1	69.1	77.3
Energy (kJ $100g^{-1}$)	438	480	347
Protein (%)	1.43	1.12	2.15
Starch (%)	20.1	24.5	16.7
Sugar (%)	2.38	1.01	1.03
Fiber (%)	1.64	1.46	1.88
Minerals (mg $100g^{-1}$)			
Calcium	29	32	8.2
Phosphorus	51	70	38
Magnesium	26	115	17
Sodium	52	1.8	3.3
Potassium	260	448	318
Sulphur	13	8.5	12
Iron	0.49	0.43	0.60
Copper	0.17	0.18	0.15
Zinc	0.59	3.80	0.39
Manganese	0.11	0.35	0.04
Boron	0.10	0.09	0.09
Vitamins (mg $100g^{-1}$)			
Vitamin A (ret. β-carotene)	0.011	0.007	0.018
Thiamine	0.086	0.032	0.047
Riboflavin	0.031	0.025	0.030
Nicotinic acid	0.60	0.76	0.38
Vitamin C	24	15	28

Source: BRADBURY (1988).

TABLE 11 Planted area, total production and productivity for sweet potato in the world and its leading producers (2006).

Countries	Planted area (ha)	Total production (ton)	Root productivity ($kg.ha^{-1}$)
World	8,661,288	127,228,146	14.7
China	4,708,503	100,222,120	21.3
Africa	2,559,223	11,326,628	4.4
Nigeria	1,021,000	3,462,000	3.4
Cuba	47,123	303,000	6.4
Japan	40,800	988,900	24.2
United States	35,130	737,000	21.0

Source: FAO (2008).

TABLE 12 Planted and harvested areas, total production, productivity and total value of production of sweet potato, divided by geographic regions and states (2006).

Regions/States	Planted area (ha)	Harvested area (ha)	Total production (ton)	Roots productivity (kg/ha)	Value
Brazil	44,406	44,357	518,541	11,690	230,768
North	382	366	866	2,366	227
Acre	10	10	88	8,800	50
Amazonas	342	326	628	1,926	103
Pará	30	30	150	5,000	75
Northeast	19,381	19,378	181,470	9,364	65,605
Maranhão	16	16	25	1,562	5
Piauí	98	98	507	5,173	268
Ceará	1,221	1,221	9,306	7,621	3,934
Rio Grande do Norte	2,198	2,197	18,753	8,535	7,461
Paraíba	5,796	5,796	51,225	8,837	18,616
Pernambuco	2,054	2,054	19,051	9,275	9,068
Alagoas	2,031	2,031	18,509	9,113	6,538
Sergipe	3,143	3,143	34,532	10,986	7,226
Bahia	2,824	2,822	29,562	10,475	12,490
Southeast	5,635	5,605	83,800	14,950	31,930
Minas Gerais	1,198	1,198	16,064	13,409	7,194
Espírito Santo	186	186	4,220	22,688	1,688
Rio de Janeiro	1,107	1,107	19,144	17,293	6,385
São Paulo	3,144	3,114	44,372	14,249	16,663
South	18,768	18,768	250,013	13,321	131,919
Paraná	2,997	2,997	49,755	16,601	22,597
Santa Catarina	2,877	2,877	44,931	15,617	15,006
Rio Grande do Sul	12,894	12,894	155,327	12,046	94,316
Center-West	240	240	2,392	9,966	1,086
Mato Grosso do Sul	6	6	90	15,000	32
Mato Grosso	30	30	180	6,000	63
Goiás	120	120	660	5,500	299
Distrito Federal	84	84	1,462	17,404	693

Source: IBGE (2008).

(Figure 3), in continuous or discontinuous processes. Acid hydrolysis reduces the time required for starch saccharification, however, it has a host of restrictions, such as equipment corrosion, the need to correct the pH of the sugar solution, partial destruction of sugars and the formation of non-fermentable sugars. Enzymatic hydrolysis takes place in reactors where enzymes of vegetal or microbial origin, especially the enzymes α-amylase and amyloglucosidase (VENTURINI FILHO *et al*., 2003).

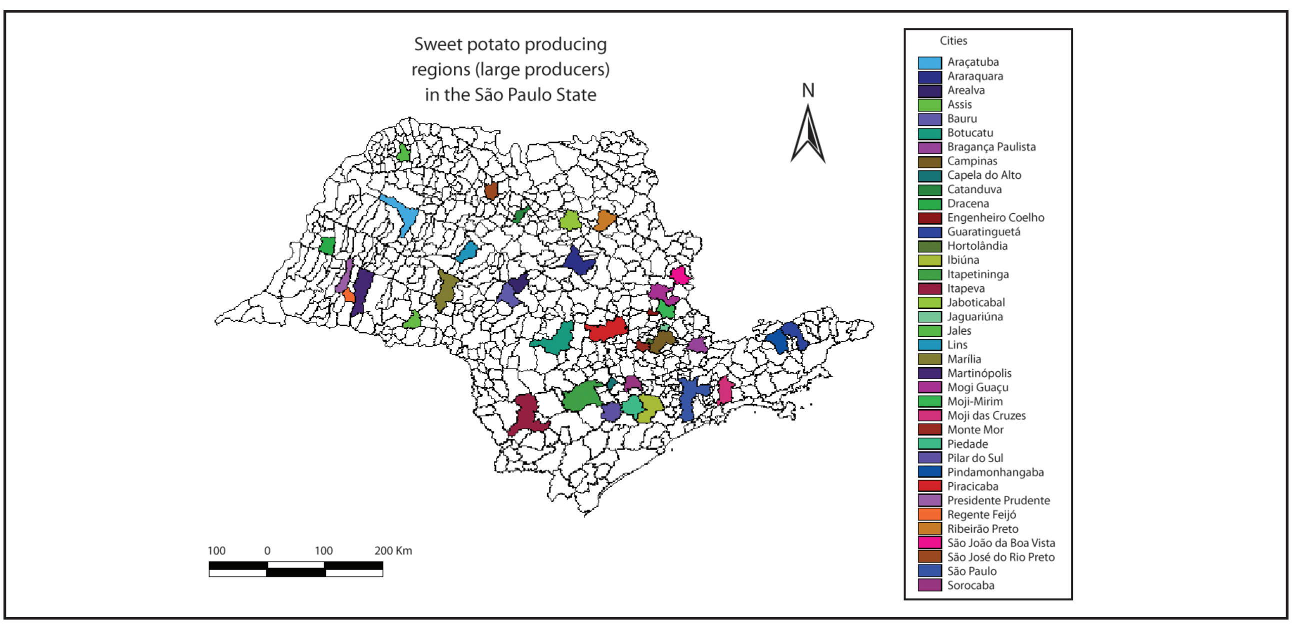
The issue of using amylaceous raw materials, with emphasis on sweet potato, for producing biofuels is not new. In 1909 a study was published assessing the key parameters (productivity and dry matter content in roots) for ethanol yield, suggesting that root productivity would be the major factor (KEITT, 1909). However, when genotypes have different starch content, it is observed that starch plays a larger role in ethanol yield (BOSWELL, 1944). Ethanol produced from sweet potato was used as fuel by Japan in World War II (NEELY, 1997).

In late 1970s, ARAÚJO *et al*. (1979) used sweet potato as raw material for ethanol production, achieving an average yield of 158 liters per ton of roots. However, they observed that the low root productivity (11 to 13 t/ha^{-1}) was the restraining factor for recommending it as alternative source for producing ethanol in Brazil.

In the 1980s, SACKS (1980) pointed out the need to replace the use of grains such as corn to produce ethanol through fermentative processes. According to this author, among the various alternative raw materials for producing ethanol, sweet potato stood out as adequate for this purpose. However, the sweet potato yield of starch per hectare should be higher than grain and plantations should have high starch content.

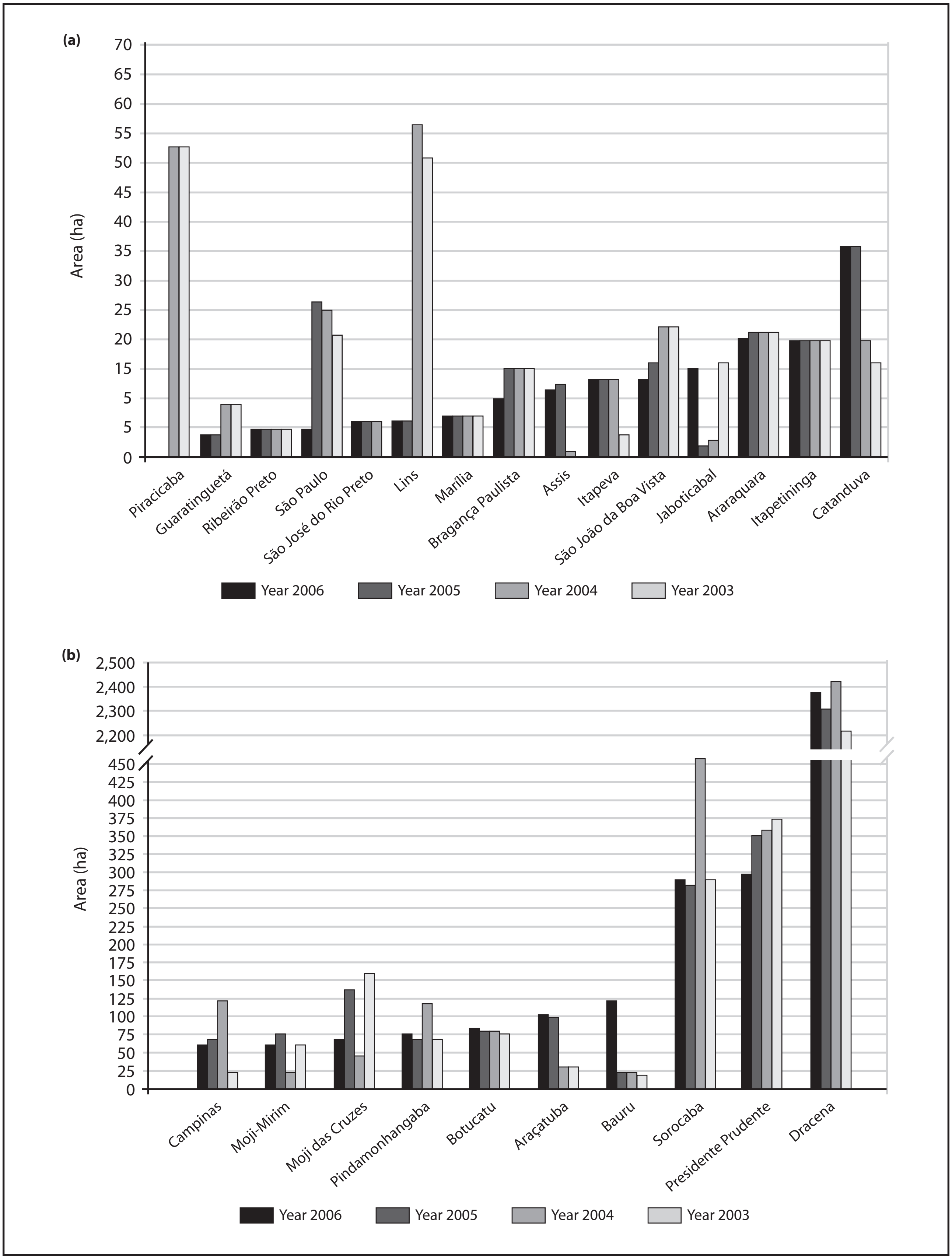
MCARDLE and BOUWKAMP (1982) assessed the sweet potato's potential for producing ethanol, using sweet potato varieties with high starch content in the roots. They found productivities higher than 5.8 t.ha^{-1} of starch in a productive system using little agricultural inputs and a conversion into ethanol higher than 76%. These authors pointed out that roots storage and transportation costs may be limiting factors for the implementation of ethanol processing plants in the US.

Efficiency of the fermentation processes of the sweet potato mash varies between 87% and 93%, depending on the variety and the roots' dry matter content (WU, 1988), which are close to



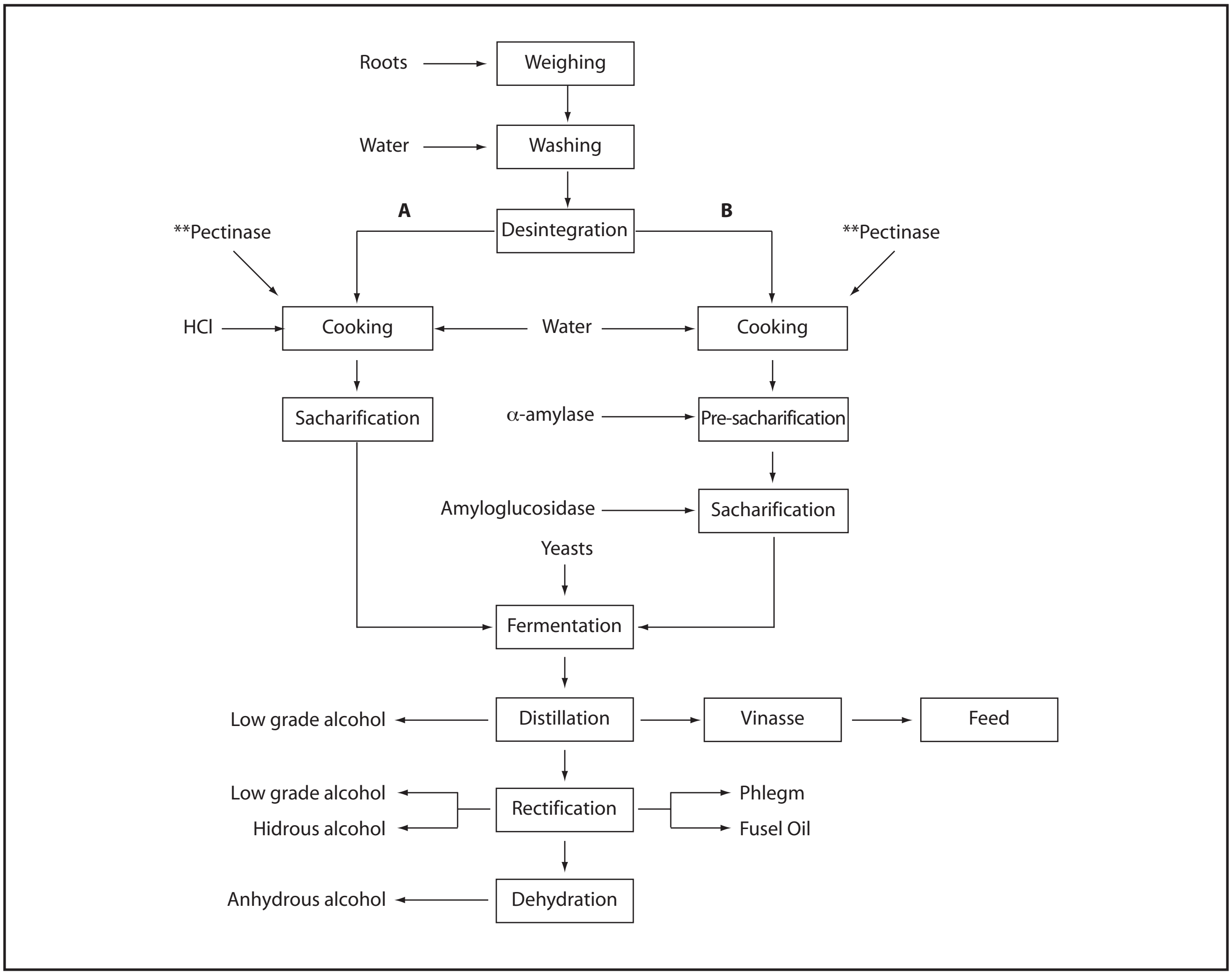
Source: adapted from IEA (2007).

FIGURE 1 Areas where the largest sweet potato producers in the São Paulo state are concentrated.



Source: Adapted from IEA (2007).

FIGURE 2 Major sweet potato producers in the São Paulo state. Areas under 60 hectares (a) and areas over 60 hectares (b).



Source: Adapted from VENTURINI FILHO *et al.* (2003), according to WU (1988).

FIGURE 3 Flowsheet of acid (A) and enzymatic (B) hydrolysis processes modified by the addition of pectinases.

the 88% obtained in the corn fermenting process (WALL *et al.*, 1983).

JONES *et al.* (1983) assessed the sweet potato's capacity to produce ethanol, using the *Jewel* and *Hi-Dry* varieties, obtaining respectively between 5,332 to 7,109 l/ha^{-1}, and between 6,660 and 10,663 l/ha^{-1} of ethanol. Nevertheless, these authors recommend the adoption of varieties with higher dry matter content and the improvement of fermentation methods to increase ethanol yield.

Other cultures may be alternative sources of raw material for producing ethanol. Along this line, TALBERT *et al.* (1983) evaluated the productive potential of eight commercial crops (corn, barley, rye, wheat, grain sorghum, sorghum bicolor, Jerusalem artichokes and sweet potato) in the Southeast region of the United States. Best results were obtained with corn, sweet potato and Jerusalem artichoke. From these, the sweet potato was the most viable for producing ethanol, obtaining 1,780 liters of ethanol per hectare, with possibilities of reaching 2,806 L.ha^{-1}, its cost varying from US 42¢ to US$ 2.01 per liter. Yield levels were close to those obtained for corn (2,132 L.ha^{-1}), like production costs between US 42¢ to 54¢ per liter of ethanol. Jerusalem artichoke's yield was lower than 1,700 L.ha^{-1}, and high production cost, at least US 94¢ per liter. These authors pointed the sweet potato as a potential culture for the production of ethanol, and observed that production costs may be lowered by using higher yield varieties and by optimizing fermentation processes.

COLLINS (1984) assessed the dry matter and protein content and the ethanol yield of nine sweet potato genotypes in North Carolina, US. In a harvest made at 5½ months, yield obtained was between 31.4 and 58.6 $t.ha^{-1}$ of roots. The *Pelican Processor* and *Jewel* varieties were the most productive, with 58.6 and 50.2 t/ha^{-1} of roots, respectively. Between these, the *Pelican Processor* stood out for its higher dry matter per hectare yield (18.3 t/ha^{-1}) and ethanol (8,597 L/ha^{-1}), with a ratio of 0.1467 liters of ethanol per kg of roots. It was also ascertained that the roots' dry matter content had a positive correlation with ethanol efficiency (r = 0.96 and p< = 0.01) and a negative correlation with the protein content (r = -0.66 and p< = 0.05). Therefore, this author suggested that sweet potato improvement programs should first select high-yield root genotypes and, secondly, select them by the roots' dry matter content.

KIM and HAMDY (1985) obtained for the sweet potato variety *Georgia Red* (23.6% ± 1.2 of dry matter and 21.4% ± 0.6 of starch) a 30.8 $t.ha^{-1}$ roots productivity, which corresponds to 4,032 liters of ethanol per hectare.

In Brazil, specifically in the Tocantins state, Tocantins Federal University (Universidade Federal de Tocantins – UFT) has been carrying out a sweet potato improvement program, initiated in 1997, specifically focused on energy (SILVEIRA, 2008). In this program, high-yield and high starch content genotypes, with were evaluated for five years in Tocantins regarding root yield, dry matter and starch content, and ethanol yield. Varieties that stood out were Duda (65.5 t/ha^{-1} of roots, 40.4% of dry matter and 24.4% of starch), Beatriz (43 $t.ha^{-1}$ of roots, 33.2% of dry matter and 26.2% starch), Ana Clara (45.7 $t.ha^{-1}$ of roots, 35.4% of dry matter and 23.4% of starch), Amanda (46.7 $t.ha^{-1}$ of roots, 32.4% of dry matter and 21.4% of starch) and Julia (40.6 $t.ha^{-1}$ of roots, 37.4% of dry matter and 24.6% of starch), with 10,467, 7,436, 7,058, 6,595 and 6,585 $L.ha^{-1}$ of ethanol, respectively. Regarding production costs, this author reported an average cost of R$ 0.42 per liter of ethanol produced.

Besides the high ethanol production capacity, mainly with varieties having high starch content in the roots, the by-products derived from the fermentation process have characteristics that make them adequate for animal feeding (Table 13), thus being able to improve the economic result of processing plants. The ethanol production rate is about 1:6.4, i.e., for the production of one kg of ethanol, 6.4 liters of stillage are obtained and the solid content in the liquid residue is between 4% and 6% (WU, 1988). However, using a mixture of 40% of ground cassava roots and 60% of macerated corn grain, the ethanol production ratio was 1:14, and the residues from the fermentation featured these physicochemical characteristics: 94.36% of moisture, 4.29% of carbohydrates, 0.93% of protein and 20.88 kcal $100g^{-1}$ for heating value (VIEIRA[2]). In addition to these, sensorial features presented good palatability to cattle.

TABLE 13 Composition in percentages of residues (moist and dry) of the sweet potato fermentation process.

Component	Moist residue (%)	Dry residue (55 °C/72 h)
Raw protein	611	14.5
Ethereal extract	0.97	2.92
Raw fiber	7	39.04
Non-nitrogenated extract	22.45	38.6
Ashes	8.98	14.02
Moisture	42	12

Source: SILVEIRA (2008).

Currently, interest in using sweet potato as raw material by China and other countries has drawn growing interest, as well as other environmental projects.

Sweet potato processing

Using sweet potato as raw material for producing ethanol causes some problems in the fermentation process, mostly related to the mash viscosity (presence of pectines), interfering in ethanol yield and in the filtering and residue concentration processes. In view of this problem, research was made to stabilize the mash and neutralize the viscosity

[2] VIEIRA, Jonas Arantes. Agroindustrial Tarumã Ltda. São Pedro do Turvo-SP. 2008.

effect in the process. CHUA *et al.* (1984) determined that the addition of depolymerase pectine to the sweet potato mash increased the release of glucose, however, the use of heating in the saccharification of starch was essential to reduce the process total time. The addition of pectinases to the sweet potato mash increased the ethanol yield, the percentage of solids and proteins in the filter pie (WU and BAGDY, 1987). Regarding the filter cake characteristics, these authors observed an increase in the amino acids content, as they were higher than those present in the filter cake obtained in cereal fermentation processes. Furthermore, the residues of sweet potato fermentation for producing ethanol, especially if concentrated as a filter cake may be used as raw material for the food industry, which contributes to the distillery economic results.

Nowadays, the processing cost of amylaceous raw materials for producing ethanol has been high, which renders ethanol from starch non-competitive in comparison to ethanol produced from sugarcane. However the adoption of varieties with high dry matter content and high root yield, plus adjustments of the fermentation process, such as the use of more efficient or genetically modified enzymes may allow better economic results, like those by SILVEIRA (2008). Nevertheless, it is crucial to add value to the by-products from the sweet potato fermentation process, which may be used for human consumption (WU, 1987) or for animal feed.

Sweet sorghum

This gramineous plant has drawn a lot of attention worldwide as a high potential raw material for producing ethanol, often compared to sugarcane. Its main reported advantages are high resistance to drought, adaptability to less fertile soil (alkaline and salted), undefined production cycle (allows planting at various periods of the year, being capable of offering two harvest seasons or sharing land with other cultures), and being more tolerant to temperature variations, as long as no freezing occurs. On the disadvantage side, the following points were observed: fast deterioration after harvest, difficulties in transportation, more difficult sugar crystallization, low juice purity and lower sugar content than sugarcane.

Because of its less stringent requirements in terms of soil and climate, sorghum has been recently considered for ethanol production in some regions of Africa, China, India, and even Europe (Italy, Greece and Romania). A large project was set up by ETA Florence in Italy (ETA FLORENCE, 2002), using resources from the European Committee to assess the techno-economic feasibility of producing ethanol from sweet sorghum in large agro industrial complexes; three locations were pre-selected: one in Southern Italy (Basilicata area) and two in China (Dongying region in the Shandong province and Huhhot in the Inner Mongolia province), all of them with colder weather, low pluviometric precipitation climates and with irrigation possibilities.

The following agricultural practices were determined for field tests, which are generally independent from the local climate:

- *Planting:* with seeds, immediately after the previous harvest; allows a ratoon, and alternation with wheat or another cereal is recommended, in two-year cycles. There are European, Chinese, and American suppliers of selected seeds at a price ranging from US$ 6 to 10 per kg^{-1}.
- *Density:* lines spread apart 70 cm, and maximum density 10 $plants.m^{-2}$ to prevent them from tipping.
- *Varieties:* several selected varieties having good yield, of the precocious, normal and late types.
- *Fertilizers:* though it is not demanding on soil fertility, sweet sorghum responds well to fertilization, 90 to 120 kg $N.ha^{-1}$ being recommended.
- *Herbicides:* preferably use them in advance of the emergency and select the type carefully if it is to be applied after sprouting.
- *Fitosanitary conditions:* it is important to treat the seeds before planting and to use varieties resistant to pests and diseases.
- *Harvest:* the harvest period is selected by a compromise between maximum productivity and the extension of the harvest period

(2 to 4 months); with adequate planning, up to two harvests per year are possible.

- *Energy demand:* it is strongly dependent on the location and the volume of irrigation water; in the Italian project, the estimate value was 21 $MJ.ha^{-1}$, while in the Huhhut (China) one, the estimate value was 0.38 $MJ.ha^{-1}$, reflecting the lower mechanization level and the absence of irrigation.

The energy complexes studied considered 7,000 ha in Italy, 19,000 ha in Dongying, and 20,000 ha in Huhhut. Ethanol productivities per year was estimated as 6,000 $L.ha^{-1}.year^{1}$ for Italy and Dongying and 5,000 $L.ha^{-1}.year^{1}$ for Huhhut, using both stalks and grains as raw material. Mechanized harvest with grain, trash and (chopped) stalks separation done in the harvest equipment.

Production costs were estimated around US$ 250 m^{-3}, considering the sale of surplus electricity and pelletized bagasse.

Energy balance showed estimated results between 0.52 $kWh.L^{-1}$ of ethanol (Italy) and 0.39 $kWh.L^{-1}$ of ethanol (Dongying).

The Indian company Praj Industries Ltd. (PRAJ, 2005) selected 14 varieties for a three-year test period (2001-2003) in West India. In this process, they also developed agricultural practices, including controlled and measured irrigation; samples were periodically analyzed to measure sugar and fiber content, biomass of leaves and purity of the juice. In terms of fertilization level, it was around 150 N/100 P/100 K $kg.ha^{-1}$, and irrigation was about 175 $m^3.ha^-1.year^1$.

Key results were: total fermentable sugars – TFS between 10.5% and 11%, 42 to 50 $t.ha^{-1}.cycle^{-1}$, 105 to 115 days cycle. Major pests and diseases were assessed and proper fitosanitary actions were suggested.

Several decades ago, SACHS (1980) analyzed raw material alternatives for producing ethanol in California; for sweet sorghum he used experiments in Texas and Louisiana, where some 4,700 $L.ha^{-1}$ of ethanol had been obtained in 110 to 130 days cultivation cycles, being, in this aspect, a better option than corn. In addition to ethanol, 13 tons of fiber (dry basis) were obtained by hectare.

In Brazil, sweet sorghum was intensely studied since the outset of Proalcool. Still in the 1970s, INT (ARAÚJO *et al.*, 1977) thoroughly assessed sweet sorghum for the production of ethanol. Three varieties were provided by the National Corn and Sorghum Research Center of Embrapa, located in Sete Lagoas – Minas Gerais, with two different maturation cycles: 90 and 105 days. Both the stalks and the grains were analyzed for the production of ethanol, while saccharification, fermentation and stillage characterization tests were carried out. Results are shown in this reference. It is worth noting that the Brix of the juices was between 14.67% and 17.87%, in the average of the varieties, quite similar to the values found for sugarcane. Fermentation tests were carried out without any problem, showing good efficiency in laboratory conditions.

A study on sweet sorghum carried out by Esalq in an attempt to combine the culture of sweet sorghum with sugarcane, aiming at having the plant operating all year round, the sorghum would be planted in the sugarcane field renewal area, and several requirements were pointed out as necessary for sorghum to be adequate for such practice, the major ones being: having a short cycle, being sterile (not generating seeds in the field), good sugar content in the period, having resistance to major pests and diseases of both sugarcane and sorghum. In one analysis of the varieties of sweet sorghum provided by Embrapa Corn and Sorghum, some problems were identified that would compromise the sugarcane/sorghum alternation as intended, mostly because of the negative interaction between the two cultures from a pest and diseases control standpoint. A warning was made about the problems resulting from soil compactation, due to sorghum harvesting in the months from January to March, when rainfall is more intense in the Center-South.

Overall, it may be said that some business experience is lacking in the use of sweet sorghum as raw material for ethanol production, both in the agricultural and distillery areas, which might give some reassurance to ethanol producers to try this option.

Jerusalem artichoke

The Jerusalem artichoke (*Helianthus tuberosus L.*), is a plant of the family of the hickory, with tubercles that are a source of inulin, oligosaccharides and fructose. The enzymatic hydrolysis of inulin produces fructooligosaccharides (FOS) with low molecular weight, polymerization degree from 1 to 10, in addition to fructose and glucose. It has an immense range of applications in the food industry and may be used as a substrate for ethanol fermentation.

It is a culture of tropical countries, widely cultivated in Europe, Canada, US, and Latin America (Brazil and Peru). It matures in around 130 days, with the overground part reaching 1.50 to 2.10 m in height; it seems to be resistant to pests and diseases and tolerates droughts well.

The agricultural aspects of growing Jerusalem artichoke were exhaustively studied by PAULA and CARIOCA (2000), motivated by works carried out in Canada, Spain, France and Germany, aiming at obtaining inulin and fructose.

In France, 37 varieties were tested, presenting carbohydrates content in a range from 55% to 75% of dry mass. In Germany, field tests showed values for dry matter between 11.5 to 14.0 $t.ha^{-1}$.

In Brazil, 27 varieties of Jerusalem artichoke were tested in the Northeast by PAULA and CARIOCA (2000), with very promising agronomical results. Dry matter yield varied from 4.6 to 19.7 $t.ha^{-1}$, being inulin between 70% and 85% of dry mass. The two most productive varieties, MFW and Columbia, produced between 19 and 20 $t.ha^{-1}$ of dry matter; these same varieties also produced above 6 $t.ha^{-1}$ of green biomass (overground part), and more than 1 $t.ha^{-1}$ of protein. Considering that two or three harvests are possible in one year, these figures become very significant when considering the production of ethanol.

Fermentation may be carried out directly with inulin, using microorganisms like *Kluyveromices maxianus*, or after inulin hydrolysis into fructose and glucose, when it will be possible to use *Saccharomyces cerevisiae*.

In SACHS' (1980) study, irrigated Jerusalem artichokes in California produced 30 $t.ha^{-1}$ in average, on a 110-day cycle and noticed that the pulp may contain as much as 15% in protein, which confers it a high nutritional value.

Sugar beet

Sugar beets are cultivated mostly in mild climate countries to produce sugar, corresponding to almost one-fourth of the world's production. It is seldom produced outside Europe and the US, however, there are some exceptions, as shown on Table 14.

Though it does not appear on Table 14, it is worth mentioning that beet productivity in Chile was 79 $t.ha^{-1}$ in that same year (2007).

It is easy to draw the conclusion that beet, in terms of productivity in liters of ethanol per area

TABLE 14 Sugar beet production worldwide.

Country	Area (1,000 ha)	Production (1,000 tons)	Productivity (tons/ha)	$L.ha^{-1}$
France	393	32,338	82.28	7,700
Germany	406	26,114	64.32	6,000
US	504	31,912	63.24	5,900
Turkey	330	14,800	44.85	4,200
Iran	160	5,300	33.12	3,100
Morocco	60	3,000	50.00	4,700

Source: FAO (2008).

unit is a good option for many countries, In fact, with the change in the European sugar regime, a large portion of the beets, that won't be used for the production of sugar any longer, is being diverted for the production of ethanol, sharing with wheat the preference for this use.

A few years ago, Syngenta Seeds (CHATIN *et al*,, 2004) concluded a seven-year project to develop sugar beet varieties adapted to warmer climates, with the objective of competing with sugarcane in tropical countries, The noted advantages would be: six-month cultivation cycle; adaptability to alkaline and salted soils, plus lower irrigation demand; Syngenta states that productivity levels between 60 and 80 $t.ha^{-1}$ with saccharose contents from 15% to 19% are obtained with an irrigation of only 10,000 $m^3.ha^{-1}$, A sugar mill using this input was scheduled to start operation in 2004 in India and another one in 2005 in Colombia. The same source estimates that half of the processing plant would be the same for either sugarcane or beet; only the front-end of the process would have to be modified: washing the tubers, slicing, diffusion, drying and pulp pelletizing.

More information on the commercial use of this raw material for producing sugar and ethanol is needed before an opinion can be drawn on its use in Brazil. However, the potential productivity is something that arouses interest. The alternative to be researched is the possible shift between beet and sugarcane, to extend the harvest. There are four plants in Pakistan and one in Egypt operating with these two raw materials.

FINAL CONSIDERATIONS

The options for raw materials for the production of ethanol are many and varied, however few reached a significant proportion as commercial alternatives. It is estimated that about 90% of the world's production of ethanol is from sugarcane or corn. Nevertheless, with the growing world production and the entrance of new countries into production, other raw materials become possibilities, mostly beet, wheat and cassava.

It is interesting to notice that the producing countries so far have always sought for an alternative among the cultures they mastered, like Brazil with sugarcane, the US and China with corn, Europe with wheat and beet, Colombia with sugarcane, and so on. This is explained by the immediate availability to start producing ethanol, technical advances in the selected culture (lower cost and risk) and cultural aspects of working with a well-known agricultural product. Thus, several promising raw material options, like sweet sorghum and Jerusalem artichoke, failed to advance due to the lack of familiarity of the prospective producers with these cultures. The lack of interest leads to a shortage of investments in developing these cultures, which on their turn remain out of the ethanol production chain, and the loop is perpetuated. Table 15 below shows some of these points.

It may be noticed that the cultures that advanced the most in terms of production – sugarcane and corn – had significant gains over the last

TABLE 15 Raw materials for the production of ethanol.

Raw material	Brazilian production (millions of tons)		Productivity ($t.ha^{-1}.year^{-1}$)		Yield in ethanol ($L.ha^{-1}.year^{-1}$)	
	1980	2005	1980	2005	1980	2005
Sugarcane	120	410	45	72	3,015	6,000
Cassava	26	27	12	13.8	2,160	2,750
Sweet sorghum	–	–	35	50[1]	1,925	6,000[2]
Sweet potato	1.6	0.54	10	11.2	1,250	1,770
Corn	16	34.9	1.5	3	580	1,200

Source: MENEZES, 1980; (1) PRAJ, 2005; (2) ETA FLORENCE, 2002.

25 years, while cassava and sweet potato remained stationary regarding production and productivity. Cassava seems to deserve more attention due to the importance of its culture in Brazil and by the potential it has to improve productivity if more effort is put toward genetic improvement and agricultural practices modernization; sweet potato seems to have some potential, but its high production costs place it in the background. Both sweet sorghum and Jerusalem artichoke deserve more attention, however they would still have a long way to go to build confidence in farmers and investors; these two plus cassava may eventually become important options for areas inadequate for sugarcane, however, having other positive features for the production of biofuels, either by their privileged geographic location for exports or for social reasons.

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Part 4

A NEW MODEL FOR INDUSTRIAL PRODUCTION AND FINAL USES OF ETHANOL

Antonio Bonomi
(organizer)

1

INTRODUCTION

Antonio Bonomi and *Maria das Graças de Almeida Felipe*

Nowadays, Brazil is facing the perspective of a significant increase in fuel ethanol demand. This forecast is based on three market realities: first, internal increase of hydrated ethanol consumption due to the success of the flex-fuel in the light automobile vehicles market; second, expansion of the Brazilian ethanol exports due to the growing world interest in the ethanol mixture to gasoline, as a way to prevent global warming; and finally, the Brazilian option for the production of biodiesel, using ethanol via the transesterification of vegetal oils.

A realistic projection foresees a significant increase of Brazilian ethanol production in the next 5-10 years. This important expansion of production is starting to become a reality through the start-up of new plants, opening new perspectives to the sugarcane agriculture. Besides, it will require a concerted effort in searching for a significant increase in productivity – liters of ethanol produced per hectare of planted sugarcane. This boost in productivity can be reached through two technological routes. The first route focuses on the agricultural area and will try, through the expansion of new varieties program and, in the future, through the use of transgenic sugarcane, to increase the present productivity level (tones of sugarcane/hectare/year). The second route, focusing on the industrial sector, will try to develop technologies for the complete utilization of sugarcane, producing ethanol or other renewable fuels, or even by means of the biorefinery concept, aggregating value to the sugarcane chain by producing new products. It will be necessary to introduce new alternatives for ethanol use as well as concentrate efforts to improve the technology available and to develop new technologies that improve ethanol production.

The project “Guidelines for Public Policies for Sugarcane Agro-industry in the State of São Paulo” tried to establish – through workshops organized by several Institutions, and with papers written by invited specialists, the required basis to build the technological Road Map for the production and use of bioethanol in Brazil, in general, and, in the São Paulo State, in particular. This part of the project, dealing with the production and use of bioethanol, was organized in four main areas:

1. state of the art of ethanol production;
2. technological improvements within the present ethanol production context;
3. 2nd generation technologies for ethanol and other biofuels production and the biorefinery concept;
4. ethanol use.

In order to define the state of the art of ethanol production, trying mainly to establish the existing technological bottlenecks, two workshops were organized by the Engineering School of Lorena – EEL-USP. The event was attended by selected researchers, working in the area of bioenergy, especially in industrial ethanol production in Brazil. The workshops focused on aspects such as: raw material quality and its consequences for ethanol production, microbial physiology and ecology, aspects related with production operations (special emphasis on fermentation and distillation); besides aspects related to the use of bagasse and trash for ethanol and other products, with emphasis on the heterogeneity of these materials and the need of pretreatment before use. Aiming at completing the state of the art of the production sector, a specialist, with long experience in industrial fuel ethanol production, prepared a global technological assessment.

In the assessment to upgrade the present ethanol production technology, some topics were selected for further discussion in various special workshops. The potential of bioelectricity generation using the residual sugarcane biomass was discussed in a workshop organized by Unicamp, during which the potential of this alternative was pointed out, which in the medium run could represent 20 to 30% of the installed electric capacity of the country, demonstrating as well that the major difficulties in its implementation are political and regulatory. There are still some technological bottlenecks, such as sugarcane trash combustion and bagasse and trash gasification. In order to identify technological alternatives to improve the electricity co-generation, an analysis of the optimization options for energy utilization in sugar, ethanol and electric energy plants was performed. The instrumentation and automation of ethanol plants were discussed in a workshop organized by embrapa-Instrumentação, in the city of São Carlos, covering the two major areas of the production chain, the agricultural phase (report included in Part 3) and the industrial phase. In this part of the workshop, the following aspects were shown. The development of mathematical modeling and simulation tools, in order to implement modern, advanced and robust techniques for the processes and unit operations control, considering also the future integration of the 2nd generation ethanol production and the diverse operations and technologies included in the biorefinery concept. The optimization of water consumption, an issue that is becoming important due to the shortage of this natural resource, was presented in a workshop organized by Nipe-Unicamp. The workshop dealt mainly with the environmental aspects (report included in Part 2), during which a significant reduction in water consumption in the mills – from 5 to 1 m^3/tone of cane observed in the last decade, was pointed out. New reductions, as well as the possibility of the mill becoming a water exporter, will require significantly much larger investments. The use of stillage to produce energy, an issue that will be considered when optimizing the Biorefinery, was discussed in a technological workshop on stillage organized by FCAV of Unesp in the city of Jaboticabal, São Paulo state. The application of to agricultural (report included in Part 3) was also dealt with in this workshop. The fact that the biodigestion of stillage is not used on a large scale was justified by the large investment and operational costs required, when compared with the ferti-irrigation alternative. A paper was prepared in order to analyze and give further details of R&D requirements associated to the production and use of stillage, identifying the alternatives that will reduce the amount of stillage/liters of ethanol ratio, as well as assessing the techniques to be used e.g. biodigestion, concentration, and combustion or incineration. The increasing level of development reached by the sugarcane industry in Brazil associated with the concept of integral sugarcane use, has generated an attractive incentive to the use of the agricultural residues of the sugarcane. With this focus, a paper was prepared to elaborate a technical and economic evaluation of some of the possible routes to collect the trash, the most important physicochemical and energetic characteristics, as well as its application in energy production through combustion. Still, within the context of assessing the technological improvements in the present production chain, Dedini S/A Indústrias de Base, prepared a paper detailing the integration possibilities of biodiesel production with sugar and ethanol plants, which present several advantages with regard to the reduction of operational costs and investments. Dedini has designed such an integrated operating plant – Usina Barralcool, in the state of Mato Grosso, Brazil.

In the new industrial model for bioethanol production, a major emphasis has been given to the so-called 2nd generation ethanol, considering the chemical and biochemical route, as well as the thermo-chemical route for the ethanol production from lignocellulosic material (excess bagasse and trash). The chemical and biochemical route was dealt in the workshop "Hydrolysis of lignocellulosic material" organized by IPT, during which some aspects were considered to be of considerable relevance to make this technology viable e.g. requirement to establish standard analysis to measure the most important fractions of lignocellulosic material; importance of using all the fractions of the lignocellulosic material, including penthoses fermentation and lignin combustion; comparison to the chemical routes. The enzymatic route for hydrolysis was considered as a more adequate alternative for the production of ethanol from bagasse and trash, producing a hydrolysate with large sugar yields and contents, and low toxicity. Besides these technical aspects, the requirement of planning and following the technological development, through technical-economic assessment studies of pretreatment, hydrolysis and fermentation technological alternatives, was also pointed out. Due to the importance of this topic, two additional papers prepared by international experts – Dr. Guido Zacchi (Chemical Engineering Department of Lund University in Sweden) and Dr. Rodolfo Quintero-Ramirez (Natural Science and Engineering Division of Universidade Autônoma, Cuajimalpa Unit, Mexico) were included in this analysis.

Regarding the thermo-chemical route, fast pyrolysis of the lignocellulosic material as a precursor of the BTL (*"Biomass to Liquid"*) process was analyzed and identified as a viable technology that must be commercially proven through the construction of demonstration plants. The workshop "BTL Technologies" was also organized by IPT, and several bottlenecks were identified, starting with the pretreatment and biomass feeding in pressurized reactors, continuing with the development of new gasification technologies, and finally, in the requirement of adapting the produced synthesis gas and the development of catalytic routes, for the production of liquid fuels, adequate to the BTL technology.

In order to complete the analysis of 2nd generation ethanol production, various papers were prepared aiming at detailing new concepts such as "energy cane", to quantify the relative importance of the increase in sugar and fiber content in sugarcane, as well as "biorefinery", listing the new routes and products produced from renewable raw-materials, especially sugarcane. Closing the assessment of the 2nd generation technologies and derived new concepts, a paper was prepared to evaluate their economic and environmental perspectives. This paper shows that the considered alternatives (hydrolysis and gasification technologies) present a great potential for integration in the Brazilian sugarcane mills, due to the large availability of low cost biomass. Besides, they represent an important environmental contribution, collaborating with the sustainable development of the sector.

In relation to bioethanol use, the logistic problem associated with its distribution was assessed. From this analysis, it was clear that the expansion of ethanol production should be planned in order to minimize transport costs and the resulting social and environmental impacts. Still considering the bioethanol use, the required importance of its quality, a fundamental issue as it becomes a world commodity, was included in the analysis. Therefore, a paper was prepared to evaluate the aspects related to regulation of the production, commercialization and use of bioethanol in Brazil, and the harmonization of the world specification for fuel use. Regarding quality, another paper analysed aspects related to the official methods of analysis and certified reference materials used in the validation and control of the quality assays methods. In the specific case of bioethanol use, papers were prepared presenting the historical background (past, present and future) of its use in Otto cycle engines and its future use as a fuel, the situation bioethanol in new engines, comparing it with new fuels, besides presenting the ongoing programs of its use in Diesel engines. Finally, a paper was prepared to evaluate ethanol use in the vegetal oils and animal fats transesterification, for the production of biodiesel, a viable alternative in Brazil that should increase the importance of the integrated production of these two biofuels.

2

ETHANOL PRODUCTION:

ASPECTS TO BE CONSIDERED

Maria das Graças de Almeida Felipe

Besides the use of ethanol in flex fuel engines, fuel ethanol has also been used in Brazil as an additive to gasoline (20% to 25%), and also exported to other countries with the objective to reduce GHG emissions.

The impending shortage of oil, the main global energy source, along with the legitimate concerns of society with environmental degradation has created space for a return of fuel ethanol. Produced from biomass, a renewable raw material, this biofuel is now economically attractive. It cab be observed that the transportation sector is one of those with the fastest growth in the world energy matrix, and thus it is not difficult to realize the impact on the world economy. Besides, its use as a fuel blend , alcohol has increasingly been used also as an additive to gasoline to reduce emissions from fossil fuel. Brazil is, at the same time, the largest exporter of ethanol in the world.

These were some of the reasons that led to the creation of the Project on Guidelines for Public Policy for Sugarcane Ethanol in the State of São Paulo, which started in 2006. This project built upon the completion of a series of "workshops" in which subjects that sought to address the entire ethanol fuel production chain were discussed. The main points discussed in the initial event in November 2006 entitled "Ethanol Production" are the subject of this article.

The fermentation process used in Brazil meets several important requirements for the production of ethanol fuel in large scale. Although alcoholic fermentation in its current state meets the needs of ethanol production, there is still ample scope for optimization of current fermentation processes. Within this context the above event brought about a first discussion of key themes: Quality of Raw Materials, Microbial Physiology and Ecology, Fermentation and Distillation processes. The main objective was to stimulate discussion of ways to improve the fermentation process, and to find solutions and reduce its cost further, to meet the large expansion of ethanol production and transforming the sugar mills and distilleries into large producers of biofuels.

The discussions resulting from this first event are presented here in this chapter, translated into topics, by questions and provocations posed by the workshop.

QUALITY OF THE RAW MATERIAL

The purpose of this subject is to discuss the prerequisites that must meet the raw materials involved in fermentation to ensure efficiency in the current conditions and projected scenarios. The quality of sugarcane (basic raw material) should be considered as the main factor to be taken into account to improve the performance of the alcoholic fermentation. Currently commercial production of ethanol only one third of the biomass is utilized, that is the sugar extracted from the stems in the broth (sucrose). Thus, the need for assessing parameters such as harvesting, loading and transportation of sugarcane due to the impacts exerted on the production process. These operations are not only expensive, but result in loss of raw materials and contribute to worsen the quality of this material.

Collecting also the cane tops during the harvest may result in problems in the industry as impurities (soil and mineral) which will require advances in mechanization. Determining where losses do occur poses the question whether current knowledge is sufficient to reduce these losses. So it becomes urgent to review the methods for determining quality (impurities of raw materials), and how best to implement them. This would avoid problems in the industry due to the importance of knowing, as soon as possible, the quality of raw material entering the process.

Studies on the correlation between physiological condition of the plant and industry are needed, if improvements of the production process are to be achieved. This could be related to raw material derived from the broth and therefore would be possible to know, for example, if the sterilization before fermentation, via radiation, could allow the use of specific-yeasts rather than the "rustic" yeasts currently used. Moreover, another possibility would be to clarify instead of obtaining the vinasse. There is, however, some concern because this procedure could cause problems for the yeasts. There is also a problem with the current practice of using insecticides to control pests and thus it is very important to know how to minimize their use so not to compromise the fermentation.

PHYSIOLOGY AND MICROBIAL ECOLOGY

Our understanding of the physiological conditions imposed by industrial microorganisms processes is undoubtedly very important so that we can identify the physical, chemical and microbiological contaminants that contribute to exercise stress effects or stimulants on the agents of fermentation (yeast) or contaminants (bacteria and other yeasts).

In commercial ethanol production several factors are already known that contribute to reducing the fermentative efficiency e.g. bacterial contamination, high foaming, high residual sugar, yeast flocculation, overgrowth or reduced growth. We can add to these the formation of unwanted by-products to the process such as glycerol and organic acids (acetate, succinate, malate, lactate). In this context, the critical point is presented as a certainty that the organism has a priority of its metabolism to generate energy – ATP for the formation of new cells. It is clear then that the need is not essential microbial conversion of sugars in the product in our concern as ethanol or of products formed by cellular stress such as glycerol and organic acids. It is also clear that the priority of the yeast is to maintain their survival, incompatible with our need. This leads to the need to direct the conditions of the fermentation process so that the metabolic flux is directed primarily to the formation of the target product, that is, ethanol.

In this sense it is important to understand what and how certain parameters contribute to the formation of these products and how they could the microbial metabolism be affected to favor the bioprocess. This would allow the maximum conversion of carbon source in ethanol at the same time that the diversion to other compounds (products) to be minimized. Another aspect of the approach is the physiological conditions of yeast in the fermentation carried out with cell recycle and also those with the use of immobilized cells, combining the techniques of molecular biology which could help to establish a sustainable fuel ethanol industry in the light of new changes that might be imposed on the production system.

Evaluating the influence factors prior to fermentation and the presence of metals in soil mixed with sugarcane was also highlighted. Metals such as iron may be responsible for physiological and biochemical changes during fermentation due to adsorption on the wall of the yeast cell flocculation and consequently after the centrifugation step.

As a recommendation to increase ethanol productivity, it was clear that the methodology should involve industrial production sectors of the yeast physiological approaches, identification and control of the stressors imposed by the industrial process in "real time". Research targets were also suggested e.g. changing the stoichiometry of fermentation to increase the formation of ethanol, obtaining alternative ways to control bacterial contamination and the use of bacteriocins as well as yeast strains suitable for industrial processes.

FERMENTATION

The fermentation process used in Brazil meet several important requirements for ethanol production on a large scale; Brazil is the most advanced country in terms of technology in the production of this biofuel. However, despite the current stage of development is still possible to improve its performance. Measures to improve fermentation include production of sugarcane varieties with higher content of fermentable sugars, increased ethanol fermentation efficiency to values higher than today (0.511 grams of ethanol per gram of reducing sugar as glucose). Other factors that interfere in this process step are reduction fermentation temperature, consumption of sulfuric acid or even its replacement, the cost of centrifugation and cell recycling, and in the volume of stillage generated. Although the increase in alcohol content (average value is around 8.5% (vol.), the use of alternatives to use antibiotics, nitrogen and potassium, the standardization of methods of analysis of fermentation, merit new proposals for other alternative to current processes.

The main approach during the discussion on fermentation was that the present model of ethanol production in Brazil uses a route-winning technology that makes it difficult to compete with other alternatives. This is a mature process (raw material represents 60% of the cost) and only small gains can be achieved that require large investment. Other proposed routes are certainly fertile ground for research and technological development; instruments to stimulate innovation in this area were used for long term funding or venture partnerships remain small.

For the vast expansion expected within the next 20 years, it will be necessary to further optimize production to lower cost; this requires considerable research effort to make the current process more reliable and productive, and adapted to the new conditions particularly in less favorable planting areas.

Highlighted was also the fact that only part of the cane is utilized, as burning still occurs eliminating almost two thirds of the available energy, while the actual content of soluble sugar arriving at the processing is low. This points out to significant gains may occur by optimizing these aspects, although very little has actually been done in this area. Also, the fact that the current processing is based on abundant availability of energy (in the form of bagasse, which had no other use) generates a huge waste for energy e.g. to extract the juice though the control loss is quite efficient. Exception is the fermentation process that can be achieved 90% of its maximum efficiency (0.511 kilograms ethanol per kilogram of sugar). Ethanol, although contains a considerable amount of usable energy from sugar, is also a huge waste of materials (more than 50% of the sugar does not enter as final products).

In addition to the limit of the maximum output of the fermentation process we have to consider that this is an integrated industrial process, both in terms of use the raw material (sugar) for energy generation required for processing, and also the co-production of sugar. This strategy of diversification and integration beyond the fact that sugarcane can not be stored, and that its composition evolves during the collection period, leads to the necessity that the process must have other characteristics e.g. high flexibility due to variations such as the quantity and quality of raw materials and high resilience (ability to recover after the changes); although it is questionable whether any surviving populations are adequate to obtain a low cost alcohol. In this context further research is needed is needed on storage, extending sugarcane harvest; and whole sugarcane harvesting.

The fermentation process has a good productivity, efficiency without sterilization (compared to other industrial fermentation processes), although these factors could theoretically at least be improved with better understanding of the physiology of populations of yeast in industrial environment (mainly subjected to many stressful conditions such as recycling and treatment acid), with better knowledge of the stoichiometry (metabolic pathways) of biodiversity. It is necessary to develop new alternatives more viable and sustainable than the current microbiological control and more strains of yeast for the start of fermentation process.

The kinetics of the fermentative process needs to be well understood to relate it better to the best components of the environment affected by the composition of the raw material. Also, the fact that the final content of ethanol is still too low in the broth, leads to overloading of the separation process while fermentation temperature must be kept low in view of the toxicity of ethanol and the presence of thermophilic bacteria.

More direct and simpler alcohol production processes using whole sugarcane is needed; more like a chemical synthesis to take advantages of both routes. Significant reductions in the cost of production have been achieved over the past 30 years shows the need for research either in their own production units or conditions (environment) with real limitations and particularities. To do so will require much more funding and research.

DISTILLATION

Considerable changes have taken place in Brazil ethanol distillation, with significant increases in productivity devices such as reducing the consumption of steam per liter of ethanol for both the hydrous and anhydrous. The main goal of distilling alcohol is to get a wine with high levels of alcohol corresponding to values from 92.6% to 93.5% and greater than 99.3% by weight (°INPM) for the hydrated and anhydrous respectively. The wine also contains small amounts of contaminants from the fermentation process itself and other alcohols, aldehydes, organic acids and others. The removal of these compounds, mainly of higher alcohols, is required as their presence affect the quality of ethanol. Within this context, the discussion was based on several aspects such as the reductions in energy consumption in distillation and losses in the process, the introduction of processes of multiple effects with a consequent reduction in energy consumption and cooling water, re-evaluating apparatus and processes used for both hydrous and anhydrous ethanol in order to increase production; the recovery of diluted products and also the introduction of sensors and automation.

Research proposals relevant to ethanol distillation in the near future from the workshop are listed below:

- feasibility of concentrated broth as well as higher alcohol content in wine that could be achieved by 16 °GL to allow the reduction in steam consumption;
- increasing the number of trays in columns and its effect on energy consumption;
- changes in construction and/or operating columns associated with the extraction of products to expand the main product (hydrated ethanol);
- development for process control systems, and energy efficient generation of products and by-products of better quality;
- better economic use of byproducts such as superior alcohols;
- development of basic configurations columns for producing hydrated ethanol fuel; the more flexible distillation units to allow the production of alcohols of different quality standards;
- investigate double integration type thermal effect for distilling alcoholic considering the difficulties as risks of formation of incrustations and problems with flow velocities in the trays;
- utilization of integrations in the process of thermal dehydration linking alcohol use to the quality and use of anhydrous alcohol, including requirements of foreign markets;
- development of new bins and fillings for distillation columns and their impact on energy consumption and investment costs;
- development of new materials for the process enabling plants pervaporation and scale appropriate to the national market or new type zeolite materials for domestic production;
- application of current knowledge in other industrial processes such as petrochemical industry with emphasis on tools for advanced process control.

It is also important to consider that the solutions to the problem of distillation are not restricted to the distillery itself due to interference exerted by the quality of the raw material which influences the cost and efficiency of its subsequent processing. Multiple effect distillation to reduce steam consumption in the distillation can be compromised due to the risk of fouling which is also a consequence of the quality of the raw material for fermentation, or the wine.

FINAL CONSIDERATIONS

The main conclusions/considerations that may be highlighted from the Fapesp workshop[1] are:

Future demand for sustainable renewable energy is signalized with a set of challenges that require specific actions, coordinated with incentives and subsidies that can turn them into viable resources internationally, including biofuels such as sugarcane ethanol. To increase their participation in the global energy matrix, needs to carry out research in several areas that has a direct impact in the production process e.g. the quality of raw materials, physiology and microbial ecology, fermentation and distillation.

There was consensus among many participating researchers in the workshop for a coordinated effort across the whole ethanol supply chain, ranging from agricultural to industrial pahses. Without this coordinated effort will be difficult to achieve the degree of competitiveness necessary to increase production of ethanol in the next 20 years.

The quality of raw material is clearly a major impact on the production process which requires the evaluation of parameters such as harvesting, transport and storage, to improve the performance of the alcoholic fermentation. Therefore, it is imperative that we take a set of actions and a review of methods for determining the quality, and at the same time to ensure they are more precise and faster implemented. This includes studies on the physiology of the plant in order to evaluate its correlation with the industrial problems.

With regard to physiology and microbial ecology, it is essential to understand how the industrial process interferes with the microbial metabolism so that it can identify the physical, chemical or microbiological benefit or those that harm the process. Increasing knowledge on the microbial metabolism in relation to fermentation is necessary so that we can achieve maximum process efficiency and reduce the amount of unwanted by-products. To achieve this it is necessary to direct the process conditions in order to prioritize the metabolic flux of targeted product (e.g. ethanol) rather than the microbial needs is the formation of energy in the form of ATP.

It can be concluded that the efficiency of the fermentation can be increased, despite the advanced level of technology today. This requires knowledge of factors such as the physiology of yeasts in industrial environments, the availability of new more viable sustainable alternatives, current microbiological control and the development of new strains of yeast. Also the evaluation of interfering factors such as the temperature decreases, the cost of centrifugation and cell recycling as well as the volume of vinasse will help improve the process. At the same time it is important to have a better understanding of the kinetics of the fermentation process so that they can properly assess the effects that the composition of the raw material can cause to this process. It is also necessary to standardize methods of analysis and evaluation of other alternatives to current processes. It is

[1] The information presented in this chapter originated from the Workshop Ethanol Production, the first of a serie of events of the Fapesp PPP Ethanol Project Diretrizes de Políticas Públicas para a Agroindústria Canavieira do Estado de São Paulo, occurred at the Escola de Engenharia de Lorena/USP November 10th, 2006. The main speakers, and collaborators are listed below:

Quality of raw material: *Dr. Carlos Eduardo Vaz Rossell* – CTBE (speaker/reporter); Dr. *Márcia Justino R. Mutton* – Unesp and *Dr. Jorge Horii* – Esalq/USP (debaters).

Physiology and Microbial Ecology: *Dr. Luiz Carlos Basso* – Esalq-USP (speaker/reporter); *Dr. Márcia Justino R. Mutton* – Unesp and *Dr. Maria das Graças de Almeida Felipe* – EEL/USP (debaters).

Fermentation: *Eng. Jaime Finguerut* – CTC (speaker/reporter); *Dr. Henrique Vianna Amorim* – Fermentec and *Dr. Francisco Maugeri Filho* – Unicamp (debaters).

Distillation: *Dr. Antonio José de A. Meirelles* – Unicamp (speaker/reporter); *Dr. Rubens Maciel Filho* – Unicamp and *MSc. Jonas Nolasco* – Dedini (debaters).

important that research be done as far as possible in production units or close to them.

Similarly, the fermentation stage of the wine distillation also has made significant advances to reach the current stage. However, the implementation of some measures may allow to improve this process. Among these could be mentioned the use of concentrated grape and higher alcohol content in wine, upgrading of equipment and processes in place for both hydrous and anhydrous; best economic use of byproducts such as superior alcohols as well as improving the quality of and products generated; the introduction of sensors and automation, and the application of current know-how in other process areas such as petrochemicals. It should also be considered that, similar to what occurs in the fermentation process, the distillation process also affects the quality of raw material thereby requiring better control to avoid losses.

As a result of this meeting of experts, it can be said that the contribution to the development of the sugar-ethanol sector with respect to the first generation ethanol, could offer in addition to improving production efficiency, the introduction of new innovative processes, cost-effective and with minimum environmental impacts.

3

RAW MATERIAL QUALITY IN THE PRODUCTION OF SUGARCANE ETHANOL

Maria das Graças de Almeida Felipe

It is urgent to advance the discussion on the guidelines that Brazil should adopt to diversify energy sources in order to reduce dependency and promote the replacement of fossil fuels. This is one of the main ways to reduce the already deleterious negative impact that human activities are causing to the environment. This agenda includes the development of technologies for the expansion of sugarcane bioethanol and its transformation into an internationally competitive commodity, as the only way to ensure the country worldwide market leadership. After all, sugarcane ethanol is at present the only fuel capable of meeting growing demand for renewable energy at low-cost and environmentally friendly. For example, gaseous emissions from burning ethanol are about 60% lower compared to emissions from burning gasoline.

Currently Brazil produces ethanol mostly from sugarcane juice fermentation. The inclusion of quality of raw material as a prerequisite for the proper performance of the alcoholic fermentation is due to the characteristics of sugarcane, including high water activity, high percentage of sugars, and the presence of amino acids and proteins that contribute to their easy deterioration. Thus, changing the harvesting system, in the near future due to phasing out of sugarcane burning practices and increasing mechanical harvesting in appropriate areas, indicates that technological innovations can be seen with growing optimism.

In addition, ethanol production proceses will expand the raw material used today e.g. sugarcane juice, to include also bagasse and trash (straw). A major bottleneck today is the cost of the raw material which represents close to 60% of the final cost of Brazilian ethanol.

This was the scenario that guided the discussions of the workshop on “Ethanol Production: Quality of Raw Materials”, held at Lorena Engineering School – EEL/USP, on May 30, 2008. This event also incorporated a number of other activities, for example, “Guidelines for Public Policies for Sugarcane in the State of São Paulo” supported by Fapesp. The main themes included quality of raw material delivered to the mills; impacts of the quality of raw materials on the fermentation process; effect of inhibiting factors in the fermentation and fractionation of bagasse and trash (straw), and new challenges facing the sugarcane sector in order to obtain ethanol.

QUALITY OF THE RAW MATERIAL DELIVERED TO THE MILLS

The sugarcane used as raw material for ethanol production is composed not only of the stalks (81.2%) in which are sugars, but also palm (6.1%), green leaves (5.6%) and dry leaves (7.1%). From a total energy contained in the cane, about 1/3 is in juice and the remainder divided equally between the bagasse and trash (straw).

The environmental and legal requirements for the end of the cane burnings and the replacing of manual by mechanized harvesting lead to discussion of the impact of each of these procedures on the production of ethanol. The type of harvesting method with the correspondent cut system and basic leaf cleaning are a major factor contributing to the levels of dirt (soil) along with the cane. The fire also contributes to the increased pollution leads to weight loss (0.3% to 2.6%) and accelerated biodeterioration by removing the wax acts as a protective film of the plant. On the other hand, mechanical harvesting of sugarcane for processing larger mass of plant, has disadvantages to allow increased rates of impurities (mineral and vegetal) favoring decay.

Still on the interference of the harvesting procedure in the fermentation process have been the fact that the cracks and fissures caused by cutting the stalks provides microbial contamination leading to the formation of acids. This could be avoided if the cane was harvested as whole cane and cutting only at the apex at the same time which would result in an increase of about 20% of the biomass to be processed. Thus, when comparing the quality of raw material, sugarcane versus burnt cane, the first is better. The problem of mechanical harvesting in today's technology that allows the harvest of sugarcane with a large amount of soil which requires further separation of impurities. This could be prevented from picking a technology that allows the removal of the cane without soil avoiding the later stage of separation. The same must be done to the trash (straw).

It is important to consider that the trash (straw) will gain space as an energy resource but still requires technological developments as the removal of soil and trash from the material being processed at the same time its separation at the time of harvest would be recommended. There is no doubt about the use of trash (straw), but there is controversy about the separation because this step would lead to use of fossil fuels. Due to the speed of the process it should work with two fractions: bagasse and trash (straw), the latter would be used to produce thermal energy at once.

Another point highlighted is that burning improves the performance of the harvester in 20% and that not only the ban on burning is necessary but also technology. The burning of sugarcane is only a matter of time and in today's scenario the cane is already harvested mainly with machine. One can not talk in technology with manual harvesting.

IMPACTS OF THE QUALITY OF RAW MATERIALS ON THE FERMENTATION PROCESS

The "plant cane" corresponds from the roots to the flowers and as a living being is subject to action of environmental factors that cause changes in gene regulation of the plant, the photosynthetic efficiency and especially the hormonal balance that influences and affects the development of the plant. In its basic composition as already mentioned in the previous section, the juice is responsible for the largest portion. Its constitution in water (75% to 82%) and soluble solids (10% to 25%) that are represented mostly by sugar (15.5% to 24%) and different compounds such as organic acids and phenolic compounds, may change due to several factors. We highlight the climatic conditions, variety and age of the plant, temperature, rainfall, crop health, harvesting, loading and transportation systems. Other indicators such as the presence of rods in the plant, alcohol, high acidity, amount of dextran, soil, burning time and the drill should be taken into consideration to increase the efficiency of fermentation. Recommended values of these indicators, in practice, are hardly attained and the quality parameters should be expanded.

Special attention should be given to the problems caused in terms of pest attacks, as the drill due to the loss of fermentative efficiency. These attacks disrupt the plant, providing the production of defense phenolic compounds, and an increase in the acidity by its hormonal system, which result in toxicity to fermentative microorganisms. The phenolic compounds are removed by clarification of the broth, but the industry does not compute the loss of viability of yeast occured due to the attack of pests. The pest control as the "froghopper" these act by reducing the size of the stems of the plant further increasing the content of phenolic compounds, is a major challenge to overcome, since the trend is that terminating the practice of burning of sugarcane. This pest is favored with the use of raw cane (cane that is harvested without burning). Besides the toxic effect caused by the attack of pests, the reuse of microorganisms is difficult because the presence of defense compounds such as phenolic compounds changes the morphology of microbes. The deterioration is also a function of temperature as in the case of crystallization of sucrose observed in the field as a function of crack caused by heat depending on burning time.

Another challenge to be overcome is the cane field management, which causes a lot of soil to stick together in the raw material throughout the whole process of fermentation. For every kilogram of soil there are approximately 10^{11} bacteria that contribute to the formation of lactic acid increasing the acidity of the environment and jeopardizing the final yield. One of the mechanisms known about the action of bacterial metabolites is the impermeability of the wall of yeast caused by them with consequent decrease in cell viability. Despite these adverse effects, the land attached to the cane carries minerals which somehow can contribute to the fermentation as the participation of these metabolites on the enzymatic activities, different in the case of sugar production since the presence of minerals is highly undesirable.

The time length in which the raw material is stored after harvest can contribute to its deterioration, as a large storage time enables the development of lactic acid bacteria. In the case of sugarcane “bisada” (which grows during two summers in the field), this is more fibrous and has more sugar, which causes it to be heavier during harvest bringing more impurities to the factory. The application of maturating agents (growth hormone inhibitor) also leads to the accumulation of sugars at the tip of the plant due to the photosynthesis processs and if applied in excess can cause death due to necrosis of the apical bud of the plant which provides development undesirable microorganisms. This technique is stressful for the plant which must be balanced against other factors such as lack of rainfall that is another stress factor. The combined action of these two factors compromises the quality of raw material. However, there is no relation to the application of maturity for the production of dextran and what may influence its production is the inadequate management of matured cane due to the accumulation of sugar on the tip of the plant.

Other relevant aspects are an increase in the harvest period (March to December) that can promote the growth of contaminants due to high soil moisture during this period and productivity (stalks/unit area) in order to obtain higher yields in the final fermentation. Also the growth of the culture of sugarcane in new areas of questionable soil quality (sandy soils), can influence the quality of products and byproducts of the ethanol industry. The mixed cultivation of vegetables and green manure are methods and proposals for the improvement of raw material generated in these new areas for planting sugarcane.

EFFECTS OF INHIBITING FACTORS IN THE FERMENTATION

Here, are presented the main factors interfering in the fermentation and their individual and synergistic effects on the fermentation process. Among these may be cited as the substrate quality, environmental considerations, the by-products formed during metabolism as a function of microbial contamination, the type of process also including the cleaning and disinfecting. Attention should be given to the production of organic acids, mainly lactic acid, because its dissociated form that allows it can enter the cell. Besides this the acetic and formic acids also inhibit the growth of yeast but a lower concentration of lactic acid by the fact that these are more soluble in lipids. Among the effects caused by organic acids are interference in cellular maintenance energy and absorption of nutrients combined with the effects caused by the pH and the inhibition of enzymes and cell death in conditions of strong acidity. The inhibitory effect caused by the acids may be enhanced due to the synergistic action exerted by these and the temperature which causes the accumulation of trehalose with its increase. For the reduction of acidification of the must during alcoholic fermentation requires the presence of a single decanter in the production line of alcohol. With the clarification of molasses is also a possible reduction of up to 90% of acid.

The presence of sulfide in fermentation medium is another factor that interferes with the process by reducing cell viability and thus decreasing the alcoholic fermentation leading up to exaggerated increase in the acidity of the alcohol produced.

Ethanol is also harmful to the fermentation process because it causes changes in the composition of the lipid layer of the cell membrane. This reduces the metabolic activity as a function of inhibition of glucose transport with consequent water stress, limits the yield, and the process productivity and also reduces the cell tolerance to higher temperatures.

The synergy between the effects of weak acids, pH, ethanol, osmotic pressure of the substract and temperature act all together in an exponential way on the strength of proton motive force. The low pH is the most stressful physiological factor in the case of *Saccharomyces cerevisiae* from the distilleries to produce ethanol in relation to other factors presented which requires attention about the pH of the must. In addition pH the cellular inhibition can be caused by the sulfuric acid added to the inoculum for the cellular deflocculation. However, research has not advanced towards the replacement of this acid. What has been studied is the use of immobilized protease and mannanase for cleavage of the bound responsible for flocculation (monosaccharides, amino acids). Research in nanotechnology have been performed and the cost of this technique is the biggest obstacle to their widespread use.

Improvement of raw material used in the manufacture of bioethanol can be achieved by procedures such as clarification of cane molasses, control the deterioration of sugarcane and asseptic milling. In the case of clarification for its implementation in industrial scale requires a reactor separate of the manufacturing line which is now the biggest obstacle. If the case of controlling the deterioration of the cane, because of its richness on biopolymers and microorganisms, it will occur losses in both the manufacturing process line for both ethanol and sugar. An efficient planning of the agricultural and industrial area will control the deterioration of the cane field. Not only the deterioration control is important, but also the insects control mainly through the use of biological control. It can be included among these control procedures to sterilize the must although there is an increasing cost associated. The gains from the reduction of impurities could be compensated by the practice of this procedure. Alternatively these can be found through the delivery of natural products that were able to inhibit the growth of undesirable bacteria.

FRACTIONATION OF BAGASSE AND STRAW OBJECTING THE NEW CHALLENGES TO OBTAIN ETHANOL

The sugarcane bagasse and straw account for 2/3 of the energy potential of sugarcane and represent a rich potential source of sugars. Research studies have been intensified to the use of these sources of renewable resources in obtaining cellulosic ethanol. The development of this technology route will allow to increase significantly Brazilian ethanol production without expanding the area cultivated. However, for the scope of this technology is a great challenge to be overcome that is the establishment of suitable conditions for hydrolysis of these materials for the release of its sugars (hexose and pentose).

Some things to consider regarding the exploitation of sugarcane bagasse and straw are presented with a focus on the incorporation of these new sources in the industrial production of biofuels as follows:

- new concept of the sugar and alcohol plants with the introduction of the sugarcane straw;
- introduction of the concept of Bio-refinery in the sugar and alcohol plants;
- creation of a research network on pretreatment of these biomasses.

Initially, it is important to note that the bagasse and straw as energy sources have the favorable characteristics to the incorporation of these in the production of ethanol, the large amount of material generated in the ethanol industry. For each ton of cane processed it generates about 140 kg dry of each of these materials. The bagasse is burned to generate energy for the plant and the surplus sold to the grid. Improving the efficiency of co-generation and distribution of this surplus will increase (currently around 10%) while the expansion of the mechanized harvest and emergence of the energy market for the straw will help to increase the availability of biomass to produce biofuel.

It is questionable which is the best option for the use of bagasse and straw due to the various alternatives presented to produce biofuels, electricity, specialty sugars or other chemicals. There are also doubts about the need for separation of straw and if this amount could be removed from the field without damaging the soil, taking into account the productivity criteria and final profitability. It is important that harvesters are appropriate for this type of biomass for production of biofuels. In the case of the production of ethanol from corn as it does in the U.S. waste processing such as the cob is ground by the harvester and left the field. Other options suggested for the use of the straw is the extraction of chemicals with high added value such as drugs since it must contain several compounds of interest to the pharmaceutical industry.

As far as the introduction of the Bio-refinery concept – development chemistry platforms through integrated technologies of biomass, this is a need anticipated for the coming years. Research in this field are essential for the development of new technologies for converting lignocellulosic biomass particularly regarding the efficient separation of its major fractions, cellulose, hemicellulose and lignin. The concept of Bio-refinery is important to the fractionation of biomass to allow the use in each fraction separately. This includes the need for advances in research on thermal, chemical and biological process agents to enable the production of both fuels and chemicals involving the conversion of biomass and integrated equipment.

In this new technological scenario which includes the production of ethanol from bagasse and straw, the discussion on biomass hydrolysis of these is undoubtedly the most prominent. Hydrolysis as a step in the production of cellulosic ethanol is now the main bottleneck to the achievement of this technology so that this biofuel can be competitive with fossil energy.

To understand what happens in the hydrolysis process is important to know the structure of lignocellulosic materilas mainly about the relationship between the physical and chemical associations between lignin and polysaccharide components of plant cell walls together with the crystallinity of cellulose. These structural features make it difficult to release the sugars from polymeric matrices therefore, requires pretreatment of biomass as a step prior to hydrolysis. There are different types of possible pretreatments such as mechanical, organosolve, alkali, hydrothermal, steam explosion and dilute acids. All these have in common an increase in enzyme accessibility to cellulose but have significant differences as a condition of reaction, process efficiency, complexity and impact on the rest of the process.

In the case of research with the bagasse this article mentions the pretreatment by steam explosion and dilute acid. In this first, an additional post-hydrolysis is required to separate the fraction corresponding to the C5 sugars from biomass allowing the fractionation of oligosaccharides into simple sugars. In relation to the use of acids, it is known that certain ions interfere with microbial activity depending on their concentrations. As well certain compounds, from the pretreatment, toxic to microorganisms, such as acetic acid and phenolic compounds also undertake the process requiring an additional step to eliminate or reduce the concentration of these. The corrosion of equipment by the action of acids must be considered. Optionally these pretreatments has been the explosion in steam environment with ammonia (Afex). The fact is that it is necessary to create a national network of researchers to work together so that we can provide the optimum pretreatment to be used in order to facilitate the next step of hydrolysis and consequently favoring the fermentation process. This will be reflected in the next step that is the distillation.

Having established the optimal conditions for pretreatment, there are still doubts as to the optimal procedure of hydrolysis, the enzymatic, chemical or combination of which requires major input of resources in relation to the fractionation of biomass. There will be technological competition, while the chemical process allows a better process control but has little selectivity, the enzyme is more selective, but is very sensitive to environmental conditions such as, pH, temperature, contaminants. At the same time it is important to consider the need for advances in research into the use of C5 sugar constituents of hemicellulose or the bagasse or straw. In this context, it is proposed to evaluate the recirculation through the chemical hydrolysis of what was not possible at this stage by returning to the reactor again.

The use of lignocellulosic wastes such as seed oil cakes extracted in the biodiesel production process should be considered in this new production process of ethanol. It can not be forgotten even in the process of production of biofuel are several devices available in the market such as in the pulp and paper industry that already has the technology of fractionation. These could be exploited, as are already optimized. Finally we will see growing interest by the businesses to replace their raw materials for biomass, however, it is important hat the plants do not just think in "commodity" ethanol but also the concept of biorefineries.

FINAL CONSIDERATIONS

The discussions during the "Workshop Ethanol Production: Quality of Raw Materials"[1], enabled various arguments and proposals on improving the productivity of ethanol of first generation and the inclusion of bagasse and trash or straw (residue left on the field after harvest cane) to produce second-generation ethanol. The main points to consider which can serve as parameters for use of resources in research and development aimed at increasing the country's competitiveness in the production of biofuels, are highlighted below:

- Both the manual harvesting of burned sugarcane or unburned cane mechanized harvesting contributes to the deterioration of the cane, even when comparing the two procedures the harvest unburned cane (raw) is better.
- Doubts exist about the need for separation of straw at the time of harvest and there is also proposal to use of bagasse and straw together.
- Care should be taken during the preparation of the straw and bagasse and remembering that boilers were not designed for the use of straw.
- The development of technology for harvesting machines that meet the new harvesting practices will allow greater availability of straw for use in energy production, ethanol or other chemicals.
- Obtention of appropriate indicators about the collection and the amount of straw that must be left in the soil.
- Fixing quality more accurate indexes of raw material.
- Definition of quality parameters of bagasse and straw for use in ethanol production due to the great heterogeneity of these materials.
- Redefining the current model of the production chain for quality control of raw material with new methods of evaluation in order to reduce the negative effects on the alcoholic fermentation.
- Adoption of efficient planning, covering both the agricultural and the industrial

[1] "Workshop Ethanol Production: Quality of Raw Materials" held at the Engineering School of Lorena – USP on May 30, 2008. This event is part of a series of other activities occurring as the project "Guidelines for Public Policy for the Sugarcane Industry of the State of São Paulo" supported by Fapesp. The main speakers and contributors are listed below:

Quality of the raw material delivered at the mills: Dr. Paulo Graziano Magalhães – Feagri/Unicamp (speaker); *Dr. Oscar A. Braunbeck* – Feagri/Unicamp and *MSc. Humberto Carrara* – Usina São João (panelists).

Impacts of the quality of raw materials on the fermentation process: Dr. Márcia J. Rossini Mutton – Unesp (speaker); *Dr. André C. Vitti* – APTA (panelist).

Effects of inhibiting factors in the fermentation: Dr. Pedro de Oliva Neto – Unesp (speaker); *Dr. Carlos Eduardo Vaz Rossell* – CTBE and *Dr. Eloísa A. Moucheti Kronka* – Unaerp (panelists).

Fractionation of bagasse and straw objecting the new challenges to obtain ethanol: Dr. Adilson Roberto Gonçalves – EEL-USP (speaker); *Dr. Antônio Aprígio da S. Curvelo* – USP – São Carlos and *Dr. George Jackson de Moraes Rocha* – EEL-USP (panelists).

phases in order to prevent the deterioration of the cane.

- Logistics for the transport of straw to the plants.
- Introduction of technological innovation, designed to remove dirt and straw from the material to be processed.
- Evaluation of quality of sugarcane (juice) not only for the content of sugars, but also acids, polysaccharides, microbial contaminants and impurities (mineral and vegetal) by negative interference of the fermentation.
- Expansion, improvement, standardization/validation of the method quality assessment of raw material in distilleries and its implementation are essential to ensure the quality of the final product.
- If plants are equipped with more energy efficient systems, existing commercial-scale surplus bagasse will increase providing greater availability of energy generation, second generation ethanol or other compounds.
- Attention to the problems caused by the attack of pests which lead to the production of plant defense compounds, such as phenolics, which are toxic to yeast fermentation undermine efficiency.
- Cultivation of sugarcane on soils of questionable quality as sand can interfere with the quality of raw materials.
- The effects of stressors in the must, that are responsible for the inhibition of alcoholic fermentation, are due not only to the individual action of each inhibitor but also to a synergistic action between them which can only exacerbate these effects, the presence of organic acids combined with the high temperature of the must.
- The period of storage of the cane after the harvest is one factor that contributes to increase the population of microbial contaminants in raw materials.
- Development of technology to obtain natural products such as the inhibitors of bacterial contaminants of fermentation and biological control of insects.
- Getting thermophilic and osmophilic yeasts.
- Assessment of our microbial biodiversity.
- It is important not only knowledge of the problems related to the deterioration of the raw material for process control of ethanol production, but the adoption of measures to solve them.
- Research to take advantage of the CO_2 generated from fermentation.
- Control of both the raw material and the fermentation process as a preventive approach to minimize the problems of the sector.
- Establishment of efficient and low cost pretreatments is essential for the introduction of bagasse and straw in the production of second generation ethanol.
- Still can not be establish which is the best procedure for the fractionation of biomass bagasse and cane straw for the inclusion of these as raw materials in the production of ethanol, however, there is evidence for the choice of a combined process such as chemical and biological.
- The use of also sugars C5 constituents of the hemicellulose fraction of bagasse and straw must be taken into account for the increased production of ethanol and/or other products.
- It is important to think in the production of second generation ethanol from the integration of a module of hydrolysis of bagasse and/or cane straw with the processes of a traditional mill ethanol production of first generation.
- Required advances in research on the expansion of production scale second generation ethanol and the economic viability of the process.
- Introduction of the concept of biorefineries in the sugar and alcohol industries.
- Implementation of actions to increase financial input in strategic research and

incentives to drive further integration of research in different areas of knowledge.

- Diversification of raw materials and products generated from them will increase the competitiveness of the sector.
- Policies to address biofuels as commodities (futures markets).
- Overcoming natural, technical and economic barriers between the productive sector, academia and government to achieve the development of technologies for producing biofuels.

4

TECNOLOGICAL EVOLUTION OF SUGARCANE PROCESSING FOR ETHANOL AND ELECTRIC POWER GENERATION

Manoel Regis Lima Verde Leal

INTRODUCTION

Brazil has a long tradition in the cultivation and processing of sugarcane for sugar production and already in the beginning of the 20th Century started to give the first steps toward the path of ethanol production. The electric power generation using bagasse went slower, initially aiming at reaching the energy self-sufficiency, and only in the last ten years the generation of surplus power for sale became an irreversible trend. However, Brazil has not been a reference in terms of technology and competitiveness all the time. Looking back from the dawn of the 20th Century to the present time one can see difficulties and adverse situations faced by the sugarcane sector as well as the impacts of the National Ethanol Program – Proálcool, launched in November 1975.

Before the Proálcool, the ethanol production was aimed mainly at reducing the offer of sugar by deviating the sugarcane surplus to this new product, to be added to the gasoline on an available basis, but normally around 5% by volume. Besides the excess of production the sector also suffered from low competitiveness in the international market, both in the agricultural and industrial areas, due to lack of technological reference, in spite of the fact that the government in several occasions had made available low interest loans for modernizing the mills. The creation of Copersucar – Cooperative of Sugarcane, Sugar and Alcohol Producers, at the end of the 1950s, offered an opportunity to consider technological improvements due to the necessity to increase the competitiveness, necessary for survival, based on the size and economic power of the new cooperative. Thus, at the beginning of the 1970s, a sugarcane breeding program was initiated; an analysis laboratory for quality control and a technical department to support the cooperative mills were created. In 1972 the Federal Government created also the Planalsucar, a full program targeted to stimulate the technological development of the whole sugarcane sector, with a major focus in the genetic improvement of sugarcane.

In the industrial area, the technology development was pushed by the Proálcool, with different focus in each one of its many phases. In the initial phase, from 1975 to 1979, the necessity to increase production to meet the Government established targets of 3 billion liters in 1980 and 10.7 billion liters in 1985, starting from the almost 600 million liters produced in 1975, induced the development of technologies to essentially increase plant throughput. In this period the ethanol production increase was achieved by annexing distilleries to existing sugar mills, but deviating from the normal way to use only exhausted molasses as feedstock for the distillery; sugarcane juice started to be mixed with the molasses that had its purity increased in the sugar factory. Therefore, the main pressure was in the common areas of the sugar/ethanol mill that were the juice extraction and steam and power generation systems. This production increase took place without much concern about factory efficiency or useful life of equipment more directly affected. With the second oil shock in 1979, the Government realized that it was necessary to accelerate further the production increase and the ethanol blending with the gasoline model should be supplemented with the production of hydrous ethanol to be used in engines specifically developed or adapted for this fuel that should start to be manufactured by the auto industry.

The auto makers responded quickly, offering to the market the first model fueled with neat hydrous ethanol already in 1979; however, it was really in 1983 when the first engine optimized to burn hydrous ethanol was produced, taking advantage of several favorable characteristics of this fuel (higher octane numbers, higher latent heat of vaporization, faster and colder burning) and solving problems associated with the initial disadvantages of ethanol fuel, such as cold start. The mill owners acted also adequately installing autonomous distilleries that produced only ethanol, from the juice directly from the milling tandem. In this second Proálcool phase, from 1980 to 1985, two new facts happened: the entrance of new entrepreneurs in the sugarcane sector from outside the sector, and the accelerated construction of new distilleries (ANNICCHINO, 1985). The concern about efficiency and productivity gained strength initiating a new phase of technology development. The targets set for 1980 and 1985 are easily met and even surpassed.

In 1986 the so called cold oil shock took place with a strong decrease of oil prices for values close to the 1978 levels. Petrobras had also done its job, increasing considerably the national oil production, thus reducing the need for imports. In this way the interest of the Government in the Proálcool dwindled and the subsidies were slowly reduced, decreasing the competitiveness of ethanol with respect to gasoline; as a consequence the rate of growth of the production was significantly reduced to close to zero leading to the third phase that can be called of stagnation that lasted until the beginning of this century. During this period the sugarcane sector was hit by several crises and in 1990 the Institute of Sugar and Alcohol – IAA, that controlled the whole sector, was extinct leading to the start of the deregulation process with the Government pulling out of the production and market control. The economic hardship that resulted from the gradual elimination of subsidies of all sorts caused the bankruptcy of the less efficient and capable producers and their mills and cane fields were taken over by better prepared sector entrepreneurs that could face the falling ethanol prices; the gains in scale, with the incorporation of the bankrupted mills to the surviving ones, and the development of more modern attitudes, concerned with efficiency and production cost reduction, pushed the technology development forward at a faster pace to reach the level of competitiveness of today. Prior to the extinction of IAA the country exported, under Government control, around one million tons of sugar per year; under a totally private control of the industry the sugar exports reached the present level of more than 20 million tons per year, and growing. It was this growth in sugar exports that helped the sugarcane sector to survive through the Proálcool stagnation phase and the necessity of competitiveness without subsidies was the main drive for the technology development and management improvement. Finally, the last phase of the ethanol cycle in Brazil that started around 2002 with the increase in oil prices was definitely consolidated by the introduction in the market of the Flexible Fuel Vehicle – FFV in 2003.

The dissemination of information and media focus on the problems associated with the climate change, together with the negative impacts of fossil fuels use on the greenhouse gas – GHG emissions, have increased the interest in biofuels in general and ethanol in particular. However, it is the volatility of oil prices and concerns with the security of supply of this fossil resource that have, in fact, motivated the use of ethanol as a fuel. Therefore, the ethanol technological development must continue at an accelerated pace aiming at the production cost reduction and the improvement of the sustainability indicators, specially the GHG emission reduction potential; this is the only way the keep sugarcane ethanol as one of the best options to partially replace fossil transportation fuels and to reduce the GHG emissions, when compared to the other alternatives.

The description of the technological evolution in the sugarcane processing to ethanol will be presented below, covering the period from the launching of the Proálcool until today. At the end, a list of suggestions will be presented on how to improve further the technical-economic viability of ethanol as a substitute for transport fossil fuels and to mitigate the climate change.

TECHNOLOGICAL DEVELOPMENT IN THE PRODUCTION OF ETHANOL

To facilitate the understanding of the evolution process in the mills and distilleries, the sugarcane processing path was divided into sectors and each one described separately, covering from the sugarcane reception to energy generation to supply the plant needs. Conventionally the distilleries are split into the following sectors: Cane Reception/Preparation/Juice Extraction, Juice Treatment, Fermentation, Distillation/Dehydration and Energy. The water and effluent treatment systems, as well as the ethanol storage and handling, will not be treated here.

Sugarcane reception, preparation and juice extraction

This is one of the most important sectors in the distilleries due to the high capital investment required, high operation and maintenance costs, high energy consumption and impact on the global plant efficiency. A sequence of heavy duty equipment forms this system fed and interconnected by belt conveyors for sugarcane and bagasse; therefore the overall performance depends not only on the individual performance of each equipment, but also on a well designed and optimized sequence of operations.

Even before the launching of Proálcool it was recognized that the cane preparation and juice extraction technology in use in Brazil was inefficient and obsolete (CTC, 1983). Copersucar, with its economic capacity and modern entrepreneurial vision, was the first institution to react to improve this situation: organized a technical group in 1974 and contracted the consulting of the South African specialist Deon Hulett (South Africa and Australia were considered, at that time, the technological reference for sugarcane processing for sugar) to start the process of developing a modern cane preparation and juice extraction technology, efficient, highly productive and well adapted to the Brazilian conditions. The concept of standardization was introduced since the beginning of the work and milling was selected as the juice extraction system since it was already the most widely used in the country (CTC, 1983). The result of this effort was a set of main and auxiliary equipment perfectly integrated and optimized as a whole and standardized to facilitate the manufacture and maintenance. The main technological improvements in this sector will be described in sequence.

Cane reception

The necessity to unload the cane from the trucks quickly led to the selection of the spiller (hilo) as the equipment to be developed and it was widely adopted by the mills together with one of the concepts of cane feeding tables: conventional, 45° and 35°. The choice of the feeding table option was based in a case by case evaluation depending on the existing equipment, space available, type of harvesting and cane transportation system; the conventional table, with an slope angle up to 18°, started to loose ground in the competition against the two other alternatives that had higher feeding capacity, provided a thinner and more uniform cane layer, facilitating the cane washing operation and efficiency, and resulted in a larger reduction in the cane mineral impurity levels. It is important to point out that the feeding table is a key item to facilitate the operation of the cane preparation and juice extraction equipment by providing a uniform and continuous cane layer.

With the increase of mechanical harvesting the feeding table design suffered several modifications to adapt it to receive also chopped cane; in this case, the changes to improve the removal of mineral impurities were very important since chopped cane cannot be washed like whole cane, due to the resulting high sugar losses.

Besides the main equipment some auxiliary ones, like the straw cush-cush (a type of screen used to separate the straw and pieces of cane from the washing water), the metallic and belt conveyors, leveler and electro-magnet. All these items had to be adapted to the increased capacity of the new juice extraction systems.

Cane preparation

With the understanding of the importance of cane preparation to the efficiency of juice extraction and to the capacity of the milling tandem, the concept of the systems in use at that time was totally modified. A quality of cane preparation is measured by the percentage of open cells in the prepared cane, named cane preparation index; for a good extraction efficiency in the milling tandem, it was established that the preparation index must be above 80%, calling for the use of a shredder in the system. The cane preparation system was then standardized with one set of knives (a rotor with a set of blades), to chop the cane, and a shredder both assembled on the metallic conveyor, between the feeding table and the milling tandem. For higher milling rates it was recommended that an additional set of knives in front of the set to act as a cane layer leveler.

The Copersucar Technology Center – CTC developed standardized designs for all these items covering the range of milling capacities commonly used by the mills, resulting in the knives COP 8 and COP 9 and shredders COP 5 and COP 6, besides the heavy duty model COP 10 for higher preparation indices (CTC, 1990). This set of equipment allowed the mills to operate with preparation indices in the 80% to 85% range, or even 90% to 92% in the case of COP 10. All these items were designed with fixed or swing blades (knives) and swing hammers (shredders) with a deposit of hard weld on the impact surfaces to increase the life of the most demanded parts of the equipment.

Milling

The main focus in the development of the milling technology was on the increase in capacity and extraction efficiency, since this sector was normally the main bottleneck for the expansion of the mill production and also, together with the fermentation, was one of the main areas of sugar losses in the cane processing. The main items developed for these purposes were feeding chute (or Donnelly chute), the press roll, the imbibition system, the feed roll, the weld deposits on the grooves (on the teeth sides), the conveyor between mills, the modification and reinforcement of some critical components (like mill shaft and headstock) and, last but not least, automation (CTC, 1990).

The Donnelly chute is a type of vertical duct with variable rectangular section installed at the inlet of the mill to create a column of prepared cane or bagasse to increase the pressure, by gravity, at the mill inlet. Besides the resulting increase in milling capacity this chute became the key item in the mill control system, with the cane height inside it being the variable used to optimize the speeds of the cane conveyor and mill rolls. Whenever the existing layout would allow the Donnelly chute should be installed at the inlet of each mill; in case where space problems exist, at least the first mill should be fitted with such equipment. Figure 1 shows the installation of a Donnelly chute, where the cane level sensors for the control system can be seen on the side of the chute.

The pressure roll, or 4th roll, became a standard item in the Brazilian mills. Together with the feed roll and the Donnelly chute it forms the set designed to increase the capacity of the existing and new milling tandems. The hard weld deposits on the tip and sides of the roll shell grooves help to drag the cane and bagasse between the rolls, thus allowing the mill to process the additional cane pushed trough by the previously described equipment. The imbibition system is a key component in the effort to increase the juice extraction efficiency. Since the mill cannot reduce the bagasse moisture to levels much lower than 50% it was necessary to develop a system that permitted the dilution of the juice retained in the bagasse, thus inducing the use of the concept of imbibition. There are three possible types of imbibition: simple, compound and with recirculation, with increasing efficiency in that order; due to practical reasons the compound imbibition became the most widely used option, where water is added to the bagasse at the inlet of the last mill, fulling soaking it, and from there on the juices from the other mills are added to the cane entering the upstream mill in such way that the imbibition liquid goes counterflow with the cane in the milling tandem.

Besides these main items it also became necessary to develop several auxiliary items and components to make it possible to reach the performance

FIGURE 1 Donnelly chute installation at the first mill inlet.

levels of today. The role of CTC and equipment manufacturers was fundamental in this process.

Tables 1 and 2 present a summary of the technological evolution of the juice extraction system in Brazil in terms of milling capacity increase and juice extraction efficiency, respectively, showing the participation of each technology in the process (DELFINI, 2004).

It is possible to see in the Tables below that the technological evolution of the juice extraction system was by steps and significant as a whole, involving a very large number of improvements combined and incremental, that demanded a lot of time, dedication and resources. Comparing the present Brazilian juice extraction system with the Australian and South African models, that have been used in the initial phase as the basis for the development, our system have reached extraction efficiency levels very close to the Australian and South African ones, but at a much lower investment and operational costs due to the higher capacity of our mills when compared with the same gage (width) mills in Australia and South Africa. Somehow, the juice extraction technology in Brazil has reached such an advanced level that has inhibited the development of promising alternatives such as the hydrodynamic extraction system that started to be developed at CTC, based on a Reunion Island patent, and was discontinued.

Juice treatment system

Prior to Proálcool, and even in the beginning of its first phase, the treatment of the juice as extracted by the mills did not received much attention from the sector, since the ethanol was produced mainly from exhausted or partially exhausted molasses. With the start of the second phase in 1980 along with the installation of autonomous distilleries in a very fast pace, the juice started to be sent directly from the mills without any treatment – called raw juice. With the improvement of the knowledge of fermentation microbiology it was possible to correlated several fermentation problems with the dirt and contaminants carried by the raw juice, thus inducing the search for

TABLE 1 Evolution of the milling capacity.

Mills (width)	Technology evolution phases (milling capacity in tons of cane/h)				
	Original	I	II	III	IV
54 inches	130	180	190	210	280
78 inches	270	375	400	440	580

Note: Technology evolution phases:
I. Cane preparation + pressure roll;
II. 45° feeding table + cane spreader + belt conveyor + Donnelly chute;
III. Redesign of conventional headstocks;
IV. Special headstocks (1st e 2nd mills) – larger mill roll diameters.

Source: DELFINI (2004).

TABLE 2 Milling juice extraction efficiency evolution.

Mills (width)	Technology evolution phases (sugar extraction efficiency, %)				
	Original	I	II	III	IV
Efficiency	91 a 93	93.5 a 95	94.5 a 96	96 a 97	97 a 97.5

Note: Technology evolution phases:
I. Cane preparation + pressure roll + compound imbibitions;
II. Donnelly chute + feed automation + roll shell weld deposits;
III. Donnelly chute (all mills) + automation (all mills);
IV. Mill adjustment + mill operation control.

Source: DELFINI (2004).

economically viable and adequate ways to treat the juice; the juice treatment for sugar production was somehow used as a model, but there was the feeling that this process was too sophisticated and expensive beyond the necessary. Still in 1990, 10 years after the boom of autonomous distilleries, persisted the doubts about the best strategy to treat the juice for the fermentation (CTC, 1990) and the focus was apparently on the physical treatments to remove impurities, but the thermal shock type treatment was already being experimented to eliminate the microbiological contaminants. The treatments to remove just the coarse impurities have proved to be inefficient and at the same time it was realized the negative effects of the colloidal impurities, leading to the start of the use of clarification process. The SRI model clarifier (trayless and short retention time), whose property rights have been bought by Copersucar from the Sugar Research Institute – SRI from Australia, in spite of having not shown the expected performance for juice treatment for sugar fabrication, was tested and approved for ethanol production. The lower investment cost, compact design and adequate performance, helped to spread its use in the ethanol path and, after a learning period, it started to show a good performance for the sugar path also and became a standard equipment for juice treatment for both sugar and ethanol productions.

In general, it can be said that the juice treatment technology is at an adequate level for fermentation, but there is still a good potential for improvements, including the combination with the broth treatment.

Fermentation

With the large expansion of the ethanol production during the two first phases of Proálcool, between 1975 and 1985, this product gained a great importance both economic and strategic for the sugarcane sector. Around 1975 ethanol represented approximately 10% of the total cane processed in Brazil and the percentage reached about 70% at the end of the second phase.

The fermentation was the step with the lowest efficiency in the whole industrial process, barely surpassing the 80% of the stoiquiometric conversion rate of 0.6474 liters of absolute ethanol per kilogram of total reducing sugars – TRS at the beginning of the expansion. Therefore it is more than justified that this process had received a high priority in the technology development effort. The most widely used process in Brazil has always been the fed batch with yeast recirculation known as the Melle-Boinot process; this process was already well known and used in several countries, including Brazil, but required a lot of study and improvements to reach the levels of productivity and efficiency obtained today. One alternative being developed in Brazil is the multi stage continuous fermentation; this development started in the 1979/1980 crushing season with the adaptation of the batch fermentation facilities of the Porto Feliz mill for a multi stage continuous fermentation. In 1983 the Cresciumal mill installed a multi stage continuous fermentation designed to produce 120 m^3/day of ethanol (CTC, 1983). At some period of time around 30% of the total ethanol produced in Brazil came from continuous fermentations; today this percentage has been reduced due to the difficulties in operating with this technology in the event of a large scale infection. However, the many advantages of the continuous fermentation has kept the interest in solving its problems in a high priority: lower investment costs, less space required for installation, less use of chemicals, easier automation and easier operation under normal conditions. It is reasonable to expect that it will dominate in the ethanol production in the future, once today's problems are solved.

In both technologies the knowledge of the process was basically empirical, accumulated during decades of the production of residual ethanol (from the exhausted molasses), and lacked a better scientific base to permit the optimization of the operation of the fermentations and also the quick identification of the problems as soon as they appear. CTC had, once more a very important action in this process. Analytical methodologies were developed aiming at the quantification, even by indirect means, of the fermentation yields and the presence of indicators of an incipient bacterial infection, in a reliable and economically viable way. The study of the fermentation kinetic model was started that would allow the conversion of measurements feasible by the analytical methodology in parameters and indices important to the operation control of the fermentation and to the design of new installations. Due to the long time required for the microbiological analyses and their deficiencies, the development of on line sensors was pursued for measuring parameters such as the alcohol content in the vats, wine and vinasse and the yeast concentration in the vats and in the yeast cream.

The study of new yeast stains was very important for improving the fermentations; in collaboration with the National Regional Research Center in Peoria, Illinois (USA) several tentatives were made to combine favorable characteristics of one strain with the ones of another strain through the fusion of both protoplasts (CTC, 1983). These experiments did not bring practical results but provided an evolution in the knowledge of the yeast potential. One very successful line of work was the study of yeast and bacteria population dynamics along the cane processing season; this work was facilitated and accelerated by the introduction, in the second half of the 1980's, of the Chromosome Polymorphism technology, also known by the name of "fingerprint" by analogy with the system of identification of persons by their fingerprints. This technology provides a standard of chromosomes organized in sequence by their length, through the use of electrophoresis, which is an unequivocal characteristic of each microorganism. In this way, it was possible to follow the variation of yeast populations in fermentations of several mills and to select the best performing strains, within the specific characteristics of each fermentation, (temperature, osmotic pressure, pH, ethanol content etc.); infection problems could have their causes more easily and quickly identified. This methodology and the selected yeast strains served as basis for the development of faster and safer fermentation start up procedures.

The fermentation vat design went through several modifications to improve the geometry (conical bottom, elimination of flow stagnation points, better agitation), the cooling (external plate heat exchangers replacing the obsolete internal cooling coils, cooling towers to close the cooling water system, and better broth recirculation), the closing of the vats to recover the ethanol carried over by the fermentation gases. In the case of continuous fermentation, it was developed the technology for foam elimination through the carry over from one vat to the next in the line, improvement of the internal circulation and the introduction of internal compartments to facilitate the operation under low production rates.

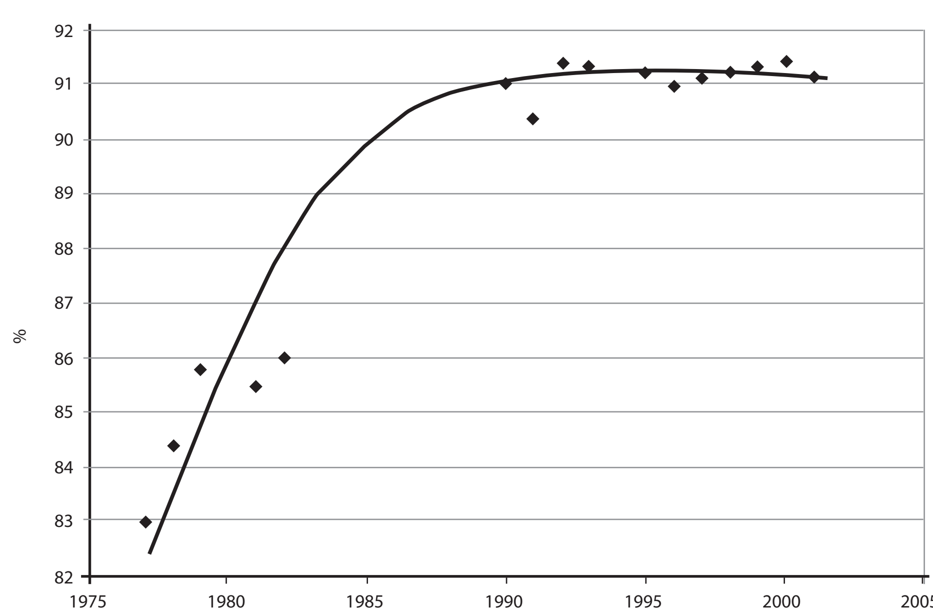
One more recent line of work, aiming at reducing the occurrence of infections in the fermentation, develops purification techniques and thermal broth treatments prior to feeding it to the vats, optimization of biocides and antibiotics use and introduction of a vat cleaning system.

Several other improvements have been developed in this 40 year period of the Proálcool, but there is no space to describe them all. The most important results are shown in Figures 2 to 4.

From these Figures it can be seen the fast and remarkable growth of the fermentation yields from 82% to 83% in the beginning of Proálcool to the 91% plateau at the end of the 1980s; gains in productivity measured by the reduction in fermentation time from 15 hours to 8 to 9 hour range, also in the same period. The increase in yeast concentration in the vats have brought the Brazilian values to a range well above what is practiced in other countries, shown in Figure 4, was one of the reasons for the gains in yields and productivities. These data are applicable to the best mills and could be used as reference to indicate to what level the others can reach. The leveling off the curves since the early 1990s indicates that the present technology in use has already reached a high level of maturity and the potential for incremental gains still possible is very low, but production cost reductions are still possible through the optimization of the use of chemicals and other inputs and by the elimination, or at least a drastic reduction, of the infections.

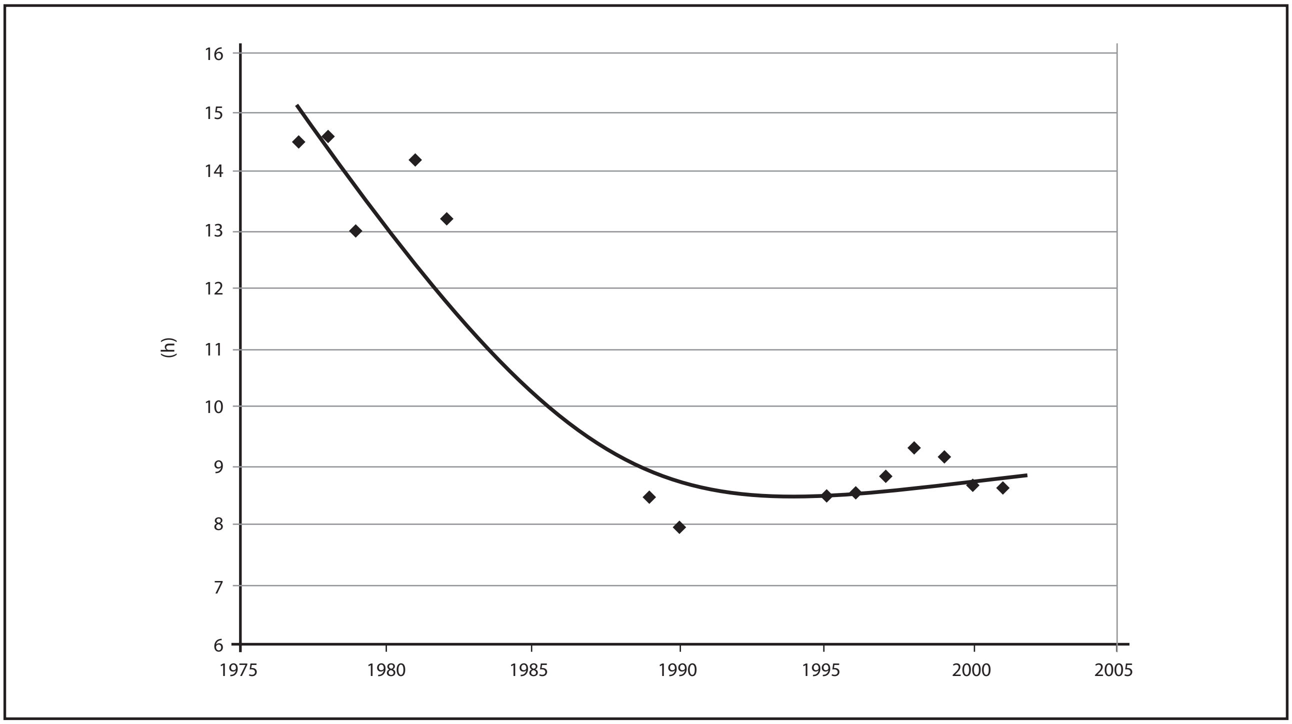
Distillation and dehydration

The distillation and dehydration technologies have been imported and supplied Brazilian equipment manufacturers as standard packages containing seven columns, grouped in four sets, and the



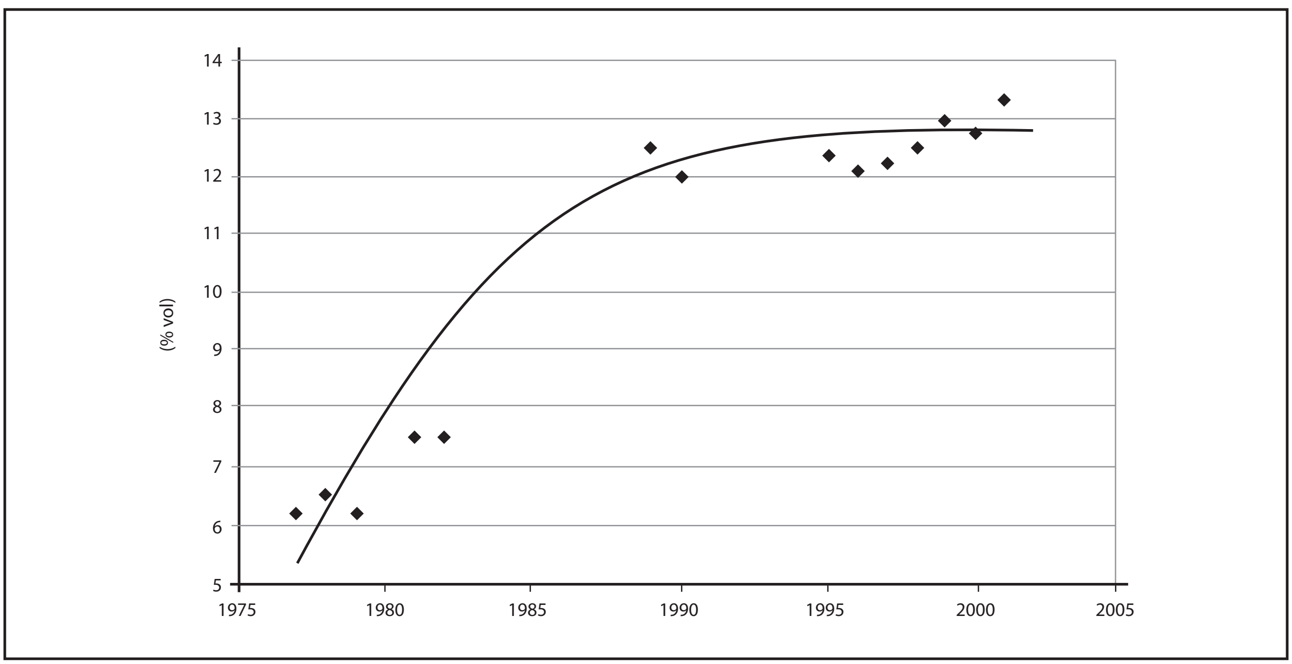
Source: FINGUERUT (2005).

FIGURE 2 Evolution of fermentation yield.



Source: FINGUERUT (2005).

FIGURE 3 Evolution of fermentation time.



Source: FINGUERUT (2005).

FIGURE 4 Evolution of yeast concentration in the vats.

auxiliary systems (condensers, settling tanks, heat exchangers, tanks and others). The four set are:

Distillation: formed by columns A, A1 and D one at the top of the other. The impurities are eliminated mainly in column D (esters and aldehydes) and ethanol is concentrated up to 40 ° to 50 °GL (ethanol content by volume) leaving as flegma in the form of steam. The bottom product is vinasse that exchanges heat with the incoming wine as it leaves the column.

Rectification: formed by columns B and B1 with the objective to concentrate the ethanol to 96 °GL, leaving as hydrous ethanol that is an azeotropic mixture of ethanol and water, which can no longer be concentrated by simple distillation. More impurities are extracted as volatile compounds and the condensates are recycled or removed as lower alcohol. The bottom product of column B1 is a spent aqueous solution named flegmasse that is recycled or eliminated from the process.

Dehydration: column C performs the operation of removal of most of the water contained in the hydrous ethanol. Up to 15 years ago the dehydrating agent was benzene, but the working safety conditions made its use very complicated, after its grading as carcinogenic substance, what caused the phasing out of its use. After several laboratory and field tests the new dehydrating agent selected was the cyclehexane. The dehydrating agent is introduced at the top of the column forming a ternary mixture dehydrating agent-water-ethanol that is heated up with steam, and the ethanol is removed from the bottom of the column as anhydrous ethanol around 99.7 °GL; the mixture water-dehydrating agent is separated in a settling tank.

Dehydrating agent recovery: column P has this function and the process is known in Brazil by the traditional name of "debenzolagem". The column receives the water from the settling tank of the dehydration system and by distillation recovers the solvent that is sent back to column C.

These sectors are the largest consumers of thermal energy, or process steam, in the ethanol production process, but since bagasse has been for a long time sufficient to supply all the energy demanded by the distillery or mill this situation persisted until today. The steam consumptions (at 2.5 bar, saturated) for distillation and dehydration remain in the ranges of 3 to 3.5 and 1.5 to 2 kg/liter of ethanol, respectively.

One of the critical problems in the beginning of the ethanol expansion growth was the large production of lower alcohol due to the necessity to produce a high quality fuel ethanol; this production could reach up to 15% of the total ethanol production in some distilleries (CTC, 1983). This product, due to its high contaminant contents such as organic acids, esters, aldehydes, higher alcohols, had a very low commercial value. Modifications in the columns were introduced in order to bring the lower alcohol level to the 3% to 4% range; these processes have been called hydroselection (column P) and "repasse" (column C). Copersucar installed a refinery for lower alcohols to process the production of this byproduct from the cooperated mills in a centralized and more economical way, creating a commercial value for it. The modifications made in the distilleries through these 40 years have reduced the production of lower alcohol close to zero.

With the introduction of neat ethanol cars in the market, the hydrous ethanol production had a sharp increase and some of the distilleries installed annexed to the sugar mills in the first phase of Proálcool had a large idle capacity in the dehydration section. A process was then developed (CTC, 1990) to use the dehydration column (column C) operating in parallel with the rectification column (column B) and introduced some modifications in the standard process; the result was an increase in the production of hydrous ethanol in the distilleries that could exceed 50% in some cases, making this alternative widely used.

The fuel ethanol specifications in the initial phase of the production expansion were established by the Institute of Sugar and Alcohol – IAA based on the existing specifications for industrial ethanol. Table 3 shows IAA specifications for hydrous ethanol for several uses.

These specifications have shown to be insufficient for the good operation of the engines and for this reason were modified as shown in Table 4.

The evolutions described above lead to the consolidation of an industrial process, shown in a simplified form in Figure 5, known today as the

TABLE 3 Specifications for hydrous ethanol for various uses.

Characteristics	Fuel hydrous	Non fuel hydrous	Refined hydrous
Specific gravity at 20 ºC	0.8076 to 0.8110	0.8076 ± 0.0011	Max. 0.8065
Ethanol content (°INPM)	93.2 ± 0.6	93.8 ± 0.4	Min. 94.2
Fixed residues max. (mg/100 ml)	–	5	–
Total acidity max. (mg/100 ml)	3	3	1.50
Aldehydes max. (mg/100 ml)	6	6	1
Esters max. (mg/100 ml)	8	8	2
Higher alcohols max. (mg/100 ml)	6	6	1
Methyl alcohol max. (mg/100 ml)	–	–	0.2
Alkalinity	Negative	Negative	Negative
Aspect	Clear and free from suspended matter	Clear and free from suspended matter	Clear and free from suspended matter

Source: CTC (1987).

TABLE 4 New fuel ethanol specifications, anhydrous and hydrous.

Characteristics	Units	Anhydrous	Hydrous
Acidity (as acetic acid)	mg/L	<30	<30
Electric conductivity	microS/m	<500	<500
Specific gravity	kg/m^3	<791.5	809.3 ± 1.7
Ethanol content	%v/v	>99.3	93.2 ± 0.6
pH	–	–	6 a 8
Evaporation residue	mg/100 mL	–	<5
Chloride ion	mg/kg	–	<1
Sulfate ion	mg/kg	–	<4
Iron	mg/kg	–	<5
Sodium	mg/kg	–	<2

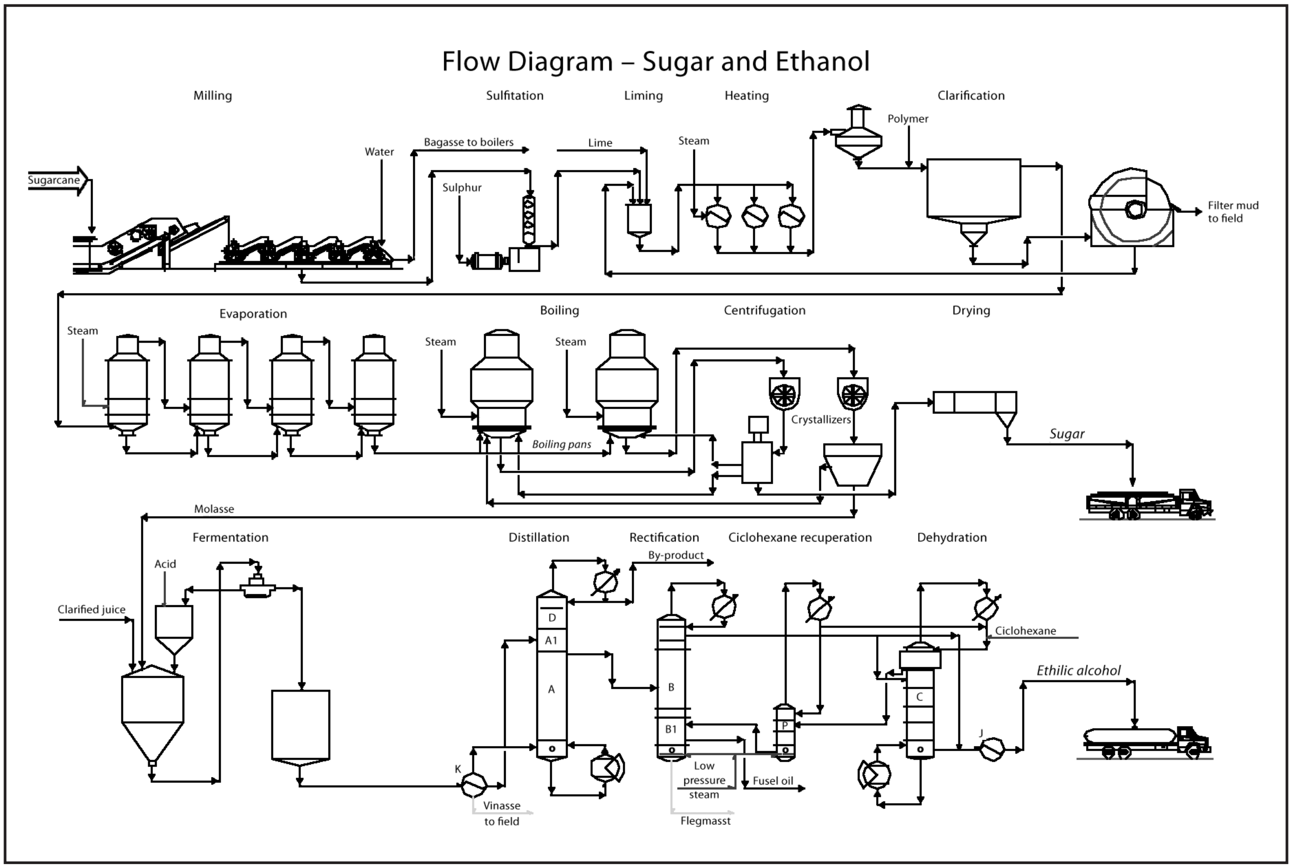
Source: CTC (1987).

Brazilian model of the integrated production of sugar and ethanol, that has a significant contribution to the competitive stage of our industry today.

Energy

The evolution of the energy sector of the Brazilian mills and distilleries was as important as the one of the other areas, but in a slower pace due to institutional factors and to the fact that bagasse was an abundant fuel at no cost for the mills that could not find other commercial use for it.

This system was composed by the bagasse fired boilers, backpressure turbines driving the electric generators and the heavier equipment such as mills, knives, shredders, boiler exhaust fans and feed water pumps. The steam at the outlet of the backpressure turbines, at a pressure around 2.5 bar, is directed to the process equipment to supply the needs for thermal energy. Figure 6



Source: FINGUERUT (2005).

FIGURE 5 Simplified flow diagram of the Brazilian model of the integrated production of sugar and ethanol.

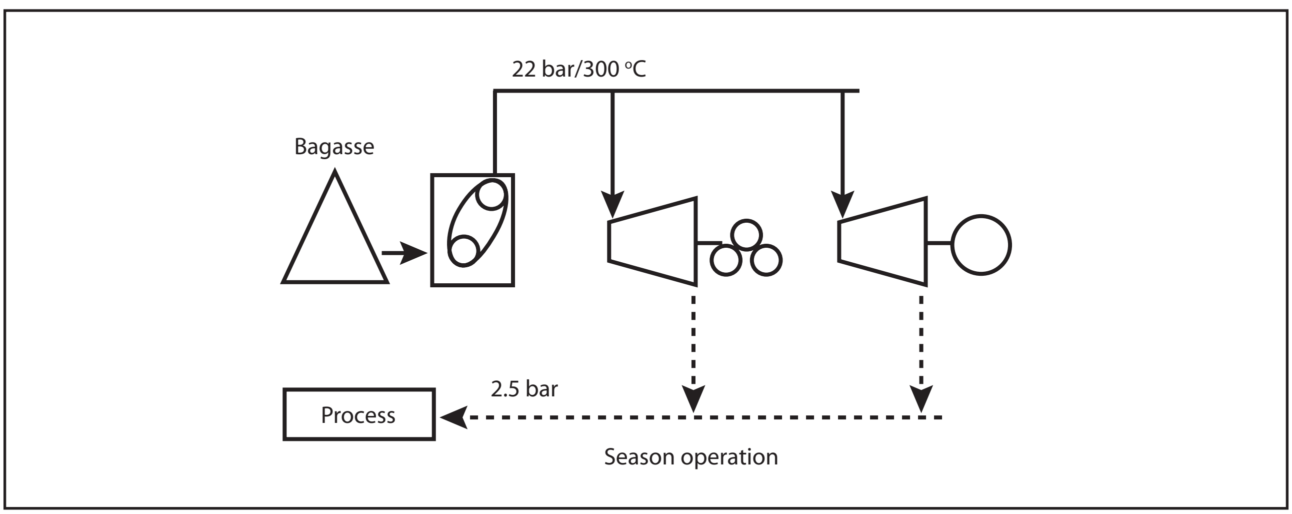


FIGURE 6 Simplified flow diagram of the mills energy system.

shows a simplified flow diagram of the mill energy system, in its most common configuration.

Figure 7 presents a simplified energy balance for an average mill in operation today.

From Figure 7 it can be seen that only a fraction of the bagasse primary energy (585 kWh/tc) is converted into useful energy, in the form of electromechanical energy (28 kWh/tc), thermal energy

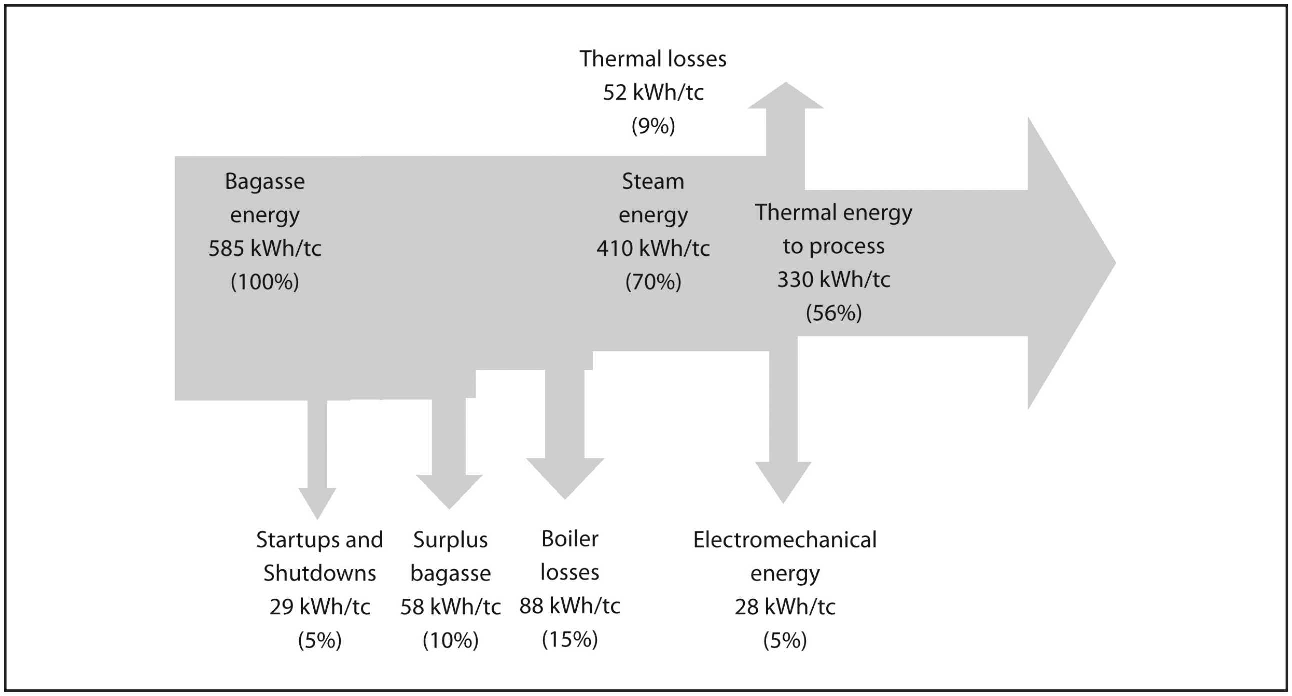


FIGURE 7 Energy balance for a typical mill processing one ton of cane (1 tc).

for process (330 kWh/tc) and surplus bagasse (58 kWh/tc), representing a 70% recovery.

Sugarcane processing is highly energy intensive, especially in thermal energy for juice concentration, ethanol distillation and dehydration. By the time of Proálcool launching most mills consumed considerable amounts of fuel wood to supplement bagasse in providing fuel for the boilers; besides that, a good part of the electric energy needs of the plant was provided by external electric power bought from the utilities still at low prices. Today the more modern mills generate all the energy needed to run the plant using only bagasse as fuel and still produce some surplus of electric power and bagasse for sale. For a better understanding of how this evolution took place the process will be divided in phases.

Pre-Proálcool phase: prior to 1975 process steam consumption normally reached values around 600 kg of steam/ton of processed cane (tc), demanding the use of fuel wood to supplement the bagasse for boiler fuel. Boiler steam pressures were in the range of 11 to 22 bar, saturated, and small size boilers dominated (<30 t steam/h), with low efficiency (<70%) and natural draft, hearth furnace, operating with excess air above 50%; the turbine generators were also small units, seldom above 1 MW, with single stage low efficiency turbines. This low efficiency configuration demanded, thus, the external energy in the form of fuel wood and electricity from the grid besides the endogenous source – bagasse.

Self-sufficiency phase: with the increase of the fuel wood and electricity prices the mills sought the improvement of the energy efficiency, initially seeking to phase out the use of fuel wood to depend only on bagasse; since the energy system operated, as is still the case today, in the cogeneration mode the steam consumption reduction had to be followed by the increase in efficiency of the turbine drives (including the turbine generators), to keep the high pressure steam and low pressure steam consumptions balanced. Boiler efficiencies were slowly, but steadily, increased with the installation of heat recovery equipment such as combustion air preheaters and economizers, and with the improvement of the combustion process by the use of secondary air (overfire air), dumping grates, suspension burning and automation. The use of multi stage turbines to drive the main equipment, such as knives, shredders and mills helped to reduce the high pressure steam consumption in this equipment and to direct this spare steam to the turbine generators to produce more electricity. The use of superheaters became very popular, thus increasing the steam energy content without requiring the increase in boiler pressure (not possible in the existing boilers). The sought self-sufficiency was finally reached by nearly all mills in the mid 1990s, with the following energy profile:

- Boiler steam conditions: 22 bar/300 ºC.
- Process steam consumption: 500 kg/ton of cane.
- Mechanical energy for the drives: 16 kWh/ton of cane.
- Electric energy for the mill: 12 kWh/ton of cane.
- Bagasse surplus: 0% to 10%.

Surplus power generation phase: the electric sector privatization, started in the mid 1990s, created an institutional and regulatory environment that liberated the electricity market from the Government total control that existed until then, making possible the mills to sell their surplus electricity to other consumers, besides the utility they were connected to. For that it was fundamental the regulation of the Independent Producer and the opening of the national grid to the independent producers requiring only the payment of wheeling tariffs established by the Government through the Regulatory Agency of the sector – Aneel – National Electric Energy Agency. With the intention to diversify country's Energy Matrix the Government created the Proinfa – Program to Incentivize Alternative Energy Sources, facilitating the insertion in the energy matrix of power generation from alternative sources namely biomass, wind power and small hydroelectric power plants (<30 MW). In the case of biomass the response was well below the Government expectations mainly due to the fact that the tariff offered by the program was not considered attractive to the sugarcane sector; on the other side, the open auctions for electricity sale have attracted a significant participation of the mills, causing a fast increase of surplus power generation. For the old mills the modernization of the energy sector is highly dependent on the stage of obsolescence of the boilers and turbine generators, since these items are expensive and have a long useful life, around 30 years. For the new mills BNDES – National Bank for Economic and Social Development, created some differential conditions for the loans favoring the projects that considered the use of boilers with pressures of 60 bar and above; this simple initiative of the bank induced the generalized use of high pressure steam conditions in greenfield mills, avoiding what could have been a regrettable loss of opportunity to increase the sugarcane sector surplus power generation. The standard for the greenfield projects today is steam conditions of 65 bar/480 ºC when only backpressure turbine generators are used or 100 bar/520 ºC in the case of using condensing/extraction or condensing/backpressure turbine generators. Using only the bagasse available at the mill, the surplus power generation increased from close to zero to values above 80 kWh/ton of cane (see Figure 8). The sugarcane straw recovery is starting slowly and could supplement the bagasse making it possible the year round power generation with a potential to reach surplus power in the range of 150 kWh/ton of cane. This practice is still incipient and technology development is required to allow its wider use.

Figure 8 illustrates the new mills energy system trends.

These three phases described above required a significant technology development in Brazil, mainly in engineering, to make them happen. This development was relatively easy due to the fact that adequate technology options already existed abroad or even in other sectors of the economy in Brazil; only the adaptation to the mill environment and conditions was required, producing the necessary economies of scale of the national equipment manufacturing industries.

The boilers, as the most expensive item and with a long useful life, evolved slowly because until 2003/2004 the expansion of the sugarcane sector took place essentially by the increase in capacity of the existing mill; the amount of greenfield projects was insignificant. Therefore, the replacement of the existing boilers by more modern and higher pressure units only happened at the end of the useful life of the former; in the initial phase of the Proálcool there was a wide variety of boiler sizes and types, but the small capacity, low pressure,

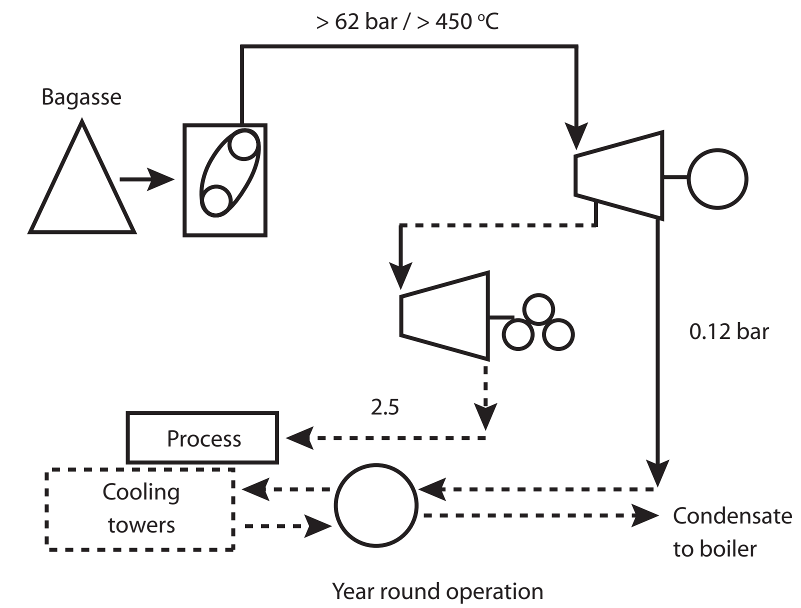


FIGURE 8 Energy system for the new mills.

saturated steam, hearth type furnace, refractory brick walls, natural draft, high excess air, no air preheater or economizer and almost total lack of automation were the prevailing conditions. The first modernization steps were the introduction of air preheater, economizer and superheater, secondary air, dumping grates, forced draft and some automation; these changes had a contribution not only in improving the efficiency but also in the most needed gain in capacity, very useful in mills in the capacity expansion process. Changes to more modern technologies and higher steam pressures were only possible by the time of boiler replacement due to obsolescence. Slower was the introduction of boilers with pressure above 22 bar, suspension burning furnace, membrane wall and full automation (drum level and combustion controls) with thermal efficiencies around 85%; steam production capacities above 100 t/h became the trend. Today, the state of the art technology offered by the national manufacturers is 100 bar/530 °C steam conditions, single drum design, steam generating capacities up to 400 t/h and efficiencies up to 89% (DEDINI, 2009); 120 bar/540 °C boilers are also available but are not being used by the mills.

Turbine generators being equipment costing a lot less than the boilers, having a shorter useful life and having a very active used equipment market had, therefore, a faster rate of modernization by the replacement of equipment even before reaching the end of useful life. The single stage turbine drives for the larger equipment such as shredders, knives and mills are being replaced by multi stage and more efficient turbines (a change from 40% to 60%, approximately). The turbine generators gained in scale and efficiency by the replacement of the several small single stage units, around 1 MW capacity, from the early Proálcool days with larger (up to 40 MW) multi stage units. The main improvement in mill driving system has been the new trend to use electric motors (either fed by inverters or driving hydraulic motors, to allow the mill speed control); with these upgrades the surplus power generated by the mills using 65 bar/480 °C steam conditions in pure cogeneration mode (no steam condensing) increased from 40 kWh/ton of cane to 60 kWh/ton of cane, by the use of the steam in the more efficient turbine (>75%) in the electric generator rather than in the lower efficiency mill driving turbines (around 60%).

TABLE 5 Technological evolution in the mills and distilleries from 1975 to now.

	1975	Today
Milling capacity: mill size 6x78" (tc/day)	5,500	15,000
Extraction efficiency (%)	93	97
Fermentation time (h)	16	8
Fermentation yield (%)	82	91
Distillation efficiency (%)	98	99.5
Total plant efficiency (%)	66	86
Boiler efficiency (%)	66	89
Turbine generator (%)	50	75

Source: OLIVÉRIO (2009) e FINGUERUT (2005).

FINAL CONSIDERATIONS

It is undeniable that there has been an important technological evolution in the Brazilian mills and distilleries, as described above, and it was this development that, together with similar developments in the agricultural and management areas, brought the sugarcane sector in Brazil to the stage of high competitiveness of today. Table 5 summarizes this technological progress in the industrial area, comparing the main indices and parameters evolution from the early days of Proálcool until today.

Seen in this condensed form, the picture of the improvements obtained practically only with a national effort is quite impressive. The high values already reached for the main indices make it very difficult the obtain significant additional gains, but it does not mean that further cost reduction are not possible; improvements in the plant management and operation controls, as well as the increase in surplus power generation (with state of the art technology and sugarcane straw recovery and use to supplement bagasse as fuel) and the gains in economies of scale are helping to continue the cost reduction in the sugarcane processing step to maintain, and even improve, the countries competitiveness in sugar and ethanol production.

This is just a short list contemplating the key issues. A more complete discussion on this subject is presented in CGEE (2009).

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5

POTENTIAL OF ELECTRICITY PRODUCTION FROM SUGARCANE RESIDUES

Arnaldo Walter

INTRODUCTION

Worldwide, sugarcane mills use their process biomass residues (mainly sugarcane bagasse) as fuel in cogeneration systems. In Brazil, during the harvest period the mills are electrically self-sufficient, that means that all electricity required is produced on-site from the bagasse. Since the second half of the 1980s, some mills (following a slow but consistent process) have done investments aiming at the production of surplus electricity to be sold to the grid. It is estimated that about 20% of the Brazilian mills, most of them located in state of São Paulo, are producing and selling surplus electricity.

However, the capacity of electricity production is significantly low regarding the potential taking into account the sugarcane production. According to the Brazilian Electricity Agency – Aneel[1] – the installed capacity of electricity production from sugarcane bagasse by middle 2008 was 3.1 GW in 248 industrial units (mills). Considering that at that time there was at least 350 mills under operation, the installed capacity was more than 3.5 GW (supposing the non declared capacity in small mills), or at least 3.5% of total existing capacity of electricity production.

The potential of electricity production depends on various factors, including the technology of the cogeneration system (e.g., pressure and temperature of the steam raised, the use of backpressure steam turbines or extraction-condensation units etc.), the availability of biomass (e.g., the potential will be higher in case of sugarcane trash use), and on the number of hours of operation (e.g., only during the harvest season, or along the whole year). For instance, considering that steam is raised at 82 bar, 480 °C[2], without reduction of the steam demand, without the use of sugarcane trash and electricity production just during the harvest period, the potential would be equal to 6 GW considering the sugarcane production in 2006 (425 Mt of sugarcane). On the other hand, considering the same steam parameters, but recovering 40% of the trash available at the field and reducing the steam demand, the potential would reach 9 GW (again supposing the operation only during the harvest period). Thus, it can be concluded that the potential is at least 2 to 3 times the installed capacity.

Conversely, considering that sugarcane production can reach 730 Mt by 2012 and even surpass 1,000 Mt in 2017, the potential of electricity production from sugarcane bagasse could be more 2 to 3 times higher comparing to the previous evaluation. It is clear that these are very expressive figures taking into account the required necessity of enlargement of the electric system in Brazil in the following 10 to 20 years.

[1] Agência Nacional de Energia Elétrica, in Portuguese, that is the regulatory body of the electric sector. Its data basis is available at: <www.aneel.gov.br>.

[2] That no longer is the best technology commercially available in Brazil.

Since many years it has been recognized many advantages of the cogeneration using residues of sugarcane, including:

(i) that it is possible to produce a reasonable amount of surplus electricity without the use of extra fuels, as the residual biomass of sugarcane has been burned anyway (the bagasse in the mills site, and the trash in the field, before harvesting)[3]. As the residues of sugarcane are renewable, the reduction of greenhouse gas – GHG – emissions is an additional benefit of this option. The reduction of GHG emissions depend on the sources of electricity production that are displaced due to the production from sugarcane residues[4];

(ii) the so called distributed electricity generation, close to the load centers, could allow the reduction of transmission and distribution losses;

(iii) in case of Brazil, the production of electricity from sugarcane residues can contribute to the electric system, as sugarcane production in the Center-South region[5] occurs during the dry period, when the hydro power plants cannot operate at their full capacity;

(iv) the technology is commercially available, the required equipments are produced in Brazil and the specific investment ($/kW installed) is relatively low;

(v) the production diversification in the sugarcane industry would allow could cost reduction, modernization (both considering technological and managerial point of views) and would be a step further on making real the biorefinery concept;

(vi) and, finally, taking into account the enlargement of sugarcane production, the cogeneration potential would significantly enlarge the electricity supply within the regions Central and Northeast.

However, despite the advantages presented above, there are still considerable constraints for the deployment of the cogeneration potential, including the following aspects:

(i) there is still a hydroelectricity culture in the Brazilian electric sector and the deployment of the remaining hydro potential is the priority;

(ii) the sugarcane sector is heterogeneous and many entrepreneurs still don't recognize the advantages of producing surplus electricity. It should also be mentioned that the required investments for surplus electricity production are meaningful vis-à-vis the investments in the core business, and this is an important reason for the lack of motivation;

(iii) regarding the topic above, as the investments for surplus electricity production are not the priority, the required discount rate is larger, with a negative impact over the production costs;

(iv) the enlargement of electricity production capacity is related with window opportunities that appear when a new mill is build or when the main equipment are changed in an existing mill. In case of inadequate conditions at the moment of the decision process, the potential will be lost for about 25 to 30 years (i.e., the useful life of boilers and steam turbines);

(v) in Brazil, the regulation regarding cogeneration has remained incomplete despite the set of actions taken along the years.

In recent years (and currently), there is a new set of factors that would negatively impact the investment opportunity for large-scale production of surplus electricity using residues of sugarcane. They are:

(i) some mills/distilleries have been built in regions where there are constraints for

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[3] The so-called trash corresponds to the leaves and tops of the plant that have been traditionally burned at the field before the manual harvesting process. In some regions – e.g., in state of São Paulo –, it will be completely forbidden to burn sugarcane previous to harvest in few years, and mechanical harvesting will be dominant technology.

[4] These benefits are larger if the bulk of electricity production is based on fossil fuels, such as coal, oil products and natural gas.

[5] Where about 90% of the sugarcane production takes place

interconnecting with the electric grid[6]. In case of high costs for selling surplus electricity, entrepreneurs decide to reduce the capacity just assuring self-sufficiency[7];

(ii) currently electricity is commercialized through public auctions and this has brought new difficulties for cogeneration from biomass. First, because the process is complex in a certain extent and this imposes a constraint for those who are not familiar with the electric sector. Second, as previously mentioned, because of the few window opportunities for the required investment;

(iii) in addition, in some cases constrains regarding the supply of equipment or the necessity of reducing the up-front costs resulted investments just for self-sufficiency.

Aiming at identify the opportunities for the enlargement of electricity production form sugarcane residues, the existing challenges and the required actions mainly regarding research and development – R&D, a workshop was held at University of Campinas – Unicamp, in January 2008. The second part of this chapter is a summary of the main discussions and conclusions of this event.

The workshop "Potential of electricity production from residues of sugarcane: opportunities, challenges and required actions" was divided in three panels. The first section had focus on the potential itself and on how this potential has been considered in the electric sector planning. The main presentation in this section was by Vicente Correa Neto, from Empresa de Pesquisa Energética – EPE[8]. The panel had also two opponents: Leonardo Santos Caio Filho, from COGEN-SP, and Celso Zanatto, from Crystalsev.

The second panel had focus on the required R&D actions aiming at deploying the estimated maximum potential[9]. Three experts on technology have discussed the main issues.

Finally, the third panel was devoted to the capacity of the Brazilian industry of equipment. The presentation was by Vadson Bastos, from Dedini, and the discussion was with all participants.

OPPORTUNITIES, CHALLENGES AND REQUIRED ACTIONS

According to EPE[10], electricity self-production in 2006 was equivalent to 10,6% of the total electricity consumption, and the growth rates have been remarkable in recent years. Only in the oil and gas industry electricity self-production is more important than in the sugarcane industry; considering electricity self-production, sugarcane bagasse is the second more important energy source, behind hydro.

In a conservative basis, EPE estimates that electricity production from bagasse in 2006 was at least four times lower than it would be possible to achieve in case of the widespread use of the best technology available at that time. This estimate is based on a survey done by EPE, covering about 10% of the existing mills.

The potential regarding the enlargement of the sugarcane industry up to 2030 was evaluated by EPE in its (first) National Energy Plan. It was estimated that the sugarcane production could reach 1,120 million tonnes of sugarcane in 2030. Even in the reference case, EPE has considered a very optimistic scenario in which by 2010 most of the mills (78%) would be relatively new, being about 60% installed during the period 2005 e 2010.

In opposition to that optimism regarding the investments, EPE has considered that the bulk of the cogeneration units would be systems with back-pressure steam turbines. It was taken into account that the water consumption for cogeneration systems with extraction-condensation steam turbines would be inadequate for the bulk of industrial units, mainly located in regions with

[6] Essentially, large distance to the grid and/or low connecting capacity regarding the capacity of surplus electricity production.

[7] In Brazil, the costs of interconnection in case of distributed generation are due to the investor in electricity production.

[8] EPE, with headquarters in Rio de Janeiro, belongs to the Ministry of Mines and Energy and is charge of all main steps regarding energy planning in Brazil.

[9] The so-called thermodynamic potential.

[10] The speaker, Vicente Correa Neto, was at that time with the Energy Resources Group, Division of Energy and Economy.

constraints at certain degree regarding water availability.

Taken into account the set of hypothesis considered regarding (i) the technology used in new mills, (ii) keeping some mills without improvements[11], (iii) the use as fuel of only 20% of the sugarcane trash available at the field and (iv) the use of a share of bagasse for ethanol production through hydrolysis, the capacity of surplus electricity production in 2030 was estimated as about 6,800 MW, being 4,350 MW in mills not yet built in 2005. It should be mentioned that this is indeed a very conservative evaluation.

The efforts in order to foster the potential included a specific auction for electricity produced from biomass[12], the construction of special interconnection facilities[13] and advances regarding the regulation of interconnection costs.

An optimistic vision was also presented by Cogen-SP[14] that at that time evaluate that would be possible to install 10,000 MW of new capacity in short to mid-term. However, the vision of potential investors was different[15] due to a set of constrains, mainly regarding the interconnection costs.

According to the existing regulation, the costs of interconnection are charged to the investors. As the plants of electricity production from biomass are smaller regarding fuel oil and coal power plants, the benefits of scale-effect are not possible. Power plants fueled by fuel oil or imported coal are designed to be built where the interconnection costs are lower, and this benefit doesn't exist for the biomass units. And it is also worth to mention that the electricity of the recent approved large hydro power plants (e.g., Santo Antônio e Jirau, in the Madeira river) were not charged with the very high interconnection costs.

The required R&D actions are discussed in the following paragraphs. According to Antônio Bonomi[16] there are six main technological challenges, being five of them specific to the technology and/or the biomass. The following points were highlighted:

(i) the technology BIG-GT (biomass integrated gasifier to gas turbines) – still not commercial – requires both the development of large-scale biomass gasifiers and of a clean-up technology that would allow fuel gas use in gas turbines;

(ii) it would be necessary to use multiple fuels in steam boilers, aiming at diversify the biomass supply;

(iii) the use of sugarcane trash as fuel is not possible at this moment, and all constrains regarding harvesting, transportation and storage should be addressed;

(iv) currently, the biodigestion of vinasse is not feasible, and priority should be given to the use of fuel for electricity production;

(v) the combined production of biofuels and electricity should be diversified and in the case of sugarcane it is necessary the development of hydrolysis and gasification process that would be integrate to the conventional production process.

It was also highlighted that the concept of biorefinery still needs to be developed to sugarcane.

Two other experts have discussed the required R&D actions for fostering cogeneration from sugarcane residues[17]; they agreed with the comments of the first speaker, but with some additional comments. Regarding the use of sugarcane trash as fuel, it was highlighted that it is necessary to develop technology in order to burn trash in the same conditions as bagasse has been burned. Due to its properties, problems as fouling and slagging are predicted in case of trash burning; the usual

[11] Even in 2030.

[12] After many delays, the auction occurred in 2008.

[13] Collecting facilities were designed and built aiming at reducing the costs of interconnection.

[14] That aims at foster cogeneration from different fuels, including biomass. The person who did the presentation was Caio Filho.

[15] Celso Zanatto, from Crystalsev, spoke on behalf of potential investors.

[16] At that time, with the Instituto de Pesquisas Tecnológicas – IPT (Technology Research Center, in São Paulo).

[17] Luiz Horta Nogueira, from Unifei – Federal University of Itajubá, and Manoel Regis Lima Verde Leal, from CTBE – Bioethanol Science and Technology National Laboratory.

alternative of boiler derating (reducing steam pressure and temperature) would imply drastic efficiency reduction of the cogeneration system.

Concerned to gasification, Teacher Lima Verde Leal stated that it is already possible to keep on the BIG-GT demonstration project that was previously considered; this unit would use residual biomass from sugarcane and could be semi-integrated to a sugarcane mill, in order to reduce costs. According to him, both in the case of bagasse/trash gasification as well as in the case of trash burning the current required actions are regarding development and demonstration rather, than basic research; thus, the role of industries is fundamental, and specific financing programs need to be defined.

Regarding vinasse biodigestion, the most important comment was about the necessity to be careful on the evaluation, as the main issues are not related to technology development but rather to the constrained feasibility of electricity production using biogas as fuel.

The issue of the national industry capability was first addressed by the company Dedini that is the largest equipment supplier for the sugarcane industry[18]. A synthesis of the main topics addressed is presented below:

(i) the national industry is able to supply the required equipment aiming at producing electricity in large-scale in with higher efficiency, including steam generators able to raise steam and higher pressure and temperature (e.g., 100 bar and temperatures higher than 500 °C). Despite critics, the industry has also positively answered to the challenges;

(ii) the national industry is able to be a partner in R&D programs, in general, and specifically in the required programs aiming at the gasification of sugarcane biomass and efficient trash burning. According to the company, the partnership with Fapesp, with an agreement signed in 2007 is a clear evidence, but in early 2008 the company was waiting for proposals;

(iii) regarding the necessary conditions to expand the production of the main required equipment, the industry believes that the main issue is the financing conditions, which need to be set according to the necessities;

(iv) the industry states that along the years learning-effects have been observed regarding the equipment of cogeneration systems produced in Brazil[19]. According to the company there are specific aspects concerned to the most adequate configuration to each mill and cost's reduction could be accelerated with the growth of the market and also with technological development (that requires both private and public funds);

(v) on the other hand, the economic benefits due to standardization of equipment will barely achieved as the optimum design is different mill to mill;

(vi) finally, regarding the lack of competition in this industrial branch, the statement is that there is no market protection and that any competitor is free to enter in the market. The national industry was ever able to answer to the market demands, and along the years has produced with quality, relatively lower costs and respecting dead lines.

FINAL CONSIDERATIONS

In short-term, the main constrains for the enlargement of electricity production from sugarcane biomass are not technological neither regarding equipment supply. The main constrains are regulation and due to the lack of adequate policies, especially in short-term, because at least a reasonable part of the potential that can be developed in the existing window opportunity will be lost. The message that was presented by EPE is that the company has understood the constraints and efforts have been done to overcome most of them.

[18] The presentation was by Vadson Bastos.

[19] Despite the statement of some experts who believe that learning-effects have not been observed regarding this industrial branch.

On the other hand, in mid – to long-term the potential of electricity production – and also the potential of production of second-generation biofuels – could be jeopardize in case of no ability in burning sugarcane trash efficiently and neither gasifying bagasse/trash in large scale. In the case of ethanol production through hydrolysis, the potential will be drastically reduced if it would be impossible to raise steam at higher pressure/temperature using trash as fuel – also with severe impacts on the potential of electricity production. In the case of biofuels production through biomass gasification, the challenge is the production of fuel gas in large scale, and also its cleaning-up.

The technology development regarding biomass hydrolysis and biomass gasification (aiming at the production of synthesis gases[20]) requires very-well defined strategies that would involve international cooperation. A reasonable number of countries have invested on such technologies and it seems that the best strategy would involve international cooperation in a certain degree; specifically regarding gasification for the production of synthesis gas, an endogenous R&D program would be slower and with more risks. Brazil is country that calls the attention of the international investors, because the availability of low-cost biomass, the tradition regarding biomass and biofuels, and also because the knowledge available; thus, Brazil is a position to negotiate with the main technological players.

It is also worth to mention the importance of the development of biorefineries concept, that requires the knowledge regarding the biomass, the know-how of pretreatment technologies and the same regarding conversion technologies (e.g., hydrolysis, gasification and gas cleaning, among others).

Taken into account the target of enhancing electricity production from sugarcane biomass, it seems that vinasse's biodigestion should receive lower priority. However, it not wise just ignoring its potential.

[20] The Fischer-Tropsch conversion process is commercial, and once the drawbacks of biomass gasification and gas clean-up would be overcame, the commercial production of biofuels would be possible in large-scale.

6

INCREASING ENERGETIC EFFICIENCY IN SUGAR, ETHANOL, AND ELECTRICITY PRODUCING PLANTS

Adriano V. Ensinas, Juan Harold Sosa Arnao and *Silvia Azucena Nebra*

The sugar-alcohol industry has been one of the most important activities in the Brazilian economy, producing sugar and ethanol for both domestic and foreign markets. This industry has been historically characterized by its low energy efficiency, consuming a considerable part of the bagasse produced as fuel in its co-generation systems, to supply the energy needs of the process. A new scenario, with the possibility of selling surplus electricity to the distribution network, or else, to use bagasse as a raw material for other processes, has motivated several plants into investing in more efficient co-generation systems, as well as in higher process energetic integration.

This chapter discusses the improvement of sugar-alcohol mills co-generation systems by increasing boiler efficiency through the use of bagasse dryers, as well as other design approaches, to these systems. Energy process integration is also included, showing that available thermal energy exploitation may lead to a significant reduction in plant steam intake, thus improving the energy efficiency of the production process.

INTRODUCTION

Through the Brazilian sugar-alcohol industrial history, it is possible to identify efforts to increase mill energy efficiency, as a result of the need to solve actual problems that came up from time to time.

Therefore, one of the first objectives achieved was freeing the industry from any auxiliary fuel, using bagasse, a waste from its own process, as sole source of heat.

The next step was the self-generation of all energy required, both thermal and electric, by developing co-generation systems adequate to the plants' needs, using exclusively bagasse for fuel.

In parallel, the thermal energy consumed in the process began to be better exploited, introducing the use of vegetal steam from evaporators.

A third challenge came up with public electricity deregulation, and hence the possibility of selling electric power to the distribution network at competitive prices.

Still, within the proposed utilization of Rankine cycles, the industry introduced new co-generation systems, with boilers and turbines working at higher temperatures and pressures.

However, new challenges are lurking around the corner, with the possibility of introducing BIG-CC cycles, as it's being planned in India, for different types of biomass (see RENEWABLE ENERGY FOCUS, 2009a), and also with the introduction of the so-called third-generation refineries (RENEWABLE ENERGY FOCUS, 2009b), in which bagasse is shifted from combustible waste into raw material.

In this chapter, the discussion will cover the shortest-range challenges, dealing with co-generation systems improvement, boiler exhaust gases exploitation system, as well as a better thermal integration of the process.

CO-GENERATION SYSTEMS

The co-generation concept has several definitions found in the literature, many of them being close to the one adopted by LIZZARAGA (1994), defining this term as the "joint generation of electricity (or mechanical energy) and usable thermal energy in a sequential process".

Anyway, it is evident that the co-generation option allows for more efficient energy generation, if compared to the independent generation of one sole form of energy, such as in a thermoelectric power generating station. The use of thermal energy enables high performance in the global use of energy, and consequently, savings in primary energy.

The growing worldwide interest in the rational use of energy, combined with minimum use of natural resources, finds in co-generation technology a very compelling technological option, which has conquered space in many industrial and utility applications.

In Brazil, sugar-alcohol industry mills have co-generation systems with the simultaneous production of heat and work for the sugar and ethanol production process, using sugarcane bagasse as fuel. The steam produced may be used to drive mills, pumps, blowers, as well as be converted into electricity, where it finds its noblest use.

Co-generation allows exploiting the energy in the bagasse, and generating electric power in a decentralized and independent manner at the various plants in this industry, that has its energy requirements fulfilled by these systems.

The need for disposal of bagasse, a residue biomass from the production process, was one of the reasons leading to the adoption of low-efficiency co-generation systems, thus making it possible to consume large quantities of residue, and locally generating the energy the process requires.

The restructuring of the Brazilian electrical power generation industry in the 1990s, following the worldwide trend towards distributed power generation, gave room to small-scale production of electricity, and fostered some keener interest in mills for more efficient co-generation systems. The possibility of non-utility generators selling their generated energy surplus contributed to increase the value of residual biomass as a source of energy for power generation.

Furthermore, increasing social demands for energy policies that value minimum environmental impact, alternative energy sources, and rationalization of energy inputs have shown the need for improved exploitation of sugarcane residues.

The structure of mills having low-efficiency co-generation systems and high power demand processes may be analyzed to improve energy usage in this industry, making it possible to generate surplus electric power that could be sold to electric utility companies. On top of using bagasse, the elimination of burning in sugarcane fields, the presence of mechanized harvest and recovering sugarcane tips and leaves, may also represent a significant increase in biomass availability for use as fuel in co-generation systems, further increasing surplus generation.

The decision on the optimum co-generation system for a mill depends on several factors to be observed, among them:

- process-required for mechanical, electric, and thermal energy;
- process-required for steam pressure and temperature levels;
- process energy intake dynamics; intermittent or continuous;
- system utilization factor;
- energy share in the final product cost;
- technical and economical feasibility of selling surplus electricity.

STEAM CYCLE SYSTEMS

Traditionally, topping-type steam cycle systems are adopted by mills, where bagasse is used to generate live steam to drive back-pressure turbines coupled to an electric generator. High pressure steam is taken to drive choppers, defiberers and mills, while the turbine low-pressure exhaust steam is used as a source of heat for various equipments in the plant.

Older systems, characterized by their low energy conversion efficiency are limited for generating electricity. Low-efficiency boilers, generating steam at around 22 bar pressure, overheated between 280 °C and 320 °C, and the process' high steam consumption, around 500 kg of steam per ton of sugarcane, are strong limiting factors to electricity generation, which makes surplus power virtually inexistent.

According to CAMARGO (1990), boilers used by the sugar-alcohol industry until the 1980s were conceived around eliminating bagasse, considered as an undesirable waste, therefore being low efficiency and low cost. Some alternatives available for increasing this equipment's efficiency in drawing energy from bagasse are described by NETO and RAMON (2002), among them the use of superheaters, thermal deaerators, savers, air preheaters, and bagasse dryers, in addition to efficiency-preserving actions, such as care in handling fuel, feed water treatment, and better control on combustion.

Systems with back-pressure turbines are limited to generation during the harvest period, as they need the process to condense the generated steam. Steam loss, or its condensation at turbine exhaust pressure is not economically justifiable, rendering off-harvest power generation unviable with such systems.

Increasing temperature and pressure levels of the steam generated by co-generation systems boilers makes it possible to increase the surplus electricity generated, which can be sold to utility companies. Furthermore, the use of extraction-condensation turbines makes it possible to generate electricity and sells it also during the off-harvest season.

Technological evolution of sugar-alcohol industry co-generation systems

In Brazil and all over the world, only steam systems are found in sugarcane mills. This is a widely known technology, using mostly locally-made equipment. There are many boiler, steam turbine, and electric generator manufacturers in Brazil, several of them also serving the international market.

It is observed that more efficient co-generation systems have been installed in the Brazilian sugar-alcohol industry, with boilers generating live steam above 60 bar and temperatures ranging between 480 °C and 520 °C.

The trend observed is towards using higher parameters in steam generation, to render more efficiency in electric power generation. The first boiler to operate at 90 bar pressure was installed in mid-2008 at Usina Equipav, located in Promissão, SP (STEFANO, 2009). DEDINI (2008) offers systems that operate at 100 bar pressure and 520 °C temperature. Internationally, KAMATE e GANGAVATI (2009) state that the highest pressure used industrially is 105 bar, in a sugar plant in Okeelanta, Florida, USA.

Inquires made to boiler and turbine manufacturers showed that there is an economic limitation to using higher temperatures to generate live steam, as steels currently produced in Brazil can only withstand temperatures up to 520 °C. Special steels, that can endure higher temperatures, would require importing the material, or ordering specific batches to Brazilian industries, which would lead to unaffordable costs (EQUIPALCOOL, 2006).

Another trend noticed was towards increasing the capacity of steam generation by boilers intended for the sugar-alcohol industry, shifting from the present systems that generate from 150 t/h to 250 t/h of steam to capacities between 300 t/h and 450 t/h.

The trend for larger capacity boilers is the monodrum type construction. The monodrum boilers technology is new to the sugar-alcohol industry; however it has been used for several years, both in and outside Brazil, in industries such as pulp & paper, petrochemical, and thermal electricity generation. According to the manufacturers, the technology used to build monodrum boilers allows adopting high steam flow rates, and pressures in excess of 100 bar (CALDEMA, 2006).

Regarding steam turbines, it is observed that Brazilian industry has been supplying the domestic demand for turbines operating at the highest pressure an temperature levels adopted for steam generation, however according to some manufacturers, the maximum power of such equipment is limited to 50 MW for economical reasons, since domestic electricity generators can only work up to this power level, importation still being unaffordable from the investment viability standpoint (NG, 2006).

However, it is observed that Brazilian industry has the technology to produce steam reaction turbines with power up to 150 MW, operating with intake steam up to 120 bar and 530 °C, however for export only (NG, 2006).

Evolution of bagasse boilers efficiency

Old 20 bar/300 °C boilers did not provide any device of how to use the exhaust gases enthalpy. With the progressive increase of steam pressure and temperature parameters, and the change in boiler design (single-pass on the gas side, at the convection beam), the temperature of gases from the steam generator increased, and for this reason devices were progressively aggregated for using this energy.

SOSA-ARNAO and NEBRA (2009) present a correlation for calculating this temperature, as a function of the vapor saturation temperature:

$$T_g = 42.94T_{sat}^{0.3962} \qquad (1)$$

Correlation valid for temperatures up to 67 bar.

Thus, for 20 bar boilers we would have a temperature of the gases of 359 °C, and for 65 bar, 401 °C (these values depend on boiler constructive features, and may vary). In any case, it is a significant amount of thermal energy, which should be exploited.

So, with the technical improvement air preheaters were initially introduced, to use the thermal energy from exhaust gases to heat the air blown into the boiler itself.

Though seldom used in the Brazilian industry, another proper piece of equipment for using the thermal energy from exhaust gases is the bagasse dryer (SOSA-ARNAO *et al.*, 2006a).

The efficiency of 20 bar boilers with air preheaters and pneumatic type bagasse dryers was determined by SANCHEZ PRIETO *et al.* (2001). The schematics of the system studied by those authors is shown on Figure 1. Gases exiting the steam generator were split, part of them being sent to an air preheater, and the remainder to a bagasse dryer.

The Tables 1 and 2 show the boiler features and the data obtained.

The boiler's overall efficiency was calculated based on the low heat capacity of bagasse; this definition particularly fails to consider the energy spent in evaporating the water it contains. Calculating the efficiency according to the high heating value, such effect is taken into account, and efficiency is decreased by around 25%, as discussed by SOSA-ARNAO *et al.* (2006b).

Due to the high particle content of exhaust gases, the most popular heat exchanger is the shell and tubes type, which, as it requires a large area to transfer heat between two gaseous flows, takes up considerable space, its size being limited by the cost/benefit ratio.

Hence, it may be observed that the exhaust gas temperature at the air preheater is relatively high, causing significant heat loss. This effect is detected by the effectiveness parameter of the

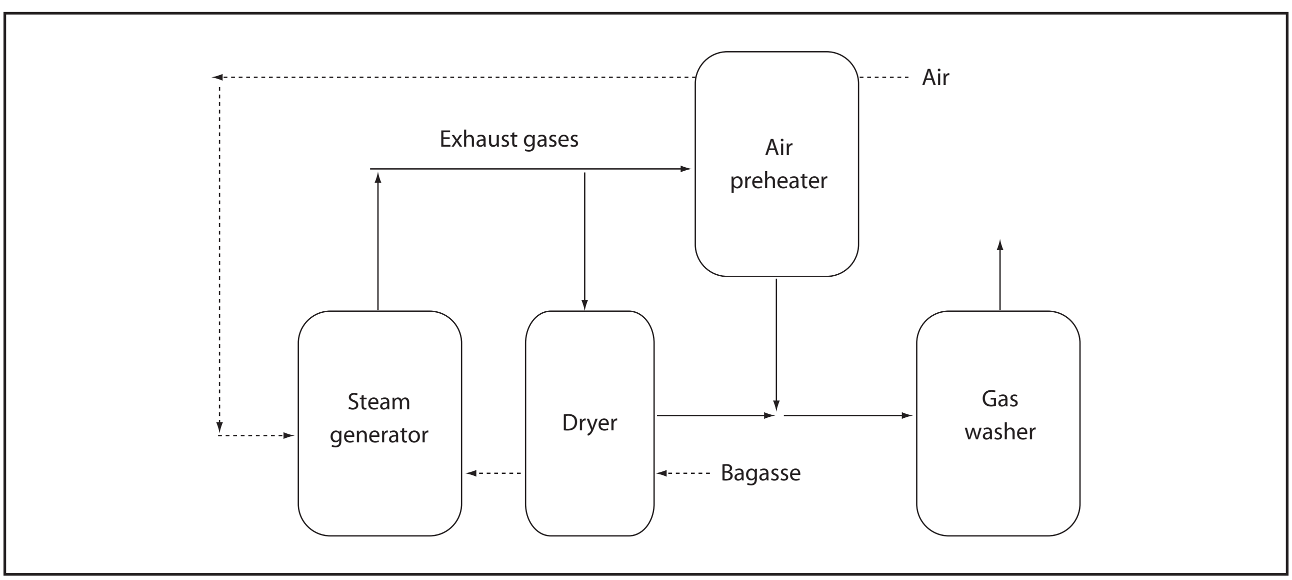


FIGURE 1 Schematics of the system studied by SANCHEZ PRIETO *et al.* (2001).

TABLE 1 Characteristics of boilers.

	Manufacturer	Temperature (ºC)	Abs. pressure (bar)	Capacity (t/h)
1	Dedini S.A.	310	21.61	68
2	Dedini S.A.	315	21.61	74
3	Caldema	320	21.61	83

Source: SÁNCHEZ PRIETO *et al*., 2001.

air preheater (HOLMAN, 1983), which shows relatively low figures.

In terms of exploiting the available energy, the direct type dryer has better performance. Gas temperatures at its outlet are lower, and its efficiency shows good values for the first two boilers. It is smaller and cheaper equipment, however it must be carefully designed to offer good results.

Another important issue is the evolution in the way of burning bagasse. At the outset, bagasse was burnt in a stockpile, which resulted in unstable and deficient burning. In these cases, only primary air was used in combustion. Over time, boiler design was changed increasing the height of bagasse feed from 1 m to 4 m, and secondary air was introduced. The result was an increase in suspended bagasse burning, less superficial burning, and increased combustion efficiency.

The Sugar Research Institute – SRI developed the vortex bagasse burning system, where the bagasse enters the boiler immersed in the spiraling air flow, which gives it more drying and burning time in suspension than the traditional spraying system (DIXON *et al*., 2003).

TABLE 2 Systems parameters.

	Boiler 1	Boiler 2	Boiler 3
Produced steam flow rate (kg/s)	18.89	20.56	23.06
Total mass of exhaust gases (kg/s)	43.33	41.05	57.32
Air pre-heating gas intake (kg/s)	11.77	15.08	11.78
Dryer gas intake (kg/s)	31.56	25.96	45.54
Temp. gases input to air preheater/dryer (ºC)	259	239	257
Temperature of gases at air preheater outlet (ºC)	175	198	169
Temperature of gases at dryer outlet (ºC)	91	83	83
Preheated air flow rate (kg/s)	14.52	11.93	20.87
Preheated air temperature (ºC)	125	124	124
Bagasse flow rate after dryer (kg/s)	6.82	7.48	9.70
Bagasse moisture after dryer (% b.u.)	40	42	45
Overall boiler efficiency (%)	75.56	78.75	72.48
Air preheating efficiency (%)	46.77	32.47	60.34
Dryer efficiency (%)	78.96	89.14	39.41

Source: SÁNCHES PRIETO *et al*., 2001.

In Brazil, there is equipment using the same vortex principle, however, it only mixes the bagasse with the spiraling air at the sprayer outlet. This system, developed from burning rice husk, was introduced in the Branco Perez mill by the company Equipalcool Sistemas Ltda., in August 2008.

Bagasse dryers

In a comprehensive review, SOSA-ARNAO *et al*. (2006a) present a series of data on different dryer types used for bagasse, both industrial and experimental. So this comprises the classic rotating dryers, the descending flow ones, and the pneumatic ones, among others.

The pneumatic type dryers were tested by the Brazilian sugar-alcohol industry, using a model developed by the former Copersucar Technology Center, today Centro de Tecnologia Canavieira (Piracicaba). Experimental results obtained on the field compared to data simulations are reported by NEBRA and MACEDO (1989).

The design of any dryer should start from a careful analysis of material shapes and sizes (NEBRA and MACEDO, 1988; SOSA-ARNAO, 2007).

One important consideration is related to the source of energy to be used. Previously, an example of use of boiler exhaust gases was given. In the case of sugar-alcohol mills, this seems to be the best option. In any case, the process integration concept explained next requires that for the drying operation – which does not demand high temperatures – thermal waste be used, at 200 °C or lower temperatures.

On top of the consideration regarding thermal waste, in the case of bagasse, care must be taken with its easy ignition. RAMAJO-ESCALERA *et al*. (2006), SOSA-ARNAO (2007), and SOSA-ARNAO and NEBRA (2009) present data relative to the combustion of this material, where it is possible to identify the point where carbon dioxide emissions (step) begins, around 200 °C. Being part of the material composed by small-particles material, which will dry quickly (NEBRA DE MACEDO, 1989), it is advisable that drying gases in direct contact do not exceed much that temperature.

Regarding the type of dryer, considering the material size diversity and its light weight, the previously tested pneumatic types seem adequate. Cyclone dryers were also tested in laboratories, with promising results (CORRÊA, 2003; CORRÊA *et al*. 2004), as they are smaller units.

SOSA-ARNAO (2007) and SOSA-ARNAO and NEBRA (2009), discussed the efficiency and the economics of an arrangement using a pneumatic dryer with a separator cyclone at its end, considered to be the best option found. Some of the results from these works are shown next.

The system concept was guided by the idea of exploiting the boiler exhaust gases thermal energy, considering the use of air preheaters, feed water preheaters (savers), and dryers. The system was designed using optimization tools, in a way to obtain a dimensioning that led to the minimum costs for the overall system.

Three possible arrangements were analyzed (Figures 2 to 4), comparing them in terms of their energy efficiency and cost. In case III, the saver is placed before the air preheater. This was done because the return water from the plant being at a higher temperature that the surrounding air, so this way the saver increases its effectiveness.

The dryer type selected was the pneumatic type, with a cyclone at its end to separate bagasse and gas. Four pneumatic ducts were considered, each of them connected to a pair of cyclones, being each of the boiler burners fed by a cyclone. In this matter, dryers surrounded the boiler, in a proper layout, with the same maximum height.

In terms of system design, the same boiler was considered for all three arrangements, with a steam production capacity of 200 t/h, at 65 bar, and 500 °C.

The calculation procedure for each type of equipment is reported on the mentioned works (SOSA-ARNAO, 2007 and SOSA-ARNAO and NEBRA, 2009).

Table 3 shows the thermodynamic data of the main system flows, in terms of their initial, pre-optimization values. Figures indicated correspond to those shown on Figures 2 to 4.

First-law efficiency, *based on the high heating value*, is 64.1% for case I, and 70.4% for cases II and III. Higher efficiencies in cases II and III is owed to the lower temperature of gases leaving the system, which contributes to reduced heat losses.

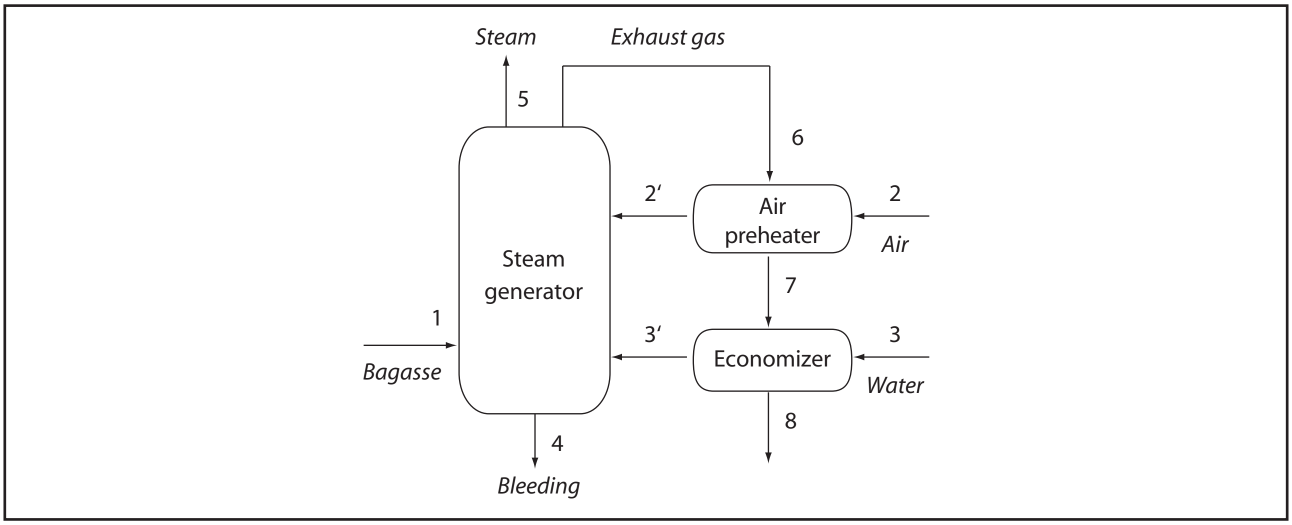


FIGURE 2 Tandem arrangement, air preheater and saver – case I.

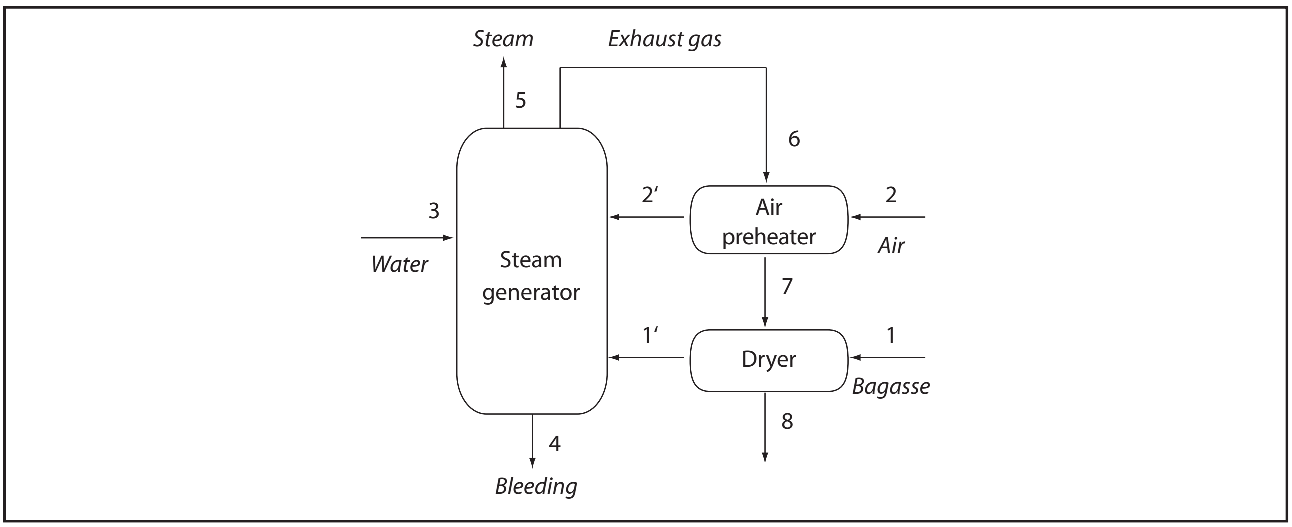


FIGURE 3 Tandem arrangement, air preheater and dryer – case II.

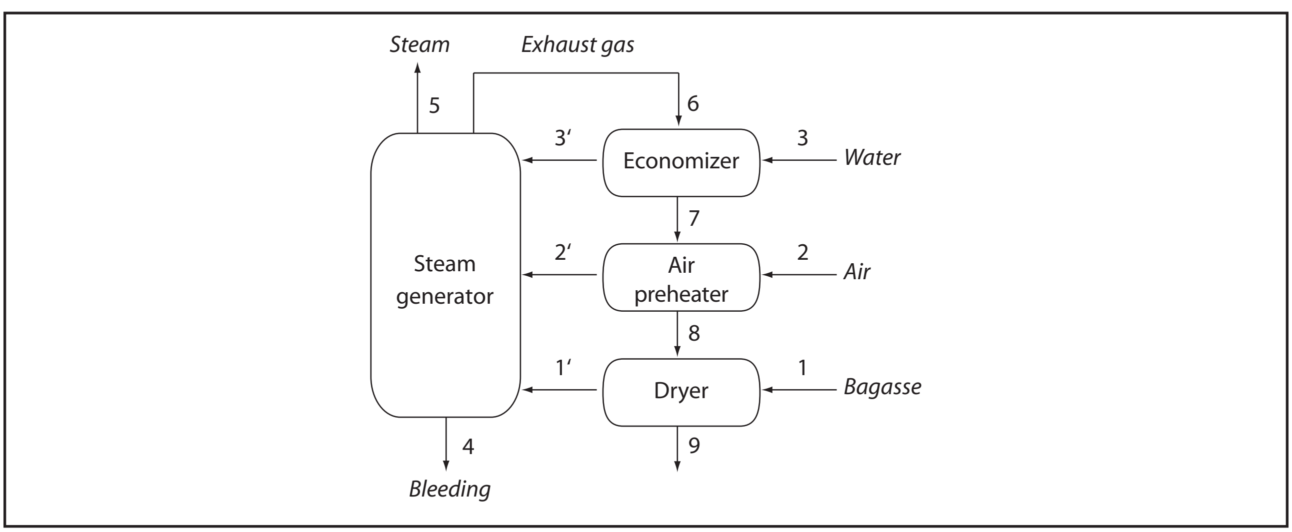


FIGURE 4 Sequential arrangement, saver, air preheater, and dryer – case III.

Costs corresponding to the initially dimensioned system are shown on Table 4. In the case of the saver and air preheater, costs were calculated based on the area of heat exchange, considering respectively values of 161.58 R$/m² (80.79 USD/m²) and 138.62 R$/m² (69.31 USD/m²). In the case of the dryer, the cost adopted was 9.70 R$/kg (4.85 USD/kg). Construction of this equipment was simulated using a 4 mm thick steel plate.

In case I, it is necessary to make a trade-off between the costs of the economizer an the air preheater, varying the temperature of air preheater outlet gases; the saver cost increases with this temperature (T7), as more energy is transferred to the water in the saver, and less to air in the preheater. This calculation may be observed in Figure 5.

The system was optimized in terms of equipment dimensioning, which led to variations in their intake and outlet temperatures, as well as their heat exchange areas and external dimensions. For optimum conditions, the temperatures shown on Table 5 and the costs shown on Table 6 were obtained.

From these results, it is possible to notice that the optimum system dimensioning corresponded to a smaller air preheater, a larger saver, always with a dryer, working with the highest input temperature allowed in the calculations: 215 °C. Under these conditions, it is possible to obtain a final moisture content in bagasse of 34.5% (h.b.).

From the results obtained in successive studies, bagasse dryers are an economical and functional option, which allows improving boiler efficiency.

PROCESS ENERGY INTEGRATION

The process integration (PI) concept came up in the early 1980s, and has been used ever since for analyzing energy usage and to reduce the environmental impact of industrial processes. This research area was initiated with research on heat recovery via the *Pinch Point* concept, however currently PI encompasses a wider universe of integration possibilities that goes beyond the use of energy in processes.

PI application in industry became a fundamental tool for planning and designing its activities, providing investment and operational costs reduction. Minimum consumption of natural resources in integrated industrial processes derives not

TABLE 3 Thermodynamic data of the main flows in the systems shown in Figures 2, 3, and 4.

Flow	Temperature [ºC]			Pressure [MPa]			Output		
	I	II	III	I	II	III	I	II	III
1	35	35	35	1	1	1	24.8	22.9	22.9
1*	–	74	74	–	1	1	–	17.5	17.5
2	30	30	30	1	1	1	95.0	75.0	75.0
2*	240	288	147	1	1	1	95.0	75.0	75.0
3	120	120	120	72	69	72	60.6	60.3	60.3
3*	171	–	165	69	–	69	60.6	–	60.3
4	281	281	281	65	65	65	5.08	4.74	4.74
5	500	500	500	65	65	65	55.6	55.6	55.56
6	401	401	401	1	1	1	119.8	97.9	97.9
7	260	215	300	1	1	1	119.8	97.9	97.9
8	165	74	215	1	1	1	119.8	97.9	97.9
9	–	–	74	–	–	1	–	–	97.9

TABLE 4 Costs of energy recovery systems before optimization.

Cases	Economizer	Air preheater	Dryer	Total cost
	[US$]	[US$]	[US$]	[US$]
I	285,013	429,032	–	714,045
II	–	547,930	149,020	696,950
III	81,618	201,594	149,020	432,232

only from optimized energy usage, but also from the consumption of raw materials and water, with analyses that include thermal and mass integration, on top of industrial waste management.

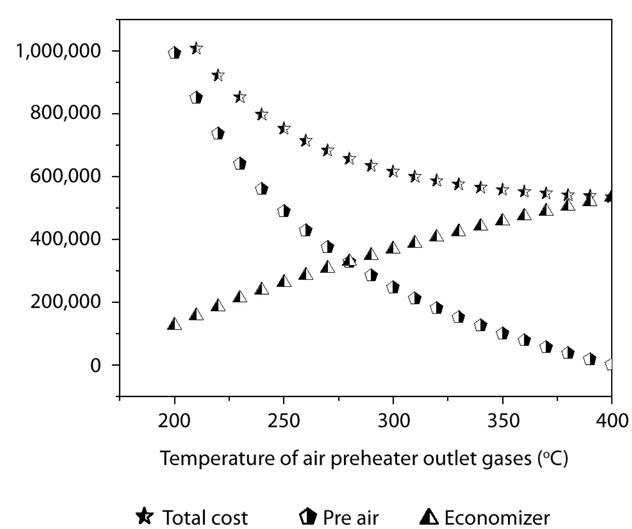
Process integration techniques application areas may be understood, at first, as those cases where less energy intake and lower environmental impact are sought; however their applications go beyond these objectives.

As a more immediate example, it may be mentioned the case of reducing energy consumption, which is usually associated to an increased investment in energy recovery equipment. The goal, in this case, is the search for a minimum total cost comprising both operation and investment. In other cases, the analysis can be made aiming at equipment cost reduction for a certain energy consumption level.

The major areas for process integration application in industry may be described as:

- new processes or retrofit design, including batch, continuous and semi-continuous operation modes;
- process operations planning;
- to increase efficiency in raw materials and energy intake, and to improve productivity (debottlenecking);
- equipment design, such as reactors, separators, and heat exchanger networks;
- integration of processes and utilities system;
- integration between industrial complexes, power plants and public HVAC systems;
- minimizing the generation of water-based effluents and process water consumption;
- minimizing residue and emissions generation.

It is important to point out that the use of process integration techniques, even in similar processes, may require different designs to fulfill the minimum desired demand goals. Each process should be studied separately, considering local investment operating costs, as well as operating conditions.



Source: SOSA-ARNAO, 2007.

FIGURE 5 Behavior of saver and air preheater cost as a function of air preheater outlet gases temperature.

TABLE 5 Temperature distribution corresponding to the optimized dimensioning of energy recovering systems.

Cases	$T_{g,6}$ [ºC]	$T_{g,7}$ [ºC]	$T_{g,8}$ [ºC]	$T_{g,9}$ [ºC]
I	401	368	–	165
II	401	215	74.5	–
III	401	252	215	74.9

The *Pinch* method

The *Pinch Point* concept for heat recovery was the most important contribution to the research area related to process integration, having been developed from works by HOHMANN (1971), UMEDA *et al.* (1978-1979), and LINNHOFF and FLOWER (1978a-b). The concept was later developed for technological application in industry, in the 1980s, by the LINNHOFF group in the University of Manchester (UMIST) in England.

Application of the *Pinch* analysis was presented in various works found in the literature, especially LINNHOFF *et al.* (1982), which describes the method in detail, being complemented by later works, such as LINNHOFF and HINDMARSH (1983), and LINNHOFF and AHMAD (1990).

Applying this method for improving usage of energy in industrial processes is the most explored alternative in studies carried out so far, though many advances have been made in other applications.

Based on analogies to the same concept, the methodology was expanded, relating transfer of heat by temperature difference to transfer of mass by difference of concentration of a certain component. This is how *Mass Pinch* (EL-HALWAGI, 1989-1990) started being used, with application in industrial processes where there are mass transfer units, such as absorbers, extractors, evaporators, distillation columns etc.

One specific application of the *Mass Pinch* concept was developed for industrial effluents treatment and waster intake reduction, evaluating possibilities for reusing, recovering, and recycling this resource. This methodology, named *Water Pinch* (WANG, 1994a-b), can also be applied to the distributed effluents treatment.

According to GUNDERSEN (2000), more recently the *Pinch* concept was applied to the so-called *Hydrogen Pinch*, developed by TOWLER *et al.* (1996), and ALVES (1999). This methodology is applied to the analysis of the distribution of hydrogen in petroleum refineries, optimizing its use, and evaluating the introduction of purification units, membranes, and cryogenic units.

Thermal process integration analysis

Pinch analysis applied to thermal integration is basically carried out in four separate phases:

- data collection on the process energy requirements and available utility systems;
- goal-setting, involving the definition of optimum performance relative to various project aspects;
- initial heat exchangers network design;
- project optimization with layout streamlining and analysis of issues such as operation ability, control, safety, and search for the minimum overall cost.

Data gathered should include the following information on existing flows in the process and utility system:

- mass flow rate;
- specific heat at constant pressure;
- initial temperature;
- final temperature;
- specific vaporization enthalpy for flows changing state;
- hot and cold utility operation temperatures available;
- heat transfer coefficient for each flow.

Having defined the problem and the data gathered of the process flows and utility systems, it is possible to move on to a preliminary analysis of the potential for thermal process integration, by determining consumption targets.

In the heat recovery area, the concept of goals is used in determining the minimum energy consumption, quantity of heat exchange equipments, total heat exchange area, and total cost.

TABLE 6 Optimized costs of the energy recovery system for the different cases.

Cases	Economizer [US$]	Air preheater [US$]	Dryer [US$]	Total cost [US$]
I	486,047	60,861	–	546,908
II	–	547,930	149,020	696,950
III	144,608	79,883	149,020	373,511

Some goals, such as energy consumption, are based on thermodynamic concepts, while others, such as quantity of heat exchange equipment, are based on heuristic rules.

In addition to the aforementioned goals, some others, like minimum generation of effluents and emissions and maximum power generation are applied; however, in all cases, under the assumption that no actual project can surpass the optimum performance obtained in such analysis, being it, in most cases, a guide to the most appropriate design.

Utility consumption goals – Table Method (Heat Cascade)

Definition of the minimum utilities intake goal may be calculated from the Table Method construction introduced by LINNHOFF and FLOWER (1978), which determines the so-called heat cascade.

This method starts by defining temperature ranges in which hot and cold flows involved in the process may exchange heat. In order to maintain the minimum temperature gap (t_{min}), preset for implementing the analysis method, temperatures in each range are determined, adding a $t_{min}/2$ value for cold flow temperatures, and subtracting a $t_{min}/2$ value for hot flow temperatures.

Temperatures are sorted in descending order, creating ranges where process flows may be ranked according to their initial and final temperatures, as shown on Figure 6.

Hot and cold flows fitting into the same temperature range have their thermal capacities (mcp) added, providing a sum for each range, considering a positive value for cold flows, and a negative one for hot flows.

This enables to build the thermal cascade, considering that the heat in each temperature range is transferred to the adjoining lower range. If there is a negative result for the energy balance at a certain range, the use of hot utilities should be prescribed. Likewise, if the result is negative, this quantity of heat may be transferred to the lower range, and so on, creating the heat cascade.

By implementing this procedure, it is possible to calculate the minimum hot and cold utilities demand in the system. The *Pinch Point* location can be so identified in the temperature range where there is no heat transfer to the next range, and where there is no demand for hot utilities.

Composite Curve

Visualization of results in graphic format by plotting Composite Curves – CCs is one of the major tools in this method, making it possible to ascertain, in a practical and simple way, the possibility of thermal integration, and the need for hot and cold utilities.

Like in the Table Method calculations, CC plotting for hot and cold flows is based on the distribution of process flows over temperature ranges. One curve for hot flows and another for cold ones may be drawn adding the enthalpy variation of the flows within each range, as shown on Figure 7, which also indicates areas where a possible thermal integration may be implemented, as well as the needs for hot and cold utilities, located on the graph extremities.

The value adopted for t_{min} defines the smallest distance between the two Composite Curves drawn, identifying the energy bottleneck, or *Pinch* that will divide the system in two parts, one below, and another above this point. This point limits the process thermal integration, representing the bottleneck from the energy recovery standpoint.

			Interval		1		2		3		4		5	
										Pinch Point				
Current	Enthalpy (k-W)	mcp (kW/ºC)	Temp. (ºC)	165		145		140		85		55		25
F1	700	6.09	Fria					◂	–	–	–	–	–	•
F2	500	8.33	Fria			◂	–	–	–	•				
Q1	700	5.83	Quente			•	–	–	–	–	–	–	–	▸
Q2	300	2.73	Quente	•	–	–	–	–	–	–	–	▸		

Source: ENSINAS, 2008.

FIGURE 6 Example of temperature ranges, indicating process flows.

The area above the *Pinch* will act as a heat absorber, consuming hot utilities. On the other hand, the region below this point will act as a heat source, requiring only cold utilities.

The separation of these two regions is important, as if cold utilities are consumed above the *Pinch*, it will be necessary to add even more hot utilities to supply the additional intake, increasing its energy demand, and consequently the energy consumption by the system as a whole.

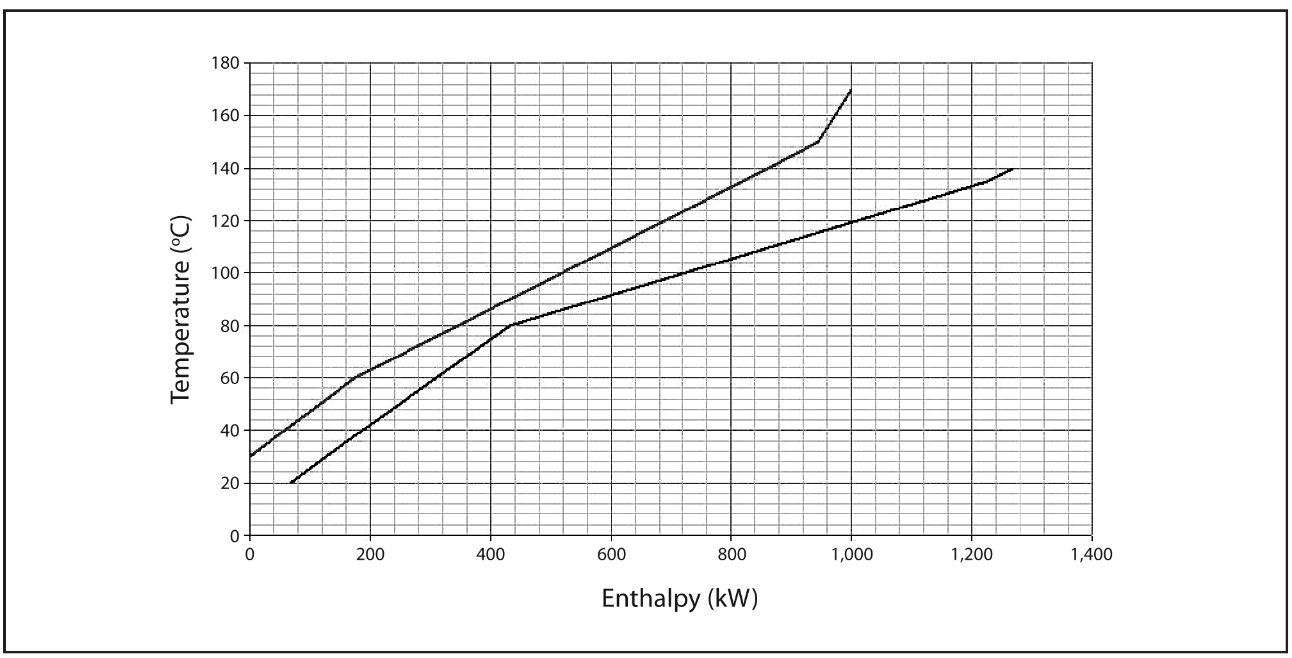
The same occurs at the region below the *Pinch*, where the addition of hot utilities implies in using cold utilities to supply the additional cooling requirement.

Thus, some basic application principles were set for the method, in order to avoid unnecessary use of hot and cold utilities:

- Do not use cold utilities above the *Pinch*.
- Do not use hot utilities below the *Pinch*.
- Do not transfer heat through the *Pinch*.

Great Composite Curve

The Great Composite Curve – GCC is yet another graphic tool for visualizing the minimum



Source: ENSINAS, 2008.

FIGURE 7 Composite Curve example

utility intake issue. This graphic representation combines the Hot and Cold Composite Curves into one, being also plotted by summing up their heat capacities at each temperature level.

Like CCs, the GCC representation is plotted on a temperature-enthalpy diagram, displacing the Hot Composite Curve to a value $\Delta t_{mín}/2$ below and the Cold Composite Curve to a value $\Delta t_{mín}/2$ above its original position, so that the two curves intercept at the *Pinch Point*.

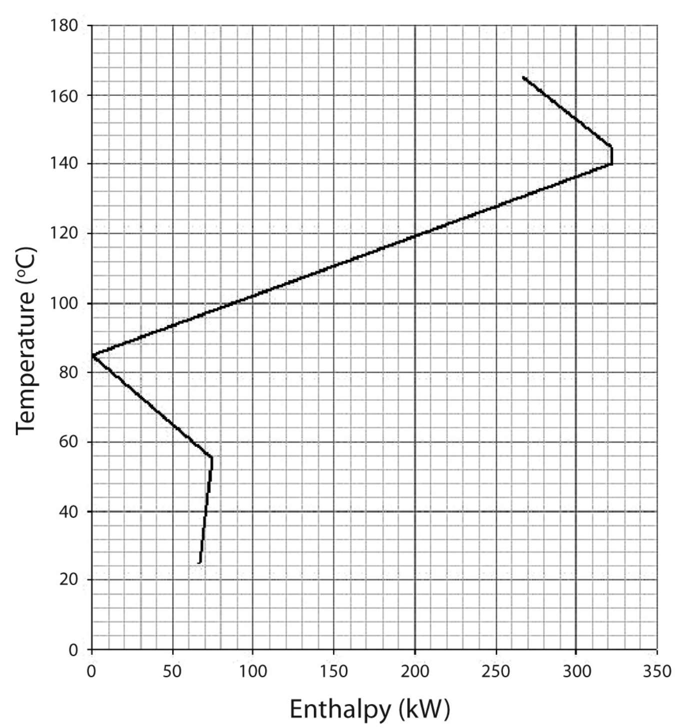
The GCC is obtained with the difference of enthalpies on Hot and Cold Composite Curves for each temperature level. *Pinch Point* is located at the point where the difference in enthalpies between the CCs is zero, as shown on Figure 8.

Hot utility requirements above the *Pinch Point*, and cold ones below it may be seen more clearly on the GCC, just as the regions where thermal integration is possible.

Furthermore, one of the main advantages of the GCC is the identification of the proper temperature level of utilities to be used, minimizing process irreversibility in the heat exchange process, and allowing the evaluation of using lower cost utilities.

By using the GCC, viability of equipment integration, such as evaporators, distillation columns, heat pumps, and steam turbines with the remainder of the process can be analyzed in detail, identifying the best applications from the energy savings standpoint. GUNDERSEN (2000) presents some basic conditions for integrating such equipments to the remainder of the process:

- ***Distillation columns:*** only if the reboiler operates at a temperature below the *Pinch Point*, or if the condenser works at a temperature above it.
- ***Heat pumps:*** only if they transfer heat through the *Pinch*, from the region below it to the region above. They should be integrated to distillation columns only if there is no possibility of integrating the columns into the process, since the implementation cost of a heat pump is usually higher than the other option.



Source: ENSINAS, 2008.

FIGURE 8 Composite Curve and Great Composite Curve example.

- *Steam turbines (back-pressure or extraction):* only if the exhaust or extraction steam has a sufficiently high condensation temperature to be used above the *Pinch*, or in the reboiler of a distillation column. Otherwise the steam should be expanded to its maximum in the condensation turbine for better energy use.

Initial heat exchangers network design

The strategy for the initial design of a heat exchangers network should have its origin close to the *Pinch Point*, where the most critical heat exchange between process flows takes place. Then the design proceeds towards the regions more distant from the *Pinch*, always ensuring that hot flows be used above it, and the same happens to cold flows in the lower region.

According to GUNDERSEN (2000), as a rule for heat exchangers located above the *Pinch*, it should be ensured that the "mcp" for cold flows be equal or higher than the "mcp" for hot flows with which they exchange heat, and that the number of cold flows be equal or larger than the number of hot flows.

Likewise, below the *Pinch Point*, the hot flows "mcp" should be higher or equal to that of cold flows with which t exchanges heat, and the total number of hot flows should be higher or equal to the number of cold flows.

If the rules above are not followed, flows should be split to achieve maximum heat recovery. Though the application of the *Pinch* method eliminates some clearly disadvantageous alternatives from the energy standpoint, there are usually several possibilities for the initial heat exchangers network design. Flow splitting usually allows more heat recovery between them; however, in some cases, there is a reduction of the total area required for heat exchange, or yet a reduction in the quantity of heat exchangers.

Advances of energy integration in sugar and ethanol production

The sugar production process presents, over its history, important technological advances relative to the use of energy. According to CHRISTODOULOU (1996), a first breakthrough was achieved by Antony Smith in 1692, upon ascertaining the possibility of using steam for evaporation instead of direct fire, as it was used until then. In 1813, Howard introduced evaporation at lower pressures, and in 1828, the tubular cooker.

However, the innovation actually considered as a milestone in world energy savings in the sugar and chemical industries was the multiple-effect evaporation system conceived by Norbert Rilleaux in 1832, which only obtained its patents in 1843, for the double-effect system, and in 1846 for triple-effect. In 1850, Robert introduced evaporators with vertical tubes that carry his name and are still used nowadays in the sugar industry

With the introduction of diffusion systems for making sugar from beets in 1870, a demand for more efficient evaporation systems appeared, as the further dilution of the juice required by this process required a higher energy consumption to concentrate it.

Technological innovations continued with the evolution of evaporators. New systems with more effects and different operating principles were developed. Descending plates and film evaporators are increasingly seen as alternatives for a more efficient concentration process. "Recompression" techniques applied to evaporation has also been explored since 1945 (VERNOIS, 1975 apud CHRISTODOULOU, 1996).

The integration of such equipments with the remainder of the process has also been studied, applying process integration techniques, which allows improving the use of primary energy. Analyses based on energy, exergy, or thermoeconomy concepts are tools that make it possible to evaluate improvements achieved with process integration, possibly complementing the integration study.

Some works are found in literature, pointing the best process integration options in sugar production by using the *Pinch* method.

The sugar from beets study was carried out in some works, like TWAITE *et al*. (1986) which analyzed the design of a British sugar mill using the *Pinch* analysis as assessment tool for the possibility of reducing the energy consumption in the plant. The introduction of six evaporation effects, replacing the five-effect system, with mechanical vapor recompression (MVR) on the first effect, was one of the proposed modifications, as the existing system was less effective in terms of reduced vapor intake. *Pinch* analysis made it possible to identify the process deficiency, especially the improper use of MVR.

CHRISTODOULOU (1996) analyzed, using the *Pinch* method, modification proposals on

works related to thermal integration in sugar from beets mills. The use of six and seven evaporation effects with falling film evaporators and plate heat exchangers were prescribed as viable and promising alternatives to reduce steam consumption in these processes.

Other studies are found in literature evaluating sugar production from sugarcane. FRANCO (2001) evaluated the integration of the evaporation system integration to the remainder of the process using the *Pinch* method, analyzing evaporators located above and below the *Pinch Point*.

REIN (2007) presents some opportunities for reducing process steam consumption in sugarcane mills, making it possible the generation of surplus bagasse in the co-generation system. From the issues raised, the following may be pointed out: the increase of the syrup Brix, leading to a higher steam intake in evaporation, however, reducing the consumption in the cooking stage; the use of vegetal steam of 1st, 2nd, or even 3rd effect to supply the demand from cookers; the reduction of the use of water added to cookers and centrifuges; the increase in the number of evaporation effects; the use of condensates and vegetal steams to heat up mixed juice at the treatment stage, and the increase in the operation temperature in evaporators, allowing better use of steam bleeds in the process.

UPADHIAYA (1992) also presents some suggestions for steam saving, aiming to increase the production of electricity generated in sugarcane mills, including the maximization of vegetal steam bleeds and the use of continuous cookers.

WESTPHALEN (1999) developed a mathematical model for static and dynamic simulation of evaporation systems, evaluating the number and setting of the effects, feed temperature, condensate utilization and thermal "recompression", however without including system integration to the remainder of the process.

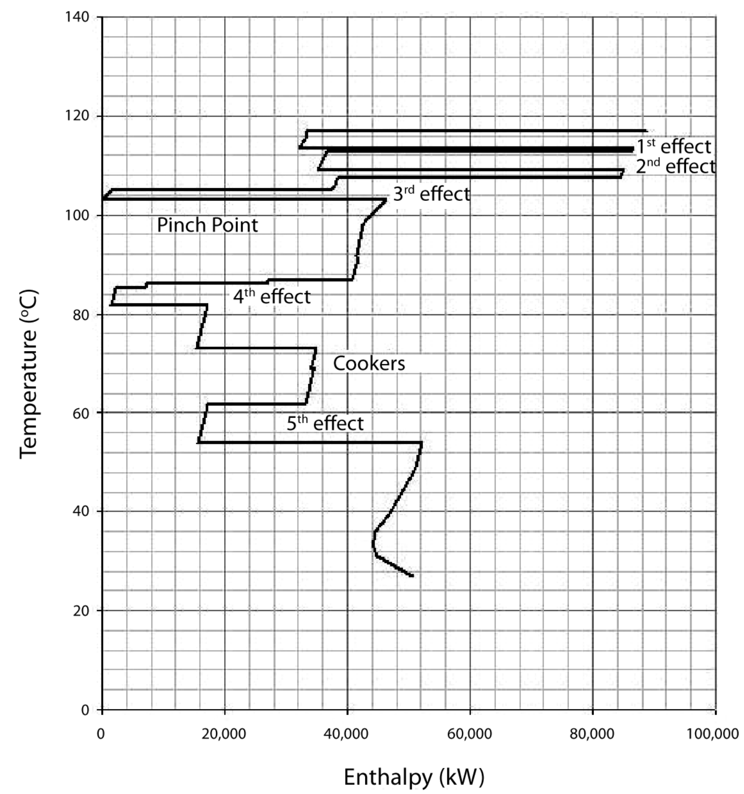
Energy integration of sugar and ethanol mills from sugarcane was studied in detail by ENSINAS *et al*. (2007a-b, 2008). The authors developed a mill energy integration procedure through the *Pinch* Method and thermoeconomic optimization that allows to determine which is the best use for the thermal energy available in the process flows, including vegetal steam bleeds, juice, mash, wine and stillage flows, on top of the energy from distillation and rectification columns. Studies show that important steam consumption reductions may be achieved without jeopardizing final costs, as economic criteria are considered, such as equipment costs for deciding upon integration options.

Figure 9 shows the profile of the Great Composite Curve for a thermally integrated mill with processing capacity of 500 tons of sugarcane per hour, directing 50% of the sugars for sugar in lump, and 50% for ethanol production. The analysis of this curve points out the major sources of heat available in the process, as well as the most interesting thermal integration regions from the energy standpoint.

HIGA (1999) also applied *Pinch* analysis and optimization techniques in the design of evaporators for sugar and ethanol mills, verifying the effect of reduced steam consumption upon shifting the bleeds to the last evaporation effects. In a later study, HIGA (2003) applied the *Pinch* analysis to the same process, aiming to increase the electricity surplus generated in the co-generation system.

Other works focused on ethanol distillation and dehydration stages, such as GUIMARÃES *et al*. (1996), who used thermal integration concepts to minimize utilities consumption in synthesizing a water-ethanol separation system through azeotropic distillation. MELO *et al*. (1998) also researched to reduce the energy intake of the extractive distillation process to obtain anhydrous ethanol.

Thermal integration of distillation columns is also analyzed by SEEMANN (2003), showing that the operation of distillation and rectification columns at different pressures, and the use of the condenser in the second column as reboiler for the first provide a significant reduction in steam intake.



Source: ENSINAS, 2008.

FIGURE 9 GCC of a thermally integrated mill.

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7

INSTRUMENTATION AND AUTOMATION IN THE SUGARCANE ETHANOL AGROINDUSTRY

Cristiane Sanchez Farinas, Ladislau Martin Neto
and *Roberto Campos Giordano*

INSTRUMENTATION AND AUTOMATION IN THE OPTIMIZATION OF SUGARCANE ETHANOL PROCESS

Despite the technological advances of the sugarcane industry in recent decades, there are still several opportunities to optimize the process and increase productivity in ethanol producing plants This is because ethanol distilleries in Brazil have given low investment priority to process control and automation. This fact could be related both to a slowdown in ethanol production in the late 1990's as well as poor understanding of the real benefits of implementing new technologies in the production process (ATALA, 2004).

With current scenarios on expanding the international ethanol market, the use of ethanol in flex fuel engines and in the processing of biodiesel, in hydrogen fuel cells and other alternative energy sources, it is expected an increase of investments in both research and implementation of new technologies, together with the automation and control of the production process (ATALA, 2004).

The implementation of a controlling system can contribute to increase process efficiency, productivity and reliability, reduce costs and reduce environmental impacts, and improve quality. One reason for this is that the key in fermentation processes for ethanol production, the microorganisms, are very sensitive to small environmental changes. Any small variation in the quality of the raw material, medium composition, pH, and temperature can significantly affect their metabolism and change the efficiency and productivity of the process. The control of the bioprocess aims to maintain the environment in which the cells are cultivated in optimum conditions for growth, biosynthesis and final processing.

The control process for ethanol production follows the same principles of an industrial plant, aiming to keep certain variables at the desirable operational limits. To clarify the nomenclature used in this chapter, Figure 1 shows a symbolic representation of a generic system/process that will be used as a basis for the description of the terminology used in the context of control, automation and optimization of ethanol production.

The input variables of the system are classified into two types: disorders variables, the vector $\underline{d}$, random in general (caused by uncontrolled changes in the environment), and controlled variables, $\underline{u}$, which are manipulated from control laws. Note that the variable $\underline{d}$ may or may not be measured.

The control variables, $\underline{u}$, are manipulated variables in the real processes (usually by opening/closing of valves, increase/decrease engine speed by using frequency converters etc.). In this case, it can be used different control strategies, being the most common the feedback control, where, once the state variables are known from measurements, it can be determined the value of $\underline{u}$ so that the process operates near a pre-determined condition (set point).

The response variables, or state variables, $\underline{x}$, are those variables defined by the model developer

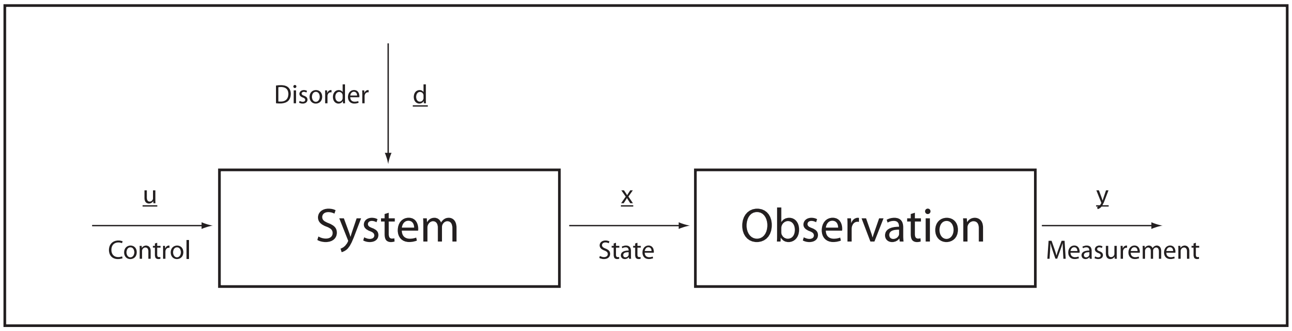


FIGURE 1 Representation of variables in a model of a monitored and controlled system/process.

as representing aspects of the reality relevant to the problem under study, in other words, are those calculated from the model equations (calculations that occur in the block "system"). Finally, the measured variables (or simply "measures"), $\underline{y}$, are those variables measured by the instrumentation available, both in real time (on-line) and off-line – for example, in an analytical center. It is important to note that the block "observation" includes equations, algebraic in general, that allows to have a problem as a function of $\underline{x}$ and $\underline{y}$. If the state variable can be measured directly, then this equation is simply x = y. Often, however, it is not possible, then you need to employ more complex relationships.

In the case of implementation of a controlling system in a fermentation bioreactor, certainly one of the state variables will be the cell concentration (typically, baker's yeast, *Saccharomices cerevisiae*). How to monitor the growth progress? For example, by optical density – OD of the medium, which would be one of the measures (part of the vector $\underline{y}$). In this case, a linear correlation is typically used in the block "observation": the calibration curve of cell concentration versus DO. However, this block may include more sophisticated computer algorithms, as mentioned later in the text about *software sensors* or *soft-sensors*.

The definition of input and output variables in Figure 1 is an abstract construction made by the modeler, assuming that the problem can be represented by a set of the most significant variables in terms of the application and the acceptable level of complexity required for the model. After all, a model is only a model, not the reality itself, and being clear about this fact is an essential starting point for discussing the importance of instrumentation and control in any case – and in particular the production of ethanol.

As can be seen from previous paragraphs, a requirement for an efficient process control is the use of an adequate monitoring methodology. Off-line monitoring, performed by collecting samples and analyzing them subsequently, although it can provide accurate data, has the disadvantage of the delay between sampling and result.

Off-line monitoring is often used during the phase of development and validation of the process mathematical models, when there is a greater demand for the amount of information. Such models can then be used in the design, optimization and control of the process. For example, measurements of the composition of the medium by high performance liquid chromatography – HPLC would allow following those state variables (composition of the main substrates and products in the middle) but not in real time. These may be essential data to adjust the parameters of the fermentation kinetic models, but are not suitable for real-time process control, due to both the cost of the analysis and the delayed responses.

In turn, the real time monitoring of process relevant variables has the advantage of providing information with small delay relative to the intrinsic dynamics of the process. This approach provides information directly from the measurable variables, $\underline{y}$ (as shown in Figure 1), and is essential for early detection of problems/failures in the process, allowing for immediate action to be taken to revert the situation, while the process is still running.

A flowchart for a typical sugarcane ethanol producing process can be divided into three steps: grinding, fermentation and distillation. During the grinding, the sugarcane juice is extracted. This juice is sent to the fermentation bioreactors, where the yeasts act in the transformation of sugar into alcohol. The product of fermentation, called the wine, is sent to distillation units for separating water and alcohol. Each of these steps offers opportunities for optimization. The real-time monitoring of all stages of the process of converting sugar into ethanol is of great importance to the effectiveness of the process as a whole.

However, controlling the fermentation step, for example, can be difficult due to the inability to directly measure some state variables (i.e., with $\underline{x} = \underline{y}$) fast enough to allow the implementation of control strategies, as the feedback control. That is the case, for example, of the measurements of the concentrations of substrate, product and biomass. Physical-chemical variables such as temperature and pH, can now be measured on-line using appropriate sensors available in the market. However, to obtain information about the concentration of substrate, product and biomass it is usually necessary to take samples to be analyzed off-line.

Thus, an opportunity in instrumentation field to be emphasized is the use of spectroscopic techniques for real-time monitoring of these process components. Spectroscopic techniques are fast and non-destructive, require little or none sample preparation, and can be used simultaneously to evaluate different components in a complex mediums. One example of application are the studies being developed by VEALE *et al.* (2008) for the on-line monitoring of fermentation using infrared spectroscopy with Fourier transform – FTIR.

Chemical sensors have suitable characteristics for monitoring certain steps of the process. Features such as low cost, relatively simple instrumentation, minimal sample preparation and easy automation of measurements make of chemical sensors an attractive tool for industrial process control. However, the practical use of chemical sensors in a complex media is often hindered by their low selectivity. For example, only pH and dissolved oxygen probes are routinely used in bioreactors.

One of the new approaches to overcome problems of selectivity is the use of systems instead of discrete sensors. Such systems for analysis of liquids and gases are called electronic tongue and nose, respectively. They are able to perform both quantitative (concentrations of components) and qualitative analysis of a multi-component medium (RUDNITSKAYA and LEGIN, 2008). Several examples of applications of these sensors are reported in the literature, including the detection of sugars, metal ions and other organic and inorganic contaminants (BRUGNOLLO *et al.*, 2008; CARVALHO *et al.*, 2007; FERREIRA *et al.*, 2007; RIUL *et al.*, 2003; FERREIRA *et al.*, 2003).

However, methods for real-time monitoring that are both robust and can be applied on an industrial scale are still relatively scarce because of difficulties related to the complexity of the composition of the sample and the specificity of the monitored components. A specific compound (e.g., a nutrient, metabolites, antibiotics) may have an important influence on cellular metabolism, even at very low concentrations. The measurement of these components in low concentrations, often in a complex medium, can also be a difficulty in bioprocess monitoring. Generally, isolation, purification, concentration and determination of these compounds are lengthy processes and are, therefore, carried out using off-line analytical methods (VOJINOVI *et al.*, 2006).

As mentioned above, electrochemical sensors for pH and dissolved oxygen monitoring remain the most commonly used sensors in bioprocesses, but recent research have resulted in the improvement of optical sensors. Optical sensors for dissolved oxygen and carbon dioxide are now commercially available, as advances in optics and electronics are continuously reducing their costs (HARMS *et al.*, 2002).

In the fermentation process, an issue that should be highlighted is the need for faster on-line methods for determining the quality of the feedstock (impurities content and composition). The standardization of a methodology to control the presence of organic and mineral matter in the raw materials used in fermentation and the streams of the fermentation process is another issue to be explored (FELIPE, 2006).

The separation/purification processes of ethanol (downstream) also have crucial importance in optimizing the overall process. The conventional process of distillation is energy intensive and integrated with other unit operations of the process, and generates sub products, including some that are very significant from the environmental point of view. The development of control systems for the distillation process, as well, and the evaluation of its effect on process performance through simulations are also a current demand.

An example of process upgrading is the use of molecular sieves in the production of anhydrous ethanol, instead of the azeotropic distillation and solvent recovery: these devices eliminate the need for the dehydrating cyclohexane allowing obtaining a product with higher purity and avoiding the need for disposal of this solvent.

The Center for Strategic Studies and Management – CGEE published a document (MACEDO, 2003) which lists some of the topics considered as important for development of industrial ethanol processing technologies (extraction, fermentation and distillation, production and energy use; analytical methodology; environmental control), and agro-industrial safety)

Several of these topics are directly related to instrumentation and automation, as follow:

- Automation: complementation of local systems and monitoring, development of sensors/equipment, smart operational controls.
- Analytical methodology: use of NIR spectroscopy on-line in the production line and to determine the quality of sugarcane.
- Fermentation: more robustness to adjust to fluctuations of feedstock quality.
- Use of new techniques for separation and concentration (membranes, ion exchange).
- Development of new products from sucrose (plastics, solvents, amino acids).
- Development of technologies for the recovery of straw at low cost (<US$ 1.00/GJ) and technologies for production of additional energy in the plants.
- Co-generation for electricity.
- Hydrolysis of cellulose for ethanol production.

The automation of an industrial plant is accomplished through the implementation of sensors and actuators, controlled by remote systems. The measurements of the sensors and the action of the actuators are carried by signals passing between a supervisory system and the plant. An automated plant, with the acquisition of process variables in real time and control strategies and set up, provides benefits to both the producer, with a reduction of complaints, returns, rework and costs, as to the final consumer, who has a product more standardized (ATALA, 2004).

Certainly, could greatly contribute to the optimization of ethanol production some techniques used in petroleum refineries, such as: real time optimization of thermoelectric balance systems, design automation techniques with tools involving electronic units, digital documentation systems, data acquisition systems, data reconciliation to close mass balance, advanced process control etc. These technologies are currently applied to the refining process and eventually could be incorporated into the sugarcane sector (OLIVEIRA, 2008).

Indeed, the use of techniques already known for analysis, synthesis, optimization and advanced control of sugarcane industry would be the interpretation of classical *Bioprocess Systems Engineering* that was developed due to a demand from oil and petrochemicals industries. This approach was recently described by PINTO (2008) and PINTO *et al*. (2009) for a cheese whey refinery, demonstrating the flexibility and capability of the technique for adaptation into the production of ethanol.

In conclusion, the current conceptual project methods, design and operation of ethanol plants should be reviewed for incorporating simulation techniques, optimization and process control. Tools that enable the implementation of methods for on-line analysis should be developed, serving as a support to this new methodology, in order to ensure a process more efficient in terms of economic, energy and environmental issues.

CELLULOSIC ETHANOL: INSTRUMENTATION AND AUTOMATION CHALLENGES

Cellulose is the most abundant natural renewable resource of the planet and energy production based on the lignocellulosic matrix is an important alternative route that has been studied and debated worldwide. Sources of cellulosic biomass that can be used for energy production, especially in the form of biofuels, include sugarcane bagasse and straw. Although there are technologies available for cellulose processing, most of them are hindered by technical or economic difficulties. Nevertheless, some experts believe that the lignocellulosic biomass will be the main feedstock for ethanol production in the future.

The industrial production of biofuels is presently at what can be called a technological crossroad. A hard competition among different technologies will be in course in the near horizon. The winners will certainly be defined by a combination of economical criteria, environmental restrictions and process robustness. Table 1 summarizes some companies that are presenting different solutions for the production of biofuels (CORTRIGHT, 2008; RENNINGER, 2008).

A route that looks very promising for the production of second generation ethanol is the chemical or enzymatic hydrolysis of bagasse (and/or straw), with simultaneous or sequential fermentation. This route, however, requires additional steps of material processing in order to convert the polymeric compounds present into fermentable sugars. This is due to the recalcitrant nature of lignocellulosic materials, which have inter and intra-molecular bonds that cause the hydrolysis of cellulose to be much more difficult than the hydrolysis of starch material, for example.

TABLE 1 Companies technological map: with biofuels production.

Route / Product	Biochemical	Thermochemical
Hydrocarbons	Amyris LS-9	Choren Shell/Virent
Alcohols	BP/DuPont Coskata Iogen Gevo Mascoma Verenium	Range Fuels

Among the hydrolysis technologies there are opportunities for development using chemical and enzymatic hydrolysis. The enzymatic conversion of lignocellulosic materials to obtain fermentable sugars has been identified as a promising and of great industrial interest to increase the ethanol productivity in a sustainable manner (OGIER *et al*. 1999; WYMAN, 1999; KNAUF and MONIRUZZAMAN, 2004).

However, the enzymatic hydrolysis route of cellulose, although an alternative of lower environmental impact, it still requires the development of technologies that can reduce the costs of enzyme production. The costs of cellulases production is considered to be one of the major constraints for the technological commercialization of the enzymatic hydrolysis of cellulose (WALKER and WILSON, 1991; EVELEIGH, 1987).

Another technological challenge to be faced is related to the pretreatment of biomass in order to reduce its recalcitrance. Along with the development of pretreatment processes that are efficient in terms of technical, economic and environmental aspects, an important technological demand is related to the development of robust analytical techniques. Techniques that allow a quick and easy characterization of the biomass composition are essential to define in advance the variables of the pretreatment and to facilitate the selection of the process, since there are different options and technologies and the appropriate choice depends on the type of feedstock.

In addition, the characterization of biomass is very important to create databases for the simulators to be used in the integration process and to define the possible routes for the biorefineries. Also of high significance is the actual development or adaptation of the simulators to incorporate the kinetic models characteristic of the process in question. This means extending the concept of classical *Bioprocess Systems Engineering* to the production of cellulosic ethanol.

The challenges are enormous, requiring considerable effort in research and development. This is due not only to the complexity of the microbial cultivation process. Even the enzymatic hydrolysis of lignocellulose has kinetic mechanisms much more complex than the classical catalysis. That is due to the fact that enzymes are molecules which catalytic action is not trivial, and in the case of hydrolysis of cellulose, there is a complex of enzymes acting synergistically on a complex substrate, and also the pretreatment process significantly alters its structural features – and therefore the reaction kinetics. Therefore, there is a strong demand for the development of modeling related to the enzymatic hydrolysis of cellulose. Models that describe the conversion rates based on changes in some properties of the substrate, such as the degree of polymerization, crystallinity and accessibility of cellulose are of interest.

The opportunities in instrumentation and automation for biomass characterization and enzyme production are presented in the following topics.

Biomass Characterization

The development of robust analytical methods is a key technological demand to assure the viability of cellulosic ethanol production, as well as for the implementation of biorefineries. This is due to the need to characterize the biomass quickly and accurately in order to define the operating conditions of the conversion process, since heterogeneity is an inherent property of biomass.

The chemical composition of biomass varies as a function of several factors, including plant genetics, environmental conditions during growth, and the method of harvest and storage. In addition, many sources of biomass to be used as a feedstock for the conversion processes are waste coming from other processes. This introduces another variable related to the efficiency of the original process as an additional source of variability in their composition (HAMES *et al*., 2003).

All this possible variability in biomass composition is difficult to control and is therefore of great importance to develop methods for rapid analysis in order to contribute to the evaluation of all steps of production and conversion, as follows:

- *Genetics of plants for development of new cultivars:* thousands of plants can be evaluated in its composition for selection of interesting mutations.
- *Harvest:* monitoring of field crops to determine the exact time to harvest.
- *Purchase of raw material:* the price of biomass can be based on quality, rather than weight.
- *Storage:* changes in the composition of biomass can be monitored as a function of time and storage conditions.
- *Mixtures of raw materials (blending):* supply of more uniform raw materials to the process.
- *Composition of biomass:* allow an adjustment of the process operating conditions according to the raw material supplied.
- *Pretreatment:* allow setting of reaction conditions to optimize the process according to the raw material being fed.
- *Monitoring and Process Control:* real-time information about the amount of enzyme and micro-nutrients that must be fed at appropriate temperature and pH, allowing the optimization of operating conditions.
- *Products:* yield and quality of products available and supplied in real time.

In this context, the area of research in instrumentation has a great potential for the development of compact equipments and sensors with an application in the development of methodologies for a fast and accurate analysis of large amounts of materials. Also advanced methods that generate new information about the characteristics and properties of biomass and its components are opportunities in the instrumentation area.

Currently, the characterization of biomass can be made through various chemical methods, both destructive and non-destructive ones. The non-destructive methods are of great interest due to the fact that it is usually not required a prior processing for chemical separation of the material prior to the determination itself. However, chemical methods can be time consuming and expensive, making difficult its application in real-time monitoring.

Therefore, there is a great opportunity for the development of instruments and methodologies using spectroscopic methods for the characterization of cellulose, hemicellulose and lignin, both in processed and raw samples. Several spectroscopic techniques have been widely applied in studies of characterization, such as Electron Paramagnetic Resonance – EPR, Nuclear Magnetic Resonance – NMR, Fourier Transform Infrared – FTIR, Near Infrared – NIR and fluorescence (MARTIN-NETO *et al.*, 2007).

EPR spectroscopy is one of the few laboratory methods that provide structural information without destroying the sample, allowing the same material to be used for further analysis (MARTIN-NETO *et al.*, 1994, 2001). This technique is sensitive to paramagnetic materials, including species that have atoms or molecules with at least one unpaired electron, including into this category ions of transition metals and free radicals (BOLTON, 1994). Besides the identification of the paramagnetic ion, it is usually possible to identify its valence state, information of great interest for plants nutrition. EPR can also provide information about the nature and concentration of organic free radicals and paramagnetic metal ions, most of them plant micronutrients (Fe, Cu, Mn, Mo) (LAKATOS, 1977; MARTIN-NETO *et al.*, 1998, 2001; SENESI, 1990).

A valuable information on biomass characterization is the presence of lignin, which are known to have a high content of stable free radicals detectable by EPR (FITZPATRICK and STEELINK, 1972; CZECHOWSKI *et al.*, 2004; FIALHO, 2007; FIALHO, *et al.*, 2007) and generally it must be separated from the cellulose in some processes configurations for production of cellulosic ethanol.

Experiments with nuclear magnetic resonance spectroscopy – NMR in studies of solid samples are usually carried out using the technique of Variable Amplitude and Cross Polarization and Magic Angle Spinning – VACP-MAS monitoring the nuclei of the isotope ^{13}C. The information obtained from the NMR analysis are such as the degree of aromatic and aliphatic samples and structural characterization, and identification of compounds such as lignin, tannins, carbohydrates, alkyl groups, methoxylated, phenolic and carboxylic (STEVENSON, 1994; PRESTON, 1996). From the results of ^{13}C NMR novel information about the chemical modifications and structural aspects can be monitored according to the characteristics of biomass, allowing following processes hitherto unknown and which was until then empirically interpreted (GONZALEZ-PEREZ *et al.*, 2004).

Another technique with potential applications in the characterization of biomass is infrared spectroscopy. This technique is based on the fact that different types of chemical bonds and molecular structures existing in a molecule absorb electromagnetic radiation in the infrared region at characteristic wavelengths and, as a result, the atoms involved enter into vibration (STEVENSON, 1994). The method is relatively affordable and the interpretation of the data is simple. However, in many situations, the overlapping bands may require complementary use of other analytical methods. There is currently a trend to associate statistical methods, such as chemometrics, to interpret the data generated.

The analysis of FTIR has been traditionally used to identify functional groups such as carboxyl, amine, hydroxyl, carbonyl and others (SCHNITZER and KHAN, 1978; STEVENSON, 1994; GONZALEZ-PEREZ *et al.*, 2004; GONZALEZ-PEREZ *et al.*, 1998; SAAB *et al.*, 1998). This information is very useful because it allows the identification of possible processes of oxidation and modification of functional groups associated with the effects of treatment of biomass.

FTIR has been used to characterize the constituents of plant biomass such as lignin, hemicellulose, and others (TRACK, 1991; FAIX and BÖTTCHER, 1991). Among the various chemical functions present in lignin, such as -OH, CH_2 and CH_3 present in aliphatic structures, carbonyl and carboxyl C = O, -C = present in aromatic structures, -COO present in acetate, and others may be characterized by FTIR. Some studies have also been developed using the technique of near infrared spectroscopy – NIR combined with multivariate analysis for rapid characterization of biomass, allowing the analysis of the composition of hundreds of samples at a low cost (HAMES *et al.*, 2003).

Mid-infrared spectra were obtained from hydrolysates samples from diluted sulfuric acid pretreatment of forest residues using FTIR spectrophotometer equipped with a cell of attenuated total reflectance – ATR. The analysis of the spectra by the method of partial least squares – PLS from each sample was performed. Regression analysis of sugar components and lignin were generated with the results obtained from chemical analysis and high performance liquid chromatography. The ATR-FTIR technique allowed analysis of samples in minutes, and the prediction of the composition of an unknown sample can be carried out very fast once the method is calibrated with known standards (TUCKER *et al.*, 2001).

The determination of phenolic OH groups present in the lignin structure can also be made through the use of UV spectroscopy method ($\Delta\varepsilon$), as described by ZAKIS (1994). This method is based on the difference in absorption at 300 and 360 nm in neutral and alkaline aqueous solutions. The technique of UV/Vis spectroscopy can also be used for determination of carbonyl groups, as described by FAIX *et al.* (1998).

Another technique of interest is the UV/Vis fluorescence (or photoluminescence), which is a technique that basically distinguishes π conjugated electronic systems. The higher the conjugation of the electronic system, the greater will be the wavelengths of absorption and emission due to lower energy required to excite electrons from its fundamental state to the excited state (MILORI *et al.*, 2004). CASTELLAN *et al.* (1996) present results for the lignin derivatives in different solvents. They observed that the method is able to distinguish the differences in the chromophores as a function of different interactions with the solvent.

The fluorescence spectroscopy is also a very selective technique, since both excitation and emission wavelengths depend on the same compound of interest, making the fluorescence signal collected characteristic for each molecule under study. Variations in this signal represent changes in the path taken during the decay of the excited state and can indicate the possible changes undergone by the molecule (GARBIN, 2004; GONZALEZ-PEREZ *et al.*, 2004; CARVALHO *et al.*, 2004; MILORI *et al.*, 2002).

Spectroscopic methods may be used for characterization of cellulose and hemicellulose, both in extracted and raw samples of lignocellulosic material. The NMR -^{13}C spectroscopy has enabled a lot of information about the structure of cellulose, particularly in its native state. This technique has been applied in studies about the secondary and tertiary structures of solid samples. Because the technique is sensitive to the chemical environment in which the analyte is present, the response is influenced by the degree of symmetry of material (ATALLA and ISOGAI, 1998).

Polymorphisms of cellulose can also be observed through the combined evaluation of different techniques (X ray, FTIR, and NMR). WADA *et al.* (2004), present results on the polymorphism of cellulose I, III and IV. They observed that the crystallinity of cellulose depends on the source material and the extraction process used.

Thermal analysis is another interesting technique for analysis of lignocellulosic material (KHAN and ASHRAF, 2007; SUN *et al.*, 2005). The thermogravimetry technique is based on mass loss of a sample when subjected to a gradual increase of temperature. Mass loss at temperatures up to 110 °C corresponds to a loss of free water and also some volatile compounds present in the structure. Cellulose and hemicellulose are degraded at temperatures ranging from 200 °C to 400 °C, depending on the degree of crystallinity of the material and how they are linked to the structure of lignin. Most of the lignin, which corresponds to the phenolic structure of the chain, is degraded at temperatures between 400 and 600 °C. Through Differential Scanning Calorimetry – DSC, it is possible to observe phase changes of different crystalline states in the cellulose and hemicellulose structure (SUN *et al.*, 2005).

Imaging technologies such as nuclear magnetic resonance – NMR, X-ray, atomic force microscopy – AFM, scanning electron microscopy – SEM show a great potential in understanding the structure of plant cell wall.

Finally, through studies of theoretical principles and applications of EPR techniques, NMR, FTIR, NIR, absorption of UV-vis, UV-vis fluorescence and laser-induced fluorescence – LIF, certainly great advances in the understanding of the chemical characteristics biomass can be achieved, and allow a much broader, specialized and updated view on this very important and challenging subject for the present and future.

Enzyme Production

Although the enzymatic hydrolysis stands out as a route of great interest for the industrial production of cellulosic ethanol, one of the greatest challenges in this area is related to the high cost of the enzymes. The development of efficient and optimized processes for enzyme production on an industrial scale is crucial to ensuring the economic viability of the application of enzymatic route for the production of cellulosic ethanol.

The fermentation process for enzymes production can be conducted both in a liquid medium, called submerged fermentation – SF, and in a solid medium, the solid-state fermentation – SSF. The SSF is defined as the process of growing microorganisms in a solid substrate containing moisture enough to maintain growth and metabolism, i.e., without of free water (RAHARDJO *et al.*, 2006).

Approximately 90% of all industrial enzymes are produced by SF, often using genetically modified microorganisms (HOLKER *et al.*, 2004). However, most of these enzymes could be produced by SSF using wild microorganisms.

In this context, the use of the SSF has been particularly advantageous for the growth of filamentous fungi, since it simulates the natural *habitat* of these microorganisms. This benefit is extended to the production of enzymes, providing a higher productivity when compared to submerged fermentation process. In addition, enzymes produced by the SSF are less susceptible to problems of substrate inhibition and also have greater stability to temperature and pH changes (HOLKER *et al.*, 2004). From the environmental point of view, the advantage of the SSF is related to the lower volume of effluent produced and the possibility of conducting the process under semi-sterile conditions. Another advantage of SSF is the use of agro-industrial residues (sugarcane bagasse, wheat bran etc.) as a solid substrate, acting both as sources of carbon and energy.

Despite all these advantages of SF compared to SSF, the SSF was held back by a disadvantage that limits its application in a broader and more direct form in industrial processes: the difficulty of monitoring and controlling the different variables involved in the process. While in the SF process the medium can be considered homogenous, in FSS there are several gradients of humidity and temperature, which can negatively influence the production of metabolites. This physical variability is particular to each process, but can be analyzed with the help of technological tools available, such as distributed data acquisition of physical and chemical parameters, actuators and automation systems. Knowing the optimal conditions of each process in a certain range, means better prediction of the behavior of the process on a larger scale. In SSF, the control of temperature, humidity, pH, water activity and gas exchange are essential for microbial growth and the consequent production of metabolites.

Among the variables involved in the process, temperature control is particularly important, since microbial growth under aerobic conditions results in a consequent release of heat, which can produce denaturation of the enzymes produced (HOLKER and LENZ, 2005) and other deleterious effects to the microorganism. Also, as SSF occurs in the absence of free water, this heat is difficult to remove due to the limited thermal conductivity of the solid substrate and the low thermal capacity of air (WEBER *et al.*, 1999). In this sense, the mechanism of evaporation has been considered the most suitable for performing heat exchange in large-scale SSF reactors (NAGEL *et al.*, 2001). However, evaporative cooling is accompanied by loss of moisture, which may cause dryness of the substrate, thus requiring the need for a combined control of temperature and humidity.

Some studies have used indirect measures for monitoring (so-called *software sensors*) as flow, temperature and humidity to control the temperature and the amount of water in the fermentation medium (SARGANTANIS *et al*., 1993; NAGEL *et al*., 2001; PEÑA Y LILLO *et al*., 2001; KHANAHMADI *et al*., 2006). The profiles of the aeration, along with monitoring of oxygen consumed or CO_2 produced during the microbial metabolism may, through the use of mass balances and energy, generate important data related to process control.

Therefore, there is a demand for the development of instrumentation that will allow the development of a system of control and automation in SSF. This is an important step towards the development of industrial scale bioreactors, since the SSF, while showing some advantages in relation to SF for the production of enzymes, imposes a series of operational limitations that hinder its scale up.

INTEGRATION OF CELLULOSIC ETHANOL PRODUCTION AIMING AT SUSTAINABILITY

The production of ethanol from lignocellulosic materials has been investigated with great interest in recent years. However, the process on an industrial scale is not feasible yet. Studies taking into account the integration of the process, the increase in fermentation efficiency and integration of individual operations are necessary to make the hydrolysis of biomass a competitive and sustainable technology.

Several studies have highlighted the advantages of second-generation biofuels in comparison to first generation. However, depending on the energy balance and its social and economic sustainability, not all biofuels bring the benefits commonly associated with fuels from renewable energy sources, such as reducing greenhouse gas emissions.

The integration of the process through mathematical modeling and simulation of the possible configurations of the technological routes will allow the proposition of computational solutions to optimize the operation of the process, to assess environmental and social impacts, as well as its economic viability. This will allow assessment of their phase of development and sustainability, as well as interest in its implementation.

Each of these aspects can be divided into several steps that are interlinked and should be evaluated in an integrated manner for decision-making, namely:

- ***Technological chain:*** production of raw materials, logistics from supply to processing, characteristics of raw materials, conversion processes, product characteristics, logistics of supply of products, use.
- ***Costs of production, processing, transportation, and use.***
- ***Environmental impacts:*** carbon balance, energy balance, emissions, sustainability of production systems.
- ***The social organization of production and market, public perception, public policy framework.***

The integration of the manufacturing process of cellulosic ethanol provides the possibility of restructuring the existing plants or the integration of new facilities close to existing ones. The residue of cane sugar is available at the site of the ethanol agro-industry, and with the improvement of energy co-generation technology it tends to increase their availability. Ethanol made from sugarcane bagasse can be produced in the same location as the conventional ethanol made from sugar, using the units of fermentation and distillation in an integrated form, which would result in lower production costs. In general, the integration can be performed at different levels, namely:

- equipment sharing;
- energy integration (sharing of current heat exchange, industry utilities etc.);
- reuse of materials, recycling streams;
- integrated wastewater treatment.

In addition, the development of mathematical modeling tools of the operations involved in the various processes in analysis will identify the needs of instrumentation, and will allow the implementation of modern techniques of process control at industrial level (BONOMI, 2008).

There are some commercially available simulation packages (ASPEN Plus, SuperPro Designer and Hysys) that were developed for a wide spectrum of industries such as pharmaceutical, biotechnology, fine chemicals, mineral processing, microelectronics, waste treatment and others. Some of the desirable characteristics of these simulation packages should be adapted to meet the objectives of the integration of the cellulosic ethanol production (BONOMI, 2008). There is also a strong demand for software development with a database of the composition of different types of biomass and physical-chemical properties of the different components involved in the process, from sugars to fermentation inhibitors.

WOOLEY and PUTSCH (1996) performed the structuring of a database of physical and chemical properties of the main components involved in the production of ethanol from wood to the simulation software Aspen Plus. This work was carried out by National Renewable Energy Laboratory – NREL – in the United States with the idea of providing a basis for all simulations in this software by the research groups involved in the project. Properties such as critical temperature, critical pressure, enthalpy of formation, density, heat capacity and vapor pressure of some key components such as ethanol, glucose, xylose, cellulose, lignin and cellulose were added to the database.

NAGLE *et al*. (1999) used the Aspen Plus software to perform an economic evaluation of an alternative configuration of the process of hydrolysis of a cellulosic material (the grass yellow poplar) using a step of two stages pretreatment, a unit of adsorption of lignin and a co-fermentation for the simultaneous fermentation of pentoses and hexoses hydrolyzate with a recombinant strain of Z. mobilis. The simulation results allowed selecting the optimum conditions of key variables on a bench scale for the future definition of a more advanced project on a larger scale.

CARDONA and SANCHEZ (2004, and 2006) studied the simulation of different process configurations for the production of cellulosic ethanol from wood including variations in the pretreatment, hydrolysis of cellulose, fermentation, separation and wastewater treatment, taking into account possibilities for process integration. The simulations were performed using the software Aspen Plus, comparing the energy expenses of different settings. The results showed that the most appropriate case would be a process with the following sequence of unit operations: pretreatment with dilute acid, simultaneous saccharification and fermentation of pentoses and hexoses, coupled with pervaporation distillation and recycling of the water used in the process. The need to consider the effect of inhibitors on the co-fermentation and the number of current recycling was highlighted in the sensitivity analysis.

The recycling of some of the process streams should also be evaluated for integration. Recycling of sugar chains, as well as the reuse of cellulolytic enzymes, offer great opportunities to reduce process costs. The suggestion for recycling of cellulases was reported by MES-HARTREE *et al*. (1987). These authors suggest the use of cellulases and the residual substrate in the step of cellulases production. GALBE and ZACCHI (1994) studied the recycling of pentose formed during the hydrolysis of hemicellulose and obtained an increase in ethanol production and a decrease in energy consumption. LEE *et al*. (1995) proposed the reuse of cellulases by different strategies of recycling from the residual substrate hydrolysis step of cellulose. The authors reported that the presence of lignin in the substrate negatively affected the activity of cellulase.

Whereas the existing technologies for the conversion of biomass into cellulosic ethanol are not fully developed in comparison with first generation ethanol, the development of software to facilitate process integration and the validation of mathematical models by experimental tests, can provide important tools for the design of optimal configurations, along with the best technical/economic, environmental and social indicators.

BIO-REFINERY: A VISION OF THE FUTURE

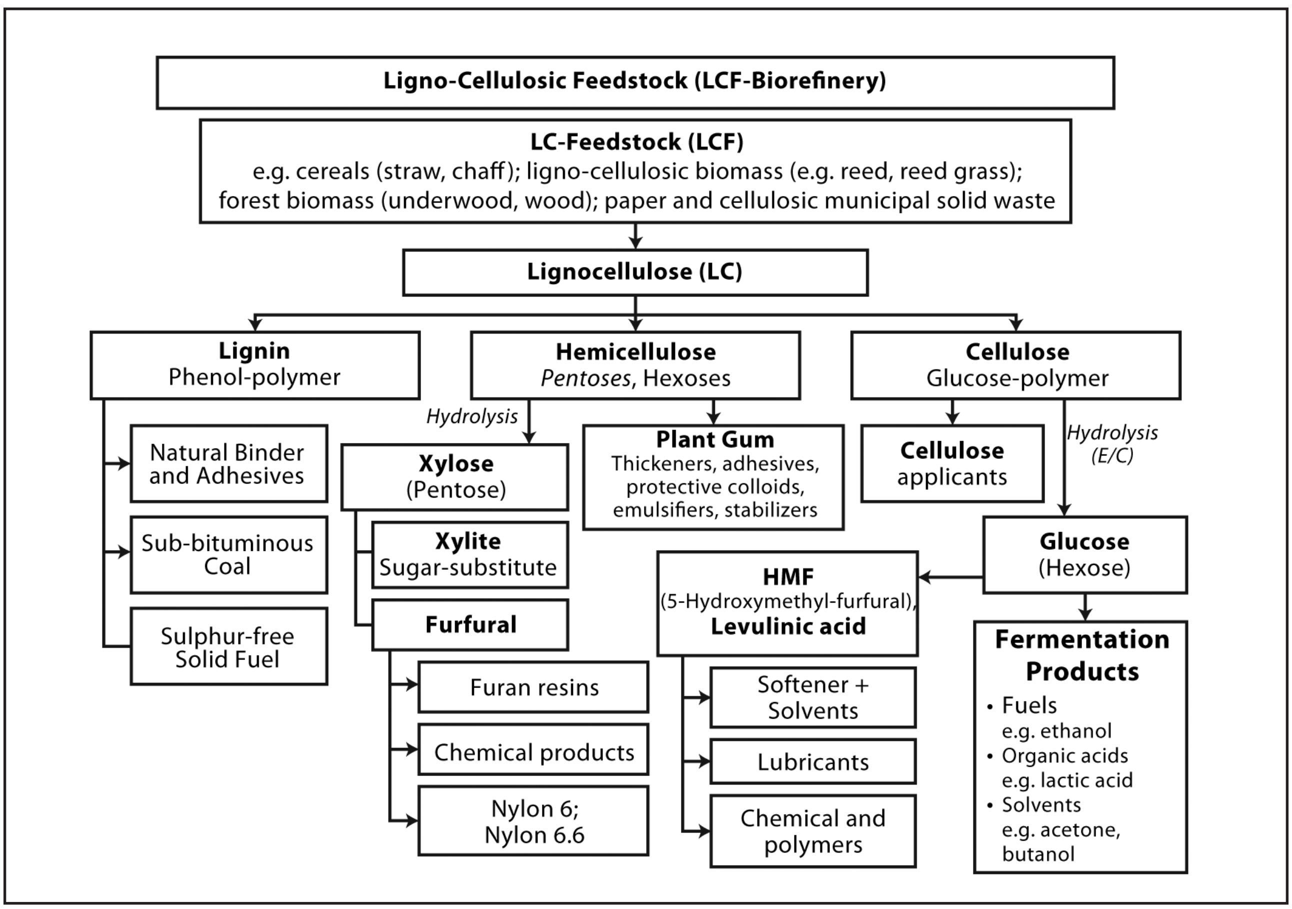
The concept of biorefineries, despite being defined in different ways by some sectors, expresses the consensual idea of processes integration in order to convert biomass into fuel, energy and chemicals. In other words, the concept is similar to that of oil refineries, in which crude oil are converted into different products for different applications in an integrated and optimized system. The concept of industrial biorefineries has been identified as the most promising route for the establishment of future new industries.

The conversion of renewable energy sources in the biorefineries can be accomplished primarily through three routes:

(1) The thermo-chemical route, which includes the processes of biomass pyrolysis, gasification.
(2) The chemical route, acid hydrolysis of biomass, production of poly (lactic acid).
(3) The biochemical route, including enzymatic catalysis and fermentation.

Biocatalysis or enzymatic catalysis is a technology that has been considered key in the biorefinery processes due to milder operating conditions and higher conversion efficiency. The biocatalysts can be applied in the production of biofuels ethanol and biodiesel, as well as in the synthesis of biodegradable plastics such as polyesters. An idea of the diversity of products with potential to be obtained from biorefineries is shown in Figure 2 (KAMM *et al.*, 2006).

Some studies have been done proposing the integration of the concept of biorefineries with the systems of agriculture and livestock (SENDICH *et al.*, 2008). The incorporation of these systems will allow an environmental and economic integrated analysis of biomass conversion into different products, fertilizers and ethanol. The authors present a comparison of the performance of various simulation models with different crops using



Source: KAMM *et al.*, 2006.

FIGURE 2 Products from biorrefineries.

some software already available in the market (DAYCENT, Integrated Farm System Model – IFSM and I-FARM) and suggest a model to be used in selecting the best alternative strategy together with the current methods of process engineering.

BONOMI (2008) proposed the concept of a Virtual Biorefinery, which has the purpose of building/adapting simulation software in order to facilitate the modeling, optimization and technical-economic assessment and sustainability of integrated processes, the main characteristic of a biorefinery. According to the author, the Virtual Biorefinery system is a computational tool that will simulate the behavior of a standard biorefinery and its various concepts (making even possible the continuous addition of new strategies for materials and processes used and products generated).

In the technical and scientific literature there are several reports regarding the mathematical modeling and simulation of various operations of the biorefinery (SADHUKHAN *et al.*, 2008; ARIFEEN *et al.*, 2008; SENDICH *et al.*, 2008). It is necessary for the construction of the Virtual Biorefinery to evaluate the proposed models, adapting them to compose the various alternatives for biorefinery, to develop the models that have not yet been developed (regarding the technologies employed and those in development) and, finally, enter all the models available in the simulation platform – on the virtual biorefinery. As an illustration below are some examples of models available in the literature that fit the needs of the construction of virtual biorefineries (BONOMI, 2008):

- fermentation industry;
- production of polyhydroxyalkanoates;
- production of ethanol from starch;
- simultaneous saccharification and fermentation of lignocellulosic material.

A typical composition of lignocellulosic materials (in dry mass) is 35% to 50% cellulose, 20% to 35% hemicellulose and 5% to 30% lignin (LYND *et al.*, 1999). Thus, using only cellulose can result in a significant amount of unused material as a byproduct of lesser value or waste. This will lead to a strong impact on both the conversion efficiency, and in the economy of the whole process. Lignin is the second most abundant renewable and sustainable source of carbon, along with cellulose, and development of technologies for its conversion should be considered.

One possible use of lignin in the biorefinery concept was proposed by KLEINERT and BARTH (2008). The authors studied mixtures of formic acid and alcohol in the reaction medium for conversion of lignin in “liquid oils”. The authors report a new liquefaction process that is able to depolymerize lignin in a liquid bio-oil with low oxygen content that can be used as a component to be mixed with conventional fossil fuels.

In addition to the technical and economic issues, the impact related to environmental and social gains arising from the implementation of biorefineries has been analyzed by the methodology of life cycle analysis. UIHLEIN and SCHEBEK (2009) carried out the assessment of the life cycle of a refinery using lignocellulosic raw material, analyzing different configurations of process and products. The best configuration resulted in yields better than the alternatives from renewable fuels, with the total environmental impacts about 41% lower. For most of the configurations of biorefinery analyzed, the environmental performance was better than the fossil fuel comparable.

In conclusion, the development of biorefineries opens perspectives for the production of a large number of products derived from biomass that can replace oil products as well as some products that can not be manufactured in conventional refineries. There is, therefore, a great potential for the biorefineries of the future to be competitive with existing fossil alternatives from technical-economic and environmental point of view, especially when the technologies are improved.

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8

R&D NEEDS IN THE INDUSTRIAL PRODUCTION OF VINASSE

Luís Augusto Barbosa Cortez, Carlos Eduardo Vaz Rossell, Rodrigo Aparecido Jordan, Manoel Regis Lima Verde Leal and *Electo Eduardo Silva Lora*

INTRODUCTION

This chapter investigates aspects related to the need for new research on vinasse, with the aim at the improvement of techniques, or implementation of new processes, which allow a reduction in the volume of this byproduct and/or its pollution potential. Sugarcane vinasse is an agri-industrial residue generated in high volumes with a high pollution potential.

The low tolerance to alcohol by the yeast *Sacharomyces Cerevisiae,* used in alcoholic fermentation, implicates a high dilution rate of the must so that the alcohol by volume of the wine is not high after distillation, in the generation of vinasse per liter of ethanol (about 7 to 14 times). Higher temperatures in the fermentation process reduce even more the tolerance of yeast to ethanol.

The technical solution found in Brazil for the disposal of this byproduct is fertirrigation, already discussed in this book. However, since there are restrictions and laws in other countries prohibit this practice, it is very important to find a reduction to the volume and even *in situ* elimination of vinasse.

There are already some options to reduce the volume of vinasse produced. For example, genetic improvement to increase resistance of yeast used in fermentation, changes in the process, such as use of vacuum, or membranes for continuous extraction of the alcohol produced or employment of refrigeration for temperature reduction and control during fermentation; which would permit an increase in the alcohol by volume of the wine. Another possibility is to concentrate the vinasse, either by evaporation or through reverse osmosis. All of these technologies are currently in different stages, needing further development and research.

In terms of reducing pollution, bio-digestion appears as a good alternative for vinasse treatment, at the same time that offers the possibility of generating energy from the biogas produced. However, bio-digestion does not solve the problem of high volume of vinasse generated.

There are still two main questions still need answers. The first concerns the optimum quantity which could be generated (volume vinasse/volume thanol produced). The second question involves the vinasse of second generation ethanol, of what could be their characteristics, that is, the volume and its treatment.

SUGARCANE VINASSE

In Brazil, the largest part of the vinasse produced comes from the fermentation of the juice mixed in different proportions to the molasses obtained in centrifuging sugar, given that currently, the majority of units produce both sugar and ethanol. Figure 1 shows a flowchart with the phases in sugar and ethanol production, and where vinasse is generated.

The quantity of vinasse generated in the production of alcohol is associated to the toxicity of ethanol to the yeasts used, indicating a reduction in the alcohol by volume during the final stage of

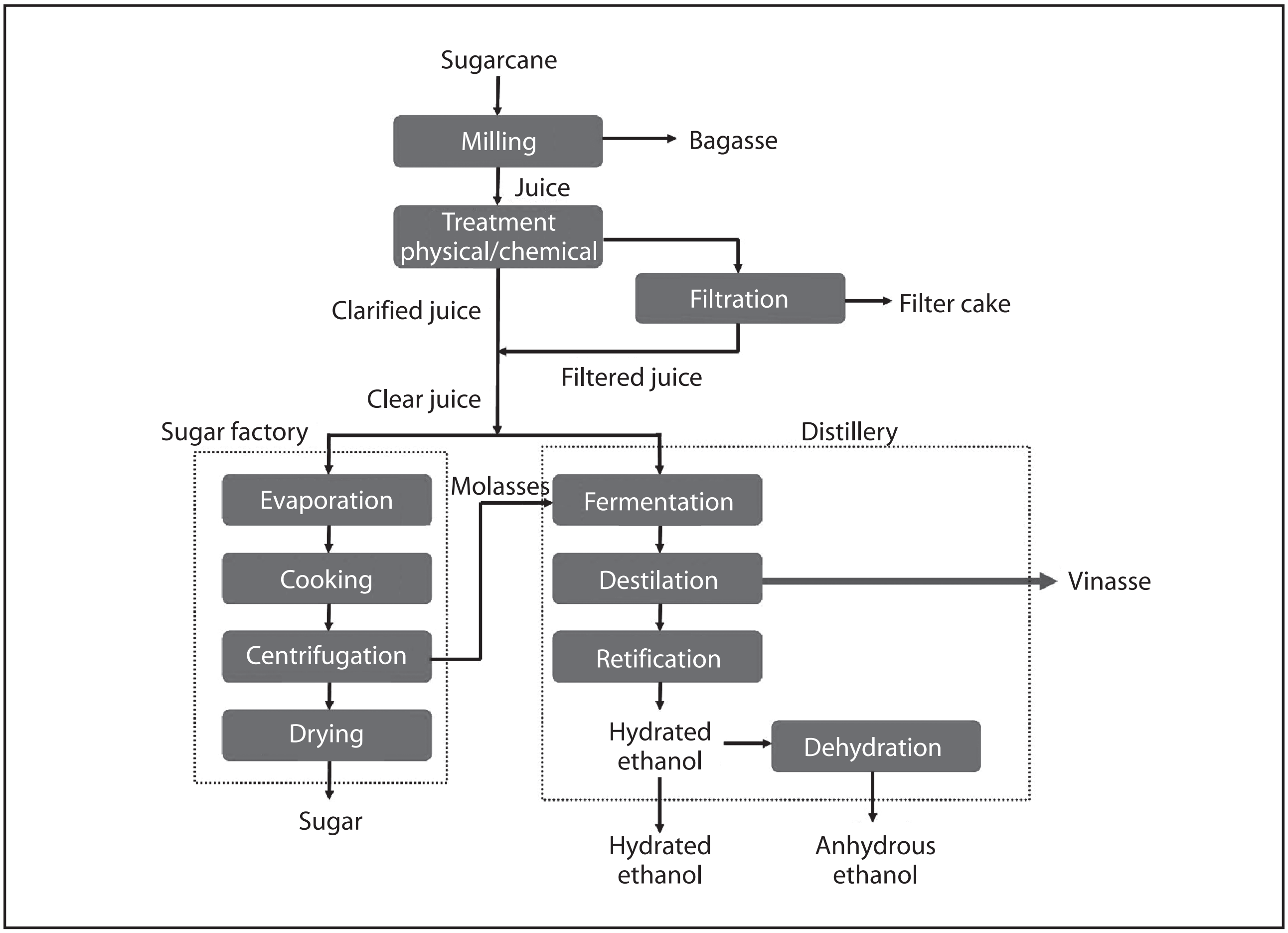


FIGURE 1 Sugar and ethanol production flowchart.

the fermentation process, including recycling of the yeast during the harvest. This causes, for the same recipient volume, a reduction in the volume of alcohol produced and an increase in the quantity of vinasse generated. With the final average alcohol by volume obtained today in the mills of about 8 to 12 ºGL[1], there is, for every liter of ethanol produced, between 7 to 14 liters of vinasse.

Generally the vinasse is of a light brown color with 2% to 4% total volume of solids when it is obtained from sugarcane, and presents a slightly reddish dark color (black) with a volume of solids between 5% and 10% when produced from sugarcane molasses.

The organic substances present in vinasse generally increase the Biochemical Oxygen Demand (BOD), generally between 30,000 and 40,000 mg/l (BHANDARI *et al.*, 1979) with a pH of 4-5. The organic acids present in vinasse are corrosive requiring stainless steel or fiberglass, or coated recipients which come in contact with the vinasse. The vinasse also contains non-fermented carbohydrates, dead yeast, as well as a variety of inorganic compounds all of which contribute to a high BOD.

When vinasse cannot be applied in fertirrigation, some distilleries employ the so-called "sacrifice areas[2]". However, depending on the location, these areas are a great risk to the water tables and rivers due to the risk of lixiviation.

[1] In average the mills with attached distilleries operate with an alcohol by volume of approximately 8.5 ºGL. This may be gradually higher however smaller the percentage of molasses incorporated. The mills which due to good cooling conditions, operate with an elevated ratio sugarcane to ethanol: sugarcane to sugar and have good installations and process management reach maximum levels of 10 to 10.5 ºGL in stable levels.

[2] The vinasse volume applied to sacrifice areas is estimated in no more than 20% of the total generated.

Due to the fact it is a highly pollutant residue, about one hundred times more than domestic sewage, which also comes out of the process at a relatively high temperature, around 85 °C to 90 °C (GONÇALVES, 2008), finding an adequate destination is one of the great challenges of the sector.

It was after the NATIONAL ALCOHOL PROGRAM (1975) that the fertirrigation technology took off in Brazil, as a disposal method for vinasse. Although it was in fact a good alternative it has economic limitations due to high transport costs when transported long distances and also due to restrictions imposed by law on the total amount that can be applied to the saoil (see Chapter 9, Part 3, *Fertilizers for sugarcane*). These restrictions forced the sector to find other alternatives close to distilleries or mills.

R&D NEEDS TO REDUCE THE VOLUME OF VINASSE

All of these aspects demand more research with the objective of finding solutions to ease the environmental and economical impacts caused by large volumes of vinasse. Some advances were achieved, such as the cooling of the fermentation towers using fresh water from rivers, which allowed some mills to reduce the fermentation temperature to values less than 34 °C, resulting in fermentation period of about 6 to 8h, considered acceptable when compared to 24 hours about 30 years ago.

However, the volume of vinasse produced is still very high, making transportation costly. Vinasse is composed almost entirely of water, as the solids level is very low (5% to 10%) due to high dilution.

Alternative uses of vinasse, to reduce the high BOD, bio-digestion to generate energy which can at the same time help to reduce the pollution potential (reducing the BOD and the volume produced, through greater vinasse concentration. Vinasse concentration is a process which may be done by reverse osmosis and/or evaporators. However the latter requires high quantities of thermal energy.

A way of reducing vinasse generation according to FINGUERUT (n.d.) quoted by PENATTI (2007) is to increase the final alcohol concentration by volume of the fermentation. Each percentage increase in the alcohol by volume corresponds to a percentage reduction in the number of liters of vinasse per liter of alcohol produced.

There are already many lines of research e.g. reduction in fermentation temperature through refrigeration systems in the recipients, increasing alcohol by volume of the wine and consequently reduce the volume of vinasse. On the other hand, the temperature reduction to less than 28 °C implies a reduction in the metabolism of the yeast, increasing the fermentation time; or the use of a vacuum process for the continuous extraction of ethanol during fermentation. These techniques, however, are still restricted to laboratory prototypes; additional where investment is necessary to scale-up. It has been also proposed, to reduce the volume of vinasse reduction, to recycle in the process, to ferment the diluting must to be e.g. process known as Biostil.

Alternatives which involved an increase in alcohol by volume in fermentation, as well as reducing the vinasse, show other advantages, an increase in the production of the alcohol in the recipient and a reduction in energy consumption in distillation due to greater concentration of alcohol in the wine.

AMORIM (2008) mentions the improvement in contamination control in fermentation as another benefit of working with higher final alcohol by volume in fermentation. Table 1, quoted from AMORIM (2008) shows the relation between the final concentration of alcohol in the wine and the quantity of vinasse generated per liter of distilled alcohol. However, data on fermentation, type or even time is not contemplated.

According to FINGUERUT (n.d.) quoted by PENATTI (2007), except from some few mills which manage to work with higher alcohol levels, most work with alcohol by volume levels between 8% and 8.5%. Some alternatives aimed to reduce or treat vinasse, are described below in more detail.

TABLE 1 Vinasse volume generated due to alcohol by volume in wine.

Alcohol by volume in wine (%)	Vinasse volume (liter/liter of alcohol)
5	20
7.5	13
10	10
14	7
18	5.5

Source: AMORIM (2008).

ALTERNATIVES FOR VINASSE VOLUME REDUCTION IN FERMENTATION

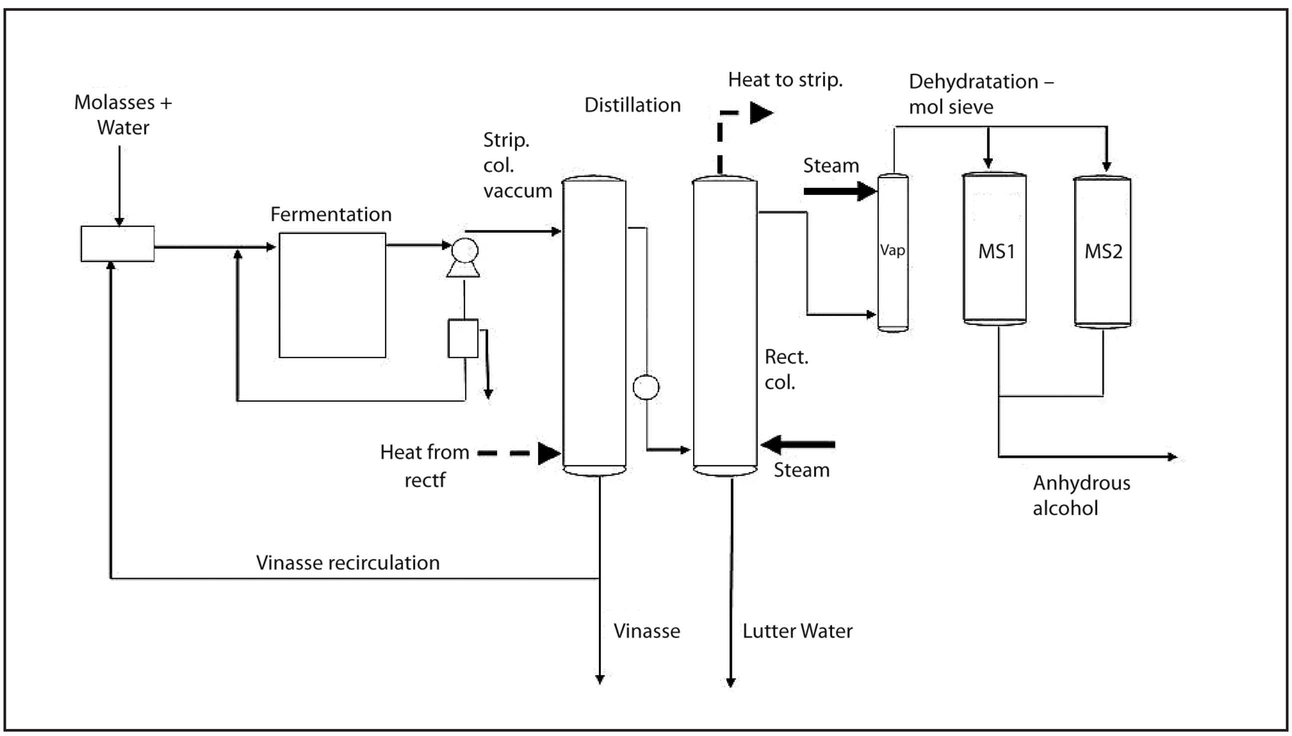
Biostil Process

The Biostil process (Figure 2) was developed with the aim of reducing the volume of vinasse by increasing the concentration of solids, which normally is of 5% to 15%, through recycling in the fermentation process, which consists in using it in the dilution of the honey in a substitution of water.

To obtain vinasse at 14.5% solids, NILSSON (1981) recommends its recycling in fermentation but which requires a substrate of higher quality, as well as other microbiological attention. The Biostil process, patented by the company Alfa Laval, was commercialized in Brazil by Dedini.

The first tests were set up for a small plant of 18,000 liters of ethanol/day, and later at Usina São Luiz, a commercial plant of 180,000 liters of ethanol/day. Dedini sold 4 units in Brazil as well as 1 in Pakistan. None of theses plants are currently in operation.

The Biostil process was developed in the 1980s, whose main objectives were operation with concentration musts and the reduction of vinasse volume. However, this process showed serious problems which hinderer its commercial viability. For example, the must was highly toxic due to vinasse recycling to dilute the concentrated molasses. Additionally, the must showed high osmotic pressure due to the presence of non-fermentable



Source: BIOSTIL, (1983) adapted.

FIGURE 2 DEDINI fermentation process with vinasse recirculation.

soluble solids in relatively high concentrations. These two factors resulted in a low productivity process (ATALA, 2004).

According to Dr. Olivério of Dedini (personal communication), when the Biostil process was introduced at the beginning of the 1980s, little was still not known how to treat vinasse. The use of vinasse in fermentation reduced the yeast life cycle. It is important to recall that the raw material used was molasses and that vinasse was still diluted for fertirrigation many times. It made, therefore, no sense to concentrate the vinasse only to dilute it later.

According to FINGUERUT (n.d.) quoted by PENATTI (2007) the Biostil process was not commercially demonstrated in Brazil, as it simply did not work as it would work in India in low efficiency and low productivity conditions, reducing its attraction for reducing the vinasse volume. A possible advantage of the Biostil process was that it was easier to evaporate the juice (to make a syrup which would be diluted with the vinasse) than to evaporate the vinasse, which due to its corrosiveness, would demand special materials for evaporation, increasing the cost.

Procknor Engenharia describes in its website (<www.procknor.com.br>) the development of projects of ethanol production plants in other countries, where the Biostil system has been applied successfully for reducing the volume of vinasse. For this, a specific yeast is used which can take high osmotic pressure. Fermentation is continuous, and yeasts are recovered by means of separating centrifuges, with no acid treatment. Dilution of the honey is made by the recycling vinasse itself. Although it is a special yeast, the fermentation environment is so hostile for its metabolism that after about one week of operation the yeast must be renovated. In this way, there would be two fermenting agents, one in operation and the other for the propagation of the new addition of yeast. When the fermentation level starts to decline, the yeast is changed using the fermenting agent on hold and so on.

According to Procknor, recycled vinasse has a Brix of around 35% and its rate is of about 3:1 (3m^3 of vinasse/m^3 of alcohol). According to information from this company, in Australia there is a system in operation with a productivity of about 3 percentage points below the productivity of the classic Melle Boinot process. As well as a reduction in viability of the yeast due to the fermentation conditions, there is the constant consumption of sugar used in the propagation of new yeast additions.

In Sarina, Australia, a distillery operating since 1989 with the Biostil process, produces 180,000 liters of ethanol/day; the vinasse with 30 °Brix is sold as liquid fertilizer to farmers in the region. In the recent past, the company Chematur Engineering took on Biostil technology and has been working to improve it, solving its serious chronic problems; according to Chematur there are about 30 distilleries in India operating with their technology. The yeast used is *Schizosaccaromyces pombe*. More information on the Biostil 2000 technology may be obtained in the Chematur company's website (<www.chematur.se>).The company PRAJ applies this process in the new distilleries built in Colombia. One of the problems faced are the infections in the fermentation musts.

Use of Refrigeration for Temperature Reduction in Fermentation

Temperature reduction in the fermentation process appears as an alternative both for vinasse reduction as for an increase in the volume of alcohol produced. Temperature is as a very important factor in the fermentation step, as increasing it implicates lower tolerance of the yeast to the ethanol's toxicity. On the other hand, reduction increases the yeast tolerance, allowing for work with higher alcohol concentration in the wine.

The recipient cooling tower technique with fresh water from rivers, in the past, when harvest was concentrated in colder months, allowed for significant improvements in the process, such as reduction in the fermentation period and production gains related to the recipient temperature reduction (AMORIM, 2005). Nowadays, as sugarcane season extends to warmer months, this cooling system has proved to be inefficient. The problem is even greater in mills installed in the warmer regions, where it is difficult to work with temperatures below 35 °C, which is according to technical literature, the top temperature limit, after which the yeast becomes more susceptible to the alcohol by volume.

With the aim of improving the cooling systems in the fermentation recipients, some mills are using cooling towers. This does not solve the problem, as these towers operate on the evaporation principle, where part of the water evaporates through forced air passage through the water current, thus promoting heat removal. However, for the process to work efficiently, the relative air humidity must be low. Contrary, evaporation is hindered, affecting heat exchange and efficiency of the process.

There are many bibliographical references on temperature in the fermentation process, among which we may quote: FINGUERUT *et al.* (2008), GUTIERRES (1993), JONES *et al.* (1981) and WALKER and CAPRIOLO *et al.* (1985) quoted by OLIVA NETO (2008), Parazzi (2008) and Amorim (2008). There seems to be a consensus as to the benefit of temperature reduction in the process. However, the economic viability of employing refrigeration for temperature reduction has always been matter of debate.

According to AMORIM (2008), the challenge of alcohol by volume levels greater than 11% is related also to the need for improving the cooling system, thus suggesting refrigeration systems.

According to FINGUERUT *et al.* (2008) one of the initial limitations for the increase in final alcohol by volume in fermentation is the resistance of the yeast population to the toxic effect of the ethanol produced, considering the need to reuse the yeast. It is possible to reduce this effect by reducing the process temperature and then working with a younger population of yeast. Considering that adopting such measures implicates greater investment,requires to balance possible costs with gains in capacity; higher electricity generation and reduction in the volume of byproducts must be also emphasized.

In the past, due mostly related to production costs, the idea of using refrigeration systems to reduce the temperature in the recipients and thus improve fermentation was eventually abandoned, due largely to high energy costs.

There is still a strong need to carry out basic research e.g. behavior of yeast in low fermentation temperatures (10 °C to 25 °C). In many research studies involving temperature, it may be seen that the values were restricted to a small range, between 28 °C and 40 °C. Yeast development however happens in a broader range of temperature.

According to JONES *et al.* (1981) quoted by OLIVA NETO (2008), the *Saccharomyces Gerevisiae* yeast tolerates up to 33 °C in industrial conditions for the production of ethanol, in spite of showing a growth rate between 10 °C and 40 °C. JIMENEZ and VAN UDEN (1985) quoted by ANDRADE (2007), the tolerance range to ethanol is in between 12 °C and 28 °C, decreasing at values greater than 28 °C. Above 35 °C the yeast becomes little tolerant to ethanol, occurring a reduction in the cellular and ethanol production (PHISALAPHONG *et al.* 2005, quoted by ANDRADE, 2007).

A complete project should consider laboratory studies of the initial phase and the scale-up of the proposed system. Once determined the optimum condition, it must be applied to a larger system, as there are factors which are affected by scale.

Using refrigeration for temperature control in a mill, considering the fact the recipients are already cooled down with water, would imply changes that are not necessarily significant to the process. In a simpler case, adopting refrigeration in a fermentation process, would sum-up to the installation of a cold water accumulating tank connected to a refrigeration system to cool the water.

The company Thermax of Brazil, in association with Procknor, is offering a system for cooling the recipients. It is an absorption chiller which produces cold water between 15 °C and 22 °C. According to information from the company the absorption system may use, to be activated, many heat sources available at the mill, such as vinasse, condensates or vapor at temperatures below 100 °C. This system is recommended for maintaining the recipient temperatures around 33 °C. There are no published economic data or results of any installation already in operation.

Dedini has an agreement with Thermax, having built a demonstration plant at the Usina Bonfim. There is a consensus nowadays as to the need to control fermentation temperature and the use of refrigeration systems by absorption; seems like an interesting solution from a technical point of view (as it uses low pressure vapor as basic energy source) and economically (as this vapor may be obtained at a relatively low cost in the mill).

Fermentation System with Continuous Extraction through Vacuum

In the last few years, many researchers have proposed the use of techniques to extract ethanol from the wine as it is produced to improve the performance of the fermentation process. Using vacuum during the fermentation is one of the proposed methods.

Francisco Maugeri through the Bio-processes Engineering Laboratory of the School of Food Engineering at Unicamp has been working on the development of continuous extraction systems during fermentation. ATALA (2004) set up in laboratory, a continuous fermentation process, with vacuum extraction through a flash type evaporator. One of the greatest challenges was developing the control method for the process. According to this author, the results obtained were excellent, showing that it is possible to work the extraction with a solution of alcohol by volume of around 50 ºGL, maintaining in fermentation a low concentration of ethanol, of about 5% (vol/vol), not very inhibiting to the yeast.

According to ATALA (2004) the flash type evaporator used in his work permits fermentation with high concentration of sugars in the reactor feeding medium, resulting in a greater production of ethanol, which would imply in cost reduction for distillery and smaller vinasse generation. On the other hand, there is additional energy consumption through the flash evaporator vacuum system.

However, the necessity of carrying out tests with this process on a larger scale must still be considered, since the system set up in laboratory used a fermenting system of a few liters. In addition, the energy consumption by most of the equipments necessary must also be considered, which was not the main purpose of the first study, which sought to demonstrate only the validity of the process.

VINASSE TREATMENT METHODS

Vinasse Bio-digestion

Given the high COD characteristics of vinasse, low level of solids and production in large quantities from a central point of the distillery, treatment via anaerobic digestion was considered, which is a method used quite successfully in the treatment of liquid byproducts with low level of solids. Many examples of application of bio-digestion can be found in the Brazilian food industry, particularly in the beer sector.

The advantages of the anaerobic bio-digestion process, LUCAS JR. *et al*. (1997) are:

- lower energy consumption in relation to the traditional aerobic treatment processes;
- lower production of muck (bacteria) in relation to the aerobic processes;
- acceptance of higher levels of organic matter;
- the methane produced may be used as fuel;
- the byproduct of vinasse treatment may still be used as a fertilizer, given that all the nutrients present in the “fresh” vinasse are also present in the byproduct.

Development of the Upflow Anaerobic Sludge Blanket Reactor, known as the UASB reactor (schematic view in Figure 3), allows treatment of the liquid byproducts with an elevated COD, as is the case of vinasse.

The UASB bio-digesters are currently used with greater success in anaerobic bio-digestion of vinasse and other liquid byproducts, as was previously mentioned. This is due to the fact that fresh vinasse has a low level of solids, which allows pumping and recirculation and therefore, obtaining a rather low residence time of only a few hours, contrary to that found in conventional bio-digester, Indian or Chinese type, which are not adequate for this purpose.

The operation principle of the UASB bio-digester is based on the recirculation from bottom to top of vinasse through a fixed blanket of microorganisms located in the middle of the reactor. The UASB reactor is characterized for having a separated superior section for the liquid phases and gases, which allows part of the liquid

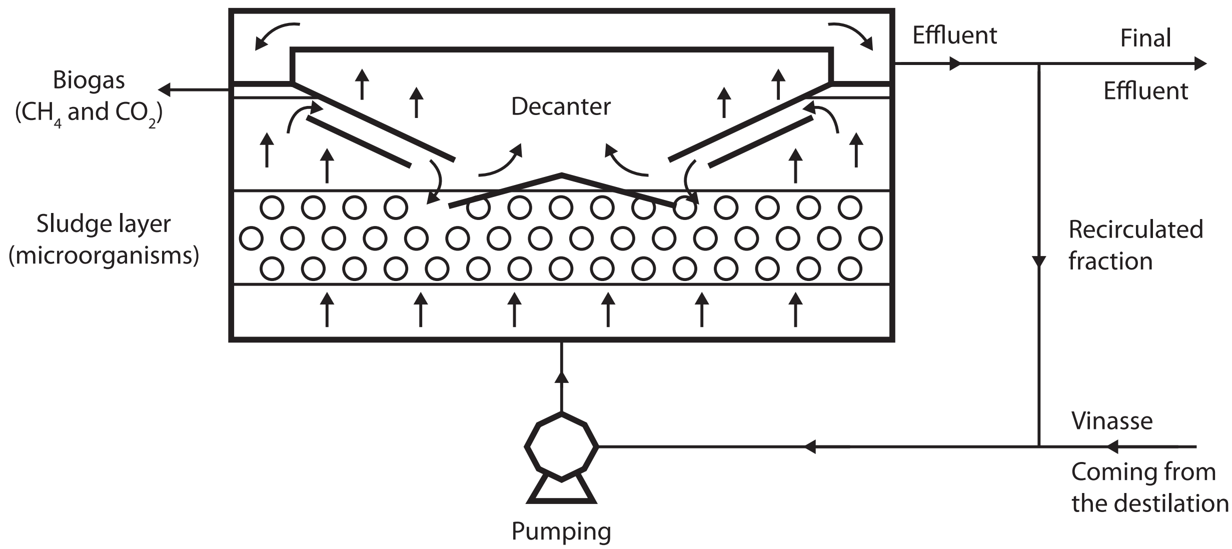


FIGURE 3 Adapted schematic sketch of a UASB reactor.

to return while it maintains the bacteria fixed in the reactor's bed.

The vinasse is, therefore, pumped externally and introduced into the lower part of the reactor passing by the muck blanket where there are the microorganisms responsible for the conversion of the organic matter present in vinasse into CH_4 and CO_2. The resulting liquid byproduct comes out of the superior side part of the reactor, while the gaseous part (CH_4 and CO_2) is confined with the help of deflectors which takes it to spaces, also located on the superior part of the reactor. These reactors are normally cylindrical.

According to PINTO (1999), in Brazil the first experience with anaerobic digestion of vinasse didn't use UASB reactors, but a modified Indian type model. In 1981 a 330 m^3 bio-digester was implemented at Destilaria Central Jacques Richer, in Campos, in the state of Rio de Janeiro. The bio-digester operated until the distillery closed in 1982, obtaining a reduction of COD by 62% with the production of 16.5 liters of biogas (with 55% CH_4) per liter of vinasse. The biogas was burned in a boiler without any modification in the burners projected originally for fuel oil.

Some initiatives conducted by the Institute of Technological Research of the State of São Paulo – IPT, at the beginning of the 1980s, allowed for a considerable gain in experience in the application of bio-digestion technology for treatment of vinasse by using ascending flow bio-digester technology, such as the bio-digestion project at Destilaria Paisa in the state of Alagoas. This project was coordinated by the Brazilian Development Bank – BNDES and aimed to control the vinasse bio-digestion technology. The laboratory reactors were financed by many governmental agencies and by the company Tigrefibra Industrial S.A. Table 2 indicates, in more detail, some results as to the composition of the vinasse treated and the byproduct resulting from anaerobic bio-digestion in this project.

Also around the 1980s, the group CODISTIL-DEDINI acquired a Dutch technology for large-sized UASB reactors, to operate with mesophylic bacteria, the METHAX-BIOPAQ process. The first large-sized unit was installed in 1986 at Destilaria São João, in the city of São João da Boa Vista, SP. The project was partially financed by the BNDES. The basic idea was to develop the vinasse bio-digestion technology, which could, without much difficulty, be adopted by other distilleries.

The bio-digestion project of Destilaria São João operated for 13 years. The reactor had a

TABLE 2 Average composition of vinasse and byproduct referring to the ascending flow bio-digester for vinasse project at Destilaria Paisa in Alagoas.

Components	Average composition	
	Vinasse	Byproducts
pH	3.73	7.3
Total solids (g/l)	25.2	10.9
Volatile solids (g/l)	19.3	5.2
COD (mg/l)	31,350	6,144
BOD (mg/l)	17,070	918
Nitrogen (mg/l)	412	343
Phosphorus (mg/l)	109	108
Sulfate (mg/l)	897	*
Potassium (mg/l)	1,473	1,221
COD reduction		
Total	80.5%	94.6%
Exceeding	91.4%	95.1%

Note: For a period of hydraulic retention = 1.5 day, maximum organic load = 18.7 kg COD/m^3.day; biogas average production = 13.1 l/l of vinasse; conversion = 0.4 l biogas/g COD_{adic}; methane level = 60 to 65%;
* Not indicated in the reference.

Source: CRAVEIRO, 1986.

capacity of 1,500 m^3 and the gasholder a capacity of 600 Nm^3 of biogas (Figure 4). The biogas generated was 70% methane and 30% carbon dioxide with traces of impurities. The biogas was then purified and compressed to 220 atm (22 MPa) in reservoirs with total capacity of 400 Nm^3. The daily production of biogas reached 6,500 Nm^3 (96% methane). The compressed CH_4 was used to move 41 vehicles (29 trucks and 12 utilitarian vehicles), representing 50% of the fleet of trucks at the distillery and 40% of the utilitarian vehicles.

In spite of the fact the project at Destilaria São João shwed technical viability, economic factors prompted biogas as a vehicular fuel to be discontinued in the 1997/1998 harvest; it was used only in drying yeasts, as in Usina São Martinho. The vinasse bio-digestion unit at Destilaria São João has been deactivated which according to Dedini, contributing factors included:

- low price of diesel oil, which was high subsidized internally (costing at the time half the price of gasoline); currently it is about 10% cheaper);
- sugarcane logistics evolved to large quantities. At the time, the power of the truck engines was of 180 HP (bus engines moved by gas were used) and today 400 HP engines are needed and there aren't such engines moved by gas;
- in addition, there was also the difficulty in obtaining extra parts for the modified diesel engines used in fleet of trucks.

Since 1987, Usina São Martinho has developed a thermophilic process (55 °C) for vinasse biodigestion using a UASB type pilot reactor with 75 m^3 capacity (Figure 5). After 5 years, the technology was considered fully developed. The thermophilic reactor was operated with an organic load applied at a rate of 30 kg COD/m^3/day producing 10 Nm^3 of biogas/m^3.day, under stable operating conditions. These values are considered twice as great as that presented in the literature on the mesophilic process (35 °C).

The most notorious cases of vinasse treatment with bio-digestion are Destilaria São João, which in the mid 1990s discontinued its operations, and that of Usina São Martinho, both in the state of São Paulo. Usina São Martinho is the only one still using bio-digestion. Both systems, despite producing good results from an energy point of view, remain economically very expensive.

Studies carried out by JOHANSSON *et al.* (1993) and quoted by SOUZA e PAULA JR. (1999), estimate the operational costs of biogas of biogas produced between 0.03 to 0.05 US$/Nm^3, where for large-sized plants these costs would be lowered to 0.02 US$/Nm^3. Considering also investment costs, for an installation with working life of 15 years and an interest rate of 10% p.a., the total costs would be of 0.05 to 0.09 US$/Nm^3. Still in accordance to SOUZA e PAULA JR. (1999), when comparing these costs with that energy in terms of US$/toe[3] (1995 figures), the costs of biogas vary between

[3] Toe = ton of oil equivalent

Source: Granted by DEDINI.

FIGURE 4 Picture of the Usina São João project showing the bio-digester and the gasholder.

Source: PINTO (1999).

FIGURE 5 View of the bio-digester installed at Usina São Martinho.

TABLE 3 Parameter comparison between the vinasse bio-digestion reactor projects, UASB and IC concepts.

Parameters	UASB	IC
Anaerobic muck	Active, concentrated	Granulated
S/L/G Separator	High biomass retention	2 stages
Height of reactor (m)	4.5-6.5	16-30
Muck activity (kg COD/kg SSV. d)	0.5	1.0
Application rate (kg COD/m^3 r. d)	6-10	20-40
Hydraulic detention time (h)	6-18	2-3
Speed of liquid (m/h)	0.5-1	5-10
Speed of biogas (m/h)	0.5-0.9	7-12
COD removal efficiency sol. (%)	80	80
BOD removal efficiency sol. (%)	90	90

Source: DIAS e DE LAMO (n.d.).

80 and 146 US$/toe, while for diesel, gasoline and alcohol, these costs were of 327, 436 and 237 US$/toe respectively. SALOMON *et al*. (2008) report a cost of 0.013 US$/$Nm^3$ when considering the external use of the byproduct as a fertilizer.

Recent technological developments in bio-digesters must be considered, as is the case of the Internal Circulation Anaerobic Reactor – IC for its ingenuity and simplicity. This reactor consists of a vertical cylindrical tank with height from 16 m to 30 m and small surface area. Like the UASB, the byproduct enters from below and comes out the top of the reactor, however with two phase separators (gas-liquid). A comparison between the UASB and IC concepts may be made using the data of the Table 3.

According to the same source, the IC anaerobic reactor has the advantages of smaller susceptibility to organic overcharges, temperature shocks, toxic products, smaller soda consumption in function of the pH through internal recirculation, smaller occupied area and principally smaller implementation cost. In the same article it is mentioned that 70 reactors have been installed in Brazil and another 340 in the world, of which 21 in bio-ethanol industries.

It is fundamental that the new reactors have low implementation cost, are robust, operate in a way that tolerates possible variations in the load composition and have good economic viability in order to be adopted by the plants. It is also important to note that the energetic reality is very dynamic and that, from 1995 onwards, there has been great variation in prices of energy products in the international market. So, any analysis should consider historical series and, as far as possible, try to forecast future tendencies, both in international oil price as in the Brazilian industry itself. It is important to discuss once again the viability of vinasse bio-digestion, considering the price of diesel oil practiced internally, the energy and environmental advantages of using the methane gas from vinasse bio-digestion.

The energy value of biogas, combined to the pollution reduction by the anaerobic treatment, makes bio-digestion a process which deserves continuity in research and in application. This is particularly interesting for the sugar-ethanol sector which seeks to minimize environmental impacts, reduce the use of fossil fuels and sugar and ethanol production costs.

After bio-digestion the byproduct still has potassium, as well as a higher level of nitrogen, which means it has a high value as a fertilizer. This question should be considered as a positive externality when calculating the cost of biogas.

Vinasse Combustion or Incineration

Direct combustion or incineration is a technology which allows almost complete disposal and definitive elimination of the polluting potential of vinasse. In spite of these advantages, there aren't records of recent experiences, especially related to sugarcane vinasse.

The idea of burning vinasse is possibly closely related to burning of black liquor, effluent in the paper production process (kraft method) (MERRIAM, 1982). In that process, the black liquor is incinerated or burned in recovery furnaces, as they recover salts present in the liquor. Hence, the incineration of the black liquor has the following purposes:

- elimination of the byproduct and, therefore, its polluting power;
- economical recovery of the salts;
- improvement of energy use.

With vinasse, the advantages would be the same, with the difference that the element to be recovered is basically potassium which a fundamental element in fertilization used in the production of sugarcane and its has high economic value and is the main economic justification of fertirrigation.. In this way, by burning or incinerating vinasse, the salts could be recovered and used as a fertilizer with the advantage of reduced transportation cost.

However, there are few experiments with sugarcane vinasse combustion. For example, in the technical literature works by NILSSON (1981), SPRUYTENBURG (1982) and CORTEZ and BROSSARD (1997). These works refer to concentrated vinasse, but without additives and also to the concentrated vinasse emulsions mixed to conventional liquid fuels, such as diesel oil and fuel oil. Athough vinasse incineration technology was presented as commercially viable by two companies in the early 1980s (ALFA LAVAL and HCG), currently there are still no commercial project in operation.

Thermal conversion of a fuel is connected to its nature and physical-chemical characteristics. With vinasse, the main problem in burning is related to the large quantity of water which makes it a product of very low calorific value and thus the first thing is to reduce its water level. The issue of vinasse concentration is discussed below.

However, what is debatable is to which point or which level of solids is it economically interesting to concentrate the vinasse. Burning tests already held, and shown below, considered that the vinasse, when showing a level of solids above 60%, already has a sufficient calorific value to burn. This concentration sould be considered a "good compromise" between good fluidity (relatively low viscosity), still allowing reasonable atomization of the vinasse in conventional boilers; also that no large amount of energy is neded for its evaporation.

However, tests conducted by POLACK *et al*. (1981) and by CORTEZ and BROSSARD (1997) did not result in successful results, most probably due to the inadequate fuel for the burning method. To continue to use atomization as burning technique, it was chosen to work less concentrated vinasse (40%) and mixed with fuel oil. This would ensure an even lower viscosity associated to a much higher calorific value of the mixture.

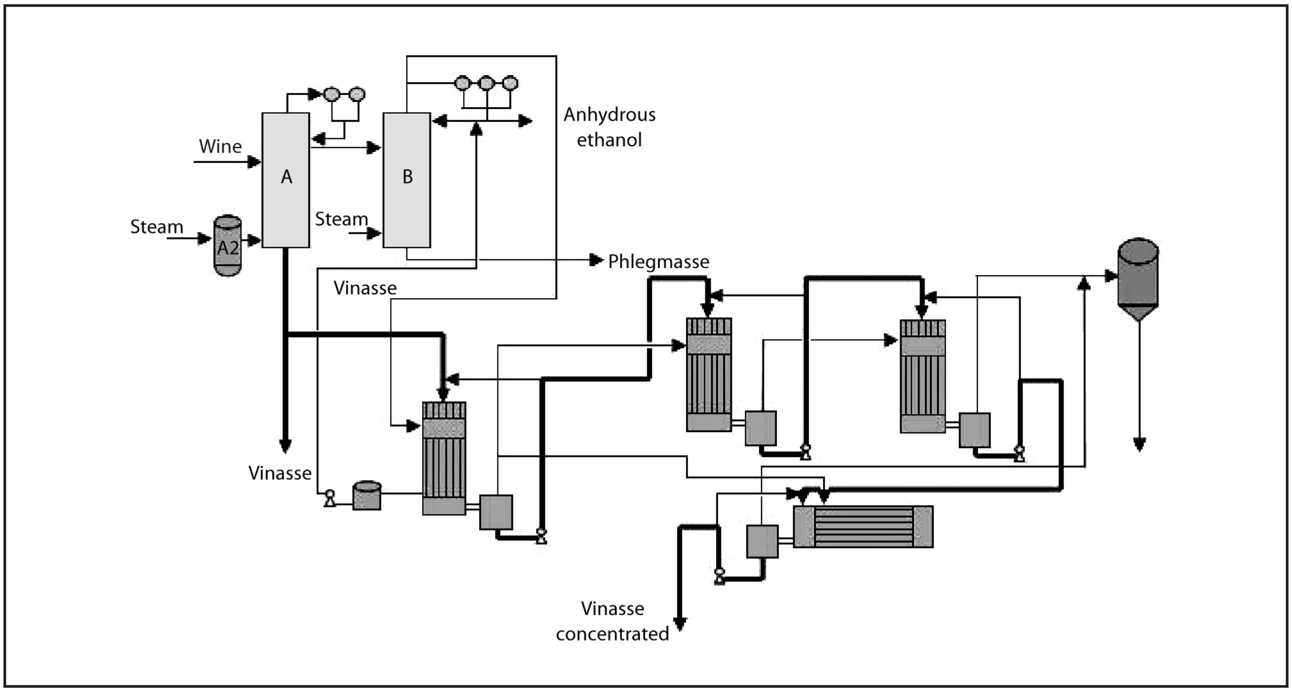
DEDINI commercializes the technology developed by Vogelbush for vinasse concentration (Figure 6), to operate fully integrated with the distillery.

Methods for Vinasse Burning

Among the known technologies for burning liquid fuels, atomization is, probably, the extensively used. However, atomization is not much used for fuels such as oils, which have a higher calorific value and practically only volatile carbons, making its combustion very easy. Atomization of vinasse represents a challenge, as its rheological characteristics change a considerably as concentration of solids increases, compromising therefore, a good atomization and consequent combustion.

There is also, however, burning technology using a fluidized bed reactor. This technology is employed in the burning of viscous products, such as remaining of liquid foods (e.g. soups), paste byproducts which show difficulty in breaking into small particles through atomization and also require, like vinasse, a very efficient thermal contact for burning.

GUPTA *et al*. (1968) were probably the pioneers in using the fluidized bed burning technology for sugarcane vinasse. The vinasse was prepared



Source: OLIVÉRIO (2005).

FIGURE 6 DEDINI/Vogelbush process of vinasse concentration.

at 30 to 40 ºBrix and burned at 700 ºC. A similar process was described by DUBEY (1974) using vinasse and pulp burnt together.

WHEELER (1976) pointed out some advantages of the fluidized bed technology and estimated in a few million squared meters the heat transference are in a reactor with only 1m diameter and particles with granulation smaller than 1mm. The same author stated that vinasse may be burned in this type of reactor with a level of solids between 30% and 35% without the use of auxiliary fuel. Finally the author proposes an incineration system for vinasse based on the fluidized bed technology. The system proposed was designated Copeland Fluidized Bed System. The installed cost of the unit was of US$ 500,000 for about 22,000 liters of vinasse/day, producing 160 kg of ash/hour.

It is considered, however, that just as important or perhaps more than the burning method, are the fuel characteristics. The German company SAAKE is developing a burner for fluids with characteristics similar to vinasse, which it plans to sell in Brazil, where it is carrying out tests for this vinasse burning technology.

Characteristics of Vinasse as a Fuel

Among the most important properties for characterization of a fuel are the calorific value and the quantities and the proportion of fixed and volatile carbon. These characteristics may be evidenced when making elementary and immediate analysis of this fuel.

CORTEZ and BROSSARD (1997) presented values of the volatile carbon level for fresh and dry sugarcane vinasse, of 48.67% and 69.31% respectively. The vinasse in question was obtained from HTM – high test molasses, fermentation of the Shepherd Oil distillery in Mermentau, LA, USA. Even though these values do not represent average values for the Brazilian distilleries, they indicate that the samples had a good potential for its energy application through combustion/incineration.

The calorific power of vinasse strongly depends, as was expected, on the vinasse concentration. The values published by KUJALA (1979) were of 7,800 kJ/kg for vinasse with 45 ºBrix molasses. According to the same author, the value for completely dry vinasse has a calorific power of up to 14,390 kJ/kg.

However, when dealing with mixtures or emulsions with fuel oil, the calorific power will depend not only of the level of solids in the vinasse, but also the proportion of vinasse to oil used.

Another important parameter in combustion is the adiabatic flame temperature of the fuel, also known as theoretical temperature of the flame. This parameter, strongly dependent of the fuel composition, was calculated by CORTEZ and BROSSARD (1997) for the vinasse obtained from the Shepherd Oil distillery. Using an air/fuel relation of 7.621 kg of air/kg of dry fuel without ashes, the values are of 700 °C for vinasse with 50% solids and 793 °C for vinasse with 60% solids.

History of Vinasse Combustion

The first tests found in the literature were published by KUJALA *et al*. (1976), of the Swedish company ALFA LAVAL. However, since World War I, the company Whitaker and US Industrial Chemicals Inc. developed the Porion furnaces. Next, REICH (1945) proposed a vinasse concentration in evaporators of quadruple effect up to a level of solids of 70% to 80% with subsequent combustion at 343 °C and recovery of the potassium in the ashes.

The same principle was used in Lucknow, in India, by CHAKRABARTY (1964) in the distillery Dyer Meaking Breweries Ltd. when a pilot plant was built to recover the potassium salts from the vinasse obtained in the alcohol production from molasses. In Brazil, it is known that two incineration plants were installed in Pernambuco more than 50 years ago, but were closed afterwards for economic reasons (D'ANDRADA, quoted by MONTEIRO, 1975).

The Dutch company NEM Bv states it has been researching vinasse combustion since 1947. According to the company, a special burner, a combustion chamber and atomization equipment have been developed and extensively tested in pilot plants. After many successful experiences on real scale, the concept was additionally improved and optimized. In 1986, the company introduced a new concept based on the installation of two boilers in the Bangyikhan distillery, in Bangkok, Thailand. Each one of these installations had processing capacity of up to 6 ton/h of concentrated vinasse, while producing 15 ton/h of saturated vapor. Both incineration plants had satisfactory operation during 12 years.

The NEW Bv system consists in the following phases: preparation of vinasse (concentration), incineration, heat recovery, energy generation and ashes recovery. Vinasse with 10% solids goes through an evaporator where it is concentrated to a 60% level. It is then pre-heated to 90 °C and, only then, follows to the incinerator.

In July 1981, the HCG company installed in Bangkok, Thailand, a sugarcane vinasse incineration plant. The distillery produced 90,000 liters of alcohol/day and 1,000 m^3 of fresh vinasse/day. The vinasse was then evaporated in multiple effect Vogelbusch evaporators and burnt with 60% solids. The HCG company also claims to have installed a second incineration system at the same plant for a 180,000 liters of alcohol/day distillery.

The Swedish company ALFA LAVAL also published (NILSSON, 1981) results of a joint-venture with Finnish company A. Ahlström AB, specialist in combustion, which indicates the technical and economical viability of vinasse combustion. In the published works the use of the swirl combustion technology for burning of 60% solids vinasse is mentioned.

In spite of the referred texts indicating technical success in the experiences held, there is lack of information as to how they were conducted. This fact is verified also in the works published and contacts made by companies such as ALFA LAVAL and HCG. This lack of information hinders the adoption of the combustion technology which could be converted into an important alternative for vinasse disposal.

Another procedure tested to incinerate vinasse were the tests held between 1984 and 1987 in the Combustion Laboratory of the Mechanical Engineering Department of the Louisiana State University, in Baton Rouge, LA. USA.

The combustion experiments held varied the vinasse and fuel oil proportions. The proportions were used in a way to initially burn only fuel oil and, after that, increasing quantities of vinasse in the mixture, (10%, 12.5%, 15%, 25%, 40% and 50%). However, more studies by combustion and salt recovery specialists are necessary, as well as a technological development in the same way as happened with black liquor burning in the paper industry.

Vinasse Concentration

In the State of São Paulo, the São Paulo State Environmental Agency – Cetesb implemented in 2005 the Normative P 4231, regulating the use of vinasse, limiting dosages that may be applied due to the cationic exchange capacity – CEC and the levels of potassium (K) in the soil. There are already deadlines for the canals and reservoirs to be made impermeable. In the soil, if the K saturation in the CTC is greater than 5%, the norm allows only the use of the dose which shall be consumed by the sugarcane in the year in question.

With this regulation on vinasse use, many areas will suffer restrictions, and the sector is already preparing to transport the vinasse to longer distances. One of the solutions being studied is vinasse concentration.

Vinasse concentration is made by removing water. The most conventional or well known way is evaporation by adding heat. However, there are other processes which may be used, but which still need research and development to adapt them to the system, making them more viable, both from the economic as the technical point of view.

Reverse osmosis consists in applying in the more concentrated solution a mechanical pressure that is greater than the osmotic pressure, obliging the solvent to go the inverse way. This technique could be applied to the vinasse concentration. However, the cost of this treatment is considered high.

Usina Santa Elisa, in São Paulo, installed back in 1978, a vinasse concentrating unit, acquired from the company Vogelbusch, which was hardly used due to the high energy cost. With the implementation of an electric energy co-generation system, in 1999, the vinasse concentrator started working, producing in the 2005/2006 harvest about 3.3 m^3 of concentrated vinasse per hour.

The high energy cost of vinasse concentration is perhaps its main restriction. However, the evaporated water may be recovered for industrial re-use, reducing the need for fresh water. This condensate may go back to dilute the honey in fermentation, soaking the sugar mill, and other purposes depending on the biological treatment used. Not to mention the superior quality of this water in comparison to water taken from reivers, which would bring improvements to the process.

Usina Mundial, in Mirandópolis, SP, studies this technology. The joint project with company Agrif, aims to transform 80% of the liquid part of vinasse into distilled water, reducing water treatment costs and promoting re-use of a natural resource. In addition, it also plans producing a pelletized or granulated potassium fertilizer, with the remaining solid part.

DEDINI recently announced projects of self-sufficient mills in water consumption and also in water producing units (ÁGUA, 2009). Reduction in water consumption in the mills is an old concern, as it is an important natural resource of limited supply. By adopting the vinasse concentration by evaporation system, it would be possible to recover the cane water and transform the sugarcane mill from consumer to exporter of water. This is possible, since sugarcane is 70% water in its composition. So, water may be yet another product obtained from sugarcane.

Water evaporation by adding heat must consider, in the mill's balance calculations, the availability of vapor in the correct pressure and temperature for such. As well as the need for a system to condensate the evaporated water.

Using cooling evaporating towers for vinasse water evaporation may be an option. However, the efficiency of this method must be considered in relation to the psychrometric conditions of the air. Like evaporation by heating, a cooling system to recover the evaporated water must be considered. In this case, due to the vapor condition of the water, condensation requires cooling to temperatures below dew point in the air, where a refrigeration system would be necessary.

According to PENATTI (2007) and FINGUERUT quoted by PENATTI (2007), vinasse evaporation difficulty is both due to its corrosiveness and incrusting tendencies (due to the presence of salts) as for the difficulty in thermal balance, that is, availability of vapor with adequate pressure and places to integrate the low-pressure vapors or water (cold currents) to condensate them.

FINAL CONSIDERATIONS

There are many methods which may be used to help solve the vinasse issue. There is no telling which one is best, as this depends on each case and what really needs to be achieved. Whether it is only to reduce the volume or also produce energy or, even, to produce water. All of these aspects are important and, therefore, must be contemplated. Many of these methods may even be applied simultaneously, for example a part of the vinasse could be bio-digested and another concentrated or incinerated. There is the possibility for energy integration of these processes, a question which should be considered further.

However, there are different points of view in respect to each technology, with each idea claiming to be the best option. The trend in R&D is that there is an urgent need to develop an *in situ* disposal technology for vinasse. It is true that there are advantages to fertirrigation for recycling or economy of fertilizers, but this technique will hardly be totally accepted in other countries or even possible in different places of Brazil which have other soils and other agronomical responses.

All things considered, the need for investment in research and development in this area is eminent, in order to develop and improve processes and, also, to eliminate certain preconceptions, considering that the environmental pressure will remain strong.

The following themes are suggested for future research:

- cooling the fermentation recipients, with integration to the processes at the distilleries;
- vinasse combustion (*in situ* disposal): concentration technology, mixture to other fuels such as pulp and biogas;
- removing the potassium from bio-digestion byproduct;
- energy integration of concentration with distillation and cogeneration;
- production of protein for animal food from vinasse;
- bio-digestion as a source of energy to dry yeast;
- definition of the relation between vinasse recirculation rate and energetic performance of concentration/combustion;
- application of the analysis of the life cycle as a comparison tool of different options for vinasse treatment and disposal;
- determining the cost of biogas, including externalities related to avoided fertilization and its use as fuel to dry yeast.

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9

SUGARCANE TRASH AS FEEDSTOCK FOR SECOND GENERATION PROCESSES

Edgardo Olivares Gómez, Renata Torres Gomes de Souza, George Jackson de Moraes Rocha, Eduardo de Almeida and *Luís Augusto Barbosa Cortez*

INTRODUCTION

The stage of development reached by the sugarcane industry in Brazil, mainly focused in the production of ethanol, has increased attractiveness in surplus bagasse through more advanced agricultural and industrial technologies, as an integral or partial recovery of sugarcane agricultural residues – SAR, basically trash, or of some of its fractions (e.g. straw and green leaves).

This vision of agro-industry development is innovative in its implementation and it could increase the gains through an important increase in energy production, based on a thermo chemical process e.g. cogeneration in the electricity, or a biochemical process to produce ethanol, in addition to many direct or indirect by-products, without additional increases in the area of sugarcane plantation. This new concept known as "integral use" will improve current productivity of ethanol per hectare of sugarcane, increasing the overall production of renewable energy during the phase of ethanol production while reducing environmental impacts.

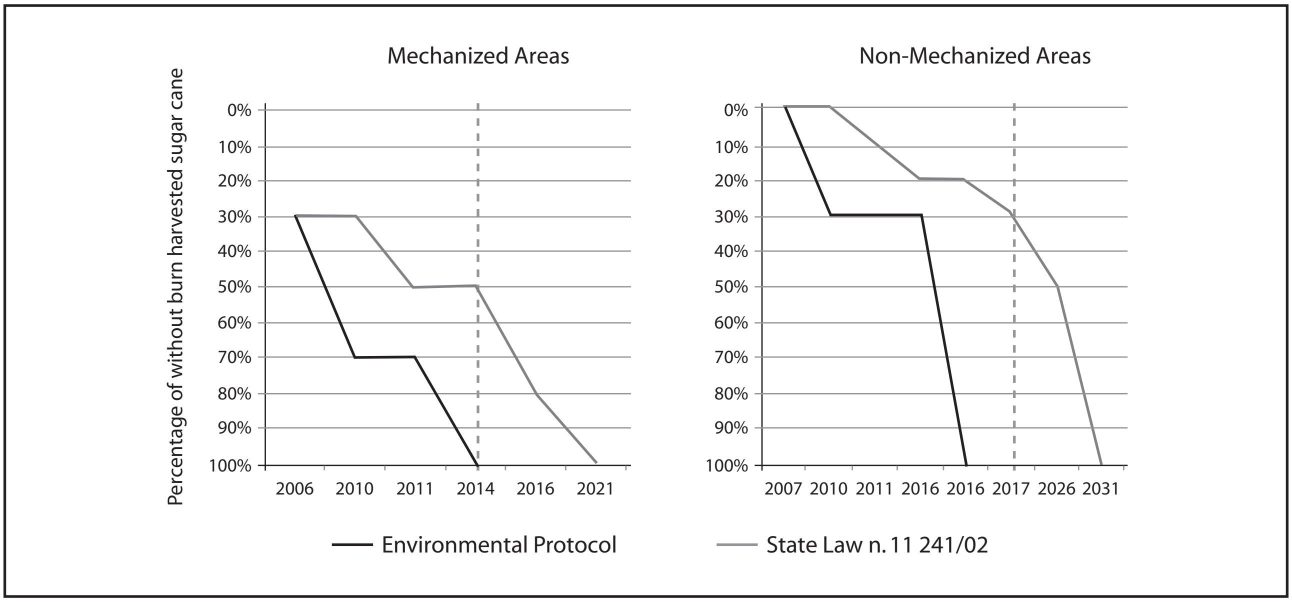
The lignocellulosic raw materials obtained as a result of the crop and the industrial processing of the sugarcane during the production of sugar and ethanol (bagasse and general residues – SAR) shows a high potential for energy production, can be obtained through conversion technologies based on biochemical routes (hydrolysis) and termochemical (combustion, pyrolysis and gasification).

By 2031 the whole sugarcane trash generated during harvesting in Brazil could be available for recovery and subsequently used. Methods of sugarcane crop and trash usage should be implemented by that time economically. At the time, cleaning systems, with recovery of straw should also be part of the industrial package of the sugar and ethanol mill. Sugarcane trash should become as important as bagasse, as a feedstock for the production of fuels and chemical products.

This chapter aims to contribute to recent thinking of how best to use sugarcane residues – SAR, based on the expectation of generation of large amounts of lignocellulosic biomass, which should be available in the next years; and partly due to law enforcement prohibiting cane burning in Brazil. This chapter assesses the technical and economical evaluation of some possible ways to utilize sugarcane residues. It discusses sugarcane residues and the main physiochemical and energy characteristics. It also considers the usage of these materials focused on the generation of energy through combustion. The base for such discussions are results obtained from research accomplished undertaken at universities, research centers and private sector primarily in the sugar and ethanol mills.

THE LAW OF SUGARCANE BURNING IN BRAZIL – TRASH HARVESTING AND RECOVERY

In Brazil, when sugar and alcohol began to be produced in a large scale producers found sugarcane burning as the easier solution to increase the yield by manual harvesting.



Note: Mechanized areas have slope less of than 12%.

Source: Adapted from UNICA, 2007.

FIGURE 1 Phasing out trash burning in the São Paulo State.

However, aware of the environmental damage caused by burning this situation is changing as a result of public pressure, and even through trade unions and other associations, sanctioning laws aimed to control or phase out burning.

At the federal level, sugarcane burning is regulated by Decree n. 2 661/98, which concerns mainly with phasing out burning in areas where harvesting can be done mechanically.

The São Paulo State Law n. 11 241/02 is more restrictive than federal laws, and aims to phase out burning both in manually mechanized harvested areas. The law aims at phasing out burning in non-mechanized and mechanized areas by 2021 and 2031, respectively. Within this context, the São Paulo State signed, in June 2007, a cooperation protocol between the State Government, the Department of Agriculture and Supply and the Union of Sugarcane Industry – UNICA. This was a major step toward for ending sugarcane burning, putting forward previously agreed deadlines set by state law (Figure 1).

It should be noted that this protocol has been signed by 155 mills located in the state, representing 90% of the sector in São Paulo, and over 24 sugarcane supplier's cooperatives (UNICA, 2009).

It is also worth noting that the São Paulo State is leader in this sector e.g. in 2007 produced approximately 60% of sugarcane planted in Brazil, compared to the second larger producer, Paraná State, with about 8% (IBGE, 2009). Other states, such as Goiás and Mato Grosso, there are also similar initiatives to phase out sugarcane burning (BNDES and CGEE, 2008).

Therefore, we can say that in a short period of time, there will be availability large amounts of sugarcane trash; there are two main options available, not necessarily exclusive: i) leave sugarcane trash in the field or ii) recover it as a raw material for of fuels or chemicals.

Sugarcane trash in the field

Regarding the effects of trash[1] left on the field, CALDEIRA (2002) pointed out the positive aspects to the soil, in terms of erosion control, moisture retention, improved biological, chemical

[1] Trash is material left in the field after harvesting; this is particularly the case with mechanical harvesting. Trash, consists of green and dry leaves, tops and fractions of stems, roots and soil particles attached to them (RIPOLI, 1991).

and physical properties arising from decomposition of crop residues on the soil surface.

On the other hand, FRANCO (2003) citing CALDEIRA (2002), emphasizes that leaving the trash in the field can cause problems such as delay in the budding due to the lower incidence of light, coupled with an decrease in soil temperature and humidity with consequent spread of disease, immobilization of nutrients, especially nitrogen, which can affect the yield; difficulties in operating machinery for implementation of cultural practices, operational problems, causing injuries and loss of stumps, and higher incidence of pests,a among other problems.

To minimize problems associated with sugarcane trash, studies have been carried out to assess the optimum amount of trash that should to left in the field. HASSUANI *et al*. (2005) recommended that about half of the trash be kept on the ground to reduce erosion, recycle nutrients and maintaining a minimum level of moisture in the soil. The documents on sustainability organized by CTC (2005) recommend the amounts of trash be between 7.5 and 9 t/ha to promote an efficient control of the most common herbs. Species that do not depend on light or change in soil temperature for germination are not controlled by trash. Following are recommendations concerning maintenance or removal of trash on the soil according HASSUANI *et al*. (2005). The trash should be removed in the following situations:

- In areas inhabited and/or near to roads due to the risk of accidental or criminals fires.
- In areas subject to risk of electrical storms (relief tops).
- Before preparing the soil, in areas suffering from soil pest infestation, requiring the complete removal of culture wastes.
- In areas of very wet winter, especially in soils with poor drainage that affect sprouting.

Trash may be removed after a technical-economic analysis in the following cases:

- In places with planted varieties whose sprouting failures are caused by trash cover.
- In areas with high infestation of pests favored by the trash in the absence of effective biological control.
- In places where the soil tillage cannot be used by the occurrence of uncontrolled plant infestation by trash or soil pests whose control depends on the soil movement.

The trash may be partially removed in the following cases:

- During or after sugarcane harvesting leaving the total amounts of trash (> 7.5 t/ha) evenly distributed aiming to produce the herbicide effect.
- In a region of approximately 60 cm above the rows of sugarcane varieties with low ability to sprout under the trash and subject to loss productivity.

The study organized by CTC (2005) concludes that trash removal can be an advantage or disadvantage depending on the agronomic conditions involved, and should be balanced, depending on specific situations and overall costs and benefits involved.

Trash recovery

Currently, the widespread use of technology for harvesting chopped cane may also allow trash recovery by two ways: recovering the trash in the field during the harvesting operation by harvester extractor, or full harvest recovering where the trash is processed by the harvester, with industrial stems and loaded later on trucks for subsequent transport to the mill (CORTEZ *et al*., 2008). Thus, in the short term the following trash recovering routes can be considered: in bulk, chopped bulk, densified and baling, and integrated harvesting.

In bulk

In traditional sugarcane harvesting, most trash is separated from the stalks by the harvester, through the pneumatic separation principle. The stalks and trash are thrown into a cleaning chamber in which there is an updraft generated by an axial flow extractor. With respect to the previously cited extractor, known as primary extractor, when programmed to operate in maximum rotation it separates most of trash and removing impurities from biomass, and then releasing them on the field. The trash and other impurities that are not removed, along with the stalks, are conducted to an elevator installed at the end the secondary extractor. In this extractor, the biomass undergoes a second process of separation and material that was not cleaned by secondary heavier extractor, is discharged into a transshipment located beside the harvester. The trash and other impurities that were separated by the secondary extractor are then laterally thrown out and left in the field. The secondary extractors are located at on top of discharge of the stalks, and then the separate impurities are released after the line where the transshipment is traveling.

It is possible to adjust the traditional sugarcane harvester with a duct that directs the separated material by a secondary extractor to a transshipment that would move alongside the transshipment of stalks and other materials not separated by the secondary extractor. Once reached processing location, the trash needs to be unloaded, cleaned, stored and forwarded to processing.

The main difficulties of this route is cost because raw trash density is about 60 kg/m^3, which leads to high transport costs even for short distances between crop and mill, unless cogeneration becomes economically more attractive.

Chopped in bulk trash

CORTEZ *et al.* (2008) state that when chopped in bulk the trash left on the soil undergoes a natural drying process and then it needs to be concentrated. After this step, the trash is recovered by a forage harvester that undergoes a process of chopping to size, approximately 10 mm in terms of average size particles. Then the chopper loads the trash in a transshipment to be transported by truck at a later stage to the processing units. Once it reaches processing unit, this material needs to be unloaded, cleaned, stored and forwarded for final processing.

This system has three major problems:

- The first refers to the technological level in the field, because this route leads to a drastic increase in trash contamination by mineral impurities due to the contact with the soil after harvesting which affect the raw trash quality, independent of the chosen technology for energy generation. In addition, agricultural machinery operations could cause serious soil compaction that may affect crop productivity.
- The second problem refers to technological level in the processing units because current trash equipment used for soil removing such as rotational and vibration sieves, is very inefficient in removing impurities, especially if trash has high moisture.
- The last difficulty refers to costs due to the low density of trash e.g. about 90 kg/m^3, that makes it economically unfeasible to transport trash to long distances, considering the low price for electricity from cogeneration.

Baling and condensing at low pressure

In order to mitigate the economic costs caused by low density trash in bulk, a route was tested in Santa Elisa Energy Company with a condensed cotton press system (LIMA, 2002).

In this mechanism, after receiving the chopped trash, the transshipment feeds the cotton press in the field. MICHELAZZO (2005) reported that the transshipment has a metering conveyor moved by a hydraulic motor to uniformly supply the press. Subsequently, the press operates in an intermittent consolidation process of low pressure in stationary units, where the own bale weight, due to its large size, ensures higher density. The bale is then transported by a special truck to the mill.

During the baling operation, the trash is recovered by the baler, at low pressure and mooring after, because the bales may become loose again. The bales are then released by the baler and left the field to be later loaded and transported to the processing unit. After transporting to processing unit, the condensed or baled raw material needs to be unloaded, unpackaged, cleaned and sent for processing.

Other the technological problems are very similar to those described in the case of chopped trash recovery in bulk: a large amount of mineral impurities is brought to the process unit, and thus it is important to solve these problems, as well as soil compaction.

Analyzing the technological difficulties facing the mill, the task of baling and compacting remains unfavorable when compared to recovery of chopped trash in bulk, because there is at least one further step that the mill needs to take, that is, uncompacting and loosing up the raw material. This is even more critical because bales are often kept together by strings, which can cause problems when processing the feedstock.

In mills that have tested this system, the bale is uncompacted with a knive chopper, which normally has high costs caused the need to change the knife and high energy consumption because its high horsepower; and also because limitations in losing up the bales to sizes that do not cause problems in traditional boiler feeders.

As far as economics go, this alternative has greater potential to enable transport to longer distances between cane fields and processing unit, as the bales density may reach up 200 kg/m^3. However, it is important to keep in mind baling or condensing operations are responsible for a significant cost in raw material.

Whole harvesting

In order to promote trash recovery during whole harvest, the harvester must operate with the prime and/or secondary extractors working partially (on and off). The prime extractor has a rotational speed control, unlike the secondary extractor that has only on-off control.

In this system the biomass unloaded at the mill feed table has the same components as sugarcane fully harvested under normal harvest conditions, such as stalk, leaves (green and dry), stumps, palm and mineral impurities. The only difference is when the extractors are off or working partially and thus the amount of trash in the mill will be higher and needs to be separated in the mill's receiving sector to avoid damaging extraction.

There are two well known industrial systems in Brazil able to perform the separation of sugarcane with light impurities (trash + soil) on an industrial scale (a feed table system, of approximately 450 tons of biomass per hour in a normal harvest). In both systems, most of the organic impurities such as palm and stumps are not separated otherwise a good proportion of stalks would be lost before reaching the extraction process.

The physical principle used is pneumatic separation inside a cleaning chamber and then depressurizing the separated material to be retained by channels/mats and transported for processing.

The difference between these systems is significant, caused by the air flow in the biomass: the first separation system is biomass counter-flow because the fans are located below the feed table taking advantage this structure; the second step is done by the separation of biomass curtain by air – flow as the fans are located below the drive shaft of the table. Both suppliers reported an average cleaning efficiency of about 70%.

To increase the removal efficiency a second air separation can be used between mats, or the adoption of mechanical cleaning by rotating brushes endowed with stalks to remove minerals and impurities adhered to cut sugarcane stalks.

SCHEMBRI *et al*. (2002) tested the efficiency of a cleaning system developed by SRI in Australia, which also uses the pneumatic separation as physical principle. The test results indicated that the cleaning efficiency of the system is affected by the mass flow of air applied to the biomass and the moisture content of the biomass when feeded.

Costs of trash recovery and transportation

FRANCO (2003) citing RIPOLI *et al*. (2003), argues that what is intended with trash recovery studies is to obtain information on two key issues: which system has the lowest cost per ton and what is the percentage of soil impurities in the trash at the mill. However, the authors believe that the most important issue is the energy cost of the trash and which system has better energy efficiency. This may occur because, although the cost per ton of a particular recovery system can be lower, the overall energy cost may not present any advantage.

TABLE 1 Technical parameters of cutting, loading and transport.

Trash (Mg, dry basis)	Reference	Rote 1	Rote 2	Rote 3
Amount of trash in the canefield	180,697	180,697	180,697	180,697
Trash transported with cane	43,909	43,909	170,759	127,934
Trash left in the field after harvesting	136,788	136,788	9,938	52,764
Baled trash	–	114,902	–	–
Trash left in the field	136,788	21,886	9,938	52,764
Trash removed in the cleaning station	–	–	119,531	89,554
Total trash available at the mill	–	114,902	119,531	89,554

Source: Adapted from HASSUANI *et al*., 2005.

Based on these observations, the Sugarcane Technology Center (CTC) published (see HASSUANI *et al*., 2005) a balance sheet of trash recovery costs of three studies. The chosen routes were:

1. Green sugarcane harvesting (unburned cane) with connected harvester fans, leaving all trash on the field for later baling (Route 1) – (Reference Route).
2. Green sugarcane harvesting with disconnected harvester fans, and collecting all trash together with sugarcane, for later separation at the cleaning station (Route 2).
3. Green sugarcane harvesting with disconnected secondary harvester fans, collecting only part of trash together with sugarcane, for later separation at the cleaning station, and the rest left on the field (Route 3).

The results found in experiments carried out by the CTC are shown in Tables 1 and 2.

MICHELAZZO (2005) studied various ways of transporting trash whose results are shown in the chart (Figure 2).

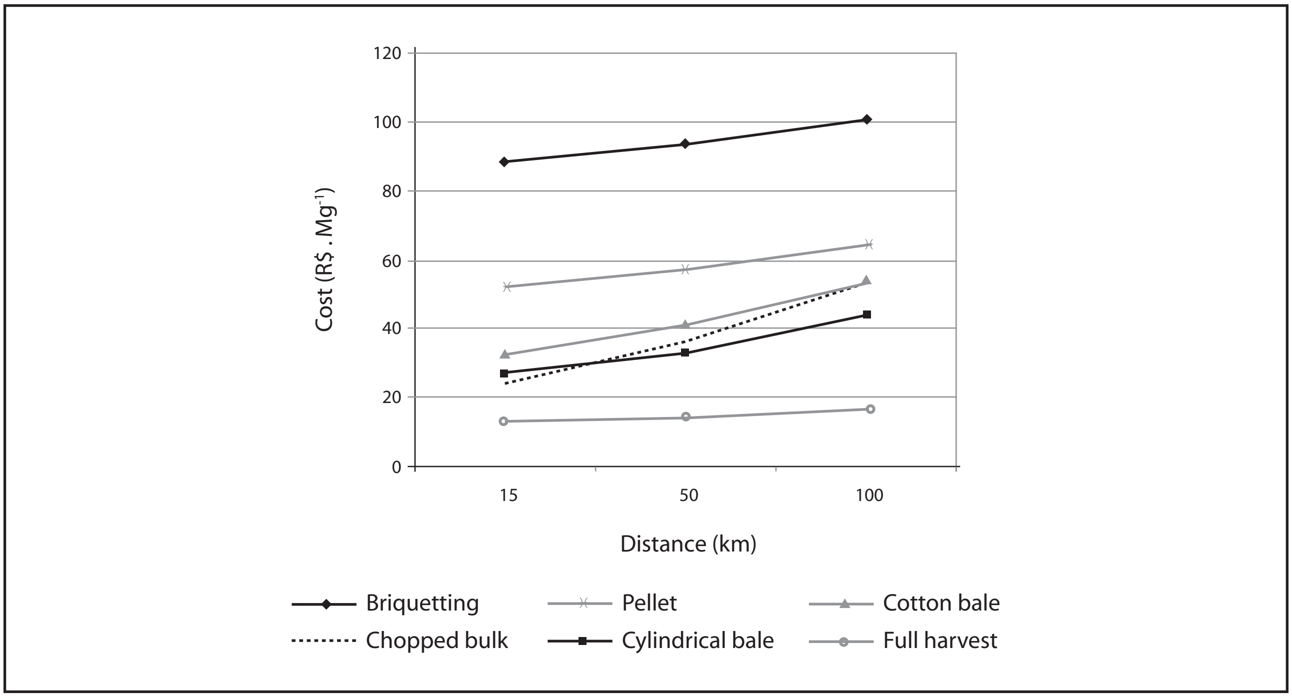
From Figure 2, MICHELAZZO (2005) concluded that transport distance has a major influence on the cost of trash recovery, as increases significantly with transport distance. He concluded that the type of system use should be based on the distance from where the trash will be collected.

TABLE 2 Trash total cost.

Items	Rote 1	Rote 2	Rote 3
Trash available in the cane field (Mg db/year)	180,697	180,697	180,697
Trash recovered (Mg db/year)	114,902	119,531	89,554
Recovery efficiency (%)	64	66	50
Cost of trash (U$$/Mg db)	18.49	31.12	13.7
Cost of trash (U$$/GJ)*	1.06	1.79	0.79

* HHV, dry basis.

Source: Adapted from HASSUANI *et al*., 2005.



Source: Adapted from MICHELAZZO, 2005.

FIGURE 2 Estimated costs of trash recovered in various systems, for distances of 15,5 and 100 km.

Various systems can be used, in accordance to the distance to be transported and the trash purpose.

If the trash is intended to generate energy, and production areas are located near the mills, a good option would to recover the trash with chopped or whole harvesting that has lower costs (MICHELAZZO, 2005). However, if the trash to be recovered is produced far from the mill and its purpose is to sell to third parties (i.e. as poultry litter or mulch) the baling systems would be more appropriate.

Trash impurities

The main impurities present in the sugarcane are soil particles, according to FRANCO (2003), citing BRAUNBECK and BIANCHI (1988) and SARRIERA (1997); the main factors influencing the presence of soil impurities are the methods used for loading and recovery e.g. type of harvester, soil type, sugarcane variety, level of exudation, number of sugarcane cuts, loading, to load the trucks, among others. FRANCO (2003) citing RIPOLI *et al.* (2003), points out that the attached soil in the remaining crop after harvesting is mainly due to the action of basal cutting discs and harvester ventilation systems, which lead to the accumulation of soil particles, making them one of the trash constituents given the nature of trash in the ground. Then, depending on the type of recovery used, the amount of soil can be minimized or increased. RIPOLI (2003) studied three trash recovery systems and found that 4.5% of soil was in the recovered trash in bulk, 1.39% occurred during whole harvesting and 0.63% in baled trash. Finally it is noted that in the literature no studies were found on "tolerable levels" of impurities caused by use of machinery that could be transported with the trash, to ensure this material does pose any problem in the distillery.

DEFINITIONS, CHEMICAL AND MORPHOLOGICAL CHARACTERIZATION OF SUGARCANE RESIDUES – SAR

Solid materials, specifically those obtained from agricultural or industrialized biomass, be it in its natural form or resulting from any process of physical or chemical nature, are composed by a large amount of particles which may have different shapes and sizes and have specific physical characteristics (CORTEZ *et al.*, 2008). Under these circumstances the material is found in polydisperse shape, i.e., it is formed by a mix of physically different particles.

In order to obtain an effective performance of any polydisperse solid material it is crucial to master the physiochemical and energetic characteristics of the particles of the material. On the other hand, it is also necessary to understand the aerodynamics (or fluidynamics) of the particles movement on the equipment, where solid particles of polydisperse biomass, in two-phase systems and others, are worked on. That leads to the calculation of the final speed of the mix of the particles, of some fractions of the mix, or even a single isolated particle, with the aim to know the aerodynamics conditions and the drag force phenomenon which might influence the expected results.

In this case, aspects of the physiochemical, energetic, and fluidynamics characterization of the stover fraction, or of a mixture of leaves and straw without differing any kind of particle present in the agricultural residues of the sugarcane, is questioned. The morphological characterization is monitored have consistently proven that, in some cases, positive correlations have been observed between the results of the physical-chemical analysis and the SEM analysis, demonstrating how important it is for these analytical techniques to be available in research centres and universities so that theoretical studies on this area are carried out in greater depth.

Sugarcane residues – SAR: green leaves, straw and trash

The approximate composition of the sugarcane *in natura* is the following:

- Stem and green leaves: 8%
- Sheath and dry leaves: 20%
- Clean Stalk: 72%

A generic definition for the Sugarcane Agricultural Residues (SAR) considers residues "vegetal residues" left on the field, in a smaller or larger amount after the harvest, and are composed of straw, green leaf, sheath, tops, stalk, including the presence of mechanical impurities, such as roots and soil. This mixture is known as sugarcane trash. Following are the definitions for each of the residues constituents.

Definitions

The definitions presented in this chapter are for the purpose of explaining the different components of sugarcane residues, specifically for analytical aims.

Sugarcane straw

Sugarcane straw refers to the dry leaves and sheaths removed from stems or stalks during the cleaning process to help the plant grow healthier. Figure 3 illustrates the constituent parts of "raw sugarcane".

Sugarcane green leaves

They refer to the green leaves located at the top of the plant, varying from 30 to 35 leaves on each tip.

Sugarcane trash

It refers to the material collected from the ground after mechanical harvesting, where a

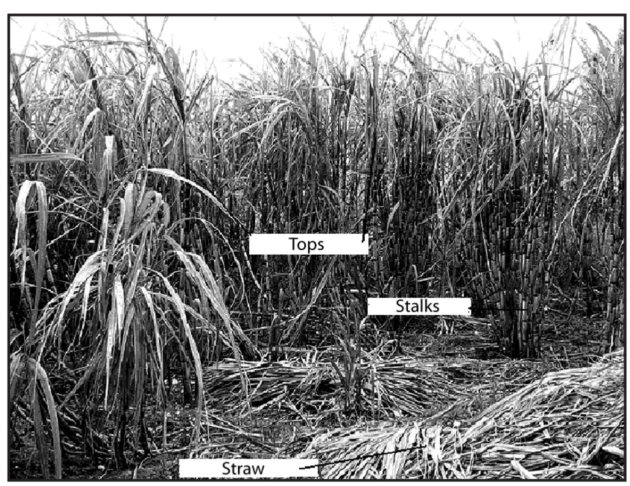


FIGURE 3 Constituent parts of the raw sugarcane at the crop.

greater concentration of a mixture of leaves and tops of sugarcane can be found. A large amount of lignocellulosic residues are left on the ground during mechanical harvesting. These residues, composed of a varied number of residual components after harvest is known as trash – basically green and dry leaves, sheath and leaves' tip, including physical impurities.

Chemical and morphological composition of sugarcane

Sugarcane straw comprises sheath and dry leaves – they have a particularly different structure from the green leaves found on the tops.

Chemical composition of the sugarcane straw

The chemical composition of sugarcane straw differs from the green leaves, trash and bagasse, mainly because the concentrations of lignin and ashes. Table 3 shows the chemical composition of the sugarcane straw.

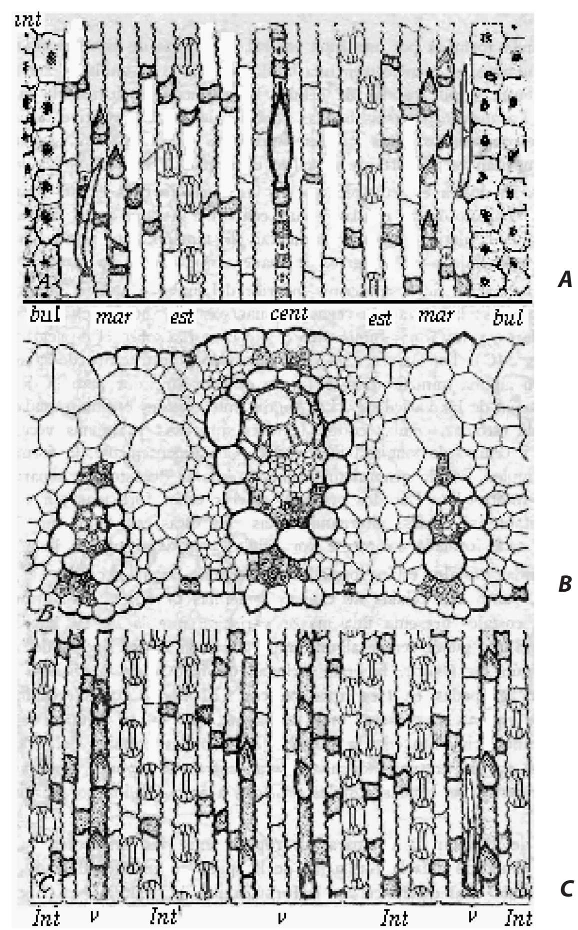
The amount of silica contained in the straw is two or three times as much as the amount found in the green leaves, causing a greater hardening and mechanical resistance in these parts of the plant. Consequently, the amount of lignin is approximately 60% smaller than those found in the green leaves. The most likely hypothesis is that the plant does not need to metabolize a lot of lignin in the straw to perform this function, since silica does the "cementing" job in its stead.

TABLE 3 Chemical composition of the sugarcane straw (sheath + dry leaves).

Constituents	% in mass
Cellulose	44.5 ± 0.5
Polyoses	30.4 ± 0.3
Total lignin	12.3 ± 0.2
Ash	7.5 ± 0.3
Extractives (Cycle-Hexane/Ethanol 2;1)	3.7 ± 0.1
Total	98.4 ± 0.3

Morphologic composition of the sugarcane straw

In terms of morphology, both the straw and the green leaves are very similar. The only difference relates to the amount of silica contained mostly in the bullate endings of the superior epidermis of the limbo or layer (or the leaf itself). Figure 4 shows a Scanning Electron Microscopy – SEM image which considers three different sections of the same sugarcane leaf (leaf in its generic meaning)



A, view of the surface of the limbo superior epidermis: ***bul,*** bullate cells; ***mar***, marginal zone with sílios of the cells and short nails; ***est***, stomate; ***cent***, central zone.

B, limbo transversal section; different kinds of epidermic cells more or less close together in category, viewed from the surface.

C, view of the inferior epidermis surface; ***Int,*** epidermic tissue which covers the intercostal region; ***v***, epidermic tissue which covers the leaf veins.

Source: DILLEWIJN, 1951.

FIGURE 4 Different sections of a sugarcane leaf.

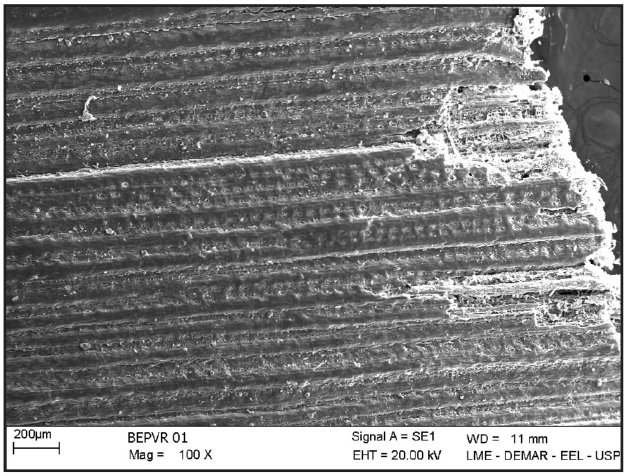


FIGURE 5 Inferior epidermis of the sugarcane leaf: image amplified 100 times, showing, at the top right-hand corner of the sample, an inner region of the leaf which was damaged during sampling, as well as the leaf veins and the stomata of the limbo.

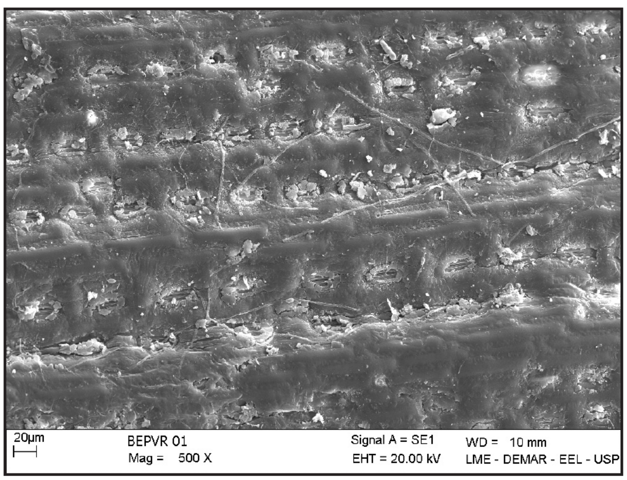


FIGURE 6 Image amplified 500 times: the inferior epidermis of the sugarcane leaf in which the leaf veins and the stomata stand out.

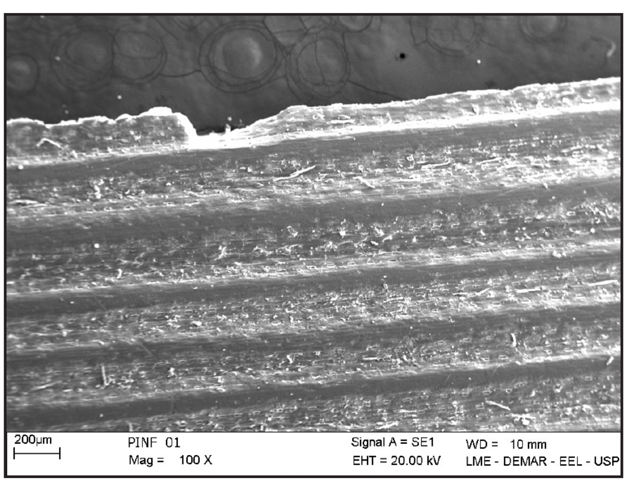


FIGURE 7 The sugarcane inferior epidermis: amplification of 100 times, standing out the most prominent veins.

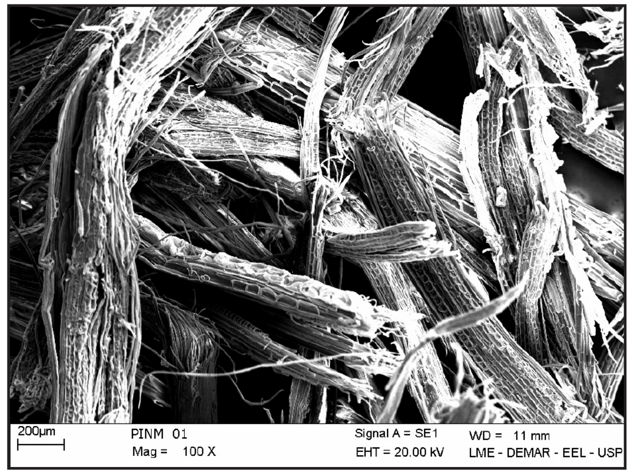


FIGURE 8 Micrographics of ground sugarcane leaves: panoramic picture amplified 100 times.

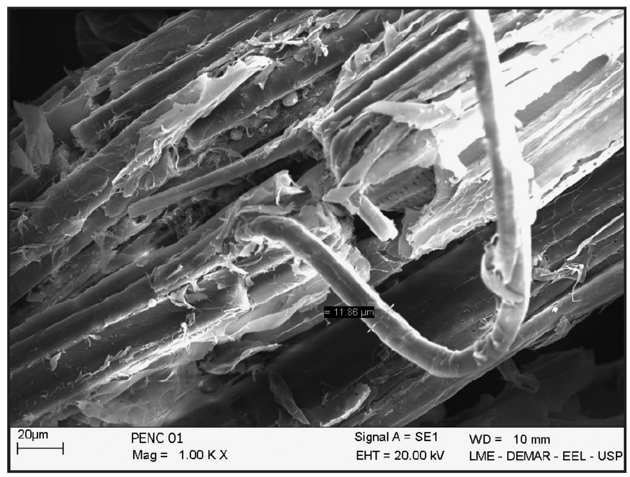


FIGURE 9 Micrographics of ground leaf: image amplified 1,000 times, standing out a cylindrical fiber with an approximate diameter of 12 micrometers.

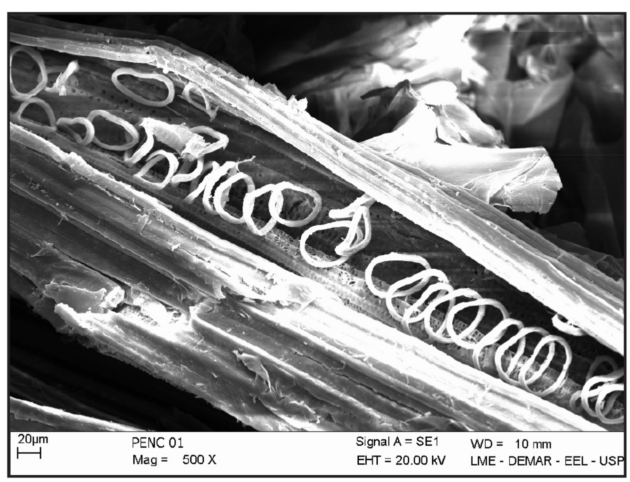


FIGURE 10 Photo micrographics of an inner part of sugarcane leaves: the elements of ring shaped vases contained in the interior of a pierced tube. Image amplified 500 times.

The photo micrographics of SEM (Scanning Electron Microscopy) presented in the following Figures – from 5 to 10, were obtained in a LEO equipment type 440, with Oxford detector, operating with a 20 Kv electrons beam, 2.82 A electrical current and I probe of 950 pA. The samples were recoated with 20 nm of gold and a Coating System BAL-TEC MED 020 metalizer and were kept in dessecator until moments before the analysis.

Chemical and morphological composition of sugarcane green leaves

The sugarcane green leaves found in their endings present a very different structure from that found in the straw.

Chemical composition of sugarcane green leaves

The chemical composition of sugarcane green leaves is shown in Table 4.

The results obtained from green leaves are very similar to those found in sugarcane bagasse as reported in literature (ROCHA, 2000; ROCHA 2005; ICIDCA, 1999), apart from the cellulose concentration in this material that presents numbers a little smaller than those found in the bagasse.

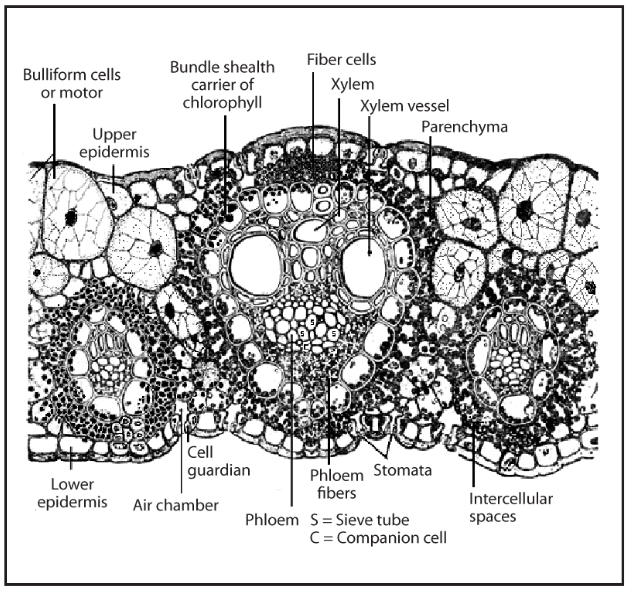
Morphological composition of the sugarcane green leaves

When it comes to morphology, green leaves are similar to dry leaves, which are compounded by layer and sheath. The green leaves are generally located in the knots, thus forming two rows in opposite sides which can be found approximately at the same level. They consist of two parts: limbo or layer (the leaf itself) and sheath, and are separated by one articulation ("dewlap", neck, leaf triangle). A completely developed green leaf is more than 1 (one) meter high. Figure 11 illustrates the transversal section of the limbo or layer of a sugarcane leaf.

Figure 12 and 13 show Scanning Electron Microscopy pictures of sugarcane green leaves with details of morphological aspects.

TABLE 4 Chemical composition of the sugarcane green leaves.

Constituents	% in mass
Cellulose	40.5 ± 0.8
Polyoses	30.8 ± 0.8
Total lignin	22.8 ± 0.2
Ash	2.1 ± 0.2
Extractives (Cycle-Hexane/Ethanol 2;1)	2.5 ± 0.1
Total	98.4 ± 0.4



Source: DILLEWIJN, 1951.

FIGURE 11 Transversal section of the leaf limbo or layer, showing a big vascular beam surrounded by two smaller ones.

Chemical and morphological composition of sugarcane trash

The trash, which is the biomass residues which stays on the field after the sugarcane harvesting, consist basically of green leaves, dry leaves, sheath, tops, stalk fractions and physical mineral impurities. It is estimated that the amount of trash remaining on the ground after raw sugarcane harvesting without recovering depends on the variety of the sugarcane, representing between 10% and 30% of the stalks. The moisture content of tops varies between 60% to 65% and that of dried leaves

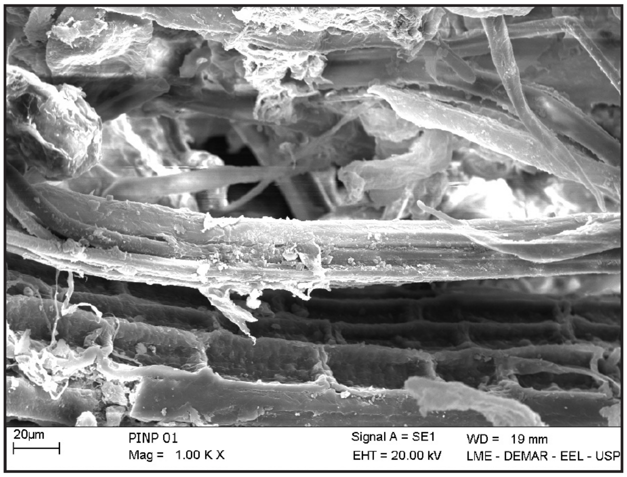


FIGURE 12 Ground green leaf microscopy: image amplified 1,000 times, showing underneath the epidermic tissue which covers the leaf veins.

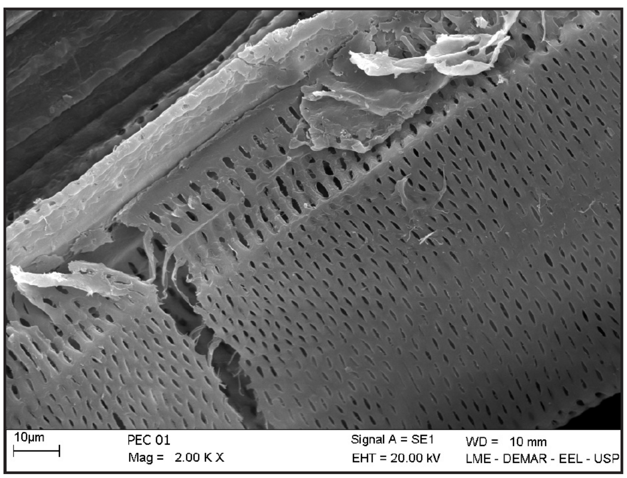


FIGURE 13 Microscopy images of a xylem vase amplified 2,000 times.

(normally let to dry on the fields) is 15%, both in wet basis.

Chemical composition of sugarcane trash

The chemical composition of the trash is shown in Table 5. It is worth noting that the material was washed prior to analysis, to remove all impurities.

The results presented in Table 5 are very similar to those found for the green leaves as shown in Table 4, proving that, in the mix of fractions of sugarcane biomass residues – SAR, the tops have

TABLE 5 Chemical composition of sugarcane trash.

Constituents	% in mass
Cellulose	40.1 ± 0.4
Polyoses	30.7 ± 0.2
Total lignin	22.9 ± 0.2
Ash	2.2 ± 0.2
Extracteds (Cycle-Hexane/Ethanol 2;1)	3 ± 0.3
Total	98.9 ± 0.3

significantly smaller concentrations than those found in the green leaves, and the tops have almost the same chemical composition.

Morphological composition of sugarcane trash

The Scanning Electron Microscopy analysis showed that the material contains a mix of elements, both in the stem and in the leaf, being very heterogeneous. Figure 14 and 15 show microscopic images of trash samples.

PHYSIOCHEMICAL AND ENERGY CHARACTERIZATION OF SUGARCANE STRAW

The physiochemical and energy properties presented in this chapter for SAR (particularly sugarcane straw) such as elementary and immediate chemical composition as well as High Heating Value, have already been published in the literature by different authors (OLIVARES *et al.*, 2008; PELÁEZ, 2007; HASSUANI *et al.*, 2005; LINERO and LAMÔNICA, 2005). Among these stand out those properties which are important in the calculations and thermal balances and thermodynamic system materials, thermal exchange surfaces, as well as in the modeling and simulation of the processes involving biomass conversion, among other processes.

The basic physical composition of the sugarcane straw considers the lignocellulosic fibers an inorganic material, mainly ash and land incorporate

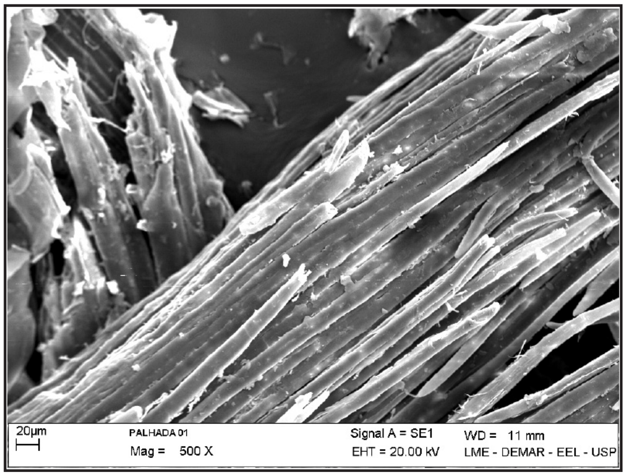


FIGURE 14 Scanning electronic microscopy of sugarcane trash: the fibers are very similar to those of the bagasse.

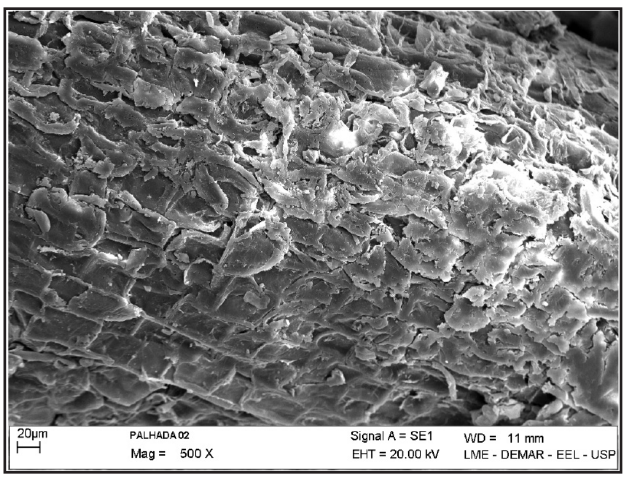


FIGURE 15 Scanning electronic microscopy showing a great number of parenchyma cells in an image amplified 500 times.

to the sugarcane during the crop process, as well as water. That is, the composition of straw ashes is largely variable depending on the criteria and agronomic practices such as the sugarcane age, the soil type, types and amounts of fertilizers used, as well as if it is influenced by other technical criteria related to the crop and cleaning procedures of the sugarcane in the dry cleaning systems which are being implemented at the mills in Brazil.

The vegetable cell of the sugarcane straw presents the same basic chemical components of the sugarcane bagasse or even wood. However, their physical-mechanics, geometric, thermal, fluid dynamics and energetic properties are different. The proportion of these properties and characteristics is important in the analysis and calculation of the project parameters and also in the operation of the hydrolysis processes, combustion, pyrolysis and gasification, influencing in variables such as processes energetic efficiency, velocity and temperature of reaction, yield, residence time etc.

When we mention the use of the sugarcane trash based on biomass obtained by dry cleaning systems, those where the sugarcane collides mechanically and it is fractioned in a pneumatic way system known as the sugarcane dry cleaning (CELLA, 2009), separating the heaviest stem from the lightest fractions, constituted by the dry leaves or straw and the leaves (still green or wet), so we can consider that the useful biomass to produce energy as being constituted just by these lighter fractions. It is this type of material that we will be calling straw, for the effects of its physiochemical and energy characterization, as well as the effects of its usage in conversion systems, unless we make some specification to identify the use of one or another lighter fraction.

The pretreatment commonly used for sugarcane straw, which is used for the production of energy or animal feed, is mainly based on the reduction of its size, may has several levels of reduction intensity depending on the specific application for what it is treated. Second Generation Technologies – SGT, seeking to add value to these materials through its mechanical or pneumatic classification, those that would allow to obtain a highly pure material and with adequate physiochemical composition for their subsequent biochemical or thermochemical conversion, are being developed.

It's normal to characterize the products or fuels obtained from biomass based on the properties which determine a specific usage. Usually the biomass used in the process to produce energy is mainly characterized according to their physiochemical and energy properties. However, the importance of more specific studies is emphasized with regard to a better characterization of these materials, which allows to identify important variables of physiochemical, biochemical and thermochemical processes.

Among the main physiochemical and energy properties of the combustible material, or lignocellulosic materials, used for energy production are the elementary analysis, immediate analysis and the high heating value. The elementary analysis supplies the fractions in mass of the atomic elements representatives of the analyzed material; they are carbon, oxygen, hydrogen and nitrogen. Other items analyzed are chlorine, sulfur and ashes. Commonly, have been used ASTM E775, E777 and E778 norms specific for wood. The immediate analysis supplies the fractions of moisture mass, volatile, ashes and fixed carbon (for difference check). In this case, has been used ASTM E870, and E872 norms specific for wood too. The high heating value – HHV of any organic material it is the maximum amount of heat produced during its combustion in perfect conditions for its burning in relation to 1 kg of solid or liquid fuel, or 1 m^3 of gaseous fuel. The difference among the HHV and the LHV is the fact of considering or not the strong condensation of the water steam present in the combustion gases.

The test standardized methods of ASTM – American Standard are the ones that are commonly used in the great majority of analyses for

TABLE 6 Approximate analysis, high heating value and low heating value of sugarcane straw samples from several authors.

Components, % d.b.*	GABRA *et al.* (2001)	PELÁEZ SAMANIEGO (2007)	LINERO and LAMÔNICA (2005)**
C	44.2	41.58	46.2
H	5.4	5.8	6.2
N	0.6	0.45	0.5
O	38.7	n.d.	43
S	0.1	0.08	0.1
Cl	0.3	n.d.	0.1

Note: n.d. – not determined.
* The sum is not necessary equal to 100% because are to missing some components.
** Analysis realized by Centro de Tecnologia Canavieira – CTC – Brazil.

TABLE 7 Elemental analysis of sugarcane straw samples from several authors.

Proprierty, % d.b.	GÓMEZ *et al.* (1999)	HASSUANI *et al.* (2005)*	LINERO e LAMÔNICA (2005)**	PELÁEZ SAMANIEGO (2007)
Moisture	9.72	10.05	29.4	9.92
Ash	7.66	8.15	3.9	11.7
Volatiles	71.34	76.23	83.3	81.55
Fixed carbon	20.99	15.62	12.8	6.9
HHV, MJ/kg	n.d.	16.98	17.4	17.74
LHV, MJ/kg	n.d.	n.d.	15.6	16.51

Note: n.d. – not determined.
d.b. – dry basis.
HHV is the high heating value.
LHV is the low heating value.
* Analysis realized by TPS company (Sweden) from Brazilian sugarcane samples.
** Analysis realized by Centro de Tecnologia Canavieira – CTC – Brazil.

different types of biomass. Correlation methods are obtained, in some cases, developed correlating energy parameters like High Heating Value – HHV, with compositional data such as content of ashes, of volatile material, content of carbon, of hydrogen, of oxygen, and moisture.

Tables 6 and 7 show data of immediate analysis, low and high heating value and elementary analysis of sugarcane straw samples.

Table 8 shows data which make it possible to do a preliminary evaluation of energetic potential of sugarcane biomass residues – SAR, based on a comparison with equivalent petroleum (adapted from ICIDCA, 1999).

In relation to the physiochemical characteristics of sugarcane biomass residues in Table 9, it can be observed that cane residues have a content of ashes between 2 and 4 times larger than sugarcane bagasse, although its moisture content is smaller and it presents a larger relationship between the content of volatile and fixed carbon components. These parameters are, without any doubt, essential in the evaluation of the combustion process of these biomass feedstocks.

As can be observed in literature, large amount ot data by different authors on physiochemical and energy properties related to sugarcane residues – SAR. However, there are, in some cases, significant differences among the quantitative values of these properties, what sustains the hypothesis that it is still necessary to study the norms being applied for analytical determination of these properties in the case of lignocellulosic products of sugarcane.

POTENTIAL TECHNOLOGINAL APPLICATIONS FOR SUGARCANE STRAW

The energy conversion of biomass can be accomplished through different processes. Among the more studied and economically attractive so far are: direct combustion, hydrolysis, pyrolysis and gasification.

Considering each one of the processes previously mentioned, it is important to mention that, due to the technological route chosen to accomplish the conversion of straw into energy, that is, the biochemical route or the termochemical route,

TABLE 8 Assessment criteria of sugarcane straw energetic potential.

Comparation criteria	Sugarcane straw (10% of moisture content, w.b.)	Equivalent oil*
HHV, MJ/kg	17	40
Boilers and furnaces thermal efficiency	75-85	85-90
Fuel needs (in mass) for generation of the same thermal energy quantity	2.85	1

* Equivalent oil is a reference term used to its energetic comparation in relation to others fuels. Its HHV is considered to be 40MJ/kg approximately.

Source: Adapted from ICIDCA, 1999.

TABLE 9 Physical and chemical properties, experimental calculations of sugarcane straw and bagasse.

Sugarcane biomass	Physical and chemical properties, % w/w (dry basis)				
	Moisture	Ash	Volatiles	Fixed carbon	HHV, kCal/kg
Straw (in the same way that those after harvest crop)	36.34	9.22	81.83	8.95	4,774
Sugarcane bagasse	47.98	2.56	83.48	13.96	4,902.3

Source: AGUILAR *et al.,* 1989.

a simple and strong system for the pretreatment of the straw will be necessary. For instance, the hydrolysis process to obtain the ethanol will be more sensitive to the sugarcane straw pretreatment than the combustion process, pyrolysis and gasification. Although it is inevitable a physical pretreatment stage in all cases. It is also very important to remember that in the specific case of lignocellulosic material pretreatment, the operational costs involved are significantly high and different, depending on the technology.

Although there is not, as yet, sufficient fundamental and technological information on the handling processes, transport and possible stockpiling of SAR, there has been significant progress in this sense, mainly due to the emergence of potential technological markets in the following application routes:

1. *Combustion in boilers:* boilers are used with furnaces equipped with burning systems in the form of grills and/or partially in suspension. It is commonly used with cane residues in mixtures with sugarcane bagasse, or conventional fuel of these industrial units. Parallel, it is already possible to discuss today some technologies that allow to fraction and, therefore, select residue samples, systems that would allow also to introduce drying in an economical way in sugarcane mills in Brazil (ROCA, 1988; ROCA *et al*., 1995).
2. *Briquetting and torrefaction:* the compacting and briquetting process, although already very known and tested with several types of agricultural and industrial residues, in the case of sugarcane agricultural residues – SAR, has not reached satisfactory techno-financial solutions yet, at least not published, probably due to technician-financial problems related to the preparation of this material. Straw and green leaves, besides the crop processes, handling and pretreatment are still being developed, they can have considerable influence on the briquetting tests results, above all for the levels of inorganic material present in the same ones which are significantly variable, that will bring technical problems to the process. In the case of the pre-pyrolysis or torrefaction process, although they are already known and widely studied, above all in Europe and United States (BHATTACHARYA, 1990 and FELFLI, 2003), they are not widely diffused mainly in applications where it is used with residues of biomass from agricultural processes. In both cases, they are still looking for viable techno-economical solutions to overcome barriers related to the morphologic characteristics of these residues, such as moisture and ash content, as well as their wide concentration of polydisperse particles according to size and form of these particles and their low apparent density.
3. *Pyrolysis:* studies have been accomplished inside and out of Brazil with sugarcane residues physically pretreated, with the purpose to obtain bio-oil and charcoal fines, and later some chemical fractions (BEZZON, 1998; ZANZI, 2001; OLIVARES, 2002; MESA-PÉREZ, 2004; PELÁEZ, 2007). The main applications in terms of properties and composition for use of sugarcane residues pretreated in pyrolysis processes are the control of its particle size composition, moisture content, and ash and inorganic materials content in general; factors which make this material to have a low standardization and a high dispersion degree, above all physiochemical.
4. *Gasification:* in the case of the gasification some studies have already been carried out inside and outside Brazil too, using sugarcane residues – SAR, as raw material (OLIVARES, 1996; ZANZI, 2001; HASSUANI *et al*., 2005). In Brazil, experimental studies in gasification pilot units with reactors of fixed and fluidized-bed, have also been carried out. The largest and most important project developed outside Brazil with sugarcane residues, was developed in partnership between the companies Centro de Tecnologia Canavieira – CTC, and the

Swedish company TPS – Termiska Processes. The project showed the technical viability of making gasification of sugarcane residues – SAR.

5. *Enzymatic hydrolysis:* this technology being studied today in Brazil using surplus of sugarcane bagasse at sugarcane mills; other sugarcane biomass residues (i.e. tops and leaves), not used yet, could duplicate ethanol production in this country per hectare of harvested sugarcane. Despite current difficulties with this technology, significant progress has already been made. Some projections and published studies indicate that economical viability of this process could be attain within the 5 to 10 years, based on criteria such as availability and cost of biomass, its pretreatment and enzyme cost.

For any of these processes, concerning application of SAR, two issues deserve particular attention: firstly, many tests are still needed to achieve long duration in demonstrative units, aiming at sequenced technical viability and technology consolidation. Secondly, it is necessary to make reliable estimates on the costs of the economical viability of these processes.

Combustion of sugarcane straw

Two are the main aspects related to recovery and energy use of cane residues in conversion systems. The first refers to costs for harvesting, handling, and transport of cane residues to pretreatment locations, which should usually be located close to final consumption location. The second aspect is the pretreatment cost of cane residues for its efficient use in energy generation.

In relation to combustion of cane residues in boilers, three aspects deserve specific attention. The first relates to the amount and heterogenity of the material, that is, with wide granulometry, sizes and forms of the particles, and low density when in bulk, in the current systems of bagasse feeding to boilers; this is because traditional dosers of bagasse boilers at sugarcane mills in Brazil cannot operate only with sugarcane residues. Secondly are problems of maintenance of the thermal load of the boiler for long operational periods – to maintain the thermal load of the boiler requires to maintain the supply of steam by the boiler with the required quality and parameters control; and thirdly, it is necessary more reliable studies in different mixtures, to substitute bagasse technically and economically by other sugarcane residues.

In order to guarantee an optimum combustion reaction of solid and liquids fuels it is necessary to establish an appropriate size of their particles. In this case, the adequate size of the fuel particles allows an economic handling of this mixture in the combustion reaction. Besides when dealing with solid fuels its adequate size allows economic handling of this material through mechanical and pneumatic systems. Based on these considerations two variables are important, the amount of specific energy consumed in the fuel pretreatment, and the medium size of the resulting particles.

The possibilities to use the sugarcane straw in the boilers of sugar and ethanol mills have being appraised recently in the industrial and agricultural sector (straw usage). Mixtures of sugarcane bagasse and straw are fed into the boilers and burned in systems with combined ways of combustion as grill and suspension of a fraction of the mass or of the total number of the particles. The main criterion for applications of sugarcane residues is the fact that the use of such residues will make possible to produce larger amounts of surpluses of sugarcane bagasse that can be used in generating electricity and/or ethanol (of second generation). After preliminary tests at industrial scale, many mills moved to the systemization phase. In this phase, it was necessary to develop reception systems and pretreatment of sugarcane residues to be used in boilers with appropriate size of particles for combustion.

Some proposed systems for sugarcane residues pretreatment in mills involve: leveling equipment for the standardization of straw mattress height, to avoid stagnation points, underdoses or overdoses of residues volume, and knife mills in 2 consecutive stages to reach the project granulometry. This system facilitates the manipulation of material and guarantees a high efficiency in the boilers.

In relation to experiences carried out on combustion of sugarcane residues in boilers of sugar and ethanol mills (ICIDCA, 1999), it can be said that this combustion has an energy quality comparable to the sugarcane bagasse, traditionally used at the plant, whenever it is correctly prepared for its combustion e.g. with moisture control and right size particle composition.

In Cuba, where the sugarcane bagasse is largely used as industrial input and raw material for the cellulose and paper production, they have been studying several technological alternatives to make possible the use of sugarcane straw as a direct substitute for sugarcane bagasse, for the production of energy in the sugarcane sector, mainly boards, bagasse fiber boards, cellulose and paper; chemical products such as furfural, hidroximetilfurfural – HMF, among others.

Any technology improvement on the conversion of the sugarcane straw into energy, in larger or smaller scale, for physical preparation is always should be encouraged. In this process, two physical properties are generally controlled: the size of the particles and their moisture.

The downsizing preparation of the straw is usually made by using a grinding system based on different operation systems, generally with systems of knives and hammers working independently or combined. The control of the size of the material is made through sieves installed in the own mills, or using transport systems and pneumathic classification.

Some experiments with sugarcane straw burning in boilers showed that samples of sugarcane straw, pretreated in different ways from the crop to the pretreatment itself, showed different physiochemical characteristics. For instance, when centers of sugarcane cleaning are used for sugarcane harvested mechanically (Cuban model), with areas for temporary stockpiling of straw, the moisture content can be reduced considerably in some cases, up to 25% (b.u.). If we use the route of transport of sugarcane picked mechanically to stations of dry cleaning in sugarcane mills (model currently being implanted in Brazil), and where the material is not stocked, but driven directly for the boilers as soon as it is separated, its moisture (wet basis) may be superior to 25% or 30%.

Tests with sugarcane straw in boilers for steam generation were carried out in Cuba in the 1980s, using sugarcane straw and bagasse mixed with straw in proportions that varied from 10% to 43% of the mass (ICINAZ, 1990). Some of the main results of these tests which have already been published are summarized in Table 10. Table 11 represents the main physical and energy properties of sugarcane straw used in these tests. A boiler which burns in fasten layers on the top of the grill was used with a capacity of 20 ton/h and pressure of 17 bar, in other words, probably one of the oldest boilers in the sugarcane industry. The obtained efficiencies operating with sugarcane straw and bagasse mixed with straw varied between 65% and 75%, being the largest values reached when

TABLE 10 Boilers operation parameters fueled several sugarcane biomass solid fuels.

Operation parameters	Sugarcane bagasse	Sugarcane straw	Mixtures (average values of 10% to 43% in mass)
Flame temperature, ºC	981	1,080	1,009
Exit furnace gases temperature, ºC	879	872	979
Exit boiler gases temperature, ºC	264	250	277
Steam boiler rate, ton/h	19.43	18.57	19.31
Fuel rate, ton/h	9.06	4.88	6.49
Air excess	1.99	2.18	1.72

TABLE 11 Several physical and energetic properties of sugarcane straw of the tests.

Sugarcane straw properties	Average values
Particles characteristics dimension, mm	11.64
Ash content, %	8 ± 2
Moisture content, %	25 ± 5
HHV, kCal/kg	2,884
Bulk density, kg/m^3	40

it was operated with mixtures containing a larger amount of bagasse.

As to the previous results there appear to be few details of operation parameters to generated steam (pressure and temperature of the steam); secondly, little is known of the long time results, related to the problems e.g. damages the thermal exchange surfaces, that is, "fouling" and "slagging" problems; thirdly, they do not discuss operational results obtained in these tests such as the consumption of fuel in the boiler, or that burning sugarcane straw only had a reduction of almost 100%, and as to the mixtures of approximately 40%, or that there is an excess of air in the boiler, whose values should have been discussed by the authors. In short, the results are very interesting and show that studies have been carried out over the past years with encouraging results; however most of them need still to be consolidated, and this demonstrates the need for new research, development and innovation – P&D&I, in this area.

Currently tests of long duration are being curried out in Brazil, e.g. burning primarily sugarcane straw in boilers in mills during the harvest period. Such tests have been intensified as Brazil started large scale mechanization in the harvesting period. They are handling data of straw mixture with bagasse of up to 25% in mass. However, it is still not possible to find published data on the conventional technical literature about the outcome of this type of evaluations. The authors of this chapter have not been able to access information from companies involved in the sugar and ethanol sector, but it is well known that the problems associated with the formation of deposits have been verified in surfaces of thermal exchange, in addition to large amount of ashes.

Other important aspects related to biomass combustion are "fouling" and "slagging". The concentration of inorganic material in the composition of biomass may be one of the causes of the existence or not of "fouling" and "slagging". It is possible that "fouling" in the thermal exchange surfaces of steam generation systems, happens when the residues generated during the combustion and deposited in the surfaces of the heat exchange, come together with substances that vaporize during the combustion, and then condense on the colder surfaces. "Slagging" happens when inorganic materials are founded, or acquire high viscosity forming deposits directly in these conditions. Both types of phenomena generate deposits of low thermal conductivity and high reflection, harming the efficiency of heat change and the boiler operation, besides accelerating the corrosion phenomenon in surfaces of thermal change.

CERQUEIRA-LEITE (2007), states that bagasse and sugarcane residues main properties are indicative of high probability of formation of deposits at temperatures in the boiler furnace from moderate to high, these are: the content of silica, potassium, sodium, and of phosphorus in the ashes, and content of chlorine in the biomass. A quantitative analysis of potential problems posed by this type "fouling" and/or "slagging" indicators have already been drawn. This is the case of the "alkalis index" – AI. According to the authors of this chapter, tests have been done with cane residues in Brazil (the authors have used cane stem); in three different tests the "alkalis index" was superior to 0.32, so it is possible to think it is correct the hypothesis of "fouling" in surfaces of thermal change of boilers. In these tests the content of alkalis in the ashes of sugarcane residues (or of the cane stem) corresponds to the sum of the concentrations of potassium oxide (K_2O) and of sodium oxide (Na_2O).

We pointed out that there are already a relatively high number of publications on aspects of combustion of solid fossil fuels, mainly mineral coal, when mixed with biomass (co-fired), in boilers using mineral coal or boilers than burn biomass (mineral coal is an auxiliary fuel in this case). Obviously, a detailed knowledge of biomass, and mineral coal properties is required, together with the interactions between these two fuels (MAGASINER *et al*., 2002).

Table 12 summarizes data from chemical analysis of the ashes of a sugar-cane straw sample (PELÁEZ, 2007).

The author identified differences between his values and the values obtained by other authors, and explains that such differences can be attributed to factors such as the cultivation and the handling of the sugarcane.

Regarding the crop, the amount and the fertilizer type may also influence in the mineral characteristics present in the sugar-cane, and the handling is responsible for the aggregation of strange particles of mineral origin that may depend on the place where the biomass is stocked and pretreated.

RESEARCH, DEVELOPMENT AND INNOVATION – RD&I

In terms of recovery and pretreatment processes, as well as hydrolysis, combustion, pyrolysis and gasification processes being carried out with sugarcane agricultural residues, sugarcane straw specifically, investigated worldwide given its theoretical and technological development, is close to commercial scale production in the case of lignocellulosic biomass (as bagasse combustion of the sugarcane, for example). However, it is possible to say that major research and development work still need required to improve our understanding of biochemical and/or thermochemical conversions to attain better yields and more efficient process, while decreasing the environmental impacts. Thus for this to become true, it is vital to:

- Elaborate a data bank with the physical, structural, chemical, thermal, energetics, fluid-dynamics and biological properties, plus biodegradation, among others, in relation to sugarcane straw. Establish new rules and analytical methodologies specifically for this material.
- Theoretical-experimental studies of the physical pretreatment of the sugarcane straw.
- Theoretical-experimental research on the influence of the physical and chemical properties of the particulate material of sugarcane and kinetics of these processes, both in laboratory and pilot plant scales.
- Mathematical modeling of conversion processes of the sugarcane straw particles.
- Development and evaluation of physical systems in order to study the phenomena involved in the processes of interest, at various scales.
- Changes and reformulation studies plus repowering of power systems into thermochemical conversion.
- Development of continuous reactors and cleaning systems and bio-oil and tar recovery in units of pyrolysis and gasification in fluidized bed respectively, for sugarcane pretreated straw.
- Studies for obtaining synthetic gas, synthetic fuels and chemicals in pyrolysis and gasification systems.
- Study of the properties of bio fuels obtained through thermochemical routes of sugarcane straw conversion and other lignocellulosic materials.

TABLE 12 Ash chemical analysis results of sugarcane straw.

Chemical composition	Content (% in mass)
Fire Loss	0.57
Silicium dioxide (SiO_2)	52.62
Aluminum oxide (Al_2O_3)	15.8
Iron oxide (Fe_2O_3)	3.93
Calcium oxide (CaO)	5.76
Magnesium oxide (MgO)	5.27
Sulfur trioxide (SO_3)	2.73
Sodium oxide (Na_2O)	0.12
Potassium oxide (K_2O)	7.8

Source: PELÁEZ, 2007.

- Long term tests in demonstrable units, aimed technical viability in production scale and consolidation of technologies.
- Reliable estimates on economic viability and environmental and social/economical impacts of the processes, where the sugarcane straw will be used.
- Reliable estimative recovery costs and pretreatment processes of the sugarcane residues for bio energy production.

FINAL CONSIDERATIONS

This chapter introduces some of the main characteristics of biomass residues of sugarcane mills – SAR, presenting properties which are not widely covered in conventional technical literature e.g. physical, morphological, chemical and energetic properties, related to the straw fraction of sugarcane. This is considerable relevance for the evaluation, processes and equipment. Some possible applications of this fraction, focusing in energy production by means of its spontaneous combustion in industrial boilers, are discussed, showing the importance to search for the technical viability of this technology for sugarcane residues–SAR. Moreover, some research experiences on sugarcane straw combustion and their mixtures with sugarcane bagasse in boilers of sugarcane power plants are also discussed. In addition, major operational technological hindrances have also been identified in experimental tests carried out with these materials. The authors are open to further discussions to these lines of research that, accordingly, must be considered in Research and Development & Innovation – RD&I, when using sugarcane straw as an energy source.

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10

INTEGRATED BIODIESEL PRODUCTION IN BARRALCOOL SUGAR AND ALCOHOL MILL[1]

José Luiz Olivério, Sérgio Tamassia Barreira and *Silvio Cezar Pereira Rangel*

INTRODUCTION

In Brazil in 1975, the National Alcohol Program – Proálcool – started, to represent the beginning of a new concept in the sugarcane sector: the production of renewable energy from sugarcane.

Ethanol production has brought on a huge growth of the industry, while mills experienced important evolution in capacity, overall yields, and optimum use of sugarcane energy, products and by-products (OLIVÉRIO, 2002).

At the end of the Program, some industry entrepreneurs enhanced the vision of the business by understanding that the mill, in its agricultural (+) industrial integration, is not a sugar and alcohol producing unit only, but an energy-and-food producing centre (OLIVÉRIO, 2002, 2006), as shown in Figure 1. It must be emphasized that the representation is simplified, since today the number of products derived from agricultural and industrial activities is much higher.

Ethanol, or bioethanol, as it is also called, was focused almost completely on the partial or total replacement of gasoline in vehicles. In the 1980s, a parallel program to Proalcohol was Pro Oil, which had as the main purpose the production of fuel as an alternative for diesel oil. Pro Oil did not prosper, but the remembrance of the alternative fuel remained.

With such background, and mainly taking the expressive European biodiesel program as reference, on December 4, 2004, the National Program of Biodiesel Production and Use was launched in Brazil, introduced by Law n. 11 097/2005, which establishes the minimum percentage of blending biodiesel to diesel and the monitoring of the introduction of the new fuel into the marketplace.

And what is biodiesel? In a simple explanation, it is the natural substitute for diesel oil, which is produced from renewable sources, such as vegetable oils, animal fats, as well as used fried oil (OLIVÉRIO, 2004). Chemically, it is defined as a monoalkylate ester of fatty acids (methyl-ester or ethyl-ester), derived from lipids (or fatty acids) of natural occurrence, and is produced, together with glycerin, through the reaction of transesterification (or esterification) of triglycerides (fatty acids) with alcohols – methanol or ethanol – in the presence of an acid or basic catalyst (BARREIRA, 2005).

Figure 2 outlines this definition. The quantities are not accurate and are presented only as a reference.

It is important to emphasize that methanol, or bioethanol, participates in the reaction with an exceeding amount in relation to stoichiometric to maximize the efficiency of transesterification and, when removing process water, it limits the parallel reaction of saponification as much as possible.

By examining Figure 1, one can see that the energy-and-food mill produces the two feedstocks

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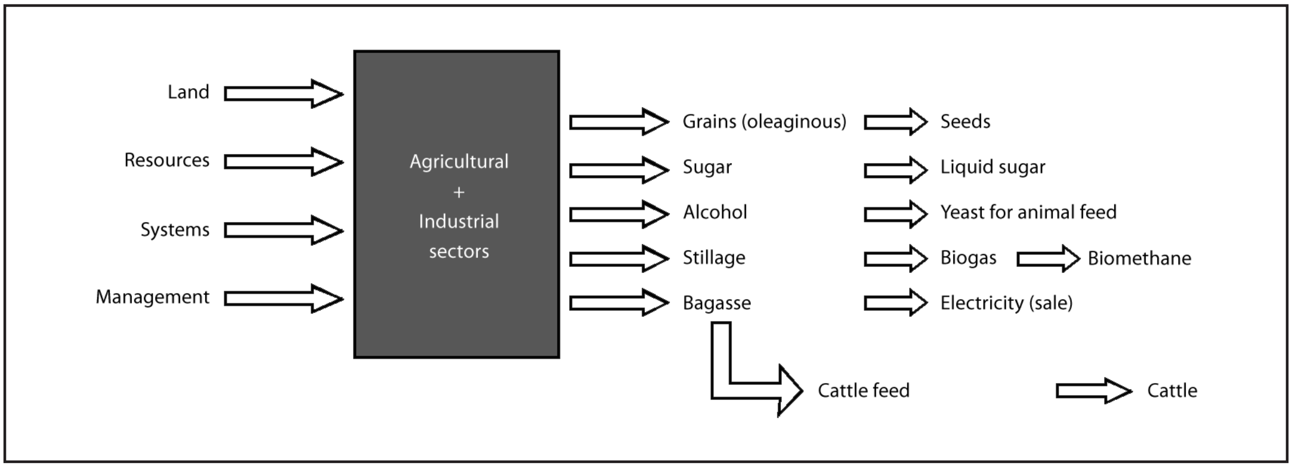

FIGURE 1 The sugar and alcohol mill defined as an energy-and-food producing unit.

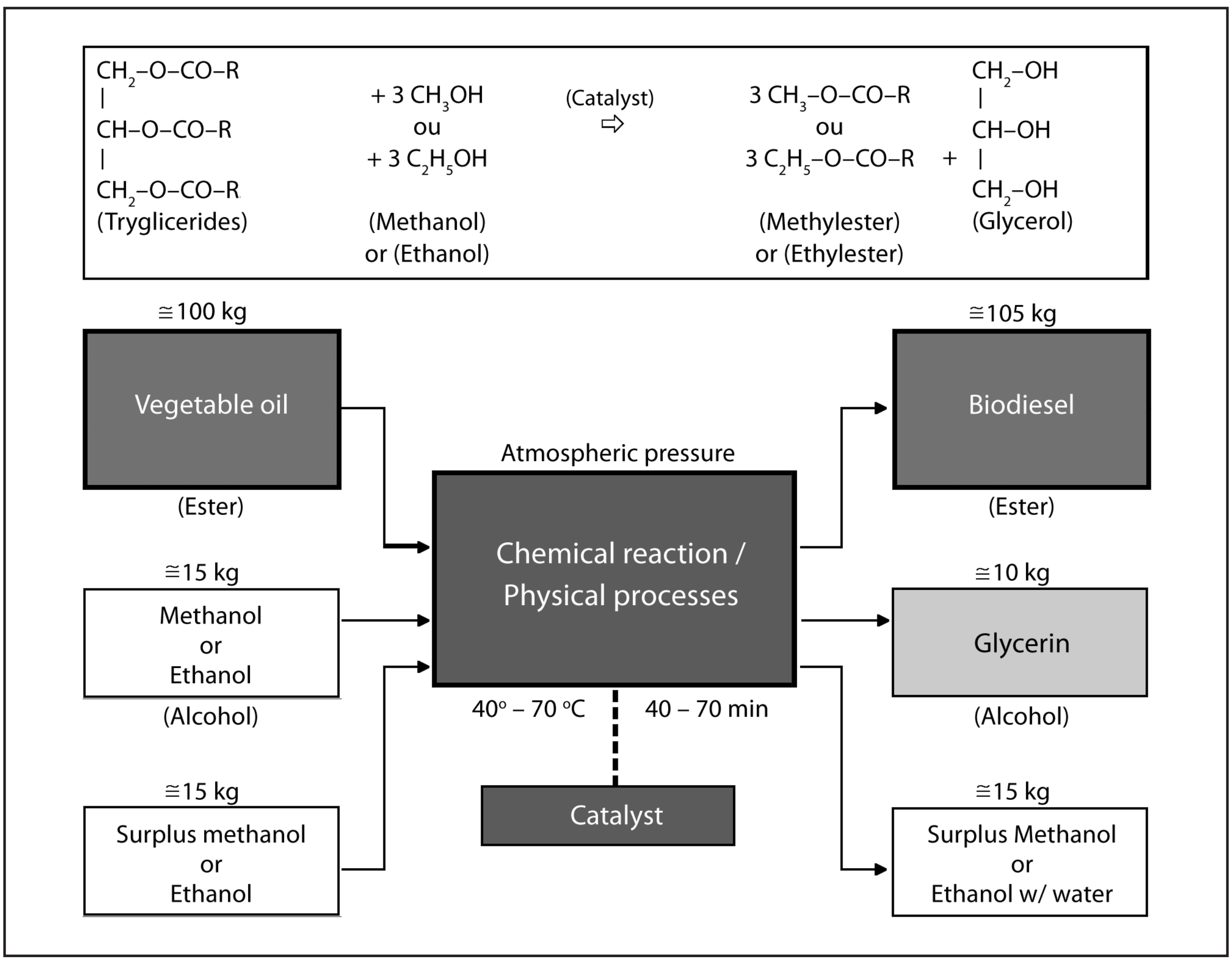

FIGURE 2 The transesterification reaction and the process used in biodiesel production (sketch).

of Figure 2 which are used for biodiesel production: oleaginous grains from which vegetable oil is extracted, and bioethanol.

From bagasse, the mill can also supply energy – thermal and electric – used in the production of biodiesel.

This first conclusion was the starting point for an in-depth investigation, when a great synergy between the production processes and uses of biodiesel and bioethanol was noticed to exist. Thus, a new pioneering concept was developed and introduced into the marketplace in November, 2004, that is, the integrated biodiesel production in sugar and alcohol mills (OLIVÉRIO, 2004).

BIODIESEL – BIOETHANOL SYNERGY, OR THE INTEGRATED PRODUCTION OF BIODIESEL IN SUGAR AND ALCOHOL PLANTS

The existing synergies and the advantages of integrated biodiesel production in the mills can be grouped into 3 classes: agricultural sector, industrial sector, management and businesses (BARREIRA, 2005).

In the agricultural sector, the know-how for oleaginous grains production in rotation to sugarcane crops is already available. It is a traditional practice, for example, the cultivation of soybean in areas of sugarcane renovation, after 4 or 5 cuts. Such practice maximizes land productivity with optimum and profitable use of the land. It also breaks the cycle of plagues and diseases and contributes to recover the soil fertility; from soybean, the oil that is the feedstock for biodiesel can be produced.

Another synergy that benefits the integration is the common use of the structure and agricultural and industrial resources, which allows costs sharing, optimized use of facilities, and minimized investments. It can include tractors, harvesters, trucks, machinery, agricultural implements, steam, co-generated electrical power, water, integrated solutions for wastewaters, agricultural and industrial labour, use of plants, facilities and support services. The surplus bioethanol with water, which derives from the biodiesel production, as could be seen in Figure 2, may be reprocessed in the distillery already available at the mill and, after dehydration, is sent back to the biodiesel process.

The biodiesel produced can be used in the agricultural sector to fuel the vehicles used in the production of sugarcane and the oleaginous grains.

Regarding management and businesses, we can point out the synergies and advantages of: a new market for use of the anhydrous bioethanol, the increase of income/profits from the new products, biodiesel and glycerin, to the production chain, which also helps to dilute market risks.

Biodiesel commercialization will be made by counting on the experience and expertise obtained from the bioethanol business, to be traded with the same clients. Finally, the same structure and management systems can be used.

When using biodiesel in the mill vehicles, the fuel is tax exempt, so it costs less (for being own production), and replaces diesel that is tax liable.

Figure 3 highlights that having as a core the land, the human, physical and financial resources, systems and management, the biodiesel-bioethanol integration takes place in the crop and in the industry, and leads to economic, energetic and process integration (OLIVÉRIO, 2004).

We understand that the integrated production of biodiesel in the sugar and alcohol plant must take place in 3 stages, and initially the synergies already available are used, which evolve to stages of higher integration (OLIVÉRIO, 2004, 2006), as shown in Figure 4.

For stages 1 and 2, technology is already available, and the 3rd is in the initial stage of development and will have a significant future impact in the additional reduction of biodiesel and bioethanol costs. To cite possible examples, bioethanol can be the solvent in the extraction process of oil from grain, replacing hexane, increasing oil production and, at the same time, producing value-added meal with higher protein content. Additionally, some sugars present in soybean may be added to the juice, thus increasing ethanol production at the plant.

At this point, it is important to emphasize that the technology for the continuous process of biodiesel production was available by the methyl

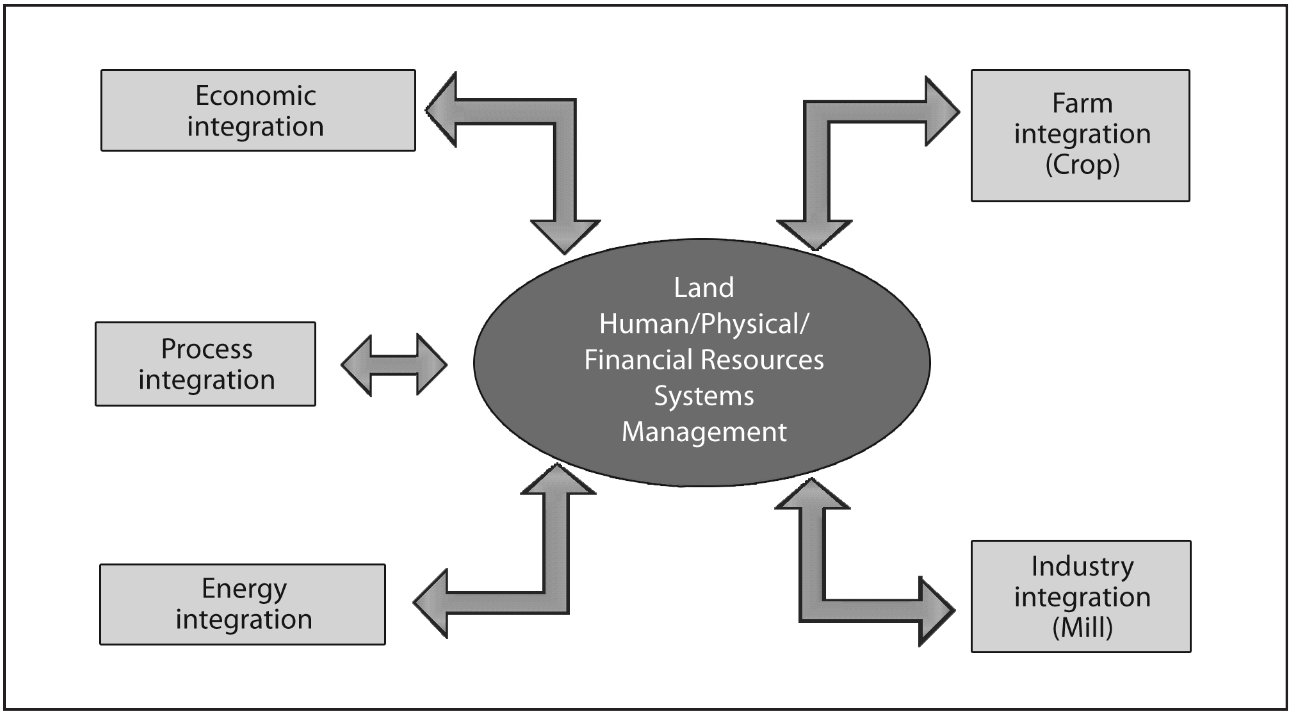

FIGURE 3 Biodiesel-bioethanol integration.

route only, developed mainly in Europe. For the biodiesel-bioethanol integration, it was necessary to develop the ethyl route in a continuous process. The conclusion of such development was presented in July 13, 2004, during the II SIMTEC – International Symposium and Technology Exhibit of the Sugar and Alcohol Agroindustry – held in Piracicaba, when Dedini and DeSmet Ballestra promoted the launching of the pioneer process of continuous production of biodiesel by the ethyl route (OLIVÉRIO *et al.*, 2004).

THE BARRALCOOL SOLUTION

What was initially a concept became reality when, in November 2005, the pioneer contract for the supply of a biodiesel plant integrated to the Barralcool Mill was signed, and operations started in November 2006. It must be pointed out that Barralcool mill was the first plant to produce bioethanol in the state of Mato Grosso, and also the first in the state to supply bioelectricity to the grid, thus becoming the first mill in the world producing the 3 BIOs: bioethanol, bioelectricity and biodiesel.

Figure 5 shows Barralcool Mill in a schematic form.

Description of the mill

Barralcool Mill is located in Barra do Bugres, MT, and was built while Proálcool was in force, for production of alcohol exclusively. Its first milling season took place in 1983, processing 58 734 tonnes of cane. From 1993, it was expanded for production of sugar. It began supplying electricity to the grid in 1996, and production of biodiesel in 2006.

Since it was founded, it has undergone expansion which will continue in the next years, according to Tables 1 and 2.

The milling season is from April to November each year.

The average diesel consumption in the crop is 2.5 litres of diesel/t crushed cane.

The sugarcane renovation, on average, occurs at every 6.7 cuts; therefore, the renovation area represents about 15% of the cutting area of sugarcane.

Soybean production is made in rotation with sugarcane, using nearly 70% of the renovation

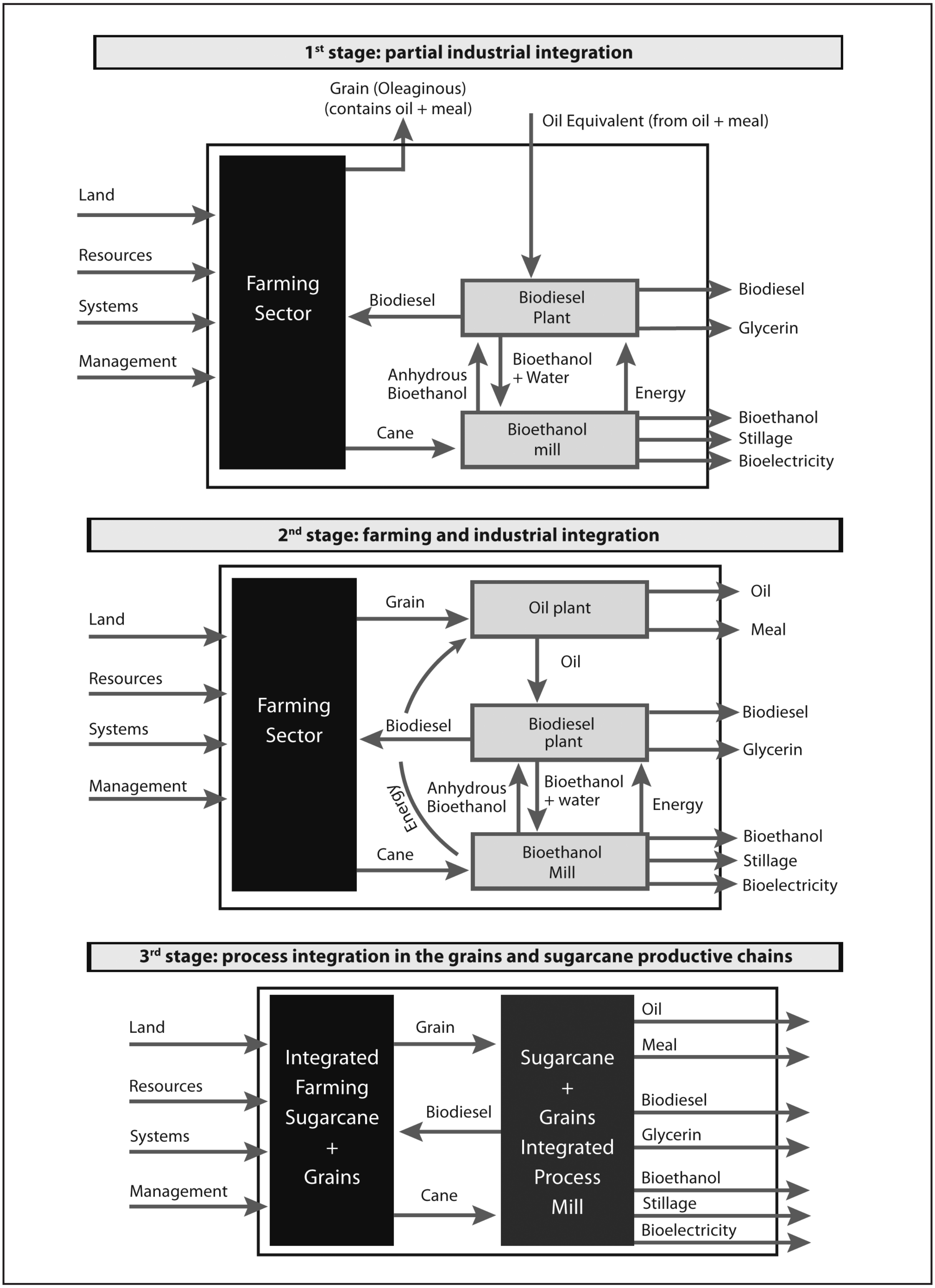

FIGURE 4 The 3 evolution stages of integrated biodiesel production in the sugar and alcohol mill.

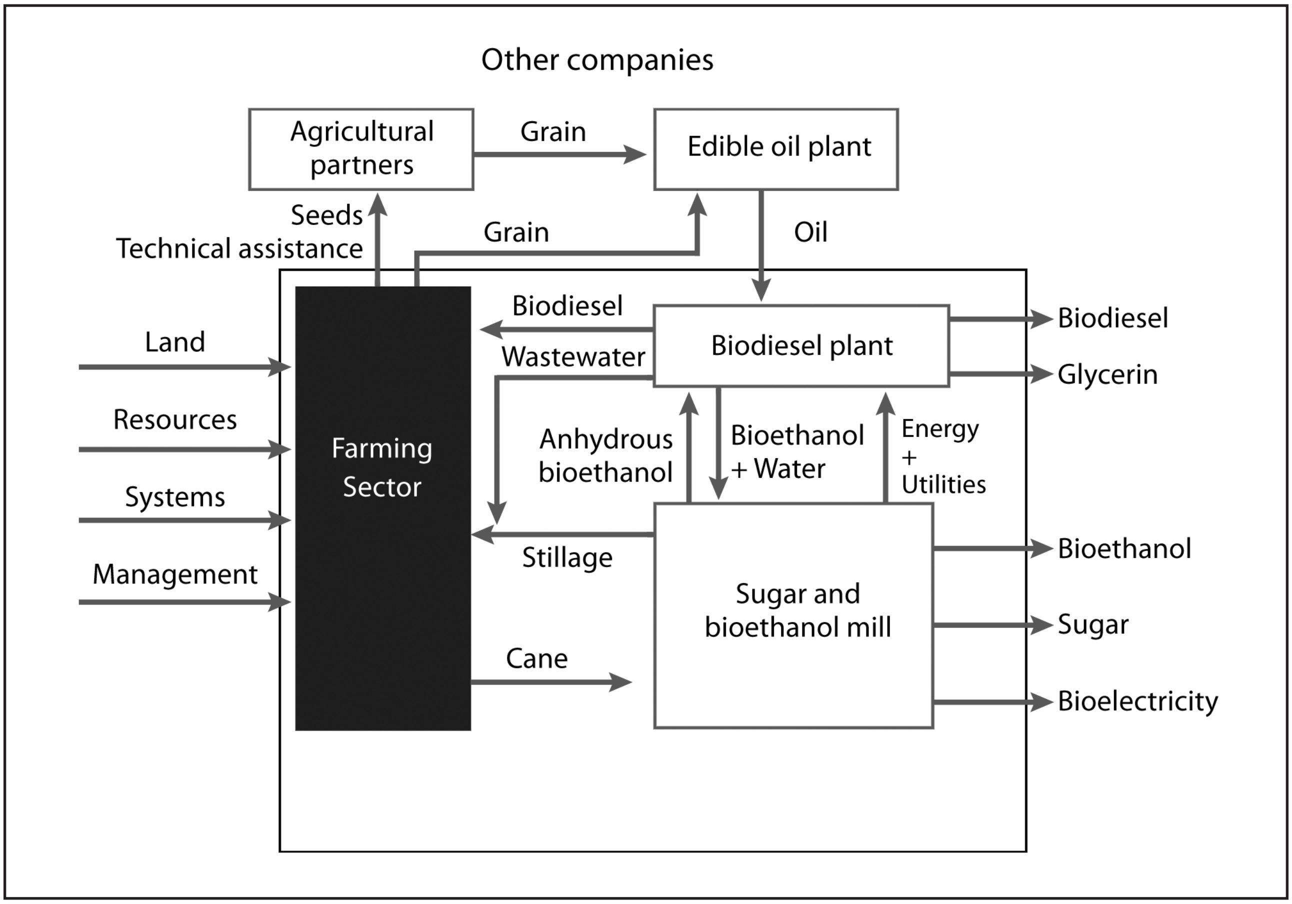

FIGURE 5 Barralcool Mill: operational flow.

TABLE 1 Historical data –2000 to 2006 milling seasons – Barralcool Mill.

Description	Unit	2000	2001	2002	2003	2004	2005	2006
Processed sugarcane	tc/y	1,080,616	1,483,786	1,780,736	1,825,597	2,154,873	1,886,464	2,221,669
Total sugarcane area	ha	20,487	21,464	24,168	26,211	28,015	26,398	32,659
Harvesting area	ha	18,724	20,378	22,769	23,981	25,997	24,811	26,649
Average daily cane	tc/d	7,946	8,243	8,816	9,128	10,615	11,790	10,733
Crushing days	d/y	136	180	202	200	203	160	207
Ethanol production	m^3/y	72,327	95,113	113,511	118,220	151,222	139,382	152,017
Sugar production	t/y	22,171.0	32,957.4	42,647.5	40,021.2	37,571.1	36,986.0	50,130.2
Soya own production*	t/y	–	–	–	1,156	3,090	6,282	6,401

* Soybean own production in sugarcane renovation area.
c = sugarcane; y = year; d = day; t = ton; ha = hectare; tc = ton of sugarcane.

TABLE 2 Forecast – 2007 to 2009 seasons – Barralcool Mill.

Description	Unit	2007	2008	2009
Total cane processed	tonne cane/season	2,400,000	2,600,000	2,800,000
Soya own production	Tonne/year	9,000	9,600	11,500

TABLE 3 Raw materials specifications.

Degummed oil specification (soya/sunflower/rapeseed)		
Parameter	**Unit of measure**	**Value**
Free fatty acid	%	0.1 max.
Moisture content	%	0.1 max.
Impurities	%	0.1 max.
Phosphorus	ppm	20 max.
Unsaponifiables	%	1 máx.
Ethanol specification – ANP 36*, 06.12.2005, except:		
Water content	%w/w	0.20 max.
Methanol specification – technical grade, and:		
Water content	%w/w	0.15 max.

* Brazilian specification.

area. In the conditions of Barralcool Mill, a higher percentage soybean production interferes in the agricultural practices required for sugarcane, which must be avoided.

Let's review the biodiesel-bioethanol integration taking as reference the 2009 milling season of Barralcoool Mill.

Barralcool's new solution will be presented by dividing it into three parts: agricultural sector, industrial sector, and biodiesel plant.

Biodiesel plant

The biodiesel plant has the following characteristics:

- capacity: 50,000 tonnes/year (around 56 million litres/year); 8,000 hours/year;
- continuous process, multi-feedstock;
- flexible route: ethyl or methyl;
- feedstocks: multiple degummed vegetable oils, beef tallow, bioethanol or methanol;
- end products: biodiesel and glycerine.

Figure 6 presents the process flowchart of biodiesel production using vegetable oils. In the Barralcool Biodiesel Plant, an esterification process stage was introduced, that produces additional biodiesel from fatty acids, increasing yields.

The use of beef tallow requires additional stages for treatment of this raw material, which will not be discussed in this paper.

Tables 3 to 8 present the materials and utilities specifications involved in the process, as well

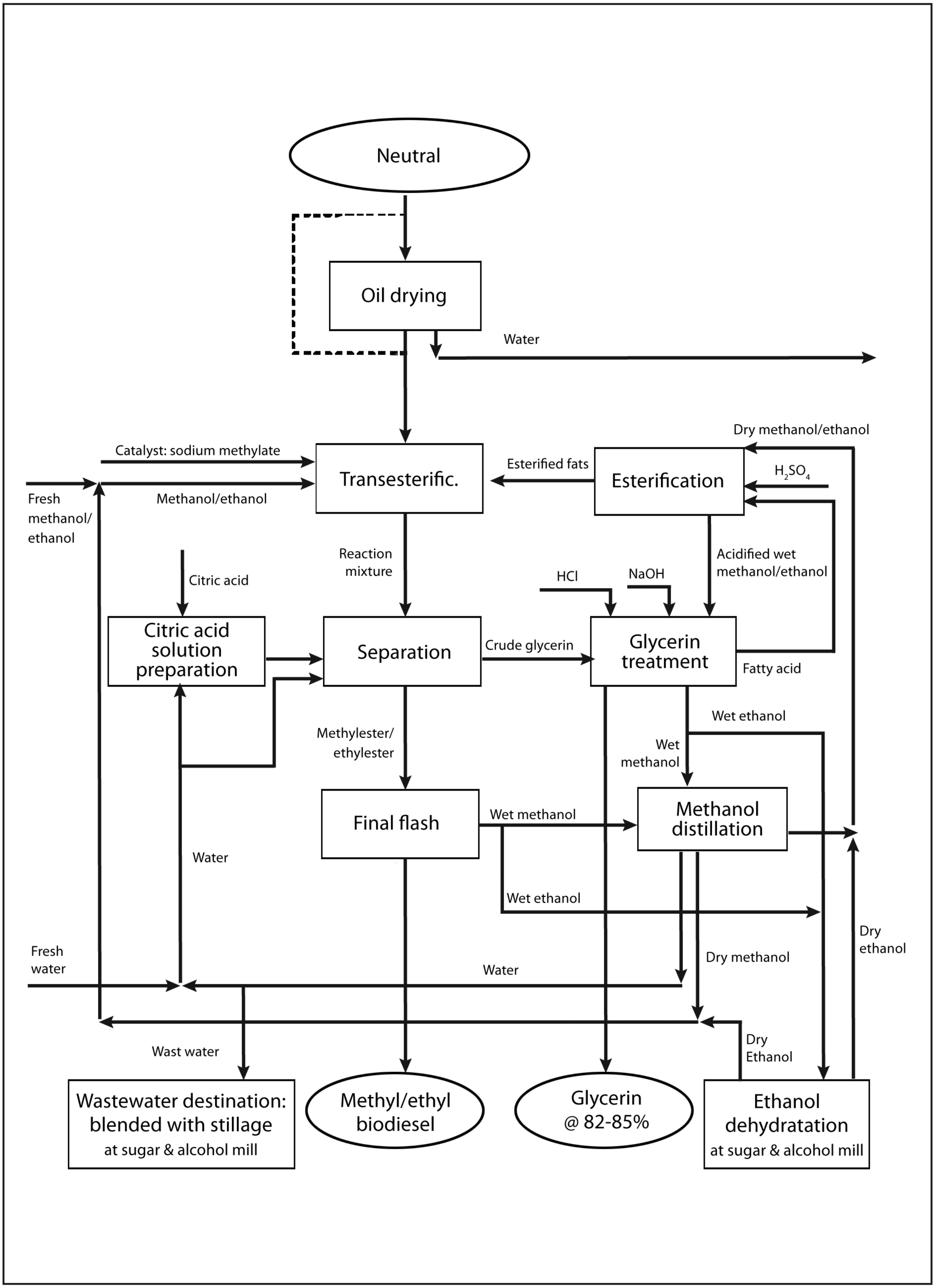

FIGURA 6 Barralcool biodiesel production process flowchart – ethyl/methyl route.

TABLE 4 Chemical inputs specifications.

Hydrochloric acid	36% concentration technical grade
Ester interchange catalyst	Sodium methylate as methanol solution 30% conc.
Caustic soda	50% weight solution
Citric acid	Technical grade mono-hydrate
Process water	Softened water (1°F hardness)
Sulfuric acid	98.5% purity

TABLE 5 Utilities specifications.

Process water	
Type	softned
Pressure	3 bar g min.
Temperature	ambient
Hardness	1ºF max
Iron content	max 5 ppm as Fe
Cooling water	
Pressure	4 bar g min.
Temperature inlet	28 ºC max
Temperature outlet	34 ºC max
Saturated steam	
Pressure	12 bar g min.
Instrument air	
Type	dried and oil free
Pressure	7 bar g min
Dew point	–20 ºC
Nitrogen	
Type	99% purity
Pressão	7 bar g mín.
Electric power	
Driving power	380 V (HOLD) – +/-5% – 60 Hz – 3 + N phases
Control and auxiliary circuit	220 V (HOLD) – 60 Hz – 1 phase
Lamps	24 V (HOLD) – 60 Hz – 1 phase

as the end products, wastewaters and respective consumptions or production.

Agricultural Sector

In 2009, soybean will/was be cultivated on 70% of the sugarcane renovation area, which represents 15% of the harvest area, giving a total of 11,500 tonnes of grains (Table 2).

This amount is not sufficient to meet the capacity of the biodiesel plant. Barralcool solution was to enter into partnership agreements with independent producers (family and small farmers) to whom the mill supplies the seeds and technical support.

Doing that, Barralcool meets the objective of social inclusion contained in the premises of the Brazilian Biodiesel Program, and the biodiesel produced by the mill is entitled to tax reduction in sales.

The soybean grain is sent to an oil industry which, through an operation called "Façon", it exchanges grains, which contain oil and meal, for the equivalent in oil, as shown in Figure 7 (BARBOSA, 2006).

Concluding, agricultural production will provide 5030 tonnes of oil/year, around 10% of capacity, and the remaining 44,970 tonnes/year will be supplied by third parties.

To increase the proportion corresponding to own production, Barralcool mill is developing procedures to produce two crops of grains in the same area and in the same period of sugarcane renovation, using soybean and peanut. Barralcool expects to increase oil production per hectare by about 30%.

A blend of 30% of biodiesel in the mixture with diesel – B30 – will be used as a first step in Barralcool. 7 million litres of fuel will be utilized in 2009 (2,800,000 t cane X 2.5 L/t cane) and the internal utilization of biodiesel will reach 2.1 million litres.

Industrial Sector

The integration of the biodiesel plant into Barralcool mill industrial sector is represented by Figure 5.

TABLE 6 The biodiesel produced meets the Brazilian specifications (ANP 42), USA specifications (ASTM 6751-3) and European specifications (EN 14214).

Characteristic	Unit	Standard		
		ANP 42*	**ASTM 6751-3**	**EN 14214**
Specific mass at 20 ºC	kg/m^3	register	–	0.86-0.90
Kinematic viscosity at 40 ºC	mm^2/s	register	1.9-6	3.50-5.00
Water and sediments, max.	% vol.	0.050	0.050	0.050
Total contamination, max	mg/kg	register	–	24
Flash point, min.	ºC	100	130	120
Ester content, min.	% mass	register	–	96.50
Distillation; 90% vol. Recovered, max.	ºC	360	360	–
Carbon residue of 100% – final distillate, max	% mass	0.10	0.30	0.30
Sulfated ashes, max.	% mass	0.02	0.02	0.02
Total sulfur, max.	% mass	register	15	10
Sodium + potassium, max.	mg/kg	10	5	5
Calcium + magnesium, max.	mg/kg	register	5	–
Phosphorus, max.	mg/kg	register	10	10
Copper corrosion, 3 h to 50 ºC, max.	–	1	3	1
Number of cetanes, min.	–	register	47	51
Cold filter plugging point, max.	ºC	–	–	–
Acidity, max.	mg KOH / g	0.80	0.80	0.50
Free glycerol, max.	% mass	0.02	0.02	0.02
Total glycerol, max.	% mass	0.38	0.24	0.25
Monoglycerides, max.	% mass	register	–	0.80
Diglycerides, max.	% mass	register	–	0.20
Triglycerides, max.	% mass	register	–	0.20
Methanol or ethanol, max.	% mass	0.5	–	0.20
Iodine number	–	register	–	120
Oxidation stability at 110 ºC, min	h	6	–	6

* PROVISIONAL ACTS n.: 214, 13/0904 and 227, 06.12.2004.

TABELA 7 Specification of the glycerin produced.

Resolution n. 42, 24.11.2004

Parameter	Specification – %
Glycerin content by mass	82 ÷ 85
Water by mass	8.0 max.
Methanol/ethanol by mass	0.1 max.
Organics non glycerol, by mass	1.5 max.
Salts by mass	7.0 max.

It must be emphasized that use is made of utilities already available at the mill, surplus bioethanol dehydration in the equipment already used to produce anhydrous bioethanol, optimum use of the existing technical, administrative, and management structure, which allows reduction in costs and investments.

In Figure 8, a picture shows an overall view of the Biodiesel Plant Integrated to Barralcool Mill, and, in Figure 9, the inauguration of Barralcool Biodiesel Plant.

IMPACTS ON INVESTMENTS, COSTS, AND MANAGEMENT

Investments

When Barralcool biodiesel plant was defined, not all existing synergies had been used.

This decision had the purpose of allowing greater flexibility in operations with less possibility of interference among them.

Yet, the investments for a non-integrated, independent biodiesel plant are 22% higher than the integrated solution of Barralcool mill, as can be seen in Table 9 next.

Costs and Management

In order to assess the cost differentials, let us compare integrated and non-integrated production in the ethyl and methyl routes.

TABLE 8 Consumptions and production.

For 1,000 kg of biodiesel (final product)	
Processing: neutral oil	
Raw materials	
Oil-methyl(1)/oil-ethyl(2)	1,000 kg(1)/956 kg(2)
Methanol/ethanol	100 kg(1)/154 kg(2)
Products	
Biodiesel	1,000 kg
Glycerin	117 kg
Chemicals and utilities	
Chemicals	
Sodium methylate (as 30%)	18.3 kg(1)/33.4 kg(2)
Citric acid	0.65 kg
Hydrochloric acid @ 36%	9.5 kg
Caustic soda @ 50%	1.5 kg
Process water	4.0 kg
Sulphuric acid	0.2 kg
Utilities	
Electric power (absorbed)	15 kWh
Steam	300 kg
Cooling water duty (recycling)	145.000 Kcal
Nitrogen	(3)
Instrument air	6 Nm^3
Effluents	
Exhaust air from vent sub cooling	1.6 kg(4)
Waste water from biodiesel	10 kg(5)

(1) methylic route;
(2) ethylic route;
(3) discontinuous;
(4) with 150 ppm methanol/ethanol;
(5) 0.3% max methanol/ ethanol, BOD 7500 ppm, PH 7/9.

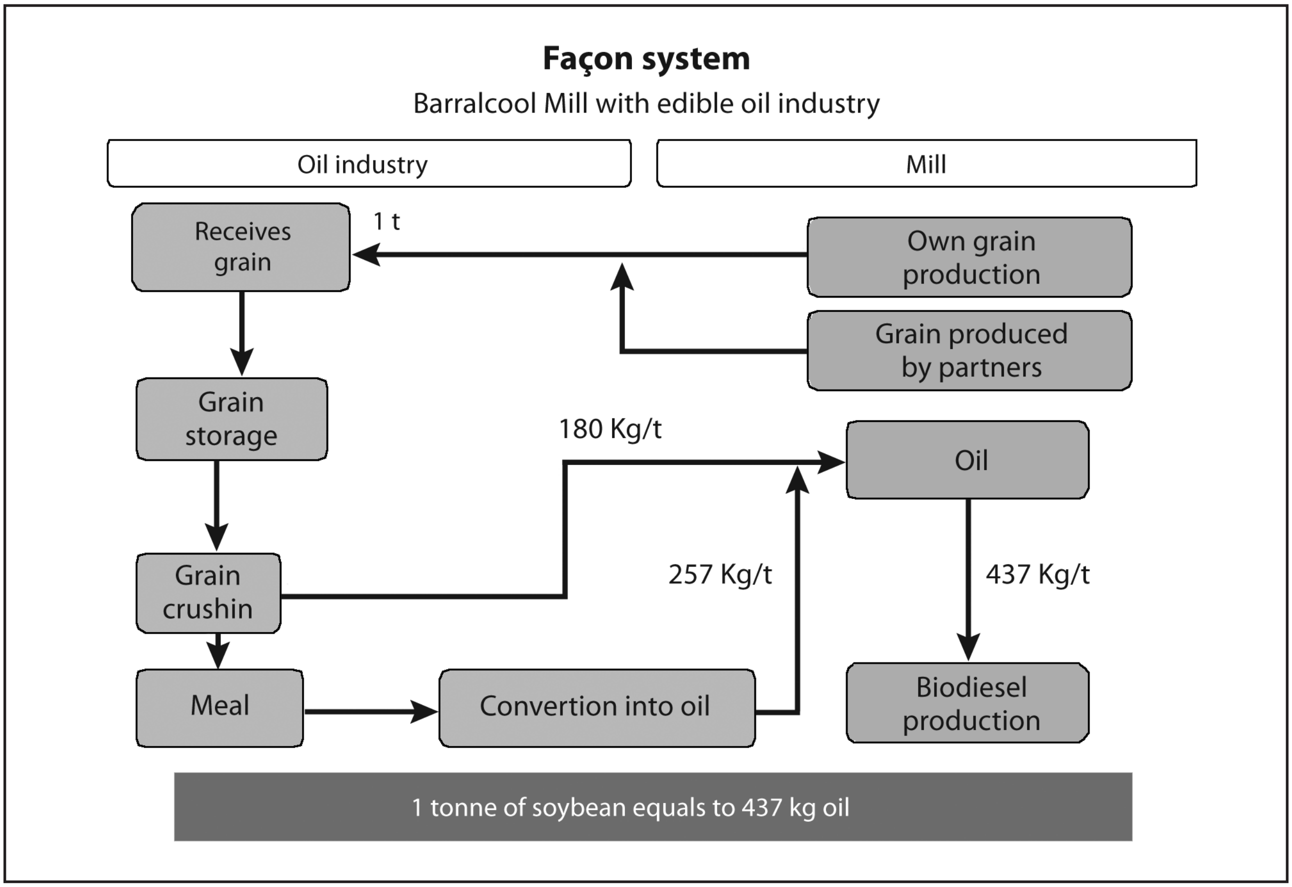

FIGURE 7 Exchange of soybean grain for oil – the Façon system.

The main components in the cost of biodiesel are the raw materials, and the vegetable oil represents around 85% of total cost.

In the integrated solution, the grain production makes available around 5,000 tonnes of oil/year, calculated at cost of production and using the façon system.

For the complementary 45,000 tons of oil, Barralcool makes use of partnership with family farming, obtaining oil at a lower cost than the market price. But to obtain a broader conclusion, let us consider that the complementary oil is acquired at normal market prices.

Table 10 presents the oil cost calculations used for biodiesel production at Barralcool, within these premises, obtaining an average value of US$ 611.56/t, using the conversion rate of US$ 1.00 = R$ 2.20.

As can be seen, own grain production integrated with cane production and conjugated with the façon system enables a significant reduction in the cost of oil, in the order of 40%.

The small quantity, around 10% of the plant capacity, suggests that solutions be developed to increase this participation, such as, for example, planting 2 oleaginous crops in the renewal area in the same harvest season, or installing 1 biodiesel plant supplied by several other mills.

Table 11 presents the total comparative cost of biodiesel production, emphasizing the most significant items and grouping the others. The bioethanol cost used is the internal production cost at the Mill.

When analysing the results, one is able to conclude that the integrated solution presents a lower cost, in which the ethyl route is more advantageous, with a cost of US$ 0.604 per litre of biodiesel. It is pointed out that the cost of diesel to the mill is US$ 0.74 per litre. The comparative reduction of Usina Barralcool's costs when us-

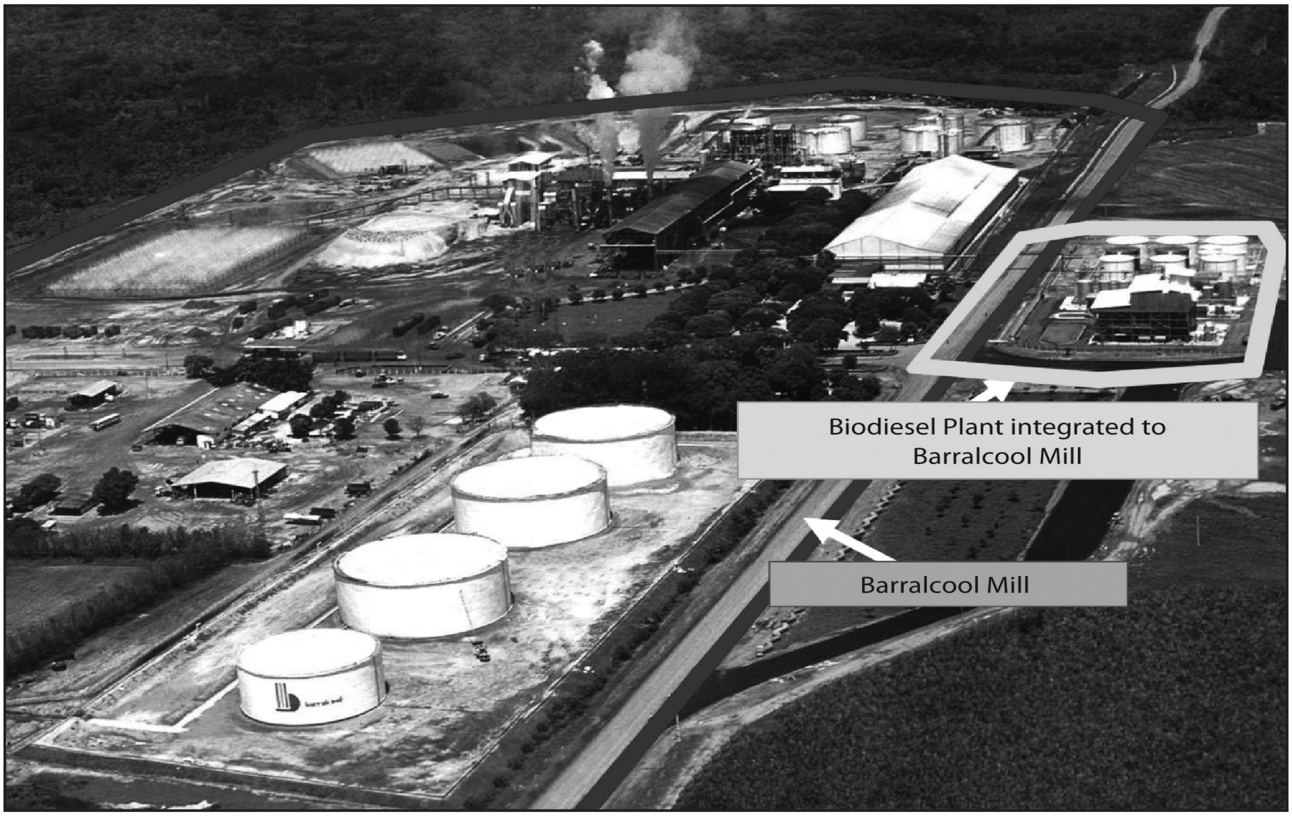

FIGURE 8 Biodiesel Plant Integrated to Barralcool Mill.

FIGURE 9 Barralcool Biodiesel Plant.

TABLE 9 Comparison of investments – Integrated biodiesel plants *versus* non-integrated plants.

Description	Investments – US$ 1,000[1]	
	Integrated Barralcool plant	**Non-integrated, independent plant**
Neutralization	1,136	1,136
Biodiesel process	5,909	6,818
Tanks/ Loading and delivery station	1,591	1,818
Pipe rack	455	682
Boiler	–	250
Cooling towers	–	114
Compressed air	23	23
Substation	682	682
N_2 plant	114	114
Cooling plant	68	68
Water treatment plant	–	91
Wastewater treatment plant	–	227
Fire-fighting installation	227	273
Laboratory	455	591
Scale	–	45
Civil works	1,818	2,273
Total	12,478	15,205
Comparative results	100%	122%

[1] Values in Real, converted by rate of US$ 1.00 = R$ 2.20.

TABLE 10 Cost of oil for biodiesel production.

Description	Quantity t/year	Cost U$/t	Annual cost 1,000 U$/year
Oil from own grain production	5,000	388.44	1,942.2
Oil acquired on the market	45,000	636.36	28,636.2
Total	50,000		30,578.4

TABLE 11 Comparative costs of 1 t of biodiesel production – integrated *versus* non-integrated production, in the ethyl and methyl routes, and calculation of 50 000 t biodiesel annual costs.

Description	Unit of measure	Integrated production					Non integrated production				
		Unit Costs US$	Methyl route		Ethyl route		Unit costs US$	Methyl route		Ethyl route	
			Consumption/t	Cost US$	Consumption/t	Cost US$		Consumption/t	Cost US$	Consumption/t	Cost US$
Degummed oil	t/t	611.47	1	611.47	0.956	584.56	636.36	1	636.36	0.956	608.36
Methanol	kg/t	0.73	100	73	–	–	0.73	100	73	–	–
Bioethanol	kg/t	0.36	–	–	154	55.44	0.64	–	–	154	98.56
Total raw material		–	–	684.47	–	640	–	–	709.36	–	706.92
Catalyzer	kg/t	1.36	18.3	24.89	33.4	45.42	1.36	18.3	24.89	33.4	45.42
Chemicals	kg/t	Various	Various	9.52	Various	9.52	Various	Various	9.52	Various	9.52
Utilities	Several	Various	Various	1.61	Various	1.61	Various	Various	16.75	Various	16.75
Labor	US$/t	–	–	6.82	–	6.82	–	–	10.23	–	10.23
Total per t biodiesel		–	–	727.31	–	703.37	–	–	770.75	–	788.84
Credit glycerin sale	kg/t	(0.136)	(0.117)	(15.91)	(0.117)	(15.91)	(0.136)	(0.117)	(15.91)	(0.117)	(15.91)
Cost per t biodiesel		–	–	711.40	–	687.46	–	–	754.84	–	772.93
Cost per m^2 biodiesel		–	–	626.03	–	604.96	–	–	664.26	–	680.18
Comparative		103.5%			100%		109.8%			112.4%	
50.000 t Biodiesel annual cost		35,570,000			34,373,000		37,742,000			38,646,500	

ing B30 (= 2.1 million litres), attains about US$ 300,000 per year.

The ethylic biodiesel sold by Barralcool will have a lower comparative cost than the biodiesel produced by non-integrated plants. Admitting that both are sold on the market for the same price, the mill will have an additional result of US$ 2.1 million/year and US$ 4.1 million/year, in comparison with the methyl or ethyl based product of the non-integrated production.

FINAL CONSIDERATIONS

The innumerable advantages of integrated biodiesel production in sugar and alcohol mills have been described in this paper.

These advantages occur in the farming and in industry, optimizing the use of land, resources, systems and management. Benefits are presented from the energy, process and economic aspects, in which costs and investments are reduced and income and profit are increased; as a result, biodiesel plants integrated with the sugar and alcohol mill provide a better return on investment than isolated plants.

Other relevant aspects deserve to be pointed out:

- The sugar and alcohol mill completes its full energy independence with the use of bagasse, bioethanol and biodiesel to meet all its energy demands.
- Integrated production makes ethylic biodiesel economically feasible. Thus, op-

portunities open for the use of ecological biodiesel, the ethylic biodiesel, 100% green and renewable, which can replace methyl biodiesel that uses the raw material methanol, of fossil origin.

- There are important environmental advantages with biodiesel replacing diesel derived from petroleum, and from the double use of the agricultural area already occupied by sugarcane, and thereby avoiding the use of new areas to install grain plantations.
- The solution of agricultural partnerships with family farmers, adopted by Barralcool, can also be applied by other mills, with the benefit of promoting social inclusion of the small farmer, and fixing persons in the rural areas.
- The use of the cane plantation renovation land can be maximized with the development of technology, new varieties and agricultural practices, which broaden the possibility of obtaining 2 harvests from the same lands and in the same sugarcane crop period. At present, the combined use of soybean, peanuts or sunflower seeds enables an increase of around 30% in grain production, when compared with the harvest of a single oleaginous crop. The potential gains are higher than 30%.
- A very attractive solution is the implementation of 1 biodiesel plant for various other sugar and alcohol mills, all producing grains in rotation with sugarcane, and using the biodiesel produced in the plantations. The plant would be installed at the sugar and alcohol mill that best benefits the set.

It is important to record that all these advantages refer to only the 1st stage of the integrated plant development.

With the expansion of biodiesel production, and therefore, the quantity of grains, implementation of an oil producing industry integrated with the sugar and alcohol mill becomes advantageous, which is the second stage of Figure 4: agricultural and industrial integration.

With the development of the activity, opportunity will be opened for the 3rd stage: integration of processes in the grain and sugarcane productive chains.

We have no doubt that this development will significantly increase the competitiveness of biofuels. And this is a challenge we understand that the sugarcane agribusiness will face in the future. It is a long road.

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11

WORKSHOP ON THE HYDROLYSIS OF LIGNOCELLULOSIC MATERIAL

Antonio Bonomi

Today the world is discussing the possibility of producing second generation bioethanol. To make this new production alternative feasible for this renewable fuel, new technologies are under development, trying to use the lignocellulosic component of biomass. Such new technologies focus on two major lines: hydrolysis of the lignocellulosic material to produce fermentable sugars (chemical and biological route), and the gasification of this material followed by the synthesis of liquid fuels (thermal route).

In the new "energy cane" paradigm, the whole cane would be harvested (with improvements and mechanization of the harvesting process), in addition to optimize the energy balance of the mill, in order to increase the quantity of surplus biomass. Residual biomass hydrolysis and gasification technologies, once developed, will be able to convert fiber into ethanol or other fuels from the fermentation of the sugar produced (hydrolysis), or from the synthesis of compounds from the gas generated (gasification). With this new paradigm, it is possible to significantly increase ethanol production per hectare/year, stepping from the current 6,000 liters to about 12,000 liters (projected level).

The use of biomass to produce ethanol fuel by chemical and biological route involves, basically, two processes: hydrolysis of polysaccharides contained in the lignocellulosic materials in sugars and the fermentation of these into ethanol or other fuels.

This theme was discussed in detail during two events that took place within the project Guidelines for Public Policies for the Sugarcane Agriculture in the São Paulo State Public Policy Research Program (Diretrizes de Políticas Públicas para a Agroindústria Canavieira do Estado de São Paulo, Programa de Pesquisa em Políticas Públicas – Etanol – PPPP). The first event was the III Technology Workshop on Hydrolysis held at the Technological Research Institute of the State of São Paulo (Instituto de Pesquisas Tecnológicas do Estado de São Paulo – IPT) on December 14th, 2006, and the second one was the meeting with Prof. Guido Zacchi, from the Chemical Engineering Department of Lund University, Sweden, which took place on February 1st, 2007, during his visit to Unicamp.

III TECHNOLOGY WORKSHOP ON HYDROLYSIS

The workshop dealt with the subject of Hydrolysis, focusing four basic themes. These themes, including key questions for each of the development areas and that were used as starters for lectures and debates, are listed below.

1. Lignocellulosic material characterization:
   - Are there significant advantages between trash and bagasse, in terms of their processing to produce ethanol?
   - Are there important interferents in the sugarcane bagasse and trash for the hydrolysis process?

2. Lignocellulosic material pretreatment and hydrolysis:
   - How to define when pretreatment ends and hydrolysis begins?

- How to separate lignin from the pre-hydrolyzed material?
- Is the hydrolysis enzymatic route better than the chemical routes?
- Can enzymes be economically produced in house in the alcohol plant?

3. Fermentation of the hydrolyzed lignocellulosic material
   - Should cellulose hydrolyzed material fermentation be coupled with the hydrolysis stage, or to the saccharose juice fermentation in the alcohol plant?
   - Is it economically advantageous to convert hydrolyzed hemicellulose into ethanol, or should other options for its use be sought?
   - Is it technically feasible, and how long would it take, to introduce in sugar and alcohol mills engineered organisms capable of fermenting simultaneously with hemicellulose and cellulose hydrolyzed materials?

4. Plant energy optimization, including hydrolysis
   - What is the limit of surplus trash and/or bagasse percentage that can be attained in a standard sugar and alcohol mill, within the context of the new "energy cane" paradigm?

The aspects detailed by lecturers are shown below, with the major issues debated throughout the event, organized into the four themes defined for the workshop.

Lignocellulosic material characterization

The alcohol from lignocellulosic materials production process starts with planting and/or harvesting the material. One factor that is critical for success is the availability of this material, its cost, and the condition it arrives to the processing venue. Here are the first questions calling for answers:

- What is the quantity of sugarcane bagasse and trash actually available for conversion into alcohol? Is bagasse and trash the only viable raw materials? Why?
- What are the ideal logistics for transporting trash to the mill? Are this logistics associated to sugarcane or not?
- How will the likely energy scenario in the next few years (mostly the demand of electricity) affect this availability?
- What are the (opportunity) costs of these materials?

After these materials arrive at the processing venue, a second series of questions may be raised upon the next operation, which is their preparation, or pretreatment, intended to optimize hydrolysis (the process deemed most viable for producing monomeric sugars, and then alcohol via fermentation, though there are other thermochemical options):

- In terms of the desired conversion of these materials into alcohol, what is their recalcitrance, i.e. what is the level of enclosure or protection of the polymers that can provide fermentable sugars? How can this recalcitrance be measured? What is the economic reduction of the recalcitrance, i.e. how aggressive pretreatment should be as a function of the composition or condition of the raw material?
- What components are present in these materials that must be changed in their structure, or that should be economically removed?
- How to process (i.e. store, transport, mix to other components, increase attack area etc.) large quantities of porous and low-density materials? What changes in the original materials' state or composition would be desirable for optimized pretreatment?

After pretreatment, there is the hydrolysis process for producing fermentable material (monomeric sugars) from polymers present in the material, which can also be affected by raw material quality:

- What is the availability of polymers, or what is the minimum polymer digestibility and concentration the material has to reach in the hydrolysis process, in order

to minimize both successive processes and energy costs? Does the original material composition affect the pretreated material composition?
- What components originally present in the material determine hydrolysis efficiency (and therefore its cost)? Do inputs (catalysts) and more or less severe hydrolysis conditions depend on raw material composition?
- How can hydrolysis performance be measured and linked to material components? Is any component originally present in the material converted into a hydrolysis inhibitor?

After hydrolysis, the monomers it generates are converted into ethanol, in general biologically in a fermentation process, preferably associated to the current process, already optimized to convert soluble sugars from sugarcane. The following questions come up:

- Does the original material composition affect the presence of non-fermentable or fermentation inhibiting material (or yet undesirable material, such as e.g. solids in suspension)?
- Do non-fiber impurities reach fermentation? What is the cost to prevent them from getting there?
- Considering material composition and minimum pretreatment and hydrolysis process costs, is it possible to discuss the convenience, or lack of it, to couple current fermentation together with the fermentation of monomers obtained from the material?

There are some other questions across the processing phases that may also be related to material characteristics, such as:

- How will SMS conditions be affected by processing large quantities of low density fibers, the presence of small inhalable particles, self-ignition below a certain moisture level, among other factors?
- Considering that it will be necessary to buy new equipment and inputs, and upon the need to get return from such investments, will it be viable to operate them during harvest time only, as it is done today (max. 200-250 days)? How can lignocellulosic material be stored for long periods of time?
- What kinds of new residues will be generated, and what is the need for post-treatment before disposal? How do material characteristics affect both quantity and quality of these residues (mainly stillage)?
- How will energy demand be fulfilled for the process that produces significantly larger quantities of alcohol? How does material quality affect these requirements?
- Does water and other utilities consumption change with any characteristic of the raw material?
- Are there any other clients interested in bagasse as raw material, e.g. electric power plants (for co-generation or even generation)? Will there be sufficient material for all of them? Is there any feature in the material that may influence the decision on its destination?
- Will thermochemical processes, considerably less demanding on the raw material composition or state, be viable? When?

Some additional issues approached in the workshop, referring to the material characteristics theme and that will have to be assessed upon defining the lignocellulosic material hydrolysis technology, were:

- The need to implement standard analysis procedures for the main components of lignocellulosic materials, to aid in mass and energy balances and to allow estimating material degradability. There is no consensus yet on the methods to follow lignin through, nor to assess degradability or enzymatic digestibility.
- The need to carry out studies on fractioning raw materials, bagasse and trash, to check the viability of removing undesirable fractions, and to check whether the most degradable fractions can be used preferentially.
- The need to define pretreatment requirements for each fraction or raw material

option. Economic and technical feasibility studies for alternative pretreatments should be elaborated.

- Need to study other sugarcane options, i.e., "energy cane" from the standpoint of raw material availability for hydrolysis and its composition, and degradability.
- Consider the quantity of pre-existing sugar in raw materials and its potential impact on lignocellulosic material pretreatment.

Lignocellulosic material pretreatment and hydrolysis

As a result from the synergy that exists among the various steps in the lignocellulosic material hydrolysis process, upon attempting to define and describe the material pretreatment and hydrolysis, it was noticed that it is essential to take into account the fermentation system to be employed.

In the case of ethanol production from glucose obtained by acid/enzymatic hydrolysis of sugarcane bagasse, the **preparation step** is defined as: screening, grinding, washing and physicochemical processes intended for the selective removal of hemicelluloses (without converting them later into ethanol) and lignin (e.g. treating with steam, hot pressurized water, moist alkaline oxidation, hydrolysis with diluted acid) and washing of the solid fraction (pulp) with alkalis, acids or ethanol. In this context, the **availability step** is considered as: enzymatic/acid hydrolysis of cellulosic pulp (coming from the preparation step) intended for the production of glucose, for later conversion of this carbohydrate into ethanol. Proceeding to the decontamination of the saccharidic solution (hydrolyte) produced in the availability step, this operation is considered as **hydrolyte preparation** for the next step of conversion into ethanol. However, for the sake of simplification, the terminology described in literature and industrial practice is used, where the operational sequence is considered: raw material preparation – pretreatment – hydrolysis – fermentation for the systems considered.

The major challenge of an economically viable production of ethanol from lignocellulosic biomass resides in determining the best option to make glucose available from cellulose hydrolysis in terms of overall cost, glucose yield, and hydrolyte fermentability. Essentially, carbohydrates availability processes from sugarcane bagasse by cellulose (and hemicellulose) hydrolysis set out the most promising technological options, in view of their adaptability to existing alcohol producing plants, and their relative ease of implementation on an industrial scale. Such processes are intended for the production of pulps with high cellulose content and huge accessibility of the cellulosic matrix to hydrolytic chemical or enzymatic agents, envisaging the production of glucose from cellulose. Striking differences between the structural and physicochemical properties of bagasse cellulose and hemicelluloses (chemical composition, morphology, molecular orientation, chemical and mechanical strength) demand the execution of hydrolytic processes in two stages, being the first to convert (and remove) hemicelluloses from the bagasse and the second to convert cellulose into glucose.

In spite of all the positive features inherent to the use of sugarcane bagasse as raw material to produce ethanol, a major challenge to be overcome lies in reducing operational costs associated to the availability of carbohydrates for biotechnological conversion. The development of eco-efficient processes for bagasse pretreatment and cellulose hydrolysis emerges in this scenario with particular relevance.

The selection among different technological options for the availability of carbohydrates from sugarcane bagasse for ethanol production must consider parameters relative to the eco-efficiency of the hydrolytic process, such as saccharide yield, selectivity, hydrolyte fermentability, effluents outflow, reuse of materials and inputs, water and energy intake, value-adding residues and ancillary operations (e.g. washing), in addition to factors associated to operational costs (inputs, maintenance, labor), capital (building material and equipment setup), as well as aspects associated to the ease and flexibility of operating systems, and the implementation of efficient technologies and processes.

The pretreatment of lignocellulosic biomass is one of the most relevant operating steps in terms of direct cost, in addition to its significant influence on the costs of the upstream and downstream steps in the process. Basically, pretreatment relates to raw material preparation operations (grinding, impregnation), as well as hydrolysis (acid or enzymatic) of cellulose (load and consumption of enzymes or acids, reaction rates), generation of enzymatic hydrolysis and alcoholic fermentation inhibiting products, saccharidic concentrations of the hydrolytes produced, purification of intermediate products, waste treatment, mechanical agitation and energy generation. In this context, perfect integration among the different operations should be sought. Performance of a pretreatment technique should be assessed on its influence on the costs associated to upstream and downstream steps, as well as operating, raw material and capital costs of pretreatment itself. Thus, the pretreatment alone should be very efficient in terms of efficiency, selectivity, functionality (ensuring accessibility of the cellulose to hydrolytic agents), operational simplicity, industrial safety and hygiene and environmental attributes, at the same time that it should require a low input of chemicals, energy and utilities. Generally, an efficient pretreatment of sugarcane bagasse for ethanol production should simultaneously offer cellulosic pulp with high fiber accessibility and reactivity to acid or enzymatic hydrolytic agents (digestibility), it should ensure adequate pentoses recovery and yet limit the generation of compounds that inhibit both the microorganisms used in fermentation and the enzymes. Additionally, features associated to the use of low-cost catalysts, inputs recycling, and high value-added by-products from lignin characterize eco-efficient pretreatment systems.

Though various pretreatment techniques are potentially applicable to sugarcane bagasse, it is particularly difficult to carry out comparative studies based on data from literature due to differences in research methodologies, to the physical characteristics of the material, as well as to the preparation methods for the raw material. Nevertheless, it is worth emphasizing the importance of improving the knowledge about the differences among the various types of pretreatment, as well as on the impact of each process on the other operations. Such initiative might aid in selecting equipment and operation sequences in an integrated system, in addition to reducing risks associated to industrial scale process implementation, as well as in identifying improvement opportunities along the integrated system, leading to optimized operating efficiency and minimizing the overall costs of ethanol production.

In practice, it may be considered that bagasse is subjected to a physical pretreatment at the time of its production, after the wet crushing of sugarcane. Due to its reduced granulometry, bagasse does not require previous grinding before the physicochemical treatment, which is an advantage in terms of raw material preparation cost. However, low density and low compaction of bagasse represent a problem in terms of the reactor feeding operation, on top of the difficulty in carrying out pretreatment with solid loads above 50%. On the other hand, the presence of impurities from sugarcane grinding (e.g., ashes, silica) applies a buffering capacity to bagasse, resulting in a higher demand of acid to attain a pH adequate to hydrolytic pretreatment processes.

Proper impregnation of the lignocellulosic biomass consists in a very important parameter for the chemical treatment efficiency of any lignocellulosic biomass. Sugarcane bagasse has a high liquid absorption capacity, as well as reduced "hardness". Furthermore, the high moisture content of bagasse coming from mills (45-50%) makes it easier to impregnate this biomass with acid and alkaline solutions. This aspect has fundamental importance regarding the acid hydrolytic pretreatment efficiency, which requires adequate concentration of hydronium ions (H_3O^+), formed from water with the dissociated acid. Insufficient water in the biomass would cause less hydronium ion formation, as well as reduced availability of conveying fluid from it to the inner biomass, and, therefore, loss of efficiency of the hydrolytic capacity of the process.

The challenge, therefore, lies in determining the "*optimum*" quantity of water in bagasse to ensure effective biomass impregnation, while a solid load is obtained in the reactor, especially in "*steam explosion*" processes. Solid loads in the

25%-40% range of dry bagasse weight with 50%-70% moisture may result in selective extractions of xylose (60% to 80% recovered) with reduced glucose loss (3% to 5%), producing pulps with high fiber reactivity (85% to 95%). Pretreatment processes with steam at 200 ºC and 210 ºC (only) evidence a significant increase in delignification and lignin fractioning.

Based on the above, it is recommended to wash the bagasse before loading the reactor, in order to promote densification/compaction of the biomass, as well as to facilitate its impregnation with the chemical agents used in the pretreatment. It is considered that, in the case of the "*Steam Explosion*" system, reactor load with 25% of solids using bagasse with 75% moisture leads to high recovery of hemicelluloses in the hydrolyte, while high fiber reactivity and high global glucose yield are obtained. Pretreatment systems with diluted acid and "*Hot Water*" may benefit from pre-washing bagasse in view of the reduction of buffering capability of biomass (caused by the removal of impurities) associated to higher material compaction. Bagasse washing may be done on the reactor feeding belt conveyor by spraying, so no complex operation is added between bagasse generation and feeding to the reactor.

Sugarcane bagasse has a high content of hemicelluloses (30%), predominantly made up of pentose polymers (xylan and xyloarabans). As a result of pentoses' high reactivity (especially xylose) at temperatures above 140 ºC, selectivity and saccharide yield from the hemicelluloses hydrolysis process may be compromised when bagasse undergoes hydrolytic pretreatments at temperatures above 180 ºC for processing periods from 30 to 60 minutes. The adoption of severe process conditions tends to increase the degradation of xylose into furfural, as well as to promote glucose degradation into hydroxymethylfurfural (HMF), compounds that potentially inhibit alcoholic fermentation. Lignin solubilization and fractioning associated to extremely severe process are potentially detrimental to later stages (enzymatic hydrolysis and fermentation), as a result of lignin buildup on the cellulosic pulp surface, as well as the generation of fermentation-inhibiting compounds, such as phenol derivates and organic acids.

Thus, it becomes difficult to obtain pentose recovery above 90% by means of conventional pretreatment in single-step processes. On the other hand, the two-step process delivers larger hydrolyte volumes with reduced saccharide concentration (10 to 15 g/l), potentially detrimental to later pentoses to ethanol conversion operations. It becomes necessary to do an economic viability assessment regarding the adoption of a two-step process, due to the energy and inputs consumption, as well as overall process productivity, on top of the generation of liquid streams with reduced saccharides concentration.

In summary, pretreatment processes should be carried out under moderate conditions, to simultaneously promote high cellulosic fibers reactivity and high hemicelluloses recovery, with minimum glucose loss in the hydrolyte, in addition to minimized generation of compounds that inhibit the later hydrolysis and fermentation steps. On the other hand, a treatment step (e.g., purification, lignin-carbohydrates separation) of the hemicellulosic hydrolyte produced should be minimized, for the sake of operational simplicity and process economy. For the SSCF (simultaneous fermentation of pentoses and hexoses), it becomes important to use both solid and liquid fractions of the material from pretreatment without any lignin-carbohydrate separation process on the liquid or pulp washing, in order to maximize saccharide recovery and the sugars concentration in the hydrolyte. Steam pretreatment processes, auto-catalyzing or in the presence of a catalyst, hot water and diluted sulfuric acid come out as the most promising technology options for the implementation of hydrolysis units next to sugar-alcohol plants.

Hydrolytic cellulose conversion has been considered one of the major technology bottlenecks of ethanol production from lignocellulosic biomass. Initially, enzymatic conversions seem to be promising alternatives in terms of total cost, from the possibility of attaining glucose efficiency close to theoretical levels, in addition to the possibility to depend on modern microbiology and genetic engineering techniques, aiming at the optimization of the steps in the integrated process.

At first, the enzymatic routes present important advantages over chemical routes, in the context of producing ethanol from sugarcane bagasse. A major challenge is to render the enzymatic process viable. Enzymatic hydrolysis processes should be conceived as a function of the type of substrate produced, the pretreatment used, as well as the fermentation strategy to be used (SHF – separate hydrolysis and fermentation, SSF – simultaneous hydrolysis and fermentation, or SSCF – simultaneous hydrolysis and co-fermentation) This way, solutions should be tailor-made, considering the specific integration features chosen for each production system.

The enzymatic hydrolysis process usually presents advantages associated to yields above 0.85 g glucose / g cellulose, under moderate temperatures (40 °C to 50 °C) and atmospheric pressure. However operational aspects related to the long processing time (48 to 72 hours), catalytic deactivation by inhibition of enzymatic activity, as well as high cost of enzymes, have caused uncertainty regarding the economic viability of enzymatic hydrolysis in the ethanol from lignocellulosic biomasses production context.

The enzymatic hydrolysis rate of a bagasse pulp tends to decrease with the concentration of carbohydrates (e.g. xylose, glucose and cellobiose) and ethanol in the reaction medium, as these compounds above certain concentration levels promote an inhibition of enzymatic activity. It has been noticed that glucose has more influence on enzymatic inhibition, if compared to ethanol, as well as there is some synergy between these compounds in this phenomenon. Such evidence points to the potential of using the liquor displacement technique after 24 hours of process during SHF operations, with partial enzymes replacement. It was also noticed that, due to higher enzymes tolerance to alcohol, the use of SSF systems (where glucose is converted into ethanol by microorganisms as glucose is produced) enables increasing enzymatic activity and consequently the increase of the overall hydrolytic yield. However, the need to analyze the various options on a case-by-case basis must be emphasized, as SSF processes are carried out *"off optimal operating conditions"* for both enzymes and yeasts, so that a gain in yield due to reduced enzymatic inhibition may be offset by less enzymatic activity as a result of not so adequate operating conditions. Though it exerts a lesser inhibiting effect than glucose or cellobiose on the hydrolysis rate, the presence of ethanol in pretreated pulp (after washing with ethanol-water) causes a strong decrease in enzymatic activity during the hydrolysis process. Therefore, organosolv acid processes using ethanol tend, by this principle, to produce pulp with enzyme inhibitors.

Washing pretreated pulp is essential in SHF processes, especially when operating with solid loads above 8%, as a result of the inhibiting effect on enzymatic activity exerted by carbohydrates (xylose and glucose), degradation compounds, and lignin derivates built up on the pulp. Pretreated pulp washing with diluted sodium hydroxide or ethanol-water increases the cellulose content due to delignification of the pulp. However, in some cases, solubilized lignin sediments back on the cellulosic matrix form a film and restrict pulp access by hydrolytic agents. As a result, glucose yield in the hydrolysis process is impaired. Furthermore, the presence of ethanol (from the washed pulp) in the reaction medium has an inhibiting effect on enzymatic activity, lowering production yield. Washing the pretreated pulp with diluted nitric acid represents a potentially interesting technological alternative (mostly in pulps pretreated by acid processes) as in addition to not presenting the aforementioned inconveniences, this technique promotes cellulose swelling, increasing its accessibility by the enlargement of pores associated to the reduced crystallinity in cellulose. Additionally, washing the pulp with diluted nitric acid allows sequestering iron cations present in the pulp, which exert an inhibiting effect on enzymatic activity. Finally, nitric acid promotes nitration and partial removal of lignin with minimum fragmentation of it, so that no substantial resetting of lignin on the cellulosic matrix takes place.

Addition of a surfactant in quantities close to 0.005 g/g of pretreated bagasse promotes a significant increase in the glucose yield in enzymatic hydrolysis processes in both SHF and SSF processes, leading to some 50% lower enzymes intake. Basically, the surfactant promotes changes in the substrate structure, making cellulose more susceptible to attack by enzymes, while it minimizes enzyme denaturation due to the shearing forces in the reaction medium and, finally prevents enzymes deactivation associated to their adsorption by the substrate. A synergy between the use of Tween-90 is evidenced with the adoption of liquor displacement regarding an increment in enzymatic activity (mostly with substrate loads above 2%) and consequently of glucose yield.

Mechanical agitation used in hydrolytic processes tends to increment enzyme activity, as it promotes further enzyme-substrate interaction, in addition to reducing resistance to diffusion in the reaction medium, especially with solid loads around 5%. However, beyond a certain "*critical value*", mechanical agitation tends to increment tangential displacement of the enzymes, as well as to incorporate shearing stresses to the medium, resulting in loss of enzymatic activity, in addition to less contact between enzyme and substrate. The loss of the β-glycosidase activity tends to be more intense in regimes having vigorous mechanical agitation, tending to increment with the increase of the residence time. Particularly SSF systems using substrate loads around 8% to 10% should adopt a different agitation profile, operating with more vigorous agitation (200-300 RPM) during the first hour of the process, aiming to promote better impregnation of the substrate with enzymes. Next, agitation should be slowed down to about 150 RPM, to minimize β-glycosidase deactivation.

The choice of an enzymes formulation exclusively based on enzymatic activity [cellulase (FPU/g) and β-glycosidase (IU/g)] may induce to mistaken conclusions in terms of hydrolytic process efficiency. Practice has demonstrated that different formulations containing the same activity may present different performances in the enzymatic hydrolysis of lignocellulosic pulps under the same process conditions. Therefore "custom made, case-by-case" solutions should be developed and tested, considering the pretreated pulp characteristics. This means that the development of a pretreating system should be integrated with enzymes production, cellulose hydrolysis, and carbohydrates fermentation.

Compared to chemical routes, from a technical standpoint, the enzymatic route appears as a more proper alternative for producing ethanol from bagasse due to better chances of obtaining high glucose yield, around 90%, with enzyme loads of approximately 7.5 FPU/g of cellulose, at the same time that hydrolytes with reduced toxicity to fermentation microorganisms are obtained. However the economic viability of this process depends fundamentally on obtaining enzymes at a landed price around US$ 1.30/kg, about 75% lower than prices currently practiced in the Brazilian market.

Based on the context that was presented, the in-house (i.e. within the sugar-alcohol plant) production of these enzymes, using part of the pretreated bagasse (about 30% – 40%) as a substrate emerges as a potentially attractive technological option. Among the potential advantages, it would be possible to mention the absence of transportation costs, the possibility of using diluted formulations, lower purification and concentration costs, lower product conservation complexity, in addition to being able to use hemicellulosic hydrolytes for cultivating microorganisms. Considering that the integrated system requires tailored solutions, in-house production of enzymes becomes extremely important. Preliminary studies indicate that it is possible to produce enzymes in-house at a total cost of US$ 20/m^3 of ethanol, i.e. about 9% of the cost of ethanol.

Basically acid hydrolysis has important advantages over the enzymatic process due to availability, guaranteed supply, and lower reagent costs, in addition to mature technology and lower restrictions in terms of intellectual property. On the other hand, there are disadvantages concerning the need of acid recovery systems (in processes using concentrated acid) and higher equipment building material costs. Processes using diluted acid pose problems associated to reduced glucose yield (50% to 60%), in addition to the formation of fermentation-inhibiting compounds, resulting from saccharide degradation. In these circumstances, there is a need to process to hydrolytes treatment, thus increasing the cost of the overall process. On the other hand, the adoption of a fed-batch fermentation strategy has emerged as an interesting technological alternative, with the purpose of minimizing such inhibiting effects, no longer requiring hydrolyte treatment.

Among the cellulose hydrolysis processes with diluted acid, special attention has been given to the use of continuous reactors in counterflow, where glucose is extracted practically at the same time it is produced. In this manner glucose degradation is minimized, while saccharide yield is maximized. Relatively diluted hydrolytes are produced, which tends to increase operational costs in later operations. The hydrolysis process with diluted acid in counterflow reactors makes it possible to obtain glucose yields around 80% to 85%. Therefore, in spite of this technological option having inconveniences associated to the higher operating complexity, the cellulose hydrolysis process with diluted acid in counterflow may be considered as a potentially interesting option for producing ethanol from sugarcane bagasse by using the hydrolyte mixed with molasses or sugarcane juice. Alternate settings, such as flow reactors with shrinking-bed-flow-through may lead to hydrolysis processes with diluted acids that can actually be competitive with enzymatic hydrolysis processes.

In strategic terms, it seems particularly proper to develop cellulose hydrolysis processes with diluted acid (including the organosolv process) to create backup solutions that allow facing the uncertainties related to the development of really competitive enzymatic processes, as well as to ensure local supply of enzymes at affordable prices.

Fermentation of the lignocellulosic material hydrolyte

The fermentation of the reducing sugars liquor obtained after the hydrolysis of lignocellulosic materials is a critical stage to reach an ethanol production process that ensures a maximum conversion of these sugars, and that is compatible with a viable production cost from both technical and economical standpoints. Yet, the following should be considered: energy consumption associated to fermentation conditions and the grade of ethanol in the final wine obtained.

To assess all possible fermentation routes for the hydrolysis liquor, it is important to take into account previous experiments made in industrial scale, demonstrations, or carried out merely to set the grounds for a demonstration process.

Diluted-acid catalyzed hydrolysis was industrially practiced in Russia until recently. The process practiced in the Tavda unit was an optimized version of the Schoeller process, which employed forest residues, processed in batches and by percolation, attaining 60% conversion of the hexoses. Fermentation was made by combining amylaceous saccharified mashes with the liquor resulting from the hydrolysis. The final wine presented very low alcohol content, 1.3 °GL, and consequently steam intake was 20 kg per liter of ethanol. Pentoses were not used for ethanol fermentation, being diverted for biosynthesis of unicellular protein. This process requires high investment in equipment and operating costs, not being economical.

The Sugarcane Technology Center (Centro de Tecnologia Canavieira) carried out an extensive study on the fermentation of hydrolysis liquor obtained with the DHR process (Dedini process, under development) to demonstrate the alcoholic fermentation stage. The liquor obtained from acid hydrolysis with the use of a solvent was mixed with waste honey and syrup to reduce the impact of inhibitors from hydrolysis, and attempting to keep fermentation in operating conditions close to optimal: process with yeast recycling, final wine with 8.5 °GL and temperature of 34 °C. Results were positive, establishing the protocol for performing alcoholic fermentation of the liquor obtained from the DHR process.

The Iogen process, in demonstration in Canada, employs pretreatment of lignocellulosic biomass by steam explosion and pre-acidification with sulfuric acid, followed by a stage of enzymatic hydrolysis made by the addition of cellulase preparations. Alcoholic fermentation is done at a later stage, mixing the liquor from hydrolysis to a previously saccharified starch mash. Pentoses are discarded, as their fermentation technology

– which Iogen intends to employ – has not yet reached demonstration stage. No hydrolysis liquor purification treatment is performed; inhibitors present are diluted to the tolerance level in the mix with the amylaceous mash.

During the pretreatment of the lignocellulosic material or in the acid-catalyzed hydrolysis processes, not only the sugars from hydrolysis, cellulose and hemicellulose dissolution are obtained. Due to the high temperatures and acid conditions where these pretreatments occur, several compounds appear, being capable of acting as potential inhibitors to fermentation. The nature and concentration of these compounds depend on the type of raw material (cellulose, hemicellulose and lignin content in percentage), on the pretreatment used, on the process conditions (temperature and reaction time) and the use of acid catalysts or not.

Degradation products, which are potential fermentation inhibitors, are grouped in three categories:

- furane derivates;
- low molecular weight aliphatic acids;
- phenolic derivates.

As a consequence of the high temperatures used in pretreatments, sugars from hydrolysis – mostly the hemicellulosic ones – degrade, generating furane-derived compounds: furfural, formed from pentose (xylose and arabinose) and 5-hydroxymethylfurfural (HMF), formed as a consequence of hexoses (glucose, manose and galactose) degradation.

On their turn, these two compounds may further degrade to other products. Furfural may degrade into formic acid or polymerize. HMF originates equimolecular quantities of formic and levulinic acids. Furthermore, from these two aliphatic acids (formic and levulinic), acetic acid is formed by hydrolysis of the acetyl radicals in hemicellulose.

The content of these inhibitors in the liquor after pretreatment depends on the nature of the lignocellulosic material used. Hydrolytes from materials that contain a comparatively higher percentage of hemicellulose present a greater concentration of furfural and acetic acid.

During pretreatment, part of the lignin also degrades, generating a wide variety of phenolic compounds. This is a quite heterogeneous group of compounds that may be found in the form of monomers, dimers, with a wide variety of replacers. Among them there are acids, aldehydes and aromatic alcohols. Phenols originated in pretreatment vary according to the type of biomass, considering that there are great variations in lignin, depending on the vegetal species it comes from.

One phenolic derivate quite abundant in hydrolytes is the 4-hydroxybenzoic acid, originated from the rupture of the ester links bonding the hydroxyl groups to the cinnamic alcohols of lignin. Other phenolic derivates abundant in hydrolytes are syringaldehyde and syringic acid, resulting from the degradation of syringil propane units in lignin. 4-hydroxybenzaldehyde, gentisic, salicylic, and protocatechuic acids, vanillin and vanillic acid, catechol, guaiacol, hydroquinone, coniferilic aldehyde and homovanillic acid have also been identified in hydrolytes.

One group of compounds (not included in the aforementioned three) released during pretreatment is the extractives. Among them there are different types of resins (fatty acids, terpenoids, sterols and waxes) and phenolic compounds (flavonoids, tannins etc.). Such compounds, though low in concentration, are present in bagasse and may act as inhibitors to the microorganisms used in hydrolyte fermentation.

Among the negative effects of furfural on microorganisms in general and fermentation yeasts for alcoholic fermentation in particular, the following are described:

- reduction of the specific growth rate;
- reduction of the volumetric or specific ethanol productivity;
- reduction of the biomass synthesis.

Negative effects caused by HMF, though less intense – considering that its toxicity to microorganisms is lower than furfural – are the same.

The toxic effect caused by furane compounds seems to be associated to the fact that, being chemically reactive aldehydes, they may react with certain biological molecules, such as lipids, proteins, and nucleic acids, or cause damage to the cell membrane.

Furthermore, furfural inhibits glycolytic and fermentative enzymes. The inhibition furfural exerts on alcohol-dehydrogenase could explain the acetaldehyde excretion observed during the first hours of fermentation.

Furfural and HMF are metabolized by both bacteria and yeasts. In anaerobic conditions, as a consequence of furfural metabolism, mostly furfurilic alcohol is produced and, in a lesser concentration, furoic acid. The hypothesis that the reduction of furfural to furfurilic alcohol is catalyzed by a NADH-dependent alcohol-dehydrogenase is practically accepted. In anaerobic conditions, during fermentation, glycerol is produced to regenerate the excess NADH generated in biosynthesis and to keep the intracellular redox balanced. In fermentation with furfural present, glycerol formation is not observed, which suggests that the reduction of furfural to furfurilic acid oxidizes the NADH in anaerobic conditions.

Though it is well documented in bibliography that weak aliphatic acids lower ethanol yield and decrease biomass production, the mechanism which causes this inhibition has not been fully clarified.

One of the mechanisms proposed to explain aliphatic acids' inhibiting effect is the uncoupling theory. According to this theory, the toxic effect depends on the acids' pKa and the medium's pH. Only the non-dissociated form of the acids penetrates the cell by diffusion, where, due to higher intracellular pH, it dissociates, causing a lower pH that should be compensated by a membrane ATPase pumping protons out of the cell at the cost of ATP hydrolysis. The lesser ATP quantity available for building the cell biomass would explain the reduced growth when aliphatic acids are present in the medium. When acid concentration is sufficiently high, the proton pumping capacity is surpassed, which causes cytoplasm acidification, and later cell death. Another proposed mechanism to explain this inhibiting effect of acids is the intracellular buildup of anions. According to this theory, while protons are excreted, anions are trapped in the cell, accumulating inside it. Inhibition could be related to anion toxicity. Though the aliphatic acids inhibition mechanism is not known for sure, the toxic effect displayed by these compounds may be due to either the uncoupling effect or the inhibiting effect of anions buildup. Quite likely short-chain aliphatic acids' effect is also due to the direct action of these compounds on membrane integrity. The insertion of aliphatic chains in the membrane may alter its structure and hydrophobicity, increasing its permeability and affecting its function as a selective barrier.

From all inhibitors identified in lignocellulosic material hydrolytes, low molecular mass aromatic compounds have been seen as the most toxic to microorganisms. Though the inhibition mechanism is not completely known, the effect of phenol derivates on prokaryotes like *Klebsiella pneumoniae* and *Escherichia coli* have been studied. The toxic effect of aromatic aldehydes may be related to the interaction with certain hydrophobic cell zones, causing membrane loss of integrity, affecting its ability to act as a selective barrier. The toxic effect of aromatic alcohols is attributed to the damage they cause on the plasmatic membrane. The inhibiting effect presented by aromatic acids may be based on similar mechanisms to the previously described for aliphatic acids. Though several studies were made on the effect of phenolic acids on yeasts, especially on *Saccharomyces*, the inhibition mechanism on eukaryotes has not been fully clarified. Since the plasmatic membrane structure is similar to the prokaryotes', it is said that the inhibiting mechanisms could be similar. Like for furfural and HMF, there is data in literature demonstrating the ability of certain microorganisms – both bacteria such as *K. pneumoniae* and *Z. mobilis* and yeasts of the *Saccharomyces, Pichia, Pachysolen* and *Candida* types – to metabolize aromatic aldehydes. However data available in literature about the role of the alcohol-dehydrogenase of *S. cerevisiae* in converting these compounds is contradictory. Other enzymes that may be acting in aromatic aldehydes' metabolism are vanillin-oxidoreductase, aldose reductase and arialcohol – dehydrogenase.

Having the intent of increasing fermentability of hydrolytes obtained after pretreatment, it is necessary to lower concentration or to eliminate completely from the medium, the toxic compounds generated in pretreatment and hydrolysis.

Depending on the mechanisms used to eliminate inhibitors, these methods may be grouped as: biological, chemical and physical.

Biological methods

They consist of using microorganisms capable of metabolizing some of the toxic compounds present in hydrolytes. One example of biologic treatment is the detoxification of hydrolytes using *Trichoderma reesei* mycelia. This microorganism is capable of metabolizing pentoses and oligomers present in hydrolytes, without being affected by the toxic products found in it. Treatment with this fungus has eliminated compounds like acetic acid, furfural, and benzoic acid.

Enzymes (lacase and peroxidase) from lignolytic fungi may also be used. Enzymes from *Trametes versicolor* have also been used for complete and selective elimination of phenolic monomers found in hydrolytes. Based on absorption spectra, it seems that the mechanism by which these enzymes reduce the hydrolytes toxic effect is an oxidizing polymerization of low molecular mass phenolic compounds to aromatic compounds with higher molecular mass, however less toxic.

Chemical and physical methods – extraction with solvents

Relatively high volatility – compared to water – organic solvents are efficient in removing aliphatic acids and aldehydes. Low molecular mass esters, from aliphatic acids and alcohols acids, like ethyl acetate present favorable partition coefficients extracting aliphatic acids and aldehydes. Ethyl acetate, for instance, is efficient in removing acetic and formic acids, and furfural.

Chemical and physical methods – treatment with alkaline-terrous hydroxides

Treatment of lignocellulosic hydrolytes with various hydroxides has been one of the most widely used methods for eliminating toxic compounds generated in pretreatment and hydrolysis. By adding calcium hydroxide (others like sodium or magnesium hydroxide) to the medium until a pH of 10 is reached, low solubility calcium salts precipitate is formed, which drags some of the toxic compounds found on the hydrolyte, like furfural, HMF, and acetic acid. This precipitate should be removed from the medium before fermentation. Treatment may be combined with the addition of sulphide, which on its own is an efficient detoxification method. By treating lignocellulosic material hydrolytes with calcium hydroxide, significant increases in ethanol yield and productivity have been achieved.

Chemical and physical methods – removal by evaporation and distillation

This treatment pursues eliminating volatile compounds like furfural, acetic acid, and formic acid. Compounds like levulinic acid, hydroximethylfurfural and phenol derivates are not eliminated. Treatment should be carried out under low pH, as compounds like formic and acetic acid are volatile only in their protoned form. Efficiency is partial, considering that only volatile inhibitors are removed, while HMF and phenolic compounds remain.

Chemical and physical methods – adsorption in active coal and vegetal coal

The use of adsorption by means of active coal or vegetal coal has shown efficiency in the detoxification of hydrolytic liquors.

By applying vegetal coal, prepared from treated wood at temperatures above 600 °C, it has been possible to increase the fermentability of hydrolytes by the selective elimination of toxic compounds like furfural, HMF and phenolic derivates, without affecting the concentration of fermentable sugars.

Physical and chemical methods – use of ionic exchange resins

Some authors have successfully used cationic resins to detoxify hydrolytes, while others report negative results, attributing them to negatively-charged sulfonic groups of the cationic resins that cause repulsion effects on the inhibitors present in the hydrolyte. Best results were obtained with strong anion resins at pH 10. With these resins, elimination of phenolic compounds is mostly achieved, due to the formation of strong links with quaternary ammonium groups (positively charged) in the resin with phenols (negatively charged). Upon treating hydrolytes with ionic exchange resins, there is also a reduction in the concentration of furanes (in this case, due to hydrophobic interactions) and aliphatic acids. In spite of the good results achieved in eliminating inhibitors through ionic exchange resins, their high cost, for the time being, renders unviable their industrial application. The loss of sugars in the resins is yet to be determined. The industrial use of ionic exchange resins has often been challenged environmentally, due to the effluents generated in the regeneration phase, and the water volumes required.

Chemical and physical methods – use of residual lignin as adsorbent

A new method proposed for detoxifying lignocellulosic material hydrolytes consists of using lignin, produced as a residue in hydrolysis, as adsorbent in an extraction using its hydrophobic properties. The advantages of using residual lignin as a detoxifying agent, compared to chromatographic resins, are mostly economical, to lower treatment costs. As lignin is a by-product of hydrolysis, after its use in detoxification, it may still be used as primary fuel.

Physical and chemical methods – use of zeolites

The term zeolites encompasses a large number of minerals, both natural and synthetic, composed of a crystalline skeleton formed by the tridimensional combination of tetrahedrons TO4 (T = Si, Al, B, Ga,) linked to each other by plain oxygen atoms. This structure gives zeolites several properties, such as:

- strong ionic exchange capability;
- high specific surface;
- presence of active centers that allow an important catalytic activity.

Though their mechanism of action is unknown, zeolites have been successfully used in many processes. They are used as catalysts in hydrolysis reactions with various disaccharides, such as cellobiose, maltose, lactose etc., in the environmental control of industrial waste for the elimination of toxic metals (chrome, cobalt, nickel). In ethanol production processes from molasses they are used to remove fermentation inhibitors, such as alkaline and alkaline-terrous salts, plus organic inhibitors present in molasses. Experiments made with hydrolytic liquors showed an improvement in fermentation conditions after depuration with zeolites.

Glucose fermentation is a fully determined process. There is no more adequate microorganism than the *Sacharomyces cerervisiae* yeast that, by its intensive use in industrial scale fermentation, has passed through a natural selection process, presenting the best performance in converting glucose into ethanol, productivity, and tolerance to alcohol. As long as the inhibitors' negative impact is under control, fermentation occurs without any major problem.

Regarding fermentation of pentoses, few microorganisms are capable of fermenting them into ethanol. Transforming pentoses into ethanol is essential for achieving an efficient hydrolysis technology. In this item, ongoing researches are following these lines:

- yeast selection and improvement procedures to naturally ferment pentoses into ethanol;
- development of recombinant strains of *Sacharomyces cerevisiae*;
- selection of thermofilic bacteria;
- selection of mesofilic bacteria.

Three yeast species were identified as having the highest potential for alcoholic fermentation of pentoses: *Pichia stipitis*, *Candida shehatae* and *Pachysolen tannophilus.* However, their performance is quite limited. Pentoses metabolism requires the presence of a minimum level of oxygen, which must be strictly controlled. These strains have low tolerance to ethanol and alifatic acids. As alternatives, the selection of stronger mutants and the fusion of protoplasts have been tried.

Studies to obtain genetically modified strains of *Sacharomyces cerevisiae* to metabolize pentoses were directed toward the following strategies:

- insertion of bacterial genes that perform xylose isomerization into xylulose (xylose isomerase), the latter fermentable by *Sacharomyces*;
- insertion of the genes that allow assimilation of xylose into *Sacharomyces cerevisiae*;
- isomerization of xylose into xylulose, by adding an isomerase.

So far no further progress was accomplished in these studies.

As to the use of thermofilic bacteria, studies have been made with *Thermoanaerobacter ethanolicus*. This organism requires operating with highly diluted pentose medium. *Clostridium thermohydrosulfuricum* has been widely studied in CDM processes (direct conversion of the lignocellulosic material by the microorganism into alcohol). Among the difficulties found, authors mention: significant formation of acetates, which leads to low alcoholic yield, low tolerance to ethanol, and vulnerability to the presence of contaminants. Genetically modified thermofilic bacteria have also been studied, aiming at preventing acetate formation in parallel with ethanol. In conclusion, the major problems related to the use of thermofilic bacteria are: low tolerance to ethanol, strong sensitivity to inhibitors, parallel formation of a significant quantity of by-products and the need to add growth factors to the medium.

Regarding the possibility of using mesofilic bacteria like *Zymomonas mobilis*, they are not capable of fermenting pentoses, however, they are very efficient in the metabolism of glucose through the Entner Doudoroff via. The introduction of *Escherichia coli* genes makes the fermentation of xylose into ethanol possible.

Zymomonas mobilis is one of the most promising microorganisms for fermenting hydrolysis liquor. It has tolerance to both ethanol and inhibitors, as well as high fermentation productivity. It is considered one of the most promising recombinant microorganisms to successfully perform pentose fermentation. Nevertheless, the problems related to the genetically modified microorganism remain unsolved on the short run. Other mesofilic bacteria capable of metabolizing pentoses in the absence of oxygen are: *Escherichia coli* and *Klebsiella.* These, after having been subject to genetic modifications, are being studied as alternatives for the alcoholic fermentation of hydrolysis liquor. It is important to observe that the only industrial experience with sugar-based mash alcoholic fermentation, using a strain of *Zymomonas mobilis,* performed in Germany in the 1990s was not successful, and the unit was phased out, returning to the conventional process using yeasts as fermentation agent. The information available says that under the conditions that fermentation is performed, a quick contamination comes up, inhibiting fermentation.

To perform the alcoholic fermentation of a liquor containing pentoses and hexoses, the possibilities being studied are: simultaneous or sequential fermentation of pentoses and hexoses. In the simultaneous fermentation, two microorganisms that respectively ferment glucose and xylose are co-cultivated. Most of the works in this field use two yeasts: *S. cerevisiae* and *P. stipitis* (pentoses). Difficulties found were:

- the metabolism of xylose is slower than glucose, causing alcoholic inhibition on the microorganism that metabolizes pentoses;
- catabolic repression of glucose on the use of xylose;
- *S. cerevisiae* competes for the oxygen present in the medium with the yeast in charge of fermenting xylose;
- possible incompatibility between the two strains.

Another option is to operate fermentation in a sequential scheme, first fermenting glucose, and later xylose (or vice-versa).

The best results achieved so far used a mutant strain of *Escherichia coli* incapable of metabolizing glucose, followed by a second glucose fermentation stage with *S. cerevisiae*.

The conversion of lignocellulosic materials into ethanol involving hydrolysis of cellulose and hemicellulose into reducing sugars, and their alcoholic fermentation may be performed simultaneously in one single step or sequentially in two steps.

In two step processes, hydrolysis (acid or enzymatic) and fermentation are done separately (HFS). The advantage of this process is that, the hydrolysis and fermentation stages being separate, each can be performed under optimal conditions. In the case of enzymatic catalysis, the hydrolysis step is done at the ideal temperature for the enzyme (around 50 °C), while fermentation is carried out at the optimum temperature for the ethanol-producing microorganism (28 to 32 °C). The main disadvantage of the HFS process is due to glucose and cellobiose being released during enzymatic hydrolysis, as they inhibit the enzymes involved in this process, causing low yield. When acid hydrolysis is used instead of enzymes as hydrolysis catalysts, hydrolytes must be neutralized before fermentation. Furthermore, a more intense generation of degradation products during hydrolysis may affect the microorganism in charge of fermentation.

In single-step processes, hydrolysis and fermentation take place in the same reactor. The key advantage of these processes is the reduced inhibition by the end product which occurs in the two-step operation, as the presence of fermenting microorganisms with cellulolytic enzymes reduces sugar buildup in the fermenter. For this reason, higher hydrolysis rates and conversion percentages are achieved in comparison with separate hydrolysis and fermentation, requiring a smaller quantity of enzymes, obtaining, as a result, increased ethanol yield. The main disadvantage of this process relates to the different optimal conditions in pH and temperature in hydrolysis and fermentation steps, respectively. For this reason, it is necessary to perform the process in one condition compatible with both steps. Considering that the optimum temperature for enzymatic hydrolysis is close to 50 °C, and that conventional ethanol producing yeasts operate around 28 °C to 34 °C, it is recommendable to use temperature tolerant microorganisms to perform both process in one step. Single-step processes may be divided into two groups:

- Processes where the same microorganism produces enzymes and performs fermentation, known as direct conversion by microorganism (DCM).
- Processes with simultaneous saccharification and fermentation (SSF), where cellulases from a cellulolithic microorganism are used (usually a *Trichoderma* fungus), with the presence of an ethanol-producing microorganism.

In DCM processes, monocultures may be used, as one sole microorganism hydrolyses lignocellulosic materials and ferments sugars into ethanol. For this, bacteria of the *Clostridium* type is used, ethanol yield is low due to the formation of by-products, the low tolerance of the microorganism to ethanol, and the limited grown of the microorganism in hydrolytes due to the existence of toxic products. Co-cultures may also be used, where there are two microorganisms. One of them performs cellulose hydrolysis (*Clostridium thermocellum)* and the other microorganism, ethanolgenic by nature, ferments the sugars produced.

Currently SSF process is the one offering the best outlook. Cellulases come from cellulolithic fungi, usually *Trichoderma reese,* and the fermenting microorganism is a yeast. *Kluyveromyces marxianus* and *Kluyveromyces fragilis* seem to be the more appropriate strains to produce ethanol in a thermofilic environment. Studies carried out to assess SSF process performance showed difficulties to perform alcoholic fermentation in a thermofilic environment. Conversion yields were below expectations, and the final wine had low alcohol content due to the strong inhibition by produced ethanol when operating at high temperatures. Authors confirmed the incidence of contamination in the operating conditions for a SSF process. Tests were carried out using *Kluyveromices* strains.

Plant energy optimization including hydrolysis

One of the major issues for inserting the hydrolysis process in ethanol production is that it assumes using with other purposes the material that is the main energy source of the mill: the bagasse.

The possibility of using surplus bagasse in the hydrolysis process for producing ethanol has been repeatedly discussed. For that, it will be necessary to optimize energy use processes in the mills, to reduce bagasse consumption.

Would the equation be so easy?

It shouldn't be neglected that the use of surplus bagasse in the hydrolysis process will increase the use of steam, mostly in the pretreatment stage and in distilling the additional ethanol, as well as electric power intake in the new mill.

The use of lignin (which has considerable heating power) and pentoses, once separated in the hydrolysis process, as a source of energy, opens the possibility to treat larger quantities of bagasse in hydrolysis.

One of the major problems in using fractions of the lignocellulosic material as a source of energy is that the lignin produced will be very moist and, quite likely, pentoses will be obtained in an aqueous solution, mixed to other components. Once again there is a need to engineer the hydrolysis process, i.e. to think technically about viable options, proper equipment, and acceptable costs.

Another possible solution is using trash. Trash is an option that may be either hydrolyzed or used to replace bagasse in boilers.

In either case, some heavy investment in research will be required: laboratory, pilot plant, and equipment development for:

- harvesting trash;
- cleaning and preparation of sugarcane trash;
- possibilities of applying the hydrolysis process to trash;
- burning the trash in boilers; characteristics and problems.

There is yet another possibility: gasification of both bagasse and trash, for better utilization in the simultaneous electric power generation, in gas turbines (poor gas), associated to recovery boilers to produce the steam required for the unit operation.

MEETING WITH PROF. GUIDO ZACCHI, FROM LUND UNIVERSITY, SWEDEN

Date: Feb. 1st 2007, from 2 PM to 5 PM
Venue: FEQ Principal's Office – Unicamp
Attending: C. V. Rossell, J. Finguerut, A. Bonomi, Filomena A. Rodrigues, R. Maciel, T. Franco, M. das Graças A. Felipe, M. Benossi, Elba Bon, Silvia Nebra, Marcelo Poppe, Ester dal Poz, and Luiz A. B. Cortez.

At the outset of the meeting, Prof. Cortez made a brief explanation to Dr. Zacchi on the objectives of the Project Guidelines for Public Policies for the Sugarcane Agriculture in the São Paulo State Public Policy Research Program (Projeto Diretrizes de Políticas Públicas para a Agroindústria Canavieira do Estado de São Paulo, Programa de Pesquisa em Políticas Públicas – Ethanol – PPPP). A report was made on the Hydrolysis Workshop: reference term, main issues, discussions and conclusions from the debates.

A debate was begun on the likely scenario for the hydrolysis technology for using fibers to produce ethanol. One scenario was described, and Dr. Zacchi suggested that other scenarios should be imagined, modeled, and used in simulation work.

Evolution led to the idea of preparing a document defining the three to five more likely or possible scenarios for the new ethanol industry in Brazil, considering from the use of the existing industrial park to more radical scenarios, such as "cane energy", or distilleries wholly dedicated to produce ethanol, without conventional extraction.

It was also reported the difficulty of obtaining data, information for simulations, e.g., regarding the energy balance in mills and distilleries, what is the energy required by the hydrolysis process etc.

These scenarios and their respective models would then be useful to answer what is required to make them viable. Questions would be about costs, kinetics, environment, others.

In a first discussion about the scenarios, these were suggested:

- current mill (conventional ethanol + sugar) with hydrolysis of C6 only, using surplus bagasse;

- distillery wholly-dedicated to ethanol; partly conventional ethanol, partly ethanol from bagasse, others, leaving lignin from bagasse for energy generation;
- same, as the preceding one, using sugarcane energy, without conventional harvesting.

However these were only suggestions. Scenarios assembly would be left to specialists. These scenarios should also consider the polemic issue of viability of acid vs. enzymatic hydrolysis, as well as simultaneous hydrolysis and fermentation vs. two separate steps.

The assembly of a multifunctional committee was suggested to work on each scenario. It should also include one chemical engineer, one agronomist, and one economist or equivalent. Each scenario should be worked on with the same computing tools and methodology, to offer comparable results.

The results of this study, from scenarios and simulations, will allow to define public investment policies in certain technologies able to ensure not only competitiveness, but also to fulfill the requirements of other areas, such as environmental protection or new jobs generation.

Prof. Zacchi suggested, regarding the development of pretreatment options, to spend more time on developing standard assessment systems than in creating many different treatments. Assessment systems should be the most encompassing possible, i.e., take into account all relevant operations (hydrolysis, fermentation etc.) in the most similar conditions to those simulations indicated as the most convenient (e.g., high solids concentration).

Next there was a discussion on the options of producing enzymes on-site versus buying commercial products. In this discussion Prof. Zacchi stated that cellulases will always cost more than amylases, for being enzymatic complexes (various enzymes and proteins with little-known functions). Additionally, the cellulases activities per protein unit are much smaller, which increases the cost of each activity unit. One major difference between commercial and on-site products is that the former have to be purified and stabilized to endure storage and transportation so they can be sold anywhere, while the on-site enzyme doesn't need these features that render the product more expensive.

There was also a comment from Dr. Zacchi that hydrolysis ethanol will never be able to compete with conventional ethanol produced in Brazil. This remark unquestionably reflects reality and Dr. Zacchi's experience, and cannot be withdrawn from this context. Of course factors like: developing a technology nonexistent today, the need Brazil has now to significantly increase its ethanol production and the future increase in land prices that may render unviable opening new areas to grow sugarcane, among others, may revert this statement, by making it compulsory and economically viable to make full use of sugarcane in ethanol production.

AKNOWLEDGEMENTS

The author aknowledges Jaime Finguerut (CTC), Henrique Baudel (UFPE) and Carlos Eduardo Vaz Rossell (CTBE) who, with the documents and presentations in the III Technological Workshop, made great contributions to this chapter.

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PRODUCTION OF ETHANOL FROM LIGNOCELLULOSIC MATERIALS

Mats Galbe and *Guido Zacchi*

INTRODUCTION

Bioethanol has been introduced in large scale in Brazil, the US and some European countries and is projected to be one of the dominating renewable biofuels in the transportation sector within the coming 20 years. At present bioethanol is produced almost solely from either sugar – or starch-based raw materials (e.g, cane sugar, corn, wheat etc) often called first generation (1G) bioethanol. However, it is a general opinion that future expansion has to be based on bioethanol from lignocellulosic materials, i.e. second-generation (2G) bioethanol such as agricultural residues (e.g. wheat straw, sugarcane bagasse, corn stover) and forest residues (e.g. sawdust, thinning rests), as well as from dedicated crops (salix, switch grass). These raw materials are sufficiently abundant and also available world-wide. They generate very low net greenhouse gas emissions, thus reducing environmental impacts. To achieve systems that are economic and sustainable it is necessary to efficiently utilize all parts of the raw materials, mainly cellulose, hemicellulose and lignin. This requires a high overall yield of ethanol produced by hydrolysis and fermentation of the carbohydrate fraction (hemicellulose and cellulose), as well as a high yield of the main co-product (lignin). Another option is to utilize the hemicellulose for other products like biogas. However, producing monomer sugars from cellulose and hemicellulose at high yields is far more difficult than deriving sugars from sugar – or starch-containing crops, e.g. sugarcane or corn. Therefore, the conversion process for lignocellulosic materials is more complex than are the other two processes.

Ethanol production from lignocellulose comprises the following main steps: hydrolysis of hemicellulose, hydrolysis of cellulose, fermentation, separation of lignin, recovery and concentration of ethanol and wastewater handling, see Figure 1. A process based on enzymatic hydrolysis and fermentation is currently regarded as the most promising option for the conversion of carbohydrates in lignocellulosic materials into ethanol in an energy-efficient way, resulting in high yields and low production cost[1, 2]. The enzymatic hydrolysis and fermentation can either be run separately (SHF) or combined into a simultaneous saccharification and fermentation (SSF). The latter has been shown to result in higher ethanol yields than does SHF. Some of the most important factors to reduce the production cost are: efficient utilization of the raw material by high ethanol yields, high productivity, high ethanol concentration in the feed to distillation and process integration in order to reduce capital cost and energy demand. The key steps for success are the conversion steps, i.e. pretreatment, enzymatic hydrolysis and fermentation (or SSF) of all sugars. It is also crucial to have a highly integrated process working at high consistency to minimize the energy demand in the downstream processing, e.g. distillation and evaporation. Pilot-scale production plants and pre-commercial demonstration facilities have recently been brought into operation in several places world-wide[3, 4, 5, 6]. However, the process concept has not yet been demonstrated on an industrial scale.

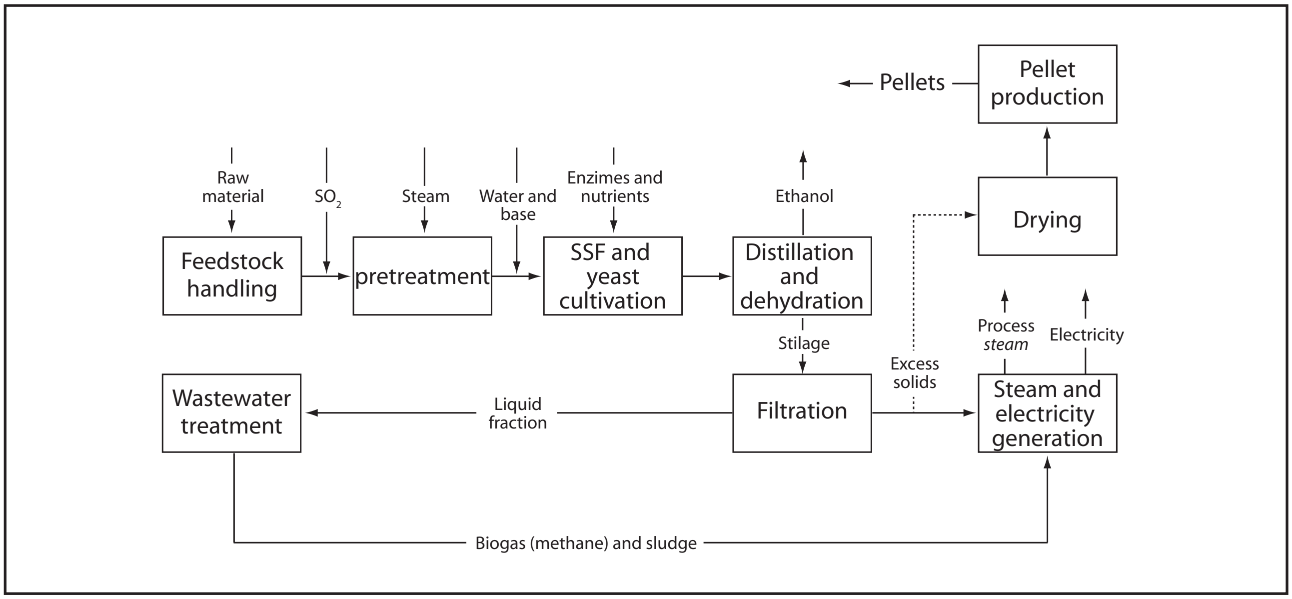

FIGURE 1 Schematic flow of the production of ethanol from lignocellulosic meterials.

External integration, with other production units, like a heat and power plant, a pulp mill or a first-generation ethanol production plant may also reduce the energy demand and the production cost. This type of studies is still only performed at lab scale and by computer simulations and the feasibility has also to be proven at pilot or demo scale.

This chapter summarizes recent developments of bioconversion processes and discusses the individual process steps aiming at fuel ethanol production with emphasis on process integration mainly based on results obtained at Lund University.

PRETREATMENT

Enzymatic hydrolysis, using cellulases, is regarded to be the most attractive way to convert cellulose to glucose[7, 8, 9]. However, due to the recalcitrant nature of most biomass species, the enzymatic hydrolysis is very slow and it is difficult to reach high sugar yields if the raw material is not pretreated prior to enzymatic hydrolysis. The pretreatment is perhaps the single most crucial step as it has a large impact on all the other steps in the process, e.g. enzymatic hydrolysis, fermentation, downstream processing and wastewater handling in terms of digestibility of the cellulose, fermentation toxicity, stirring power, energy demand in the down-stream processes and waste water treatment demands.

An effective pretreatment should have a number of features[10]. It has to:

- Result in high recovery of all carbohydrates.
- Result in high digestibility of the cellulose in the subsequent enzymatic hydrolysis.
- Produce no or very limited amounts of sugar and lignin-degradation products[11]. The pretreatment liquid should be possible to ferment without detoxification.
- Result in high solids concentration as well as high concentration of liberated sugars in the liquid fraction.
- Require a low energy demand or be performed in a way so that the energy can be re-used in other process steps as secondary heat.
- Require low capital and operational cost

Several pretreatment methods have been investigated during the last two decades. The various methods can be classified in different ways, e.g. physical (e.g. milling, grinding, and irradiation), chemical (e.g. alkali, dilute acid, oxidizing agents and organic solvents), physico-chemical (e.g. steam pretreatment/autohydrolysis, hydrothermolysis, and wet oxidation) and biological, or combinations of these. Several reviews on pretreatment have been written during the last few years[10, 12, 13, 14, 15] and the classification is not always consistent between these. It is difficult to clearly assign a pretreatment method to one group, since several mechanisms may be involved to break down the material.

PHYSICAL METHODS

Physical methods comprise chipping, milling and grinding. The biomass is turned into a fine powder, which increases the surface area of the solid material and to some extent also improves the decrystallization of cellulose. In order to achieve a high digestibility in the enzymatic hydrolysis step very small particles are required which calls for prohibitively high power consumption. It can be even higher than the theoretical energy content that is available in the biomass[16]. However, physical treatment in an extruder combined with heating and addition of chemicals could be an interesting option[17].

CHEMICAL METHODS

Dilute acid pretreatment is performed by soaking (or by spraying) the material using a dilute acid solution and then by heating to temperatures between 140-200 °C for a certain time (from several minutes up to an hour). Sulfuric acid, at concentrations usually below 4 wt-percent, has been of most interest in such studies as it is inexpensive and effective. The hemicellulose is hydrolyzed and the main part is usually obtained as monomer sugars. It has been shown that materials that have been subjected to acid hydrolysis may be harder to ferment because of the presence of toxic substances[18, 19, 20].

Alkaline pretreatment is performed at lower temperature and pressure than acid hydrolysis. Soaking of the material in an alkaline solution, like sodium, potassium or ammonium hydroxide, followed by heating leads to swelling of the pores in the material. This results in an increase in the internal surface area, and a decrease in the degree of polymerization and crystallinity. Alkaline pretreatment breaks the bonds between lignin and carbohydrates and disrupts the lignin structure, which makes the carbohydrates more accessible to enzymatic attack. This pretreatment method is more effective on agricultural residues and herbaceous crops than on wood materials, as these materials in general contain less lignin. For woody materials the concentration of alkali has to be increased considerably, thus the procedure is more like a Kraft pulping process.

Pretreatment using lime instead of sodium hydroxide is an alkaline method, especially suited for agricultural residues, e.g. corn stover, or hardwood materials, such as poplar[21, 22]. Lime has attained more attention due to low cost and the possibility to recover it from water when reacted with CO_2 to yield almost insoluble $CaCO_3$. The latter can then be converted to lime using the lime kiln technology.

Addition of calcium to the system may however result in problems like fouling in other parts of the process as calcium salts have rather low solubility. In the process the pH and the temperature vary from unit to unit which means that precipitation may occur in some unexpected places especially if process streams are recirculated. This is a well-known problem in the pulp and paper industry.

Another approach is to use an organic solvent, like methanol, ethanol, acetone, ethylene glycol, triethylene glycol and phenol, with addition of inorganic acid catalysts (H_2SO_4 or HCl). These so called organosolv processes[23] dissolves the lignin which is recovered in the organophilic phase. These methods require total recovery of the solvent both for economic and environmental reasons and also as the solvent may be inhibitory to the enzymatic hydrolysis and fermentation steps. A special case is the use of ethanol as solvent as this is already produced in the process which facilitates the recovery.

PHYSICO-CHEMICAL METHODS

This category comprises methods that combines a physical and a chemical effect like steam pretreatment with addition of a catalyst (acid or alkaline), hydrothermolysis, wet oxidation and ammonia fibre explosion (AFEX).

Steam pretreatment is one of the most widely used methods for pretreatment of lignocellulose materials. In reality, it is a chemical method very similar to dilute-acid hydrolysis although usually performed at much higher dry matter content in a steam environment. The raw material is usually treated with high-pressure saturated steam at typical temperatures between 160 and 240 °C for 1-20 minutes, after which the pressure is released. The acid can either be present in the raw material or be added, such as H_2SO_4 or SO_2, to enhance the hydrolysis. Most agricultural residues and some types of hardwood contain enough organic acids (mainly acetic acid) to act as catalysts for the hemicellulose hydrolysis, so called auto-hydrolysis. The latter usually starts at neutral pH and ends at a pH around 3.5-4 depending on how much acid is released. Addition of an acid to reduce the pH considerably, often below 2, results in an increased recovery of hemicellulose sugars, and also improves the subsequent enzymatic hydrolysis of the solid residue but may also cause further degradation if too severe. It has been widely tested in pilot scale equipment, for example, in the NREL pilot plant in Golden, Co (USA)[24], in the SEKAB pilot plant in Örnsköldsvik (Sweden)[5] and is also used in a demonstration scale ethanol plant at Iogen in Ottawa (Canada)[4] and is considered to be close to commercialization.

Hydrothermolysis is similar to steam treatment but is performed in liquid hot water at somewhat lower temperatures and lower dry matter content. This results in solubilization of diluted sugars in oligomer form[25, 26] which results in energy-demanding down-stream processing. In cases where an acid is added, the method becomes similar to dilute-acid pretreatment.

Wet-oxidation pretreatment involves the treatment of the biomass with water and air, or oxygen, at temperatures between 120-200 °C, sometimes with the addition of an alkali catalyst. This method is suited for materials with low lignin content, since the yield has been shown to decrease with increased lignin content, and since a large fraction of the lignin is oxidized and solubilized[27]. As with many other delignification methods, the lignin cannot be used as a solid fuel, which considerably reduces the income from by-products in large-scale production.

Ammonia fibre explosion (AFEX) is also an alkaline method, which similarly to the steam pretreatment process operates at high pressures. The biomass is treated with liquid ammonia about 10-60 minutes at moderate temperatures (below 100 °C) and high pressure (above 3 MPa)[28, 29]. Up to 2 kg of ammonia is used per kg of dry biomass. The ammonia is recycled after pretreatment by reducing the pressure, as ammonia is very volatile at atmospheric pressure. During pretreatment only a small amount of the solid material is solubilized, i.e. almost no hemicellulose or lignin is removed. The hemicellulose is degraded to oligomer sugars and deacetylated[30], which is a probable reason for the hemicellulose not becoming soluble. However, the structure of the material is changed resulting in an increased water-holding capacity and a higher digestibility. Like the other alkaline pretreatment methods Afex performs best on agricultural waste, but has not proven to be efficient on wood, due to its higher lignin content[31, 32]. According to SUN *et al*. the Afex process does not produce inhibitors that may affect downstream biological processes[11].

Another type of process utilizing ammonia is the ammonia recycle percolation (ARP) method[33, 34]. In the process aqueous ammonia (10-15 wt-%) passes through biomass at elevated temperatures (150-170 °C) after which the ammonia is recovered. ARP is an efficient delignification method for hardwood and agricultural residues, but is somewhat less effective for softwood.

BIOLOGICAL METHODS

Biological pretreatment can be performed by applying either enzymes or microorganisms to the lignocellulose material. In most cases investigated the purpose has been to degrade the lignin fraction by use of some white – and soft-rot fungi[32, 35]. Biological pretreatment has not attracted much attention as the rate of biological pretreatment processes is far too low for industrial use. However, the method could be used as a first step followed by some of the other pretreatment methods.

ASSESSMENT OF PRETREATMENT

For evaluation of the various pretreatment methods one important thing is the effect the pretreatment has on the constituents of the biomass, i.e. cellulose, hemicellulose and lignin, and the properties of the solid fraction remaining which is to be hydrolysed by enzymes. Based on this the chemical and physico-chemical methods can be divided in classes depending on the pH of the pretreatment.

- *Low pH methods*, i.e. addition of acids, e.g. dilute acid hydrolysis and steam treatment with addition of acids. Most of the hemicellulose is usually hydrolysed to monomer sugars and to some extent oligomer sugars available in the liquid fraction after pretreatment. Depending on the severity, i.e. temperature, acid concentration and residence time, also a part of the cellulose may be hydrolysed. Also, a minor part of the lignin is solubilized as phenolic compounds, but the major part remains in the solid fraction although redistributed. These pretreatment methods usually also result in production of sugar degradation products, like furfural and HMF.
- *High pH methods*, e.g. alkaline pretreatment, ammonia fibre explosion and wet oxidation with addition of alkali. These methods result in partial solubilization of hemicellulose and solubilization of the major fraction of the lignin. An exception to this is the Afex method where a fractionation is obtained but both hemicellulose and lignin are still in the solid fraction. The hemicellulose sugars that are solubilized are however obtained mainly as oligomer sugars. This then requires hemicellulases acting both on solid and dissolved hemicellulose.
- *Methods working close to neutral conditions* at the start of the pretreatment e.g. steam pretreatment and hydrothermolysis. Most of the hemicellulose is solubilized due to the acids released from the hemicellulose, e.g. acetic acid. However, the sugars are obtained as a mixture of monomer and oligomer sugars. This thus requires hemicellulases or acids acting on soluble oligomer fractions of the hemicellulose.

In all methods above the cellulose fraction mainly remains in the solid fraction and is made more accessible for the cellulase enzymes used during enzymatic hydrolysis. The digestibility of this material, as well as the amount of the hemicellulose sugars that are solubilized and the extent of degradation that occurs is dependent on the severity of the pretreatment. The severity increases with increased temperature and residence time and with increased catalyst (acid or alkaline) concentration.

A high severity in the pretreatment is often required to enhance the enzymatic digestibility of cellulose[36]. The reason why cellulose becomes more accessible for enzymatic attack is still not fully understood. Many structural parameters have been studied, like cristallinity, pore size distribution etc. but there are no clear relations between digestibility and these factors. It is however established that the removal of hemicellulose enhances the enzymatic digestibility of the cellulose fibers. However, more severe conditions during pretreatment will cause greater degradation of hemicellulose sugars[37, 38, 39]. The optimum conditions are often a compromise between very high digestibility and high yield of hemicellulose sugars, i.e. low sugar degradation.

Assessment of pretreatment is usually done by using some standard method for enzymatic hydrolysis at low substrate concentration, very often at 2 wt-percent water-insoluble solids (WIS), or alternatively at 1% cellulose, to avoid end-product inhibition[40]. It is also common to wash the solids from the pretreatment in order to avoid inhibition from water-soluble compounds released or formed during pretreatment. In some cases enzymatic hydrolysis is replaced by SSF. The pretreatment efficiency is then assessed by measuring the amount of sugars released during pretreatment and enzymatic hydrolysis (or indirectly from ethanol produced in SSF). Fermentation of the pretreatment liquid to assess inhibition of the fermentative microorganism is also performed in some cases. Enzymatic hydrolysis or SSF can be performed using various conditions, e.g. enzyme dosage and yeast concentration. Usually the enzyme dosage is rather high in the assessment procedure, 25 FPU per g substrate or even higher. The cellulase load in industrial scale must be much lower.

This type of assessment gives the maximum achievable digestibility or glucose yield but it does not reflect the yield obtained in a full-scale process where the enzymatic hydrolysis would be performed at other conditions. Such a process could involve performing SSF on the whole slurry from pretreatment at high substrate concentration (above 10 wt-%) and low enzyme dosage and low concentration of yeast in order to reach high ethanol concentration and low production cost.

The overall ethanol yield depends also on the concentration of inhibitors, which influence the fermentability. These compounds include both substances present in the raw material, e.g. acetic acid from the hemicellulose, extractives, or compounds formed during pretreatment, e.g. the sugar degradation products furfural and 5-hydroxymethylfurfural (HMF) and lignin degradation products. The concentrations of these and all other inhibitory substances in the fermentation step depend on the configuration of the preceding process steps.

PRETREATMENT RESULTS

There are a lot of raw materials that have been investigated using various pretreatment methods and this is well summarized in several recent review papers on pretreatment[10, 12, 13, 14, 15]. We have at Lund University mainly being working with acid-catalysed steam pretreatment. A summary of results obtained with softwood is given in the review by GALBE and ZACCHI 2007[10] with sugar yields up to 80% of the theoretical based on the sugar content in the raw material. Table 1 summarizes the maximum sugar yields obtained for some of the other materials investigated[41, 42, 43, 44, 45, 46]. For

TABLE 1 Pretreatment conditions and sugar yields for various raw materials after pretreatment and enzymatic hydrolysis expressed in g/100 g raw material (ODM). The pretreatment conditions are chosen for maximum yield in glucose. Yield as % of theoretical in brackets.

	Salix			Wheat straw	Corn stover	Sugarcane bagasse
Pretreatment conditions	200 °C, 8 min. 0.5% H_2SO_4 [41]	205 °C, 4 min. 2.5% SO_2 [42]	210 °C, 14 min. no catalyst [42]	190 °C, 10 min. 0.2% H_2SO_4 [43]	190 °C, 5 min. 2.5% SO_2 [44]	190 °C, 5 min. 2% SO_2 [45]
Glucose in liquid after pretreatment	5.2 g (11.2%)	8.4 g (18.3%)	1.8 g (4%)	1.8 g (4.7%)	5.8 g (14%)	2.3 g (4.7%)
Glucose in EH	37.4 g (81.3%)	34.1 g (74%)	40.1 g (87.2%)	37.6 g (95.7%)	29.8 g (72.9%)	42 g (87.2%)
Xylose in liquid after pretreatment	11.6 g (68%)	10.4 g (61%)	3.4 g (20%)	17.1 g (75%)	14.7 g (58.6%)	13 g (47.1%)
Xylose in EH*	1 g (5.8%)	1.1 g (6.5%)	1.7 g (10%)	4.6 g (20.2%)	4.9 g (19.3%)	1.1 g (4%)
Overall yield of glucose + xylose	55.2 g (87.5%)	54 g (85.6%)	47 g (74.6%)	61.1 g (98.2%)	55.2 g (83.6%)**	58.4 g (77.1%)

* EH: Enzymatic hydrolysis at standard conditions (2% WIS, 40 °C, 15 FPU/g WIS, 96 hours).

** The sugar yield obtained without another batch of corn stover, from Italy, pretreated at the same conditions resulted in higher yields of sugars, 41.0 g glucose (90% of theoretical) and 24.4 g xylose (85% of theoretical)[46] in spite of the fact that this straw had a higher content of glucan and xylan than the corn stover in the table (of Hungarian origin).

TABLE 2 Typical composition of various lignocellulosic materials (% of dry material) and theoretical ethanol yield (L/ton DM) based on available carbohydrates (given as anhydrous sugars).

	Salix	Wheat straw	Corn stover	Sugarcane bagasse
Glucan	41.4	35.5	36.8	43.4
Xylan	15	20.1	22.2	24.3
Arabinan	1.2	3.3	5.5	1.5
Galactan	2.3	0.8	2.9	0.4
Mannan	3.2	–	–	–
Lignin*	26.4	26.5	23.1	22.3
Others**	10.5	13.8	9.5	8.1
Ethanol from hexoses	332	257	280	310
Ethanol from pentoses	117	169	200	187

* Both acid soluble and acid-insoluble.
** Ash, extractives, protein etc.

these materials the hemicellulose consists mainly of xylan, see Table 2, so the sugar yields are given for xylose and glucose only. For most materials the glucose yield is above 90% of the theoretical while the xylose yield varies from 50% for sugarcane bagasse to 95% for wheat for most of the raw materials the pretreatment conditions resulting in the highest glucose yield differs from those yielding the maximum yield of xylose. For instance, for salix the overall xylose yield could be increased to 14.6 g/100 g raw material corresponding to 86% of theoretical for pretreatment conditions 0.5% H_2SO_4, 180 °C and 12 min. However at these conditions the glucose yield decreased to 73% of theoretical compared with 92.5% obtained at 0.5% H_2SO_4, 200 °C and 8 min. The same pattern is valid for the sugarcane bagasse. For pretreatment using 2.0% SO_2, 180 °C and 5 min the xylose yield increased to 18 g/100 g raw material, corresponding to 67% of the theoretical. However, also in this case the glucose yield decreased to 80.5% of theoretical compared with 92% obtained at 2.0% SO_2, 190 °C and 5 min.

This would suggest two-stage steam pretreatment, in which the first stage is performed at low severity to hydrolyse the hemicellulose, and the second stage at a higher degree of severity, in which the solid material from the first step is pretreated again. This would result in a high yield of both hemicellulose sugars and of high digestibility of cellulose. Major drawbacks are, however, the higher capital cost and the higher energy demand. In a study by WINGREN *et al.*[47], on two-stage steam pretreatment of softwood, the overall ethanol production cost was shown to be very much dependent on the way the two pretreatment steps are performed. The key issue is if the pressure is released or not between the two steps, but also on the dry matter concentration after the second step.

It must once again be emphasized that the yields obtained are affected by the method of assessment, especially the enzymatic hydrolysis. ÖHGREN[48] obtained a higher yield of both glucose and xylose when the enzymatic hydrolysis was performed with a small addition of xylanase enzymes in the hydrolysis vessel. The overall glucose yield after enzymatic hydrolysis increased from around 83% to near 100% and the xylose yield from 71% to 96% for pretreatment with 3% SO_2 at 190 °C for 5 min. When pretreatment was performed without catalyst at 190 °C for 5 min addition of xylanases had an ever higher effect. The glucose yield increased from 69 to 94% and the xylose yield from 74.6 to 85% of theoretical. It should be noted that the addition of xylanases had a higher effect on the improvement of cellulose hydrolysis than on the increase of hemicellulose sugars. This means that the pretreatment severity can be decreased in case xylanases are added to the enzymatic hydrolysis. It must be pointed out that most assessments of pretreatment of various raw materials found in literature are based on enzymatic hydrolysis (or SSF) without the addition of xylanases.

Also the origin of the raw material, especially for agricultural residues, may affect the pretreatment results. The data on corn stover in Table 1 shows that the same pretreatment conditions resulted in higher sugar yields when using Italian corn stover than when using Hungarian corn stover, which was the material used in optimization of the pretreatment conditions. This is important to keep in mind when comparing results from different studies on the same type of raw material. It is more adequate to compare different pretreatment methods using the same raw material, which was done in a study undertaken in the U.S., where the same batch of corn stover was pretreated using various pretreatment methods (dilute acid, Afex, hot water treatment etc.). The pretreated materials were then subjected to standard evaluation techniques and the total sugar yields were found to be more or less the same, around 90% or more, for all methods[49]. However, it is questionable if the standard assessment is the best way of doing the comparison as the different pretreatment methods yield different types of pretreated materials as discussed above.

To be successful pretreatment has to be developed as an integrated part of the whole process, including enzymatic hydrolysis, fermentation, downstream processing and wastewater treatment. Each pretreatment method has to be assessed based on the process configuration and process conditions suitable for this specific pretreatment method. For instance, the use of hemicellulases in the enzymatic hydrolysis, instead of only cellulases, will be beneficial to pretreatment methods that result in a large amount of oligomer hemicellulose sugars. In the same way, fermentability tests of pretreated slurries from methods generating inhibitors should be performed using adapted yeast.

Figure 2 shows some options of how the pretreated material may be utilized. The assessment

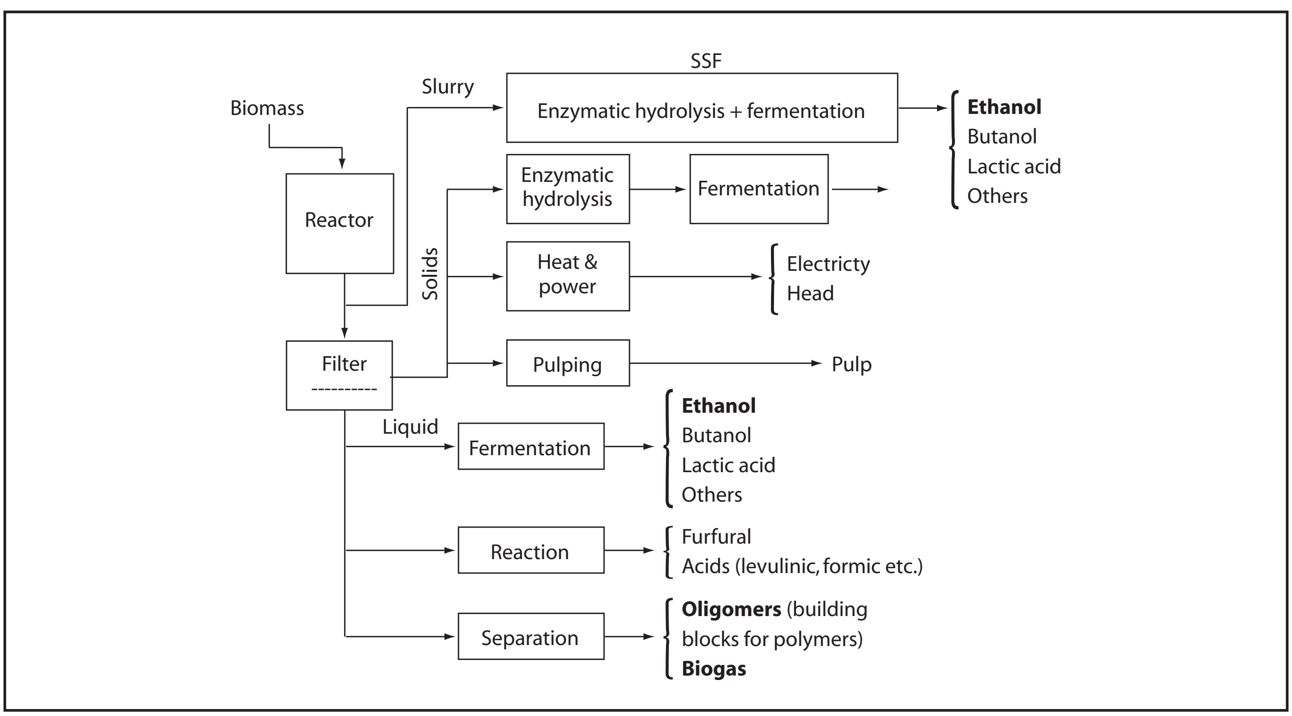

FIGURE 2 Some possible scenarios for utilization of pretreated biomass.

of the pretreated material should thus also reflect the process option that is used and what product is produced from the various parts of the fractionated raw material.

It is our conviction that there is no “best pretreatment” that is the most suitable for all kinds of raw materials or process configuration options. The choice of pretreatment depends mainly on what co-products are produced besides ethanol, the process configuration including process integration as well as how the ethanol production is integrated with external processes, e.g. heat and power production or first-generation ethanol production.

HYDROLYSIS AND FERMENTATION

Enzymatic hydrolysis is performed using cellulases, i.e. a mixture of various endoglucanases and cellobiohydrolases, which attack the amorphous areas of cellulose and cleave cellobiose units from both ends of the cellulose chain, respectively. They are supplemented with β-glucosidase, which cleaves cellobiose into two glucose molecules. The enzymes are end-product inhibited, i.e. most cellulases are inhibited by cellobiose[50, 51] and β-glucosidase is inhibited by glucose[52], so the build-up of any of these products affects cellulose hydrolysis negatively. The maximum cellulase activity for most fungal-derived cellulases and β-glucosidase occurs at 50 ± 5 °C and a pH of 4.0-5.0.

Fermentation is performed using a microorganism, usually yeast, which converts sugar to ethanol. The most commonly used yeast for ethanol fermentation today is *Saccharomyces cerevisiae*, also called baker's yeast. It has a high ethanol tolerance and has also been shown to be rather tolerant to inhibitors produced during pretreatment of biomass. However, it only ferments hexose sugars, i.e. glucose, mannose and under certain circumstances galactose, but it is not capable of fermenting pentose sugars, like xylose and arabinose, which are the main constituents of most hemicellulose variants.

Enzymatic hydrolysis and fermentation can be performed either separately, so called SHF, or combined, so called simultaneous saccharification and fermentation (SSF). The latter can also be preceded by a pre-hydrolysis to diminish the viscosity in the SSF step, as is practice in the starch-based first-generation ethanol production. Whichever configuration is chosen it is important to maintain a high concentration of carbohydrates in the hydrolysis step in order to reach a high concentration of ethanol in the fermentation vessel. This is important primarily to diminish the energy demand for distillation of ethanol and for evaporation of the stillage stream, in case this is included in the process. Figure 3 shows the energy demand for distillation as function of the ethanol concentration in the feed for a distillation system comprising 3 heat-integrated columns. The shape of the curve is the same also for other distillation configurations although the absolute value of the energy demand may vary. The curve starts to level off at around 5 wt-% ethanol so this concentration may be considered a minimum concentration to achieve in the fermentation or SSF step.

SHF

Separate enzymatic hydrolysis and fermentation (SHF) has the advantage that each of the two steps can be optimized separately concerning temperature and pH but also regarding the design of the equipment including stirring. Cellulases usually have a maximum activity around 50 °C or higher while most fermenting microorganisms, e.g. *S. cerevisiae*, do not tolerate temperatures above around 37 °C. Conventional ethanol fermentation is usually performed below 35 °C. It is thus obvious that running the enzymatic hydrolysis at 50 °C results in a higher productivity than when running it at 35 °C. However, at the temperature for maximum activity the enzymes are also deactivated faster than at lower temperatures. This means that although the enzymatic hydrolysis is faster at 50 °C it may very well be so that the sugar yield after 48 or 72 hours hydrolysis is higher at 40 °C, or even lower temperatures, due to the enzyme deactivation[53].

Another advantage of SHF is that the fermentation is performed with a liquid broth, instead of slurry containing solid material which is the case in

SSF, which facilitates the mass transfer and makes it possible to recycle the yeast after fermentation by filtration or centrifugation.

The main drawback for SHF is that the cellulases are end-product inhibited, i.e. the productivity decreases with increasing sugar concentration. This is especially noticeable when the hydrolysis is performed at high consistency, which is a prerequisite to obtain high ethanol concentration in the subsequent fermentation step. The enzymes may also be inhibited by the inhibitors present in the pretreated biomass slurry such as sugar – and lignin-degradation products. TENGBORG *et al.* (2001)[54] showed that inhibition from these compounds were even larger than the end-product inhibition in the hydrolysis of steam pretreated SO_2-impregnated spruce.

Another drawback is the loss of sugars in the separation of solids and liquids after enzymatic hydrolysis. This may be diminished by washing, but this will on the other hand lead to dilution of sugars even if a countercurrent washing system is used. This is avoided when SSF is employed as the ethanol is separated from the slurry by stripping in a distillation column.

SSF

The main advantage of SSF is that the sugars formed by enzymatic hydrolysis are converted by the yeast as soon as they are released. This maintains a low concentration of sugars in the broth which alleviates the end-product inhibition of the cellulases and also diminishes the risk for infections. Another advantage is the capability of the yeast to partly detoxify the slurry[54]. These two effects result in an increased enzymatic hydrolysis productivity also compared to enzymatic hydrolysis performed at higher temperatures. This leads to higher overall ethanol productivity, which means a lower total reactor volume. It has also been shown in several studies that the ethanol yield is higher

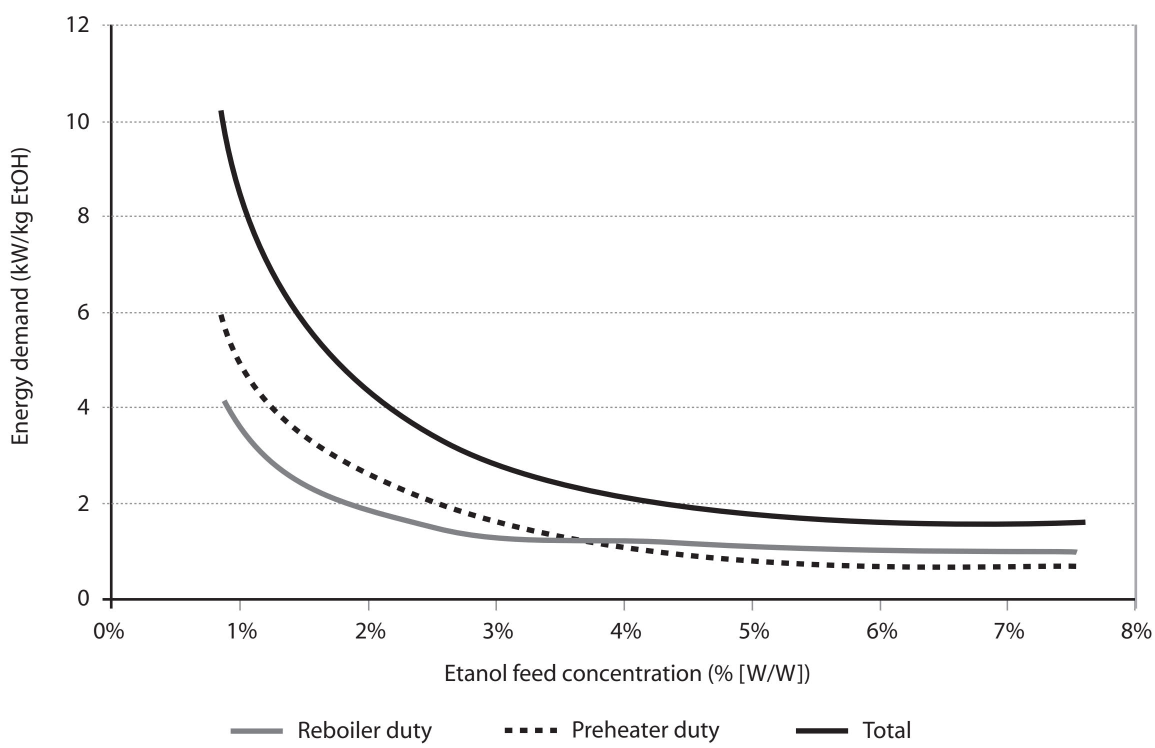

FIGURE 3 Energy demand in distillation of ethanol to 94 wt% in a distillation unit consisting of two stripper columns and one rectification column connected in series on the vapour side. The set-up is described more in detail in reference 58.

after SSF than after SHF both for softwood and agricultural residues[55, 56].

The main drawback with SSF is that the yeast after SSF is difficult to recover as it is mixed with the residual solid, i.e. mainly lignin. In spite of this we consider SSF as a better option than SHF for all raw materials we have investigated so far. The use of SSF is also cost-effective since it reduces the number of reactors[57].

As pointed out earlier one of the remaining challenges is to produce ethanol at a high concentration. This can be achieved in various ways:

I. The most obvious is to perform enzymatic hydrolysis or SSF at high dry matter concentration. Figures 4 and 5 shows a comparison of the energy demand and production cost as function of the solid concentration in the SSF for ethanol production from corn stover, salix and spruce[58, 59]. The capacity is 200,000 ton raw material (DM) per year for all cases and only the hexose sugars were assumed to be converted to ethanol. It is clear that the solid concentration is a crucial parameter. The higher ethanol production cost for salix and corn stover, compared with spruce is due to lower production of ethanol as the pentose fraction constitutes a high percentage of the sugars, see Table 2. High dry matter concentration also means high concentration of inhibitors, which requires a robust yeast that may be obtained by adaptation, e.g. cultivation on pretreatment hydrolysates[60] and by control of the fermentation process[61].

II. The other important factor is to utilize all the sugars available in the pretreated material, i.e. including pentose fermentation. This will lead both to a higher ethanol concentration and to a lower production cost. The production cost for the base case in Figure 4 would diminish from 5.49 to 4.54

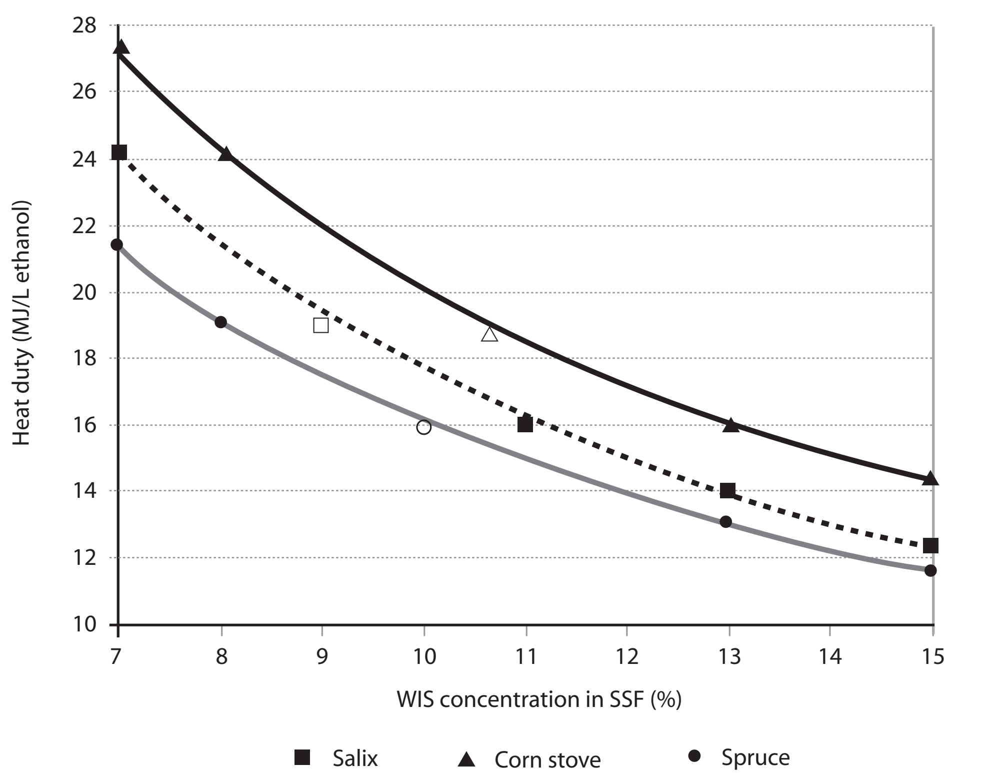

FIGURE 4 Overall process heat demand as function of WIS concentration in SSF. Ethanol yields are maintained at the same level as in the base cases, which are represented by open symbols. Adapted from reference 59.

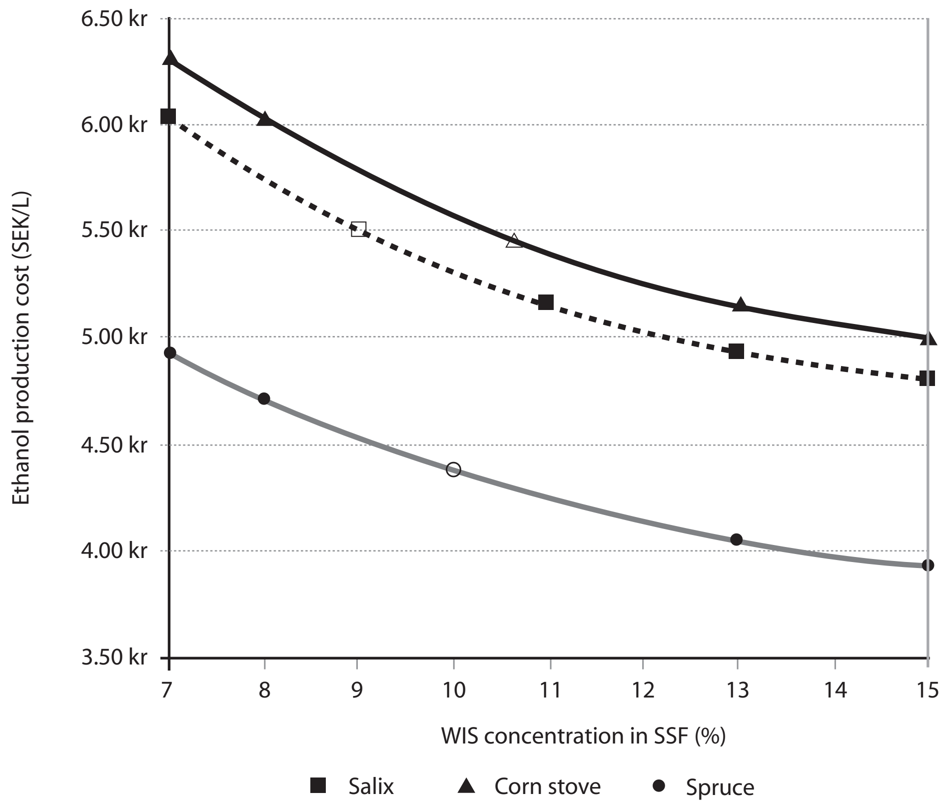

FIGURE 5 Ethanol production cost as function of the WIS concentration in SSF. Ethanol yields are maintained at the same level as in the base cases, which are represented by open symbols. Adapted from reference 59.

SEK/L for salix and from 5.45 to 4.25 SEK/L for corn stover[60].

III. In the study discussed in point I the ethanol yield was assumed to be constant for all WIS concentrations, equal to that in the base case, which was obtained experimentally. However, the increase in concentration of inhibitory compounds with increased dry matter may lead to a decreased ethanol yield. To cope with this, an option is to separate the solid and liquid fractions and only use the solid fraction, i.e. the cellulose, for ethanol production such as in the Ibus process[62]. The liquid could then be used for other applications, e.g. biogas production, where it may be diluted without negative effects in the product recovery as this would be a gas phase.

IV. Integration with first-generation ethanol production as outlined below.

PROCESS INTEGRATION

A large effort has been put in to genetically modify various microorganisms, e.g. *S. cerevisiae*, so that they can ferment xylose, which is the most abundant sugar in most hemicelluloses. The progress on genetically modified *S. cerevisiae* is presented in a review by HAHN-HÄGERDAL *et al.*, 2007[63] where it is also compared with other microorganisms. In some recent studies a recombinant *S. cerevisiae* strain has been used in SSF of steam-pretreated corn stover, see Figure 6[64] and on sugarcane bagasse[65] and wheat straw[66] with very promising results. However, some challenges remain, e.g. that the yeast's affinity for xylose is much lower than for glucose, and is more sensitive towards toxic substances.

Process integration is important especially to reduce the energy demand in the process but also to diminish capital cost. SSF could be seen as

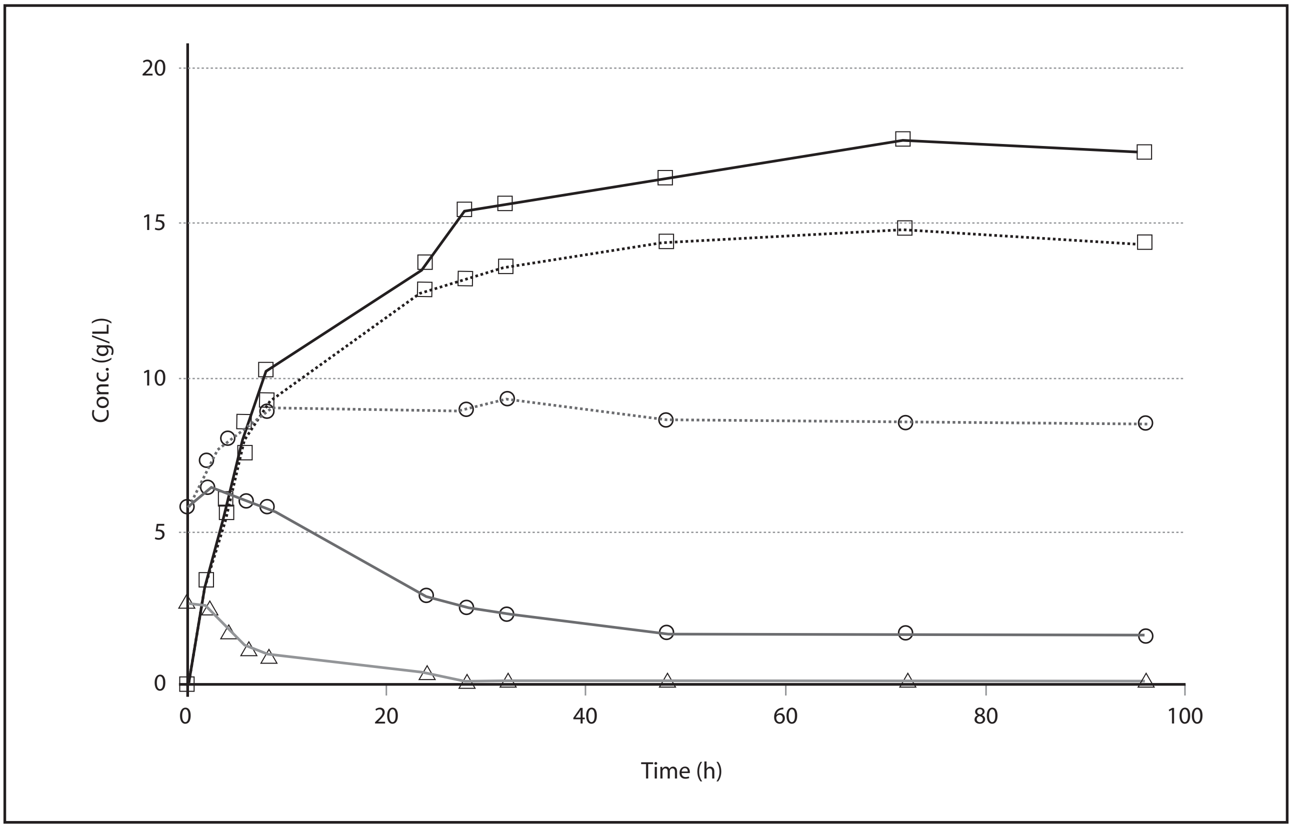

FIGURE 6 Time course of ethanol (□), glucose (△) and xylose (○) concentration during batch SSF of steam pretreated corn stover at 5% WIS using normal baker's yeast (dotted line) and the genetically modified yeast TMB3400 (solid lines).

one type of integration that results in both lower energy demand and lower capital cost. It can also lead to better utilization of sugars. Several studies[66, 68] have shown that the utilization of xylose, using pentose-fermenting yeast, was improved when SSF was used as slow release of glucose facilitated the uptake of xylose, compared with when all glucose is available from the start, which is the case in SHF. The slow release may be controlled either by the enzyme dosage, by the temperature during SSF or by a combination of both[67].

The most obvious way to reduce energy demand is by heat integration of various steam-requiring equipment by using the secondary steam obtained, e.g. by integration of the distillation with the evaporation plant or by increasing the amount of units in the multiple-effect evaporation unit[68]. A somewhat different concept is to introduce mechanical vapor recompression in distillation or evaporation. Another option is to replace energy-demanding process units with a less energy-demanding process step. The evaporation of the stillage is very energy demanding, see Figure 7, and is performed mainly as a waste-water treatment step. The non-volatiles in the stillage stream are concentrated to dry matter content above 50-60 wt-% and then burnt in a boiler to produce heat for the ethanol process. However, the energy obtained from the combustion of the concentrated stillage stream is in the same range as that required in the evaporation plant. By replacing the evaporation plant with anaerobic fermentation for production of biogas the energy demand for evaporation can be eliminated and also the capital cost. Both volatile and non-volatile organic compounds are converted to biogas, which can then be used in the boiler for production of heat and power to the process. Alternatively, the biogas can be upgraded to pure methane to be used as transportation fuel. In a study performed by WINGREN *et al*. (2008)[69] on production of ethanol from steam-pretreated spruce the evaporation plant was assumed to be

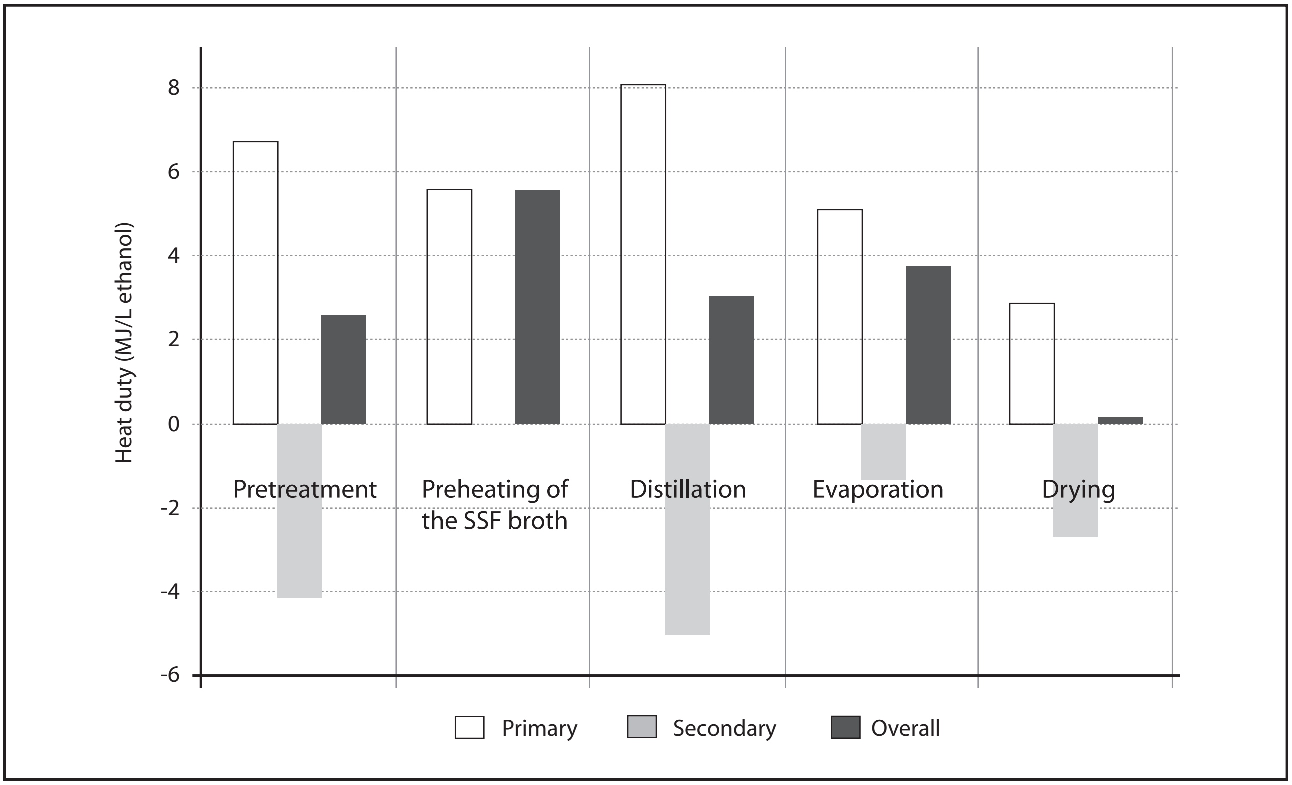

FIGURE 7 Heat duty of the most energy-demanding process steps in ethanol production from spruce based on steam pretreatment and SSF for a capacity of 200,000 ton spruce (DM) per year. The process is explained more in detail in reference 68. White bars = primary steam demand; grey bars = amount of secondary steam generated; black bars = difference between primary and secondary heat, i.e., the net heat demand for the process. Adapted from reference 69.

replaced by anaerobic digestion producing 0.35 m^3 methane per kg COD with removal of 50% of the total COD in the stillage stream. This resulted in a decrease in the energy demand in the process by 48% and the total production cost decreased by 8%. However, this process configuration has to be verified experimentally for each specific stillage stream to assure that most of the organics are fermented. Also the requirement of an aerobic fermentation step for final waste water handling needs to be evaluated. The sludge formed from the fermentation process also needs to be discharged.

EXTERNAL PROCESS INTEGRATION

One approach to reduce the production cost is integration of ethanol production with another suitable plant, e.g. a combined heat and power plant, a starch-based ethanol plant or a sugar based ethanol plant. Regarding the immediate future, we believe that these integrated plant concepts will be used in the first successful industrial-scale production of lignocellulosic fuel ethanol.

INTEGRATION WITH HEAT AND POWER PLANT

Integration of cellulose-based ethanol production with a combined heat and power plant has in a recent techno-economic study[70] been estimated to reduce the ethanol production cost by up to 20 percent for conditions prevailing in Sweden and it is the main strategy pursued in the Swedish cellulose-to-ethanol effort. The study was based on ethanol production from 200 000 ton of spruce per year. In all cases the live steam required in the ethanol process was generated by burning a part of the solid residue (together with the concentrated liquid from evaporation of the stillage and possibly some biogas generated in waste-water treatment). Five different scenarios were investigated where various combinations of co-products, i.e. pellets,

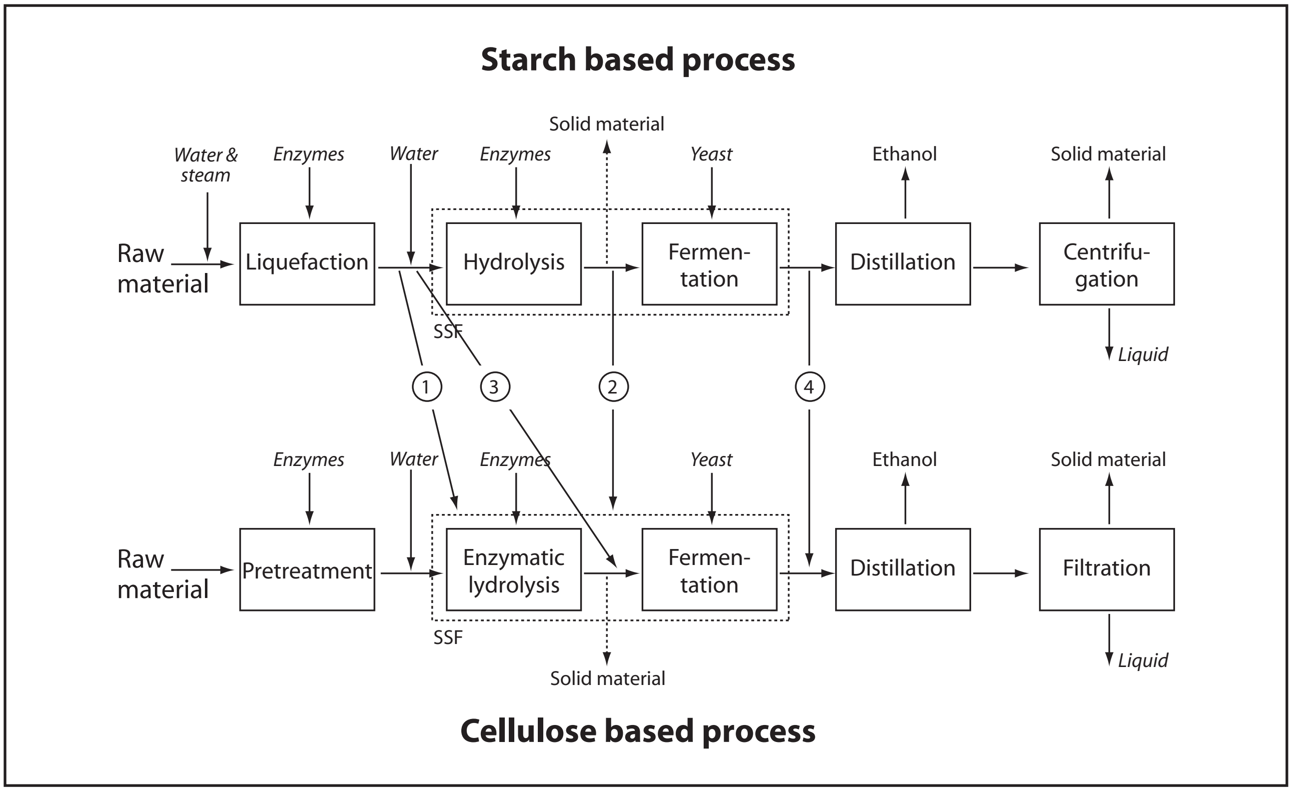

FIGURE 8 Schematic flowsheet for possible points of integration between first and second generation bio-ethanol production.

electricity and district heating were produced. The energy efficiency, defined as the energy output in the products (ethanol, pellets, excess electricity and/or district heating) divided by the energy input varied from 53% to 92%. The ethanol production cost varied from 4.73 SEK/L for the case where ethanol and pellets were produced to 3.87 SEK/L for the case of producing ethanol, electricity and district heating. The latter option restricts the location of the plant as there must be a demand for the surplus heat. Similar conclusions were reached in a study on co-production of ethanol and electricity from softwood, based on conditions in California[71]. One of the benefits is that the syrup or lignin residue can be used for steam production without prior drying.

INTEGRATION WITH FIRST GENERATION ETHANOL

Another option is to integrate 2G cellulosic ethanol production with 1G starch-based or sugar based ethanol production to use the whole agricultural crop. Examples of agricultural residues are corn stover, wheat straw and sugarcane bagasse and trash.

Taking it further the two methods could be integrated at some suitable point in a plant allowing the two methods of producing ethanol to share some common process equipment. Figure 8 shows some possible integration schemes for a starch-based 1G plant. Due to the similarities in the two processes several points of process integration exist. The easiest point would be after fermentation and solid residue separation before the distillation as the two processes would have separate and dedicated equipments for pretreatment, hydrolysis and fermentation. However, by combining material streams further upstream the equipment cost for adding a second-generation technology into an existing first-generation plant could be lower and the energy demand could be decreased.

Integration of the two concepts can be beneficial for both processes. As an example, the 2G ethanol production has an energy surplus in the form of lignin, which can be used in the whole

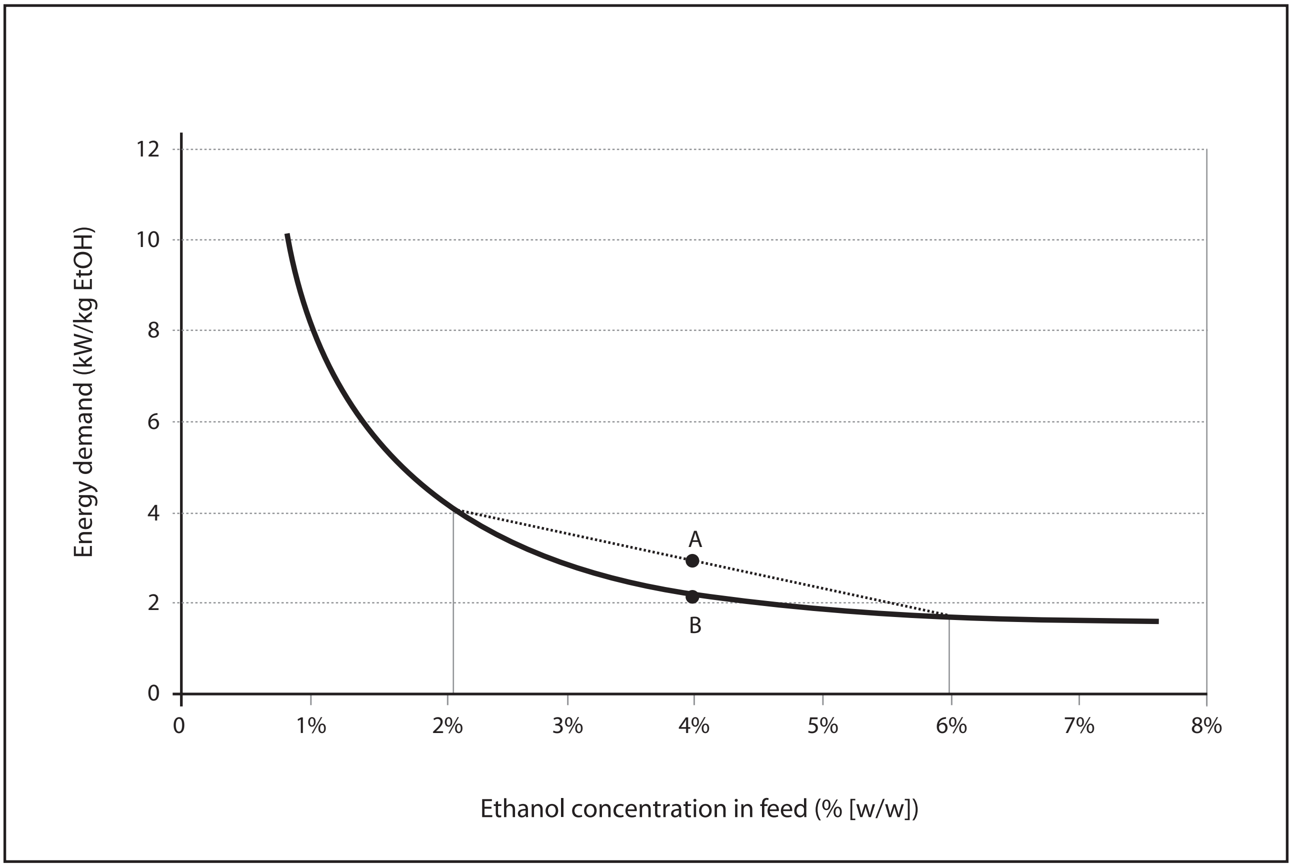

FIGURE 9 Energy demand in distillation of ethanol to 94 wt-% (see Figure 3). The dotted line show the energy demand when two streams containing 2 and 6 wt-% ethanol are distilled separately (for instance point A for a 50/50 mixture). This is always higher than the energy demand for distillation for the mixture, which is on the solid line (point B for a 50/50 mixture).

plant. It is also usually difficult to reach high sugar and ethanol concentrations in the 2G ethanol production while starch – or molasses – based ethanol production require dilution of the sugar. By combining the process flows at some point in the plant, the energy situation in the distillation can be improved compared to two stand-alone plants. The blended distillations feed solutions, for instance at 2 wt-% and 6 wt-%, has a lower energy demand compared to stand-alone processes, as can be seen in Figure 9. Also, the energy demand for evaporation of the stillage stream, not shown in the simplified process scheme in Figure 8, can be diminished for some of the process configurations. It might be a disadvantage if the residue cannot be used for animal feed (DDGS). However, it will still have a fuel value, which will help to improve the economics of the overall process. Also the investment cost may be diminished for some of the integration alternatiIntegration may also alleviate some of the inhibitory effects occurring from formation of toxic compounds in the pretreatment step. If the process streams are mixed prior to fermentation the lignocellulosic streams will be diluted by the starch-based streams.

Figure 10 shows one result from batch SSF of steam-pretreated wheat straw at 5% WIS and a 50/50 mixture of steam pretreated wheat straw and wheat meal at a total WIS of 5%. The overall ethanol yield in the SSF was 81% for the wheat straw case and 94% for the 50/50 mixture, based on theoretically possible from the available fermentable sugars.

To summarize, we believe that integration of first – and second – generation bioethanol production results in higher ethanol yield, lower energy demand and lower production cost than by using a stand-alone second-generation ethanol production.

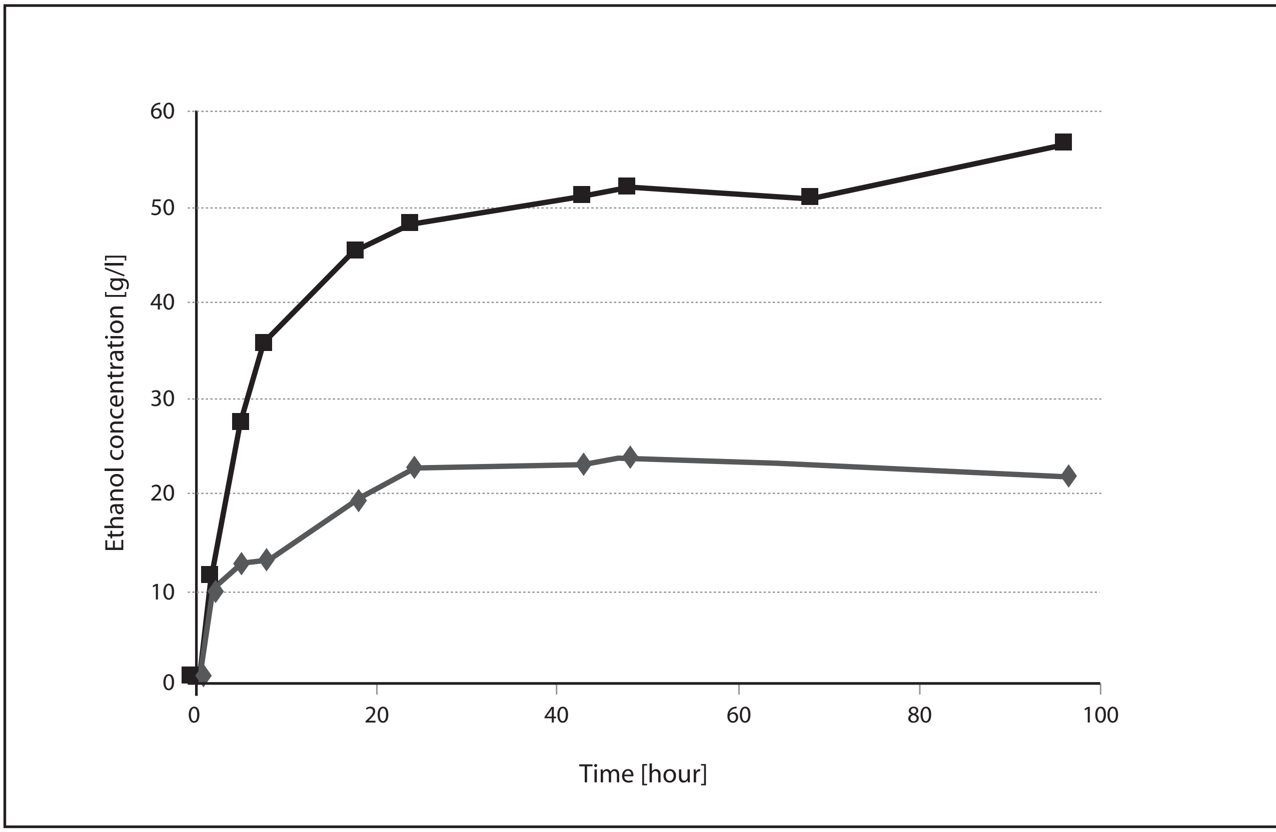

FIGURE 10 Time course of ethanol concentrations during batch SSF of steam pretreated wheat straw (♦) at 5% WIS and a 50/50 mixture (■) of steam pretreated wheat straw and wheat meal at total WIS of 5%.

To define the most optimal way of integration requires detailed studies, e.g. by flowsheeting calculations based on reliable experimental data. This work is at present in progress at Lund University using flowsheeting to evaluate various process concepts.

FINAL CONSIDERATIONS

In summary substantial progress has been achieved in the field lignocellulosic fuel ethanol production, especially within research. However, the transition into a mature industrial technology requires further research and development efforts to cope with the following major research challenges in the areas summarized below:

- Improvement of enzymatic hydrolysis with efficient enzymes, reduced enzyme production cost and novel technology for high solids handling.
- Development of robust fermenting organisms, which are more tolerant to inhibitors and ferment all sugars in the raw material in concentrated hydrolysates at high productivity and with high ethanol concentration.
- Extension of process integration to reduce the number of process steps and the energy demand and to re-use process streams to eliminate the use of fresh water and to reduce the amount of waste streams.
- Process integration with other types of industrial processes, e.g. a combined heat and power plant or a starch-based ethanol plant, which will reduce the production cost further.

Finally, one of the most important issues is to verify all process steps in an integrated way in pilot scale. Especially critical process steps as pretreatment and SSF have to be verified at large scale but also more technical issues like filtration of lignin and the influence of process integration and recycling of process streams on fouling.

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5 Pilot plant in Örnsköldsvik, Sweden [http://www.sekab.com/default.asp?id=1137&refid=1037]

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13

HYDROLYSIS OF LIGNOCELLULOSIC BIOMASS

Rodolfo Quintero-Ramirez

INTRODUCTION

The production of liquid biofuels from lignocellulosic biomass can significantly reduce the world dependence on oil, so it has become a research area of great interest to many governments, academic groups and companies.

Today it is possible due to advances in agriculture and biotechnology to propose the inexpensively production of biofuels, especially bio-ethanol based on lignocellulosic biomass as well as other biomass feedstocks.

So far, Brazil[2] and USA[4] have made significant advances in the production and use of bioethanol, in the first case derived from sugarcane (currently 15 billion liters of ethanol are produced) and the second uses corn (for 2017 it is expected to reach a production of 132 billion of liters). This situation has caused a controversy in the use of soil, water and other resources between food *vs* energy. For this reason in several parts of the world, in universities and companies, there are research programs trying to understand the best way to use lignocellulosic materials for production for bioethanol and other biofuels.

Abundant and inexpensive lignocellulosic biomass does not compete with the production of food crops. Economically, lignocellulose has an advantage over other agriculturally important biofuels feedstocks such as corn starch, soybeans and sugarcane because it can be produced quickly and at significantly lower cost than food crops. Lignocellulosic biomass is also an important component of the major crops already mentioned; it is the non-edible portion of the plant, which is currently underutilized but could be used for biofuels production.

Availability of lignocellulosic biomass is not in general a limitation in most parts of the world. For example, USA has a large amount of underutilized biomass, Table 1. In fact, non-food biomass, including trees, grasses and agricultural residues, constitutes more than 80% of the biomass; in 2005 it was estimated that 1.3 billion dry tons of this non food biomass could be available for large scale bioenergy and biorefining industries by the middle of the 21st century. This much biomass has the energy content of 3.8 billion barrels of oil; an amount equivalent to approximately half the oil consumed in that country in 2006.

Lignocellulosic biomass feedstocks for biofuels production can be derived from both, forest and agricultural resources. Forest resources include residues such as tree bark and scrap wood and urban wood residues consisting mainly of municipal solid waste. Agricultural resources consist mainly of crop residues, which are mostly leaves and stems (v. gr. corn stover), from crops grown for food and fiber such as sugarcane, soybeans, corn and wheat. Additionally more recently several researchers have proposed grasses (v. gr. switch grass) and fast-growing trees (v. gr. poplar) to be considered specifically for bioenergy.

The key bottleneck for the use of lignocellulosic biomass as raw material to obtain biofuels is the lack of technology for the efficient conversion of biomass into liquid fuels. The limiting factor is simply that low cost processing technologies to effi-

TABLE 1 Potential USA biomass resources[4].

Biomass	Million dry tons *per year*
Forest biomass	
Forest products industry residues	145
Logging and site-clearing residues	64
Forest thinning	60
Fuetwood	52
Urban wood residues	47
Subtotal for forest residues	*368*
Agricultural biomass	
Annumal crop residues	428
Perennial crops	377
Misc. process residues, manure	106
Grains	87
Subtotal for agrocultural resources	*998*
Total biomass resource potential	1,366

ciently convert a large fraction of the lignocellulosic biomass energy into liquid fuels do not yet exist.

A comprehensive understanding of the fundamental chemistry, science and engineering underpinning the chemical transformation of lignocellulosic materials into biofuels is necessary to build on the many advances that have already been made in the development of bio-ethanol production processes.

For the transformation of lignocellulose into bio-ethanol, several steps are needed: collection of lignocellulosic biomass, a pretreatment stage, a hydrolysis stage to obtain sugars from cellulose and hemicellulose present in biomass, conversion of sugars into bioethanol by fermentation and elimination of water in the biofuel in order to reach the technical specifications required.

In this paper I present a review of the state of art of one of these stages: hydrolysis of lignocellulosic biomass. But before doing so, some comments will be made about what are the main components of lignocellulosic materials and what it is known about its chemistry and structural composition.

BIOMASS AS RAW MATERIAL

Lignocellulosic is much more difficult to convert into ethanol than sugars, starches and oils. Lignocellulose is the fibrous material that forms the cell walls of the plants "architecture", It consists of three major components, Figure 1:

- Cellulose, which consist of high molecular weight polymers of glucose that are held rigidly together as bundles of fibers to provide material strength. The cellulose typically accounts for some 40 wt% of the lignocellulose.
- Hemicellulose, which consists of shorter polymers of various sugars that glue the cellulose bundles together. It usually accounts for some 25 wt% of the lignocellulose.
- Lignin, which consists of a tri-dimensional polymer of propyl-phenol that is imbedded in and bound to the hemicellulose. It provides rigidity to the structure. It accounts for some 20 wt% of the lignocellulose.

In Table 2, it is shown some of the main resources of lignocellulose and their chemical composition in terms of cellulose, hemicellulose and lignin. It can be appreciated that the potential of sugar production in most of them vary from 60-70% that is 600-700 Kg of sugar/ton of dry lignocellulosic material. Also in Figure 1 there is a representation of structure and attachment that are between the three polymers: lignin occludes polysaccharides and for that reason it is necessary to remove it.

Due to this difficulty in structure several production processes have been developed, in Figure 2, three of them are shown. All try to explore different options looking for better yields and lower cost of processing:

a) The conventional thermochemical route to biofuels brakes down starch (or other biomass) into a mixture of carbon monoxide and Hydrogen. This mixture is then converted catalytically into synthetic diesel.
b) Conventional biological routes convert starch to Glucose, which is then fermented by microorganisms to produce ethanol.

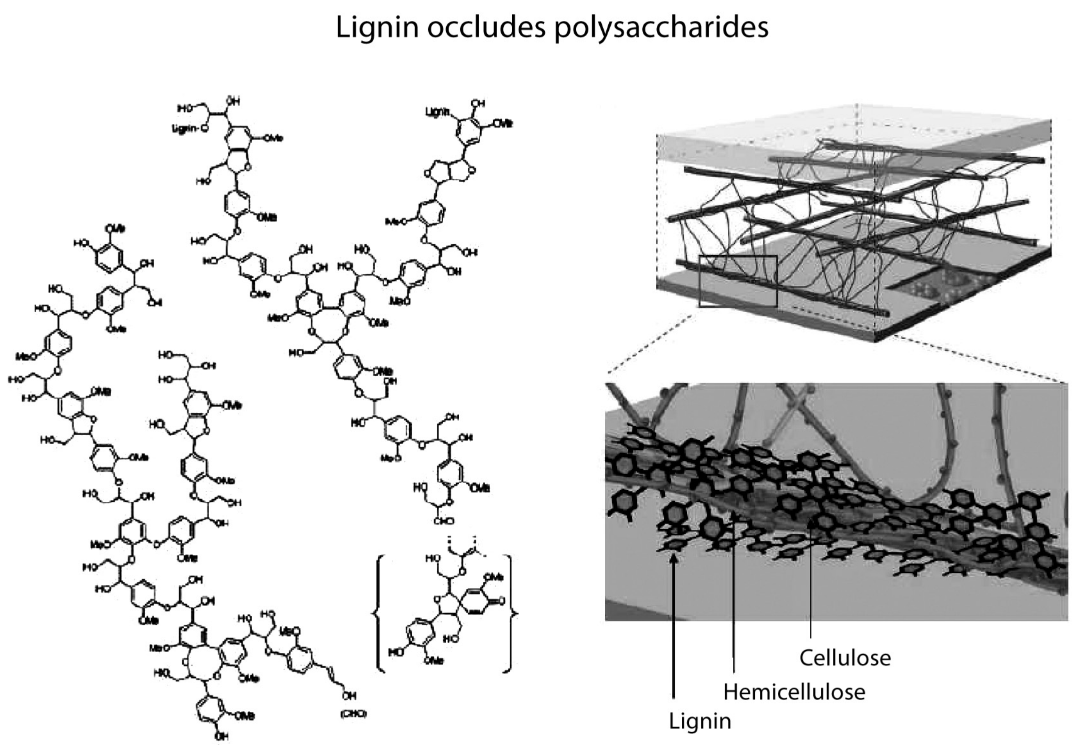


FIGURE 1 Polymer structure of lignocellulosic biomass.

TABLE 2 Chemical composition of different lignocellulosic resources (%)[4,5,13].

Resource	Cellulose	Hemicellulose	Lignin
Barley straw	40-44	28-30	20-22
Wood	44-50	20-26	17-30
Bagasse	50	20	30
Corn stover	36	23	17
Wheat straw	33	25	23
Rice straw	34	25	23

c) This hybrid route that enzymatically converts starch into fructose. An acid-catalyzed reaction converts the fructose intro 5-hydroxymethylfurfural (HMF), which undergoes another catalytic reaction with hydrogen to yield the potential fuel 2,5-dimethylfuran (DMF).

Which is the best process? which one offers the greatest benefits? Etc. These questions are still unanswered especially with regard to economic feasibility.

In the following section lignocellulosic biomass conversion into its monomers will be discussed: cellulose will yield mainly glucose and hemicellu-

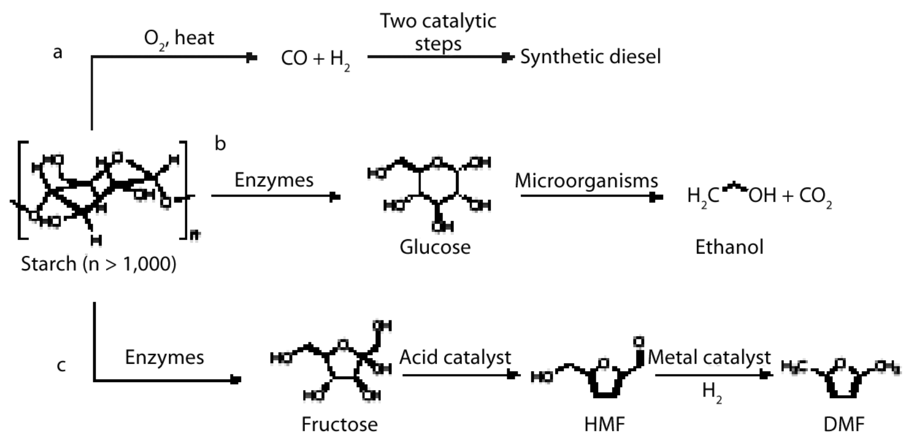


FIGURE 2 Conventional and Hybrid Biofuel Production Processes[4,11].

lose a mixture of sugars of 5 carbons (v. gr. xylose) and 6 carbons sugars (v. gr. fructose).

PRETREATMENT OF LIGNOCELLULOSIC BIOMASS

To achieve high yields of glucose, lignocellulose must first be pretreated, that is removed. The goal of pretreatment is to decrease the crystallinity of cellulose, increase biomass surface area, remove hemicellulose, and break the lignin seal, Figure 1. This pretreatment changes the biomass structure and improves downstream processing. Pretreatment methods include physical, chemical and thermal of some combination of the three. Pretreatment is one of the most expensive processing steps for the production of sugars from biomass, and the costs has been estimated to be as high as \$0.09 per liter of ethanol. Pretreatment is also one of the least understood processing options and recently several reviews have been published[6,7,14,15]. According to Wyman *et al.*[15], the following is a list of desirable pretreatment attributes:

1. Low cost of chemicals for pretreatment, neutralization, and subsequent conditioning.
2. Minimal waste production.
3. Limited size reduction because biomass milling is energy-intensive and expensive.
4. Fast reactions and/noncorrosive chemicals to minimize pretreatment reactor cost.
5. The concentration of hemicellulose sugars from pretreatment should be above 10% to keep fermentation reactor size and reasonable level and facilitate downstream recovery.
6. Pretreatment must promote high product yields in subsequent enzymatic hydrolysis or fermentation operations with minimal conditioning cost.
7. Hydrolysate conditioning in preparation for subsequent biological steps, should not form products that have processing or disposal challenges.
8. Low enzyme loading should be adequate to realize greater than 90% digestibility of pretreated cellulose in less than 5 days and preferably 3 days.
9. Pretreatment should facilitate recovery of lignin and other constituents for conversion to valuable co/products and to simplify downstream processing.

Physical pretreatment methods include ball milling, comminution (mechanical reduction of biomass particulate size) and compression milling. Solvents such as H_2O_2, ozone, gluyerol, dioxane, phenol, or ethylene glycol have been used for biomass pretreatment, and these solvents are known to break apart cellulose structures and promote hydrolysis. However, solvent pretreatments appear too expensive for practical purposes. According to MOSIER *et al.*, the most cost-effective and promising pretreatment methods are dilute acid, uncatalyzed steam explosion, pH controlled hot water, treatment with lime, and treatment with ammonia.

Table 3 shows the effect of various pretreatment methods on the chemical and physical structure of lignocellulosic biomass. Uncatalyzed steam explosion is used commercially to remove hemicellulose for the manufacture of fiberboard and other products by the Masomite process. High pressure steam is applied to wood chips for a few minutes without the addition of chemicals, and this process is terminated by decompression of the steam. This process increases the surface area without decrystalizing the cellulose and cellulose downstream is significantly improved.

Water treatments at elevated temperatures (200-230 °C) and pressures can increase the biomass surface area and remove hemicellulose. Three types of reactors are used for hot water pretreatment including co-current (biomass and water are heated together for a certain residence time), countercurrent (water and lignocellulose move in opposite directions), and flow through (hot water passes over a stationary bed of lignocellulose). The advantage of hot water treatment is that acid addition and size reduction are not needed. A disadvantage of these methods is that hot water treatment forms sugar degradation products (furfural from pentoses and HMF from glucose). The degradation products can be minimized by controlling the pH of the hot water by addition of bases such as potassium hydroxide.

Dilute sulfuric acid treatments can be used to hydrolyze hemicellulose to sugars with high yields, change the structure of the lignin, and increase the cellulosic surface area. The disadvantage of this process is that not requires corrosive acid, with corresponding downstream neutralization, and special materials for reactor construction. Ammonia fiber/freeze explosion (Afex), where anhydrous ammonia is contacted with lignocellulose, can increase the surface area of the biomass, decrease crystallinity of cellulose dissolve part of the hemicellulose, and remove lignin. Treatment of the biomass with a less concentrated ammonia solution is known as ammonia recycled percolation (ARP). Ambient conditions can be used for lime treatments; however, the time required for these treatments is in terms of weeks. This process in-

TABLE 3 Effect of promising pretreatment methods on the structure and composition of lignocellulose biomass[7].

Pretreament method	Increases surface area	Decrystalizes cellulose	Removes hemicellulose	Removes lignin	Alters lignin structure
Uncatalyzed steam explosion	**		**		*
Liquid hot water	**	ND	**		*
pH controlled hot water	**	ND	**		ND
Flow-through liquid hot water	**	ND	**	*	*
Dilute acid	**		**		**
Flow-through acid	**		**	*	**
Ammonia fiber explosion (Afex)	**	**	*	**	**
Ammonia recycled percolation (ARP)	**	**	*	**	**
Lime	**	ND	*	**	**

* minor effect; ** major effect; n.d. = not determined.

volves mixing lime with water and spraying it onto the biomass. The mayor effect of lime pretreatment is removal of lignin. The biomass surface area is increased, and the acetyl and uronic acid fractions of hemicellulose are removed.

Table 4 shows the results of different pretreatment methods followed by enzymatic hydrolysis for production of sugars from corn stover. Table 5 lists the reaction conditions for the pretreatments. Using corn stover feed-stocks sugar yields of over 90% were obtained with the various pretreatments. A hot water treatment with a flow through reactor was the pretreatment method with the highest overall soluble product yield; however, the xylose monomer yield was only 2.4% meaning this method did not produce xylose monomers. A dilute cid pretreatment method produced the highest amount of sugar monomers with a 92% yield. Results are expected to be different with other feedstocks.

An economic analysis of ethanol production using the various pretreatment methods shows that the cost increases as dilute acid < Afex < lime < ARP < hot water. The reason hot water

TABLE 4 Xylose and glucose yelds of corn stover after various pretreatments followed by enzymatic hydrolysis[14].

	Xylose yilds (%, max 37.7)			Glucose yields (%, max. 62.3)			Total sugar yields (%)		
Pretreatments system	Stage 1	Stage 2	Total	Stage 1	Stage 2	Total	Stage 1	Stage 2	Total
Dilute acid	32.1(31.2)	3.3	35.3(34.5)	3.9	53.3	57.2	36.0(35.1)	56.6	92.5(91.7)
Flowhrough	36.3(1.7)	0.8(0.7)	37.1(2.4)	57.0	61.5(61.4)	40.8(6.1)	57.8(6.1)	57.8(57.7)	98.6(63.8)
Partial flow pretreatment	31.5(2.8)			4.3(4.2)					
Controlled pH	21.8(0.9)	8.9	30.7	3.5(0.2)	54.7	58.2	25.3(1.1)	63.6	88.9
Afex		ND (30.2)	ND (30.2)		61.8	61.8		ND/92.0	ND/92.0
ARP	17.8(0)	17.0	34.8(17.0)	0	59.4	59.4	17.8(0)	76.4	94.2(76.4)
Lime	9.2(0.3)	20.2	29.4(20.5)	1.0(0.3)	59.5	60.5(59.8)	10.2(0.2)	79.7	89.9(80.3)

Stage 1 is pretreatment of com stover and stage 2 is enzymatic hydrolysis after preteatment with a cellulose loading of 60 EPU/g of glucan in the origina com stover. The value reported in each column is sugars plus oligomers, while the value in parentheses is the value for monomers only. A single value indicates that only monomers were observed.

TABLE 5 Optimal pretreatment conditions for ethanol production from corn stover[15].

Pretreatment system	Chemicals	Temp (°C)	Pressure (atm)	Reaction time (min)	Solid conc (wt %)
Dilute acid	0.5-3.0 wt% sulfuric acid (0.49 wt%)	130-200(160)	3-15	2-30(20)	10-40(25)
Flowthrough	0.0-0.1 wt% sulfuric acid (0.0 wt%)	190-200(200)	20-24	12-24(24)	5-30
pH controlled	water or stillage	160-190(190)	6-14	10-30(15)	5-30(16)
AFEX	100% (1.1) anhydrous ammonia	70-90(90)	15-20	<5(5)	60-90(62.5)
ARP	10-15 wt% ammonia (15 wt%)	150-170(170)	9-17	10-20(10)	15-30
Lime	0.05-0.15 $Ca(OH)_2/g_{biomass}$ (0.08)	25-60(55)	1	2-8 weeks (2 weeks)	10-20

The optimal reaction parameters are in parentheses.

pretreatment is so expensive is that it requires more enzymes to break down the xylose oligomers. If the oligomers could be successfully converted into ethanol (for other products), then the cost of making ethanol for the various pretreatment method decreases for the hot water, ARP, and lime methods, all of which make a significant amount of oligomers.

HYDROLYSIS OF LIGNOCELLULOSE

The hydrolysis reaction for cellulose conversion into sugar polymers is:

$$(C_6H_{10}O_5)_n + nH_2O \text{ à } nC_6H_{12}O_6.$$

Hydrolysis of cellulose is significantly more difficult than for starches because cellulose is in a crystalline form with hydrogen bonding, Figure 3. The hydrolysis reaction can be catalyzed by acids or enzymes. Cellulose enzymes are able to catalyze the reaction with yields close to 100% at 50 ºC. The National Renewabl e Energy Laboratory (NREL) of USA has estimated that the cost of unrefined sugar monomers, in an aqueous solution, produced from lignocelullose would be 12-14 ¢/kg of sugar and others have projected the price of sugar could decrease as low as 5.3 ¢/kg.

Earlier cellulose hydrolysis kinetic models, developed by Saeman and others[1,10,13], involve two first-order reactions where the first involves cellulose hydrolysis to glucose followed by glucose decomposition. The accept model for acid hydrolysis, with diluted acid at high temperatures is shown in Figure 4.

Undesired byproducts including 5-hydroxymethylfurfural (HMF) and levulimic acid are produced by acid-catalyzed degradation of sugars. Most hydrolysis data were fit to his sample model from 1945 to 1990, and Table 6 shows the model parameters from various studies. Using these parameters the maximum yield of glucose is always less than 70%. Enzymatic hydrolysis can produce glucose yield above 95% as shown in Table 4. The acid hydrolysis of cellulose has a lower activation energy than lignocellulose, thus showing the effect of ligning on the acid hydrolysis reaction.

More complicated kinetics models have been developed based on mechanistic data. Oligomer

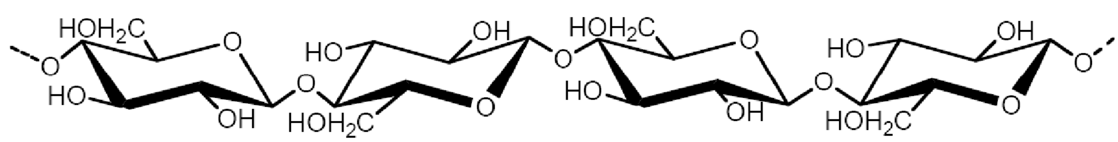


FIGURE 3 Chemical structure of cellulose (crystalline polymer of glucose connected via beta linkages)[1].

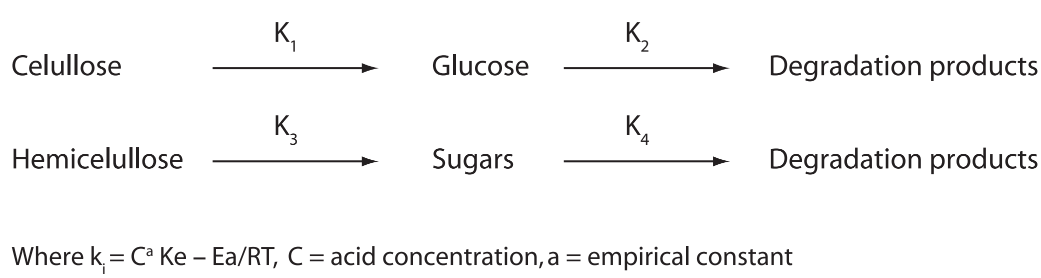


FIGURE 4 Model of acid hydrolysis at high temperature[10, 13].

TABLE 6 Kinetic parameters for acid hydrolysis of various biomass feedstocks with the Saeman Model[1, 10].

Feed	Temp (°C)	Acid conc (wt %)	K_1 (mim^{-1})	K_2 (min^{-1})	E_1 (kJ/mol)	E_2 (kJ/mol)	*m*	*n*
Glucose	160-260	?		1.85×10^{14}		136		1.0
Cellulose	100-130	5-40 H_2SO_4	1.57×10^{14}		142		1.42	
Douglas fir	170-190	0.4-1.0 H_2SO_4	1.73×10^{19}	2.38×10^{14}	180	137	1.34	1.02
Kraft paper	180-230	0.2-1.0 H_2SO_4	28×10^{19}	4.9×10^{14}	189	137	1.78	0.55
Newsprint	200-240	1.0 H_2SO_4	28×10^{19}	4.8×10^{14}	189	137	NR	NR
Solka-floc	180-240	?	1.22×10^{19}	3.79×10^{4}	178	137	NR	NR
Cane bagasse	100-130	5-40 H_2SO_4	1.15×10^{21}		152		1.42	

Saeman model is represented as cellulose + water $\underset{k_1}{\rightarrow}$ glucose $\underset{k_2}{\rightarrow}$ degradation products where $k_1 = K_1 (Con_{acid})^m \exp(-E_1/RT)$ and $k_2 = K_2 (Con_{acid})^m \exp(-E_2/RT($ with Con_{Acid} in wt fraction of acid.

conversion into glucose is 2-3 times faster than conversion of cellulose to glucose; however, oligomers have been observed during hydrolysis. These observations lead to the development of a two-step model where cellulose is converted into oligomers, which are then converted into glucose. Others have observed[8] that in addition to the hydrolysis pathway another pathway occurs that produces a modified cellulose that cannot be hydrolyzed to glucose. Importantly, this model suggests that cellulose structural rearrangements can occur with high-temperature treatments. The acid-hydrolysis reactions are heterogeneous with the solid biomass reacting with liquid acid. Thus, mass transfer limitations also can play a role in hydrolysis.

The mechanism for C-O-C bond cleavage in cellulose involves protonation of glucosides bonds. The proton can either attack the oxygen bond between the two glucose units of the cyclic oxygen, which define two different pathways. The mechanism is thought to involve the rapid formation of an intermediate complex with the oxygen and proton, followed by the slow splitting of glucosidic bonds by the addition of a water molecule.

Heterogeneous reactions occur during cellulose hydrolysis in the biomass where the acid first penetrates into disordered cellulose regions leading to an initial rapid decrease in the degree of polymerization (DP). After the rapid initial decrease, the DP reaches an asymptotic value where the DP remains at a constant value called the degree of polymerization (LOPD). The LOPD is dependent on the type of cellulose samples and is reached when only 2-5% of the sample has been hydrolyzed. The average length of crystallite in the cellulose sample is considered to be the same as the LODP. Oxidation of cellulose (with oxidizing agents such as H_2O_2, $NaClO_2$, O_3, $KBrO_3$ etc.) prior the hydrolysis or during progressive hydrolysis reduces the DP of partially hydrolyzed residues. This treatment decreases the aldehyde concentration and increases the carboxylaldehyde concentration, which prevents recrystallization. Recrystallization can occur during acid or enzymatic hydrolysis.

Prior the enzymatic hydrolysis, the cellulose structure must be pretreated to open up the structure of biomass for reaction of the cellulose with cellulose. Initially, a process was designed to produce ethanol through enzymatic hydrolysis by separate hydrolysis and fermentation (SHF) steps. This involved using improved enzymes from the fungus *Trichoderma reesei*. Problems with these methods are that cellubiose and glucose inhibit the reaction, which increased enzyme cost. This problem can be reduced by a process known as simultaneous saccharification and fermentation (SSF) where the vessel contains both cellulose and fermentative organisms to covert glucose rapidly to ethanol. This process significantly reduces the concentration of glucose. Although the temperature of the SSF process in lower than the optimal temperature for enzymatic hydrolysis because the fermentation organisms are not stable and these higher temperatures, the rates, concentrations, and yields are still better than for SHF.

Cellulases, the enzymes that catalyze cellulose hydrolysis, were initially categorized based on the reaction they catalyze. More recently, they have been classified based on structural properties[5]. Three major types of enzymatic reactions are reported including (1) endoglucanases or 1-4-β-D-glucan glucanohydrolases, (2) exoglucanases or 1-4-β-Dglucan glucanohydrolases (also known as celloextrinases) and (3) β-glucosidases or βglucoside glucohydrolases. Endoglucanases react with internal amorphous cellulose sites to produce shorter chains of varying lengths and expose chain ends. Exoglucanases hydrolyze the ends of cellulose produced by endoglucanose in a progressive matter to produce cellobiose as the major product. β-glucosidases convert cellodextrins and cellobiose to glucose. The hydrolysis mechanism in an enzyme occurs using a proton donor and nucleophile or base. Cellulase systems act in a coordinated manner to efficiently hydrolyze cellulose and consist of more than just a combination of the three enzymes systems. Recent reviews have been published on kinetic modeling of cellulose enzymatic hydrolysis.

There are only two companies in the world that today produce commercially celullases, Genencor in USA and Novozymes in Europe. Last September, Genencor introduced a new enzymatic preparation known as Accelerase1000 which has 4 different enzymatic activities. Figure 5 presents the results of using such enzyme on washed acid-pretreatedcorn stover and sugarcane bagasse; it is interesting to observe that a yield of almost 90% was achieved for cellulose digestibility.

Even that hemicellulose offers an important amount of fermentable sugars, its enzymatic hydrolysis is more complicated that the one of cellulose. This polymer is composed of a mixture of sugars of 5 and 6 carbons which required several different enzymes to break it[5]. In Figure 6 the main glycoside hydrolase and carbohydrate esterase enzyme families for degrading hemicellulose are shown: endoxylanase, beta-xylosidase,

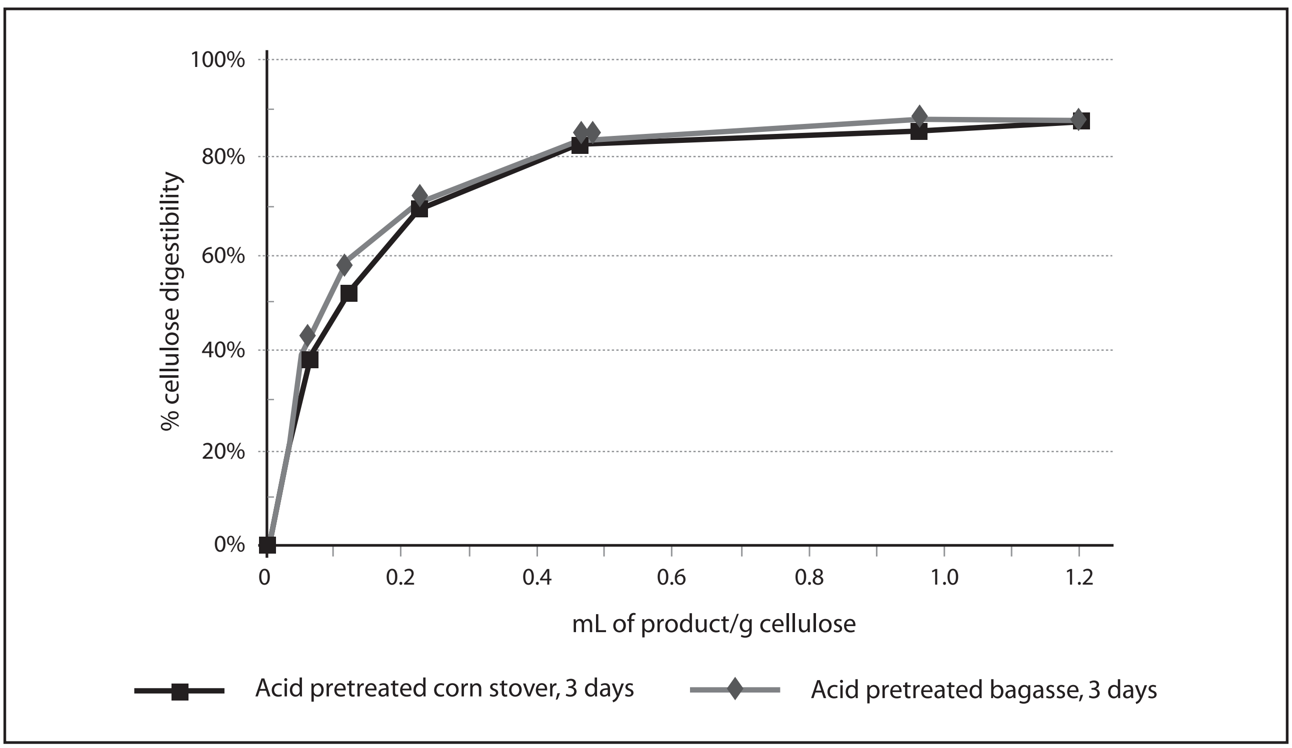


FIGURE 5 % Cellulose digestibility vs mL of product per g cellulose for washed acid-pretreated corn stover and sugarcane bagasse using Accellerase™ at 7% cellulose loading, 50 ºC, pH 5.0, and in 3 days[3].

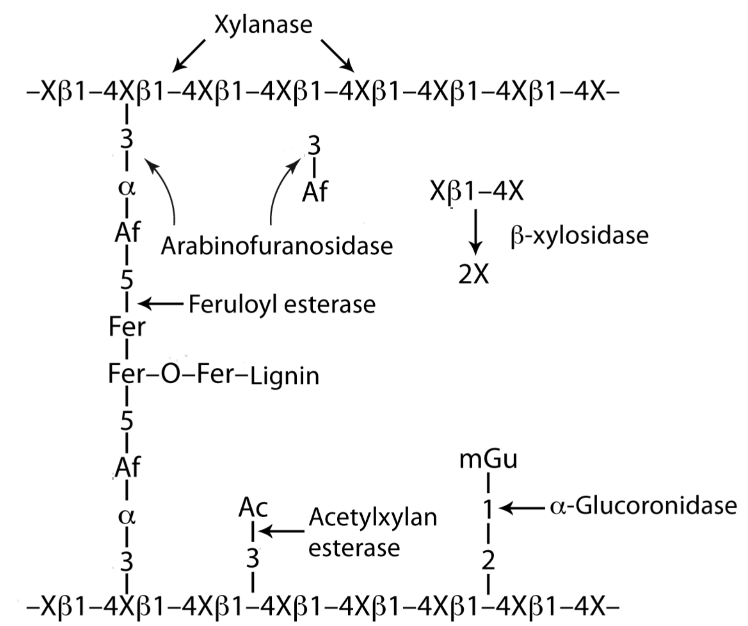


FIGURE 6 Different enzymes require for hydrolysis of hemicellulose[5].

alpha-Larabinofuranosidase, alpha-glucuronidase, alpha-galactosidase, acetylxylan esterase and feruloyl-esterase. These requirements make difficult and expensive the enzymatic hydrolysis of hemicellulose.

Acid hydrolysis of hemicellulose occurs under less harsh conditions than cellulose because hemicellulose is an amorphous polymer. Hemicellulose hydrolysis even occurs in hot water (~ 210 °C), where the water is thought to break down hemicellulose and release acetic acid, which continues to catalyze the reaction. Water-soluble oligomers from in high yields with hot water treatments. Dilute acid treatment of lignocellulose at 160 °C, 10 min reaction time, and 0.7 wt% acid, yields 85-90% of the hemicellulose sugars. Kinetic models usually incorporate two types of hemicellulose a fast hydrolyzing type and a slow hydrolyzing type. The proportion of fast and slow fractions is typically 65 and 35% as determined by fitting kinetic data. Oligomer intermediates are experimentally observed but frequently ignored in kinetic models. Although significant effort has been devoted to describing the kinetics of hemicellulose hydrolysis, the models do not predict consistent results. For example, the rate of xylose degradation in kinetics models is different than the rate of pure xylose degradation. The hemicellulose also is associated with lignin, and this type of bonding could change the kinetics. Future mechanistic work could help clarify the heterogeneous mechanisms of acid hydrolysis of biomass leading to further process improvement.

Some research groups are focusing their efforts into the design and development of new catalytic systems for cellulose hydrolysis. An interesting approach published recently[12] takes into account the knowledge of enzyme structure and function and while still been based on acid catalysis uses the dicarboxilyc maleic acid, in this case the difunctional nature of the acid enables it to have hydrolytic activity while at the same time minimizes the degradation of the monosaccharides that are formed.

ECONOMICS OF LIGNOCELLULOSE CONVERSION PROCESSES

Numerous studies have discussed the economics of biomass conversion processes over the last 20-30 years. Some these studies have been revisited and compiled using a single base and a single set of assumptions. For this purpose, the manufacturing costs have been split into two major contributions, namely the feed and the processing costs. The former covers the cost of purchasing the feedstock. The latter covers the cost of installing and running the manufacturing plants, v. gr. the cost of plant, the labour as well as the energy and chemical consumed. The economics of the various technologies can then be visualized by plotting the processing cost against the feed of the various process alternatives, as done in Figure 7. The diagonal "eco-cost" lines represent overall manufacturing cost.

Figure 7 displays processes that produce transportation fuels from bio and fossil feedstock, v. gr. from lignocellulose, starch and vegetable oil as well as from crude oil and natural gas. It shows that the cost of oil refining is dominated by feed cost whereas the costs of gas conversion (v. gr. meOH or Fischer-Tropsch synthesis) are dominated by technology. Similarly, biofuels derived from vegetable oils are dictated by feed cost whereas those derived from lignocellulose are dominated by technology. The economics of biofuels derived from starch and sugars is intermediate to these two extremes. There is obviously a trade-off between feedstock cost and plant cost. Feedstocks, such as vegetable oil, may be expensive ($ 13-18/GJ or $ 500-700/ton) but they are easy to convert. Others like lignocellulose may be cheap ($ 2-4/GJ or $ 34-7/ton dry) but are very difficult to convert.

The diagonal lines also indicate that production of biofuels typically cost $ 15-25/GJ, which exceeds the $ 5-15/GJ of fossil fuels. Biofuels appear to be competitive with oil refining only at high oil prices, between $ 50-75/barrel.

Despites the high processing costs, the cost of the biomass conversion plants reported in the literature appeared to follow the same general laws as those of chemical and fuel plants. Irrespective of the technology applied, the plant cost of biofuel plants correlates with the overall energy loss of the plant exactly as do other chemical and fuel plants. It is then not surprising to see the cost of biomass conversion plant decreasing with increasing energy efficiency, after recalculation to a single plant size of 400 MW intake (v. gr. 680 kt/a lignocellulose), Figure 8.

Based on the analysis presented above, it is imperative to reduce the processing cost of lignocellulosic feedstock. Improvements could be

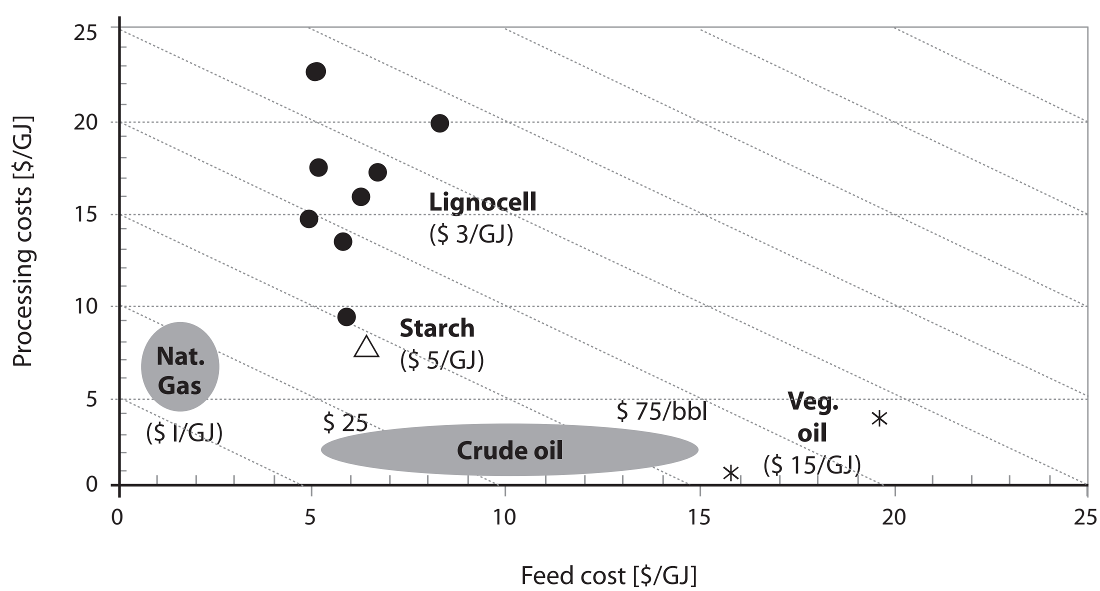


FIGURE 7 Feed and processing cost of transportation fuels derived from lignocellulose and fossil resources (the biofuel plants are set at 400 MW intake, which corresponds to 680 kt/a of lignocellulose)[6].

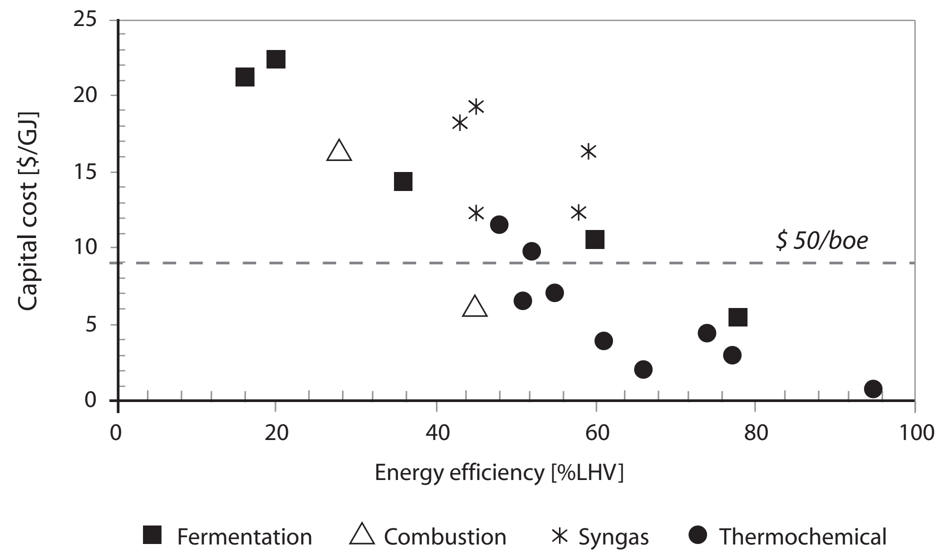


FIGURE 8 Capital cost of biomass conversion plants (400 MW intake, 25% capital charge, $2005)[6].

sought in the overall energy demand of the plant. One could, for instance, look at the handling and pretreatment of solid feedstock, which require heavy and energy-consuming equipments. The purification of the product can also be energy–and capital-intensive. For instance, hydrolysis and fermentation technologies often result in a product that is highly diluted in water and requires expensive recovery by distillation or extraction.

Equally important is to increase the scale of the process as much as possible. The contribution of the plant cost to the overall manufacturing cost is known to decrease by 2025% for a two-fold increase in plant size[6]. However, the scale of biofuel plants might not be limited by technology but rather by the amount of feedstock that can be collected within a reasonable radius and transported to the plant at reasonable cost. In fact the intake of 400 MW (or 680 kt/a of lignocellulose) assumed here requires a fairly large collection area of some 6,000 km^2.

The analysis here was limited to the manufacture of finished biofuels. The economics of coverting the biomass to biocrude, electricity or chemicals was omitted for the sake of simplicity but is discussed elsewhere. Accordingly, biocrude may complete with fuel oil at an oil price of $ 50-80/barrel, biofuel may compete with gasoline and diesel at $ 70-110/barrel, and green-electricity is affordable at $ 80-100/barrel oil.

Even in USA the advocates of cellulosic ethanol put the capital costs of constructing a manufacturing plant at more than twice those for a corn-based facility, and other estimates range from three times the cost to five[9]. Many researchers believe that the most promising way to make cellulosic biofuels economically competitive involves the creation-of the discovery-of "superbugs", microorganisms that can break down cellulose to sugars and then ferment those sugars into ethanol. The idea is to take what is now a multistep process requiring the addition of costly enzymes and turn it into a simple, one-step process, referred to in the industry as consolidated bioprocessing.

But if cellulosic biofuels are to being replacing gasoline within five to ten years, facilities will need to start construction soon. This fall, Range Fuels, a company based in Broomfield, Colorado, announced that it had begun work in Georgia on what it claims will be the first commercial-scale cellulosic-ethanol plant. The Range facility, which will use thermochemical technology to make ethanol from wood chips, is scheduled to reach a capacity of 20 million gallons in 2008 and eventually increases to 100 million gallons a year. Meanwhile other company, Mascoma has announced several demonstration units, including one facility in Tennessee that will be the first cellulosic-ethanol plant built to use switchgrass. But these production plants are federally subsidized or are a result of partnerships with state development organizations which makes difficult and risky the economic evaluation of such projects, they are still in the phase of demonstration.

Being one of the most important limitations for the hydrolysis of lignocellulose, the price of cellulase. Several companies and research groups have directed their efforts into finding new ways, less expensive, to produce the enzyme. One of these studies carryout an economic analysis evaluating two different methods for production of cellulase; the traditional submerged fermentation (SmF) and the new solid state cultivation (SCC). As it can be seen in Table 7, the SSC method requires less investment and has lower cost of production, $ 15.67/Kg of cellulase vs $ 40.36 using SmF method. In the market the price is $ 90/Kg.

RECOMMENDATIONS FOR FUTURE RESEARCH

In the document of the State of São Paulo Research Foundation[2], are described many research projects which are currently being developed in Brazil concerning new technologies for the use of sugarcane bagasse and its conversion into ethanol.

As a conclusion of this review, Table 8 was constructed to summarize the main problems to be solved in the processing of lignocellulosic biomass to obtain bioethanol:

a) The design of the process has been done by stages and carried out in a linear way. This scope has permitted a limited advance in the last 30 years or so. It is recommended that a more holistic view should be tried in the development of new bioprocesses.
b) The process involved several stages, each stage has a yield lower than one and the total yield then is lower than 50%. The lower yields are usually in the pretreatment and in the hydrolysis steps.
c) The total cost of producing ethanol from lignocellulosic materials is obtained adding the costs of each stage and the cost of the lignocellulose source and of the enzymes required are the more important ones.
d) The idea will be to increase yield, reduce costs (decrease the number of the stages) and in that way the cost of production of ethanol will diminish.

For a research strategy in the area of hydrolysis of lignocellulose, I will answer the following questions:

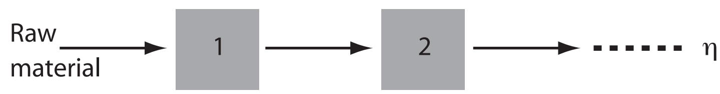
1. Is Brazil doing the right research?
   According to the document of Fapesp[2] the projects at laboratory and pilot plant that are being carried out have focused the problem on the right track. In the short term most probably acid hydrolysis of lignocellulosic materials will be the method to use, and in that sense the Dedini Rapid Hydrolysis Process seems to be a very important initiative. Also it is recommended that at least 2 or 3 projects are financed in the area of celluloses: looking for new strains for production, searching for new enzymatic activities and more important one, the preparation of a cocktail of enzymes and the testing of them with real raw materials. In this regard it has to be

TABLE 7 Economic analysis of cellulase production methods for bioethanol (data in million of dollars)[16].

	SmF	SSC
Investment		
– Main equipment	4,898	3,562
– Direct fixed capital	28,627	22,021
Annual cost		
– Raw materials	3,753	0.458
– Utilities	16,907	0.164
– Operarion costs	30,576	8.230
Cellulase cost (dollars per Kg)	40.36	15.67

SmF: Submerged fermentation
SSC: Solid state cultivation

- Process design by stages in a linear way



- Yield per stage: $Y_i < 1$
- Total yield, in general is low due to several stages involved: $\prod_{i=1}^{\eta} = Y_i = Y_T \leq 1$
- Cost per stage: $C_i > C_{\text{lignocelluosic biomass}}$
- Total cost: $\sum_{i=1}^{\eta} = \Sigma_i = C_T \qquad C_T >> C_{\text{lignocelluosic biomass}}$
- Cost of bioethanol = $\frac{C_T}{Y_T}$

FIGURE 9 Main Problems in the Processing of Lignocellulosic Biomass to Obtain Bioethanol.

taken into account that Novozymes has a production facility in Brazil and most probably they were produce cellulases if the market needs them.

2. **Are there human capacities to overcome the difficulties?**
   During my stay to São Paulo I visited two universities, Unicamp and Lorena, in both places I found a research group with the strong experience and clear ideas of what to do next. The Fapesp document indicates that in Rio de Janeiro there are other strong and large groups working on biotransformation of lignocellulose into ethanol. One missing element is the economic analysis of the projects and the developed production processes. I strongly recommend the construction or buying an economic simulator in order to do frequently economic evaluations.
3. **Is industry university partnership important?**
   Hydrolysis of lignocellulose has been a research area for more than 63 years and the results have been limited and in some cases useless. I believe that the partnership between university and industry is a must in this field. The new processes will required development of new equipment, for example for acid hydrolysis at high temperatures the reactor must be very well design and constructed with the right materials, also the problems of the scale-up will be present all the time in this field, so there must be pilot plant facilities at least.
4. **Is international cooperation important and possible?**
   Brazil is a world leader in ethanol production, together with USA; both countries are trying to develop new technologies to use lignocellulosic materials. One way in which Brazil could advance more rapidly is through international collaboration, for example if there are research groups in Mexico or Chie or in Europe or Canada, they should be contacted and the establishment of joint

collaborative programs should be promoted and financed. In the process of lignocellulose to ethanol, today the bottleneck are in the pretreatment and hydrolysis stages, the rest of the process is quite well known and mastered by researchers and companies in Brazil. One area which has not been developed yet, is what will be the real yields using real raw material in large scale. The six plants that USA has set up for production of ethanol based on lignocellulose and using different technologies will be on stream in a few months and it will be interesting for Brazil to follow up the results.

5. **What is the future of the different hydrolysis technologies?**
   No one knows for sure, of the six demonstration plants in USA, three of them use enzymatic hydrolysis and the others chemical technologies. Also all of them are based on different raw materials in order to find out what are the difficulties in large scale production. The price of oil will be an important factor to determine which technology will be the winner and again it comes to mind the need for an economic simulator to study different technologies but also options for production scenarios. The topic of production of enzymes is also a present concern because today only two companies can produce cellulases at commercial scale, most probably there will be other enzyme producers in the world.
6. **Will hydrolysis technologies ever become competitive?**
   Again the answer it is still in the air. All the theoretical evaluations about hydrolysis of lignocellulose indicate that the potential for ethanol production is very large but at the same time today the cost of production is only competitive when the barrel of oil is very high. Also as it has been mentioned several times in this paper, the real problems or large scale have not been solved and is even less known what will be the economic impact of them.

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14

FAST PYROLYSIS AS A PRECURSOR OF BTL

Juan Miguel Mesa Pérez, José Dílcio Rocha,
Luís Augusto Barbosa Cortez and *Rodrigo Aparecido Jordan*

INTRODUCTION

Fast Pyrolysis is a thermochemical biomass conversion process. Its feature is the thermal degradation of the solid fuel in the absence of oxygen in a short reaction time, in just a few seconds.

The main product obtained from a biomass pyrolysis process is the bio-oil, but there is also tproduction of charcoal powder, acid extract and gases.

Figure 1 shows the physical appearance of the pyrolysis products of the sugarcane trash processed in the Fast Pyrolysis Plant with a capacity of 200 kg/h of biomass. This technology based on fluidized bed was developed at Feagri-Unicamp in partnership with the Bioware, a company incubated and graduated from Incamp (Incubator of Unicamp). The equipment construction of the pilot plant was done by Termoquip Energia Alternativa Ltda (<http://www.termoquip.com.br>).

Other product of this technology, the gases, is not showed on Figure 1, because these gases are burned and reused on its own production system.

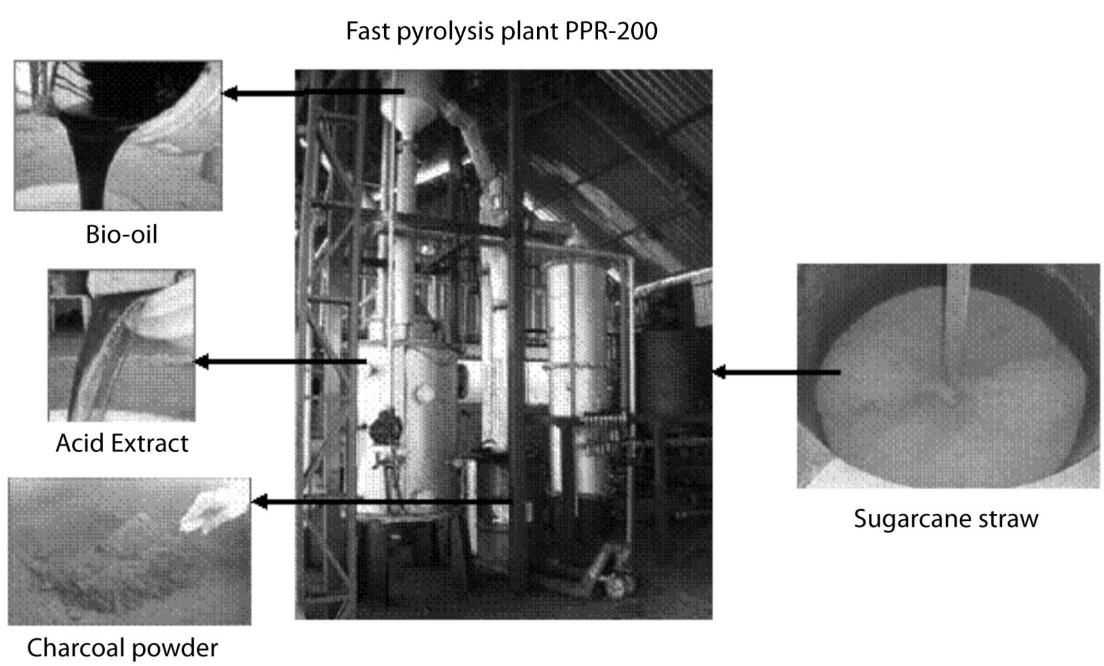

FIGURE 1 Feagri-Unicamp demonstration plant, the utilized raw material and obtained products.

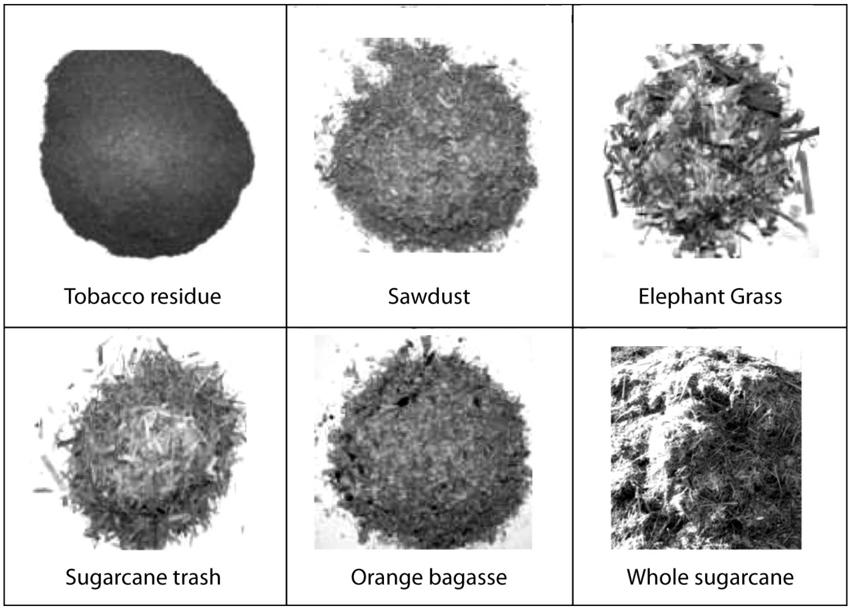

FIGURE 2 Raw materials processed at FEAGRI-UNICAMP pyrolysis pilot plant.

The fast pyrolysis of biomass aims to maximize the productivity of bio-oil. To acieve this, it is necessary to ensure that the biomass, used as raw material, has particles in the size range between 1 and 4 mm and water content up to 15%. Figure 2 shows the physical features of some biomasses that were processed in the pilot plant.

THE YIELD OF PYROLYSIS PRODUCTS

The obtained yields from fast pyrolysis, in laboratory scale bio-oil recovery equipment, can reach up to 75% mass based (Table 1). This yield considers the total mass of recovered liquid, such as: water, acids, extractives and the bio-oil. In pilot plants of pyrolysis using air as fluidizing agent, the productivity of bio-oil (5% to 7% of water), acid extract and charcoal, are showed on Table 2. The used calculation basis corresponds to the dry organic matter in the fed biomass to the reactor. The organic matter is calculated subtracting the water amount and ashes in the biomass and, deducting the percentage of biomass that is combusted by the oxygen in the fluidization air. The use of air in the process of pyrolysis ensures the auto thermal operation of the reactor.

TABLE 1 Yield of the typical products obtained by means of different kinds of pyrolysis of wood (dry basis).

Process	Process conditions	Liquid	Charcoal	Gas
Fast pyrolysis	Moderate temperature (450 ºC to 550 ºC), short time of vapor residence (0.5 to 3 s) and biomass with low granulometry.	75%	12%	13%
Carbonization	Low temperatures (400 ºC to 450 ºC), long residence times (it can be hours or days), large particles (pieces of wood).	30%	35%	35%
Gasification	High temperature (900 ºC)	5%	10%	85%

Source: BRIDGWATER, 2002.

TABLE 2 Yield of pyrolysis products in the Feagri-Unicamp pilot plant using sugarcane trash (dry organic matter basis).

Products	Yield (%)
Charcoal	20
Bio-oil	30
Acid extract	10
Gases	40

FAST PYROLYSIS AS A PRETREATMENT STEP OF BIOMASS

The fast pyrolysis has two features that are highly beneficial: (1) its main product is the bio-oil (liquid fuel) and (2). Technical and economical feasibility in a scale of 1 to 2 ton/h of biomass feeding. The bio-oil is the biomass in a liquid form, and this way, it has some advantages on transportation, pumping, storage and handling. These characteristics the solid biomass does not have because of the high water content. Thus the bio-oil can benefit of all the structure currently used for the liquid fuels. In what concerns the scalability, the fast pyrolysis plants have demonstrated to be much more efficient in a low scale. This way, the little plants or even mobile plants, can go near the biomass in the processing location, avoiding the expensive transportation of the biomass through long distances. The biomass in a liquid state, in other words, in the bio-oil form, is more convenient and feasible the long distance due to its high energy concentration, less humidity and characteristics of the liquid fuel. The economical availability of the small size plants is a differential of this technology that allows a decentralized use.

PRIMARY ENERGY FROM BIOMASS

The use of biomass as energy needs to consider the energy balance of the productive chain for its production and transformation afterwards. All the energy used for the production and packaging of biomass must be uncounted of its primary energy. In the diagram of the block displayed in Figure 3 there is a representation of the above mentioned. The advantage of primary energy of the whole sugarcane, for example, can be an interesting alternative regarding the use of the bagasse, the straw or the sucrose in an independent way.

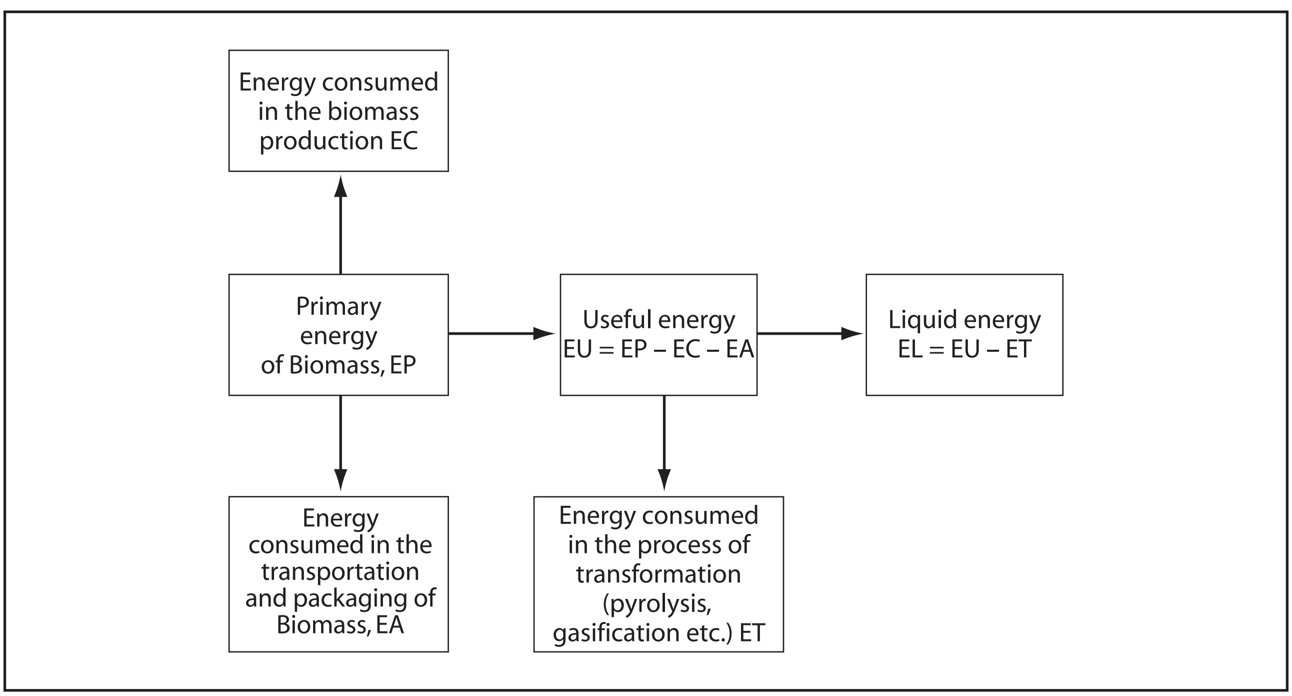

FIGURE 3 Diagram of the primary energy consumption in the productive chain of biomass transformation.

These kinds of studies are recommended with the purpose of developing or upgrading techniques that allow to use in a more efficient way the primary energy of the sugarcane.

POTENTIAL APPLICATIONS OF PYROLYSIS PRODUCTS

All the products of fast pyrolysis has potentially important application even as intermediary in other industrial processes, as final product after chemical transformations to adapt to other applications or directly with renewable fuel, as showed in Figure 4. In all the applicable possibilities, the bio-oil is always a renewable substitute for fuels or raw materials traditionally resulting from fossil sources.

Studies are being performed, considering a scenario where the bio-oil will always be used as source for the production of synthesis gas. The bio-oil will be obtained in a fast pyrolysis plant in a fluidized bed in low scale and from a great variety of biomass available as residue of several agricultural, agro-industrial and agro forestry system. The mixture of all bio-oil production will be storaged in a large size plant to be gasified and to produce synthetic fuels, fertilizers and other products through catalytic synthesis, as showed in the chapter about BTL – *biomass to liquids*. This is a description of a biorefinery based on synthesis gas. Its structure must be of a large size since the catalysis plants are expensive and only justifiable for big volumes of production. This proposed model allows and justifies the use of fast pyrolysis in its best scale.

The gasification system can be easily pressurized and so oxygen can be use instead of using atmospheric air, so this is the main advantage on gasify the bio-oil. This method produces high quality synthesis gas because it avoids its dilution on nitrogen of the atmospheric air and results in high concentrations of two components of synthesis gas, the hydrogen and the carbon monoxide. In addition, the pressure to obtain the synthesis gas, when elevated, aids the following step of catalytic synthesis that needs the synthesis gas on high pressures, in the range from 50 to 100 atm.

BOTTLENECKS IN THE TRANSFORMATION STEPS OF BIOMASS PYROLYSIS

The biomass to be the raw material in the process of fast pyrolysis must fulfill the requirements of particle size uniformity and water content. The first step is to deal with the logistics for the packaging of polydispersed biomass. Brazil, a particularly strong agricultural country, annually produces about 300 million tons of agricultural and agro industrial residues. However, only a small part is used as energy source, as these residues have poor energetic features (low density, low calorific power and high moisture), and then results in higher costs during transportation, handling and storage. In other words, the logistics for whole use of this residue *in natura* can be extremely expensive.

What is named as pretreatment of the biomass for the thermo-chemical conversion may be an industrial facility as big and expensive as the main process. To think about all the production stages of a biofuel is a task that can vary considerably depending on the kind of raw material and fuel that is intended to obtain.

All the productive chain of the biomass production has several operation units (collection, transportation, packaging, processing) that can make impracticable its use due to the high production costs. Thus, a forest raw material will have a different flowchart from the agricultural origins raw materials (straw, corn stalk, cassava stalk etc.), agro industrial (sugarcane bagasse, filter cakes etc.), livestock (manure, suet, poultry litter etc.), aquatic biomass (marine of freshwater) or urban waste (trees pruning, mud from sewer, organic waste). Besides, there are three types of fuel: solids, liquids and gases. And for each one of them these operations have a great variation.

The solid state is the most current type that the biofuels are found, have problems concerning the form diversity and particles size, high moisture and low energy density. The liquid state (vegetable oil, alcohols, biodiesel, bio-oil etc.), is the most practical way of biofuels, making easier its handling and the logistics. The gases, biogas, landfill

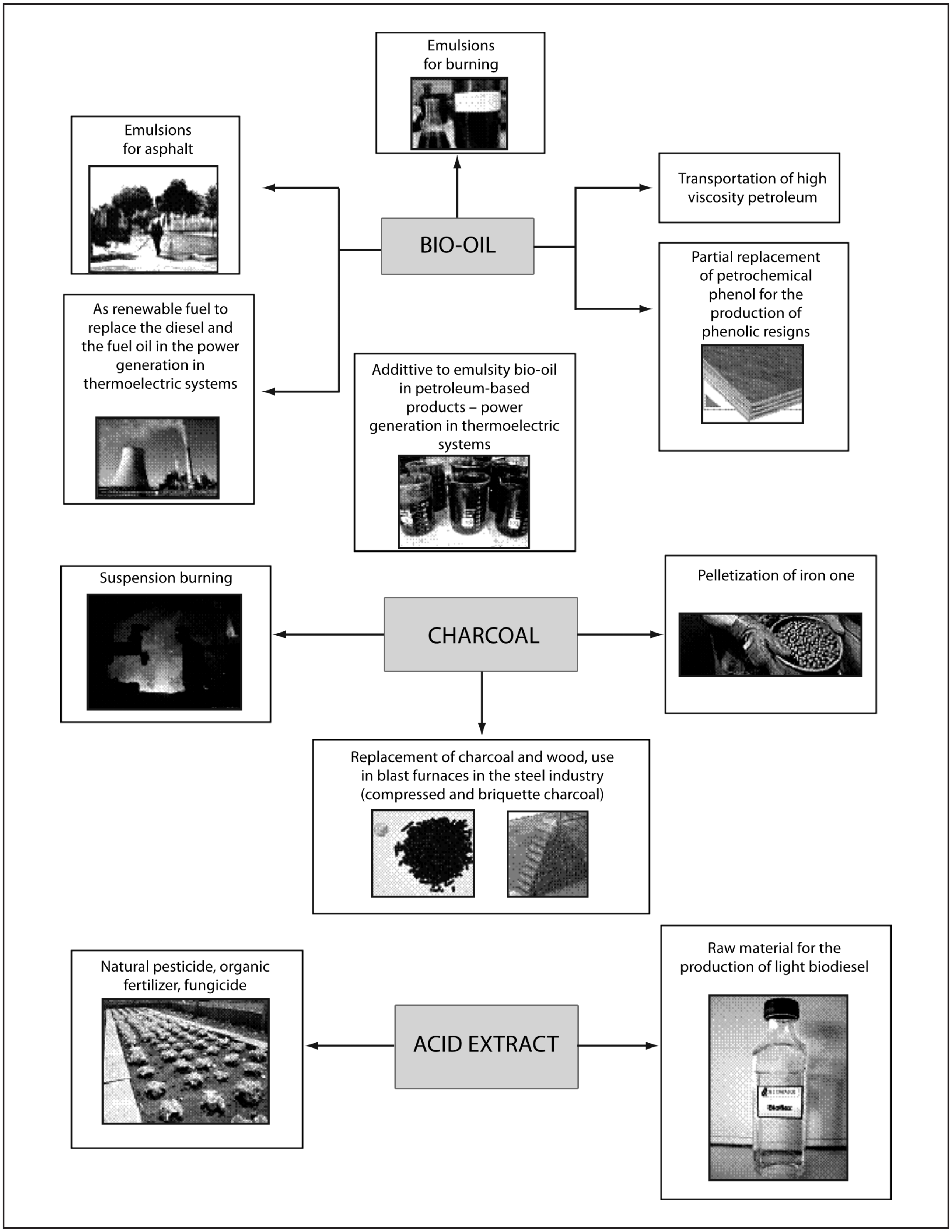

FIGURE 4 Fast pyrolysis products and its potential applications.

gas and mud from sewer gas, besides synthesis gas, usually cannot be transported in long distances and should be used locally.

The bioenergy logic is very different from the logic of fossil energy. The bioenergy is linked to the concept of distributed generation and to small and middle scale plants because the fossile fuels, that is, the non renewable energy, the generation/production is better centralized and is in a big scale. The mining stages (sourcing and exploring) of non renewable fuels are replaced by the agriculture stages in bioenergy and in agro energy. Generally, the biofuels are composed by oxygenated compounds without sulfur and the fossils are hydrocarbons (C and H) and have sulfur as one of its main heteroatom. The presence of oxygen in the biofuels reduce its calorific power, however it grants a better burning quality, because already have intramolecular oxygen.

LOGISTICS

Biomass is logistics. A new biofuel/bioenergy production unit should carefully consider the availability of raw material in its coverage radius so that there is some savings in the process to be implemented. The way between the field of agricultural production and the area of raw material reception in the industrial plant must have a distance that does not charge the final cost of the biofuel/bioenergy above the acceptable level. The production cost depends on the case in study. The coverage radius of the sugarcane industry (for each manufacturing plant) is well-defined, the same way, the energy forests know its transportation costs.

STORAGE

Immediately after the harvest, the biomass goes to the storage, or alternatively, goes to processing that will originate a residue or co-product that shall be appropriately stored.

The storage stage can really be critical in the stage of the biomass pretreatment for the energy, it must be adequate to ensure the constant supply, avoid changes in the fundamental features of the raw material (decay, deterioration etc.) and allow, for instance, the loss of the needed moisture naturally.

Therefore, the residue must be treated as raw materials to avoid that during the handling occurs the incorporation of inorganic materials (land, stones etc.) that are unfavorable elements in any process of pre and post treatment. Essentially, in the case of planting of energy crops, as the case of the elephant grass, there is the need to face all agricultural process as a pretreatment of biomass not only about production yield by hectare (productivity), but also about the composition of the contents like: cellulose, hemicelluloses, lignin and ashes to assess its actual energetic potential in a specific technology.

DRYING

Biomass drying needs to be avoided or made in a natural way in the cases that the biomass is a residue normally spread. An example of this is the sugarcane trash that is dried in 3 days on its own land where it has been cut and transported in the form of bundles to the factory. In biomass packaging is the low production cost and to save as much of its primary energy that is important.

The appropriate storage can help in the loss of initial biomass moisture. Many processes usually have exceeding heat energy that can be used for drying. This is an advantage in plants attached to an existing manufacturing plant.

There are processes that take place in aqueous means, as the case of the biotechnological processes: fermentation, biodigestion etc., however for the thermal processes is important to have the dry biofuel or compatible moisture varying between 8% and 15%, and for that, energy is required. Although in Brazil the sugarcane industry is gradually specializing in the direct bagasse burning with high moisture, other processes of thermo-chemical conversion like the fast pyrolysis and the gasification usually work with biomass with low moisture.

The availability of dryers in the Brazilian market is quite large. The equipment is dimensioned with capacities that vary from less than a ton to several tons per hour. These technologies are rotating bed, transportable bed, cyclonic bed, fluidized bed and even permanent bed (for wood), usually provided by several manufacturers.

HOMOGENIZATION

This stage comprises the following operations: picking, milling and sifting. These unit operations are used for the reduction and the standardization of the particles sizes. The fast pyrolysis demands the homogeneity of the particles and the control over the size distribution is necessary and critical, ensuring a strict range of sizes. The equipment like wood picking, ball, knife and hammer mills and vibrating sieve system are all equipment available in the Brazilian market with performance warranty of the manufactures.

FAST PYROLYSIS

Finally, the fast pyrolysis of the biomass to obtain bio-oil is the stage of transformation of the solid and low density biomass in a renewable combustible in the liquid state.

There is much debate and controversies around the plant scalability of fast pyrolysis of biomass. The Canadian companies use several technologies with high capacities installed, from 100 to 200 tons of biomass a day. However, these scales do not have a lot of success due to the complexity of the plants. In Brazil, the studies reached the scale of 200 kg/h and the plant from 20 to 40 tons a day is possible to work satisfactorily. This scale is already designed; it is necessary investments for its construction as fundamental step of "scale up".

The great technological difficulties involved in the "scale up" are linked to the fluid dynamics of the reactor of fluidized bed that is complicated. Stable operations of the reactor (this is, pressure profile and temperature along the reactor in immobile regime) are only possible if the blend of the inert material and the biomass are appropriate. Located problems of temperature rise, sintering, gas leak are common when the fluid dynamic of the bed is not dominated. The increased scale, a situation equivalent to the increasing of the diameter of the reactor has the inconvenient in which the feeding point does not ensure the homogeneous blend of the biomass along the perimeter of the diameter of the bed. To put distributed feeding points may help to solve the problem, however the economical and financial aspects in the implementation of this solutions must be evaluated with caution. Parallelly use reactors may be a less risky practice.

Another technological bottleneck is the recovery of bio-oil which is accomplished by Canadian technologies that use electrostatic precipitators. The biomass transformation technology must be robust and easy to operate. The use of expensive equipment although efficient is not always viable when the subject is biomass. In Brazil there is a technology of centrifugal separators that, although operates with less productivity is robust and cheaper. We can say the same thing about the expensive pneumatic biomass feeding systems that in Brazil are replaced by screw feeders.

Pyrolysis occurs in atmospheric pressure and moderate temperatures (between 450 °C and 500 °C), so, it is created operational conditions that make easier the construction and operation of the plants. Another variable is the residence time that must be short so that the vapors do not suffer intense cracking and the unwanted gasification of the bio-oil still in the vapor phase occurs, negatively affecting the productivity of this main fraction.

Considering that it is safe to reach a feeding rate up to two tons per hour (24 tons per day). A possible scenario is to produce the bio-oil in a decentralized and distributed way and to concentrate all production to be processed in a big gasifier, using oxygen and high pressures; this could be a beneficial arrangement.

Inside these operations of pretreatment, the use of energy (energy balance) and the water consumption (mass balance) for the preparations of the vegetal materials must also be considered, searching for the rational use and the energetic efficiency of the processes.

This arrangement can make viable the technology of fast pyrolysis of biomass in Brazil with the benefit of having a great availability of raw material and competitive costs.

A common strategy to create the consumer market of an innovative product consists in the search of partnerships with the final consumer and the performing of market tests with the products derived from the technology. The partnership University-Company is essential in this stage.

INVESTMENTS IN COMMERCIAL DEMONSTRATIVE PLANTS

The technological necks associated with the change of scale can only be completely solved if resources are dedicated for the implementation of plants of demonstrative pyrolysis (500 to 1000 kg/h of biomass feeding). The scale change is also an innovation and a necessity to put the technology in the market and demonstrate its commercial viability. The investments in these stages contributed to the introduction of this technology in the short-term market by means of the production of samples and adequacy of the pyrolysis products in the consumer market. The technical-economic viability has already been demonstrated and the increasing of scale will prove commercial viability of the technology of fast pyrolysis in fluidized bed.

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15

BTL TECHNOLOGIES

Ademar Hakuo Ushima

INTRODUCTION

The energy content of the main residues generated in the Brazilian ethanol and sugar mills, bagasse, trash and vinasse, are currently been wasted or used inefficiently and presents a huge economic potential for the production of fuels, power and products of higher value-added like chemicals products by using BTL technology – Biomass to Liquids. At the same time this technology can contribute to the solution of serious environmental problems, such as those caused by burnt trash in the field and contamination of the water table by vinasse dispersion in the soil.

In addition, the employment of biomass as power and energy supply does not compete with food production as the first generation technology does, based on production of ethanol or biodiesel from sugar, starch and vegetable oils, and does not stimulate agricultural area expansion in the country.

DESCRIPTION OF BTL TECHNOLOGY

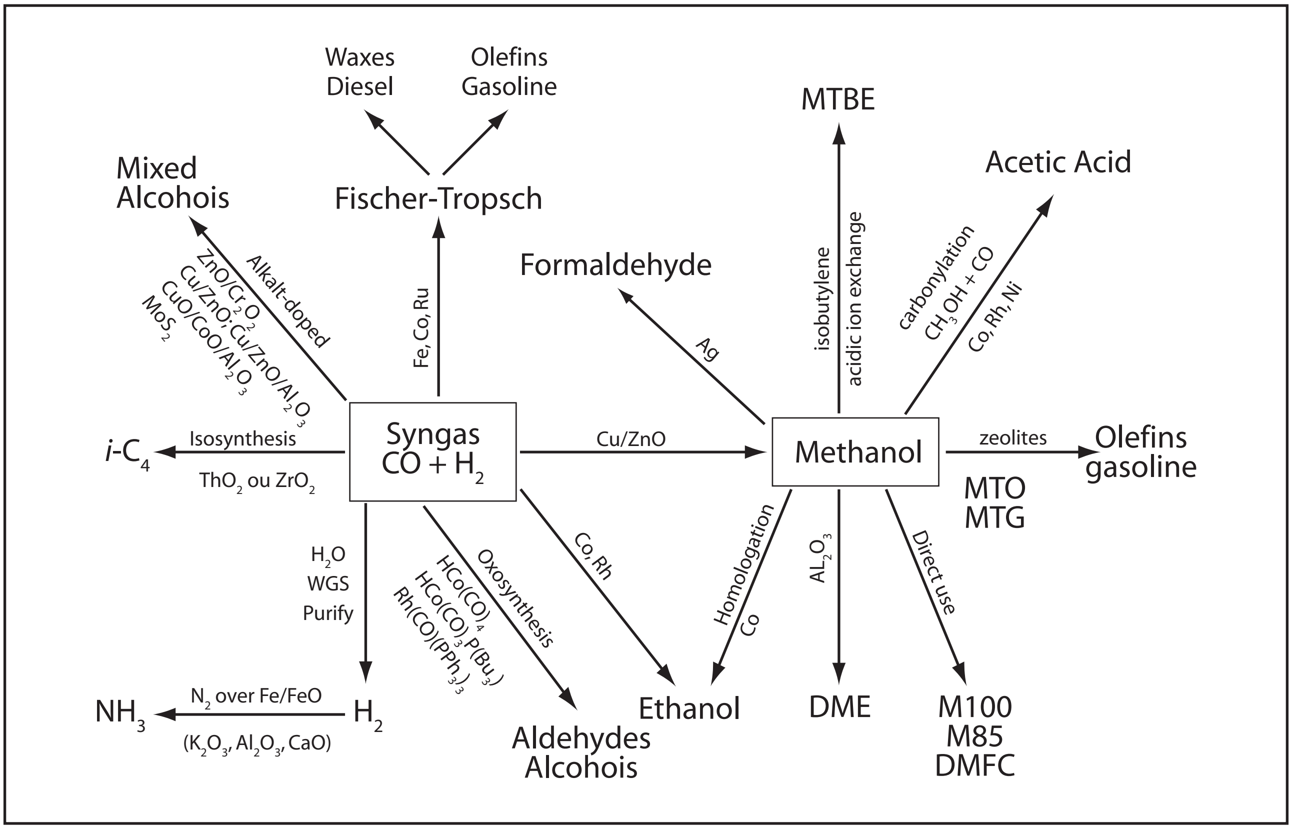
BTL technology, briefly, is the conversion of biomass into synthesis gas (gas with high concentration of CO and H_2), followed by conversion of the gas into liquid chemicals products via catalytic reactors. It is one of the main technological routes currently in development in the world for the utilization of the solar energy accumulated in the biomass, also called second generation technologies, able to convert the current sugar and ethanol mills/distilleries into petrochemicals refineries equivalent units, also known as biorefinaries.

Comparatively to biomass enzymatic hydrolysis technology, BTL technology offers the advantage to use all the components of biomass (lignin, cellulose and hemi-cellulose), and not only a fraction of it, as is the case of enzymatic route that can convert only cellulose into liquid fuels. It can also be a supplementary to the enzymatic route, converting fractions of lignin and hemi-cellulose into gaseous fuels or power.

CTL technology – coal to liquids, equivalent to the BTL in the carbochemical sector, uses coal or petrochemical wastes for the generation of synthetic gas, and is already commercial, with several units in operation or under construction in world, especially in South Africa, China, Europe and USA. The consumption of mineral coal in the US in 2007, only for the production of chemicals via gasification, reached 30.8 million t (DOE/EIA-0121-2008/01Q). In Brazil a fertilizer industry (450 MW_{th}), located in Araucaria city, Paraná, is producing ammonia from the gasification of asphaltic residue (RASF) with oxygen since 1983. RASF consumption unit is 1,000 t/d and ammonia production is 1,300 t/d.

Some of the products which can be obtained through BTL technology are presented in Figure 1. As can be seen, the range of products is very extensive, extrapolating liquid and gaseous fuel production.

Among the fuels that can be generated from BTL technology it can be highlight methanol, ethanol, gasoline, diesel oil, dimethyl ether – DME, hydrogen etc., all of them, with the exception of



Source: NREL/TP-510-34929, dec. 2003.

FIGURE 1 Products that can be obtained from synthesis gas.

ethanol, presently obtained in large scale from fossil fuels.

A chemical with great potential generation from biomass and of great economic importance in Brazil is ammonia (NH_3), consumed in large scale as fertilizer. It is obtained currently from fossil fuels (NG and petrochemicals waste) and a large part of the Brazilian consumption is imported, largely used in sugarcane cultivation.

A generic flowchart of BTL process is presented in Figure 2. Biomass, with humidity around 10% m. b., is gasified with oxygen in a pressurized gasifier, generating synthesis gas. The oxygen is often used in place of air due to the higher temperatures attained in the gasifier, which leads to an increased conversion rate of biomass into gas and lower tar content. Another important factor is that the nitrogen of the air generally acts as an inert agent in the synthesis reactor increasing the flow of gas in the reactors, power consumption and investment in equipment.

The gas generated in the gasifier must be cooled and cleaned before being sent to a catalytic reactor. Depending on the type of gasifier used (co-current, counter current, fluidized and entrained bed) the exit temperatures of gases and the levels of contaminants can vary significantly (150 °C to 1,400 °C and 1 to 100 g/Nm^3, respectively) as well the heat recovery and gas cleaning systems. In most of the gasification process gas leaves at high temperatures and its enthalpy can be used to generate steam, before its cleaning, which can be dry or wet. In the gas cleaning operation particulate material, tars and ammonia present in the gas must be removed and the water contaminated with them must be treated before their remanufacturing or disposal of.

In biomass gasification with oxygen, the molar ratio H_2/CO is usually just below 1 and for catalytic synthesis processes, depending on the product this relationship has to be higher. For example, in the case of methanol or aliphatic hydrocarbon production, the relationship must be slightly above 2. To do this, after gasification, usually it is introduced a catalytic conversion of CO to H_2, called "shift".

In the "shift" reactor CO reacts with steam, generating H_2 and CO_2 that is removed from the gas by acid gas absorption via regenerative solutions as mono and diethanolamine compounds, potassium hydroxide, methanol at too low temperatures etc. In these systems can also occur separation of other contaminants as H_2S, COS, H_2O and hydrocarbons larger that methane. The elimination of these contaminants from synthesis gas is important because they cause the deactivation of catalytic converters and the levels permitted usually fall below 1 ppmv. The regeneration process of the absorbing solutions, which involves heating and decompression, usually demands significant quantities of energy, and in the evaluation of the process economical viabilities it must be considered.

Clean synthesis gas usually needs an additional compression step, since the synthesis reactors operates at pressures higher that can be achieved in gaseifiers, ranging from 60 to 100 bar.

The compressed gas is sent to a catalytic reactor where it is converted in product and by-products. The rate of conversion of the gas in the reactor never is complete, typically rated at 35%, which obliges the recycling of gases that is not converted. As some components of synthesis gas present in smaller quantities, such as CH_4 and N_2, act as inert in catalytic reactors synthesis, there is the need to promote a system purge of these gases, to avoid its accumulation in the internal circuit. To minimize the exhaust of reagent gases (mainly H_2) with the purge gas, PSA units (Pressure Swing

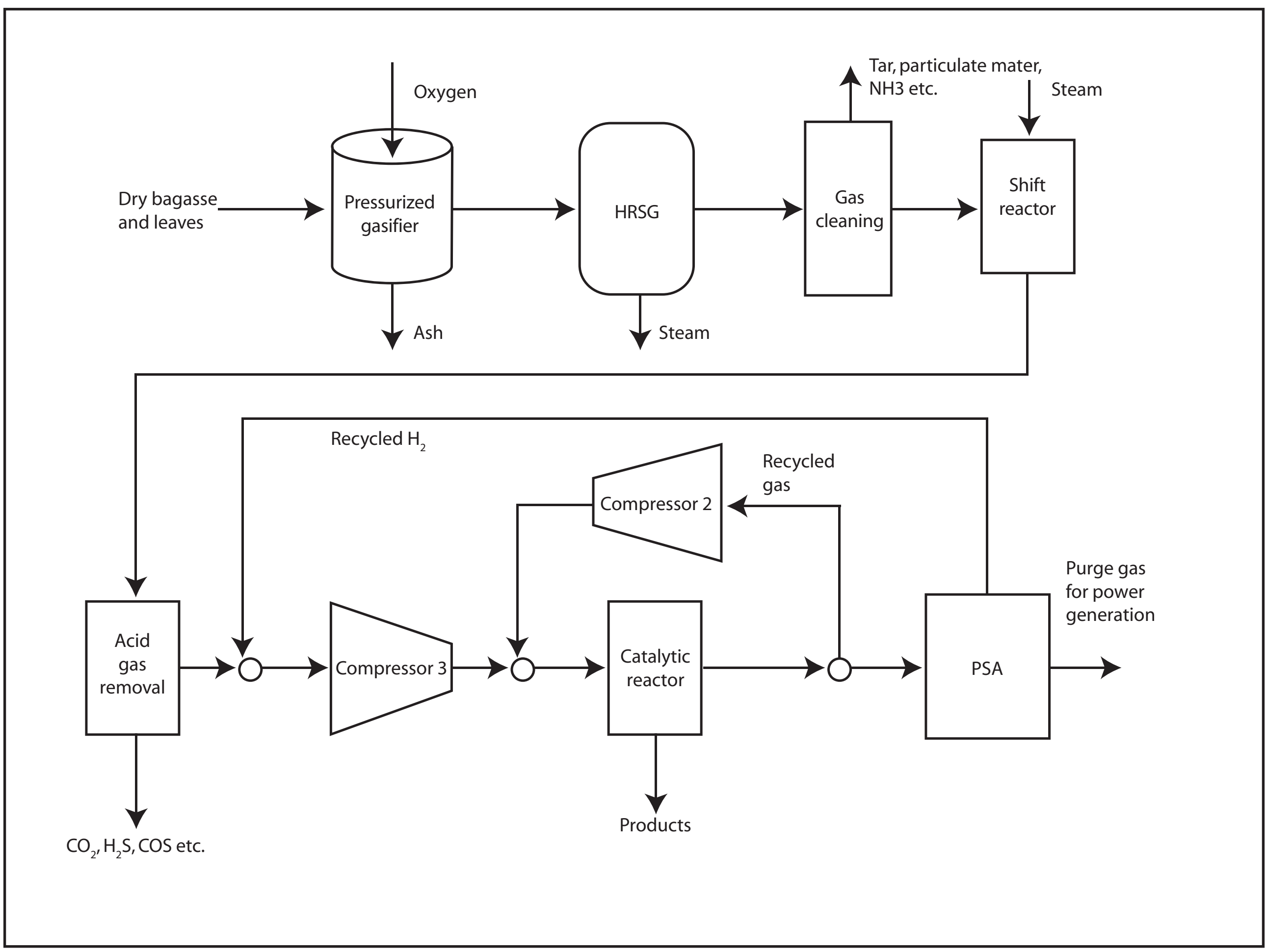


FIGURE 2 Generic flowchart of BTL process.

Adsorption), based on difference of diffusivity in porous media, promotes the remaining hydrogen separation of the gases, which is recycled to the process, as shown in Figure 2. The purge gas still contains high levels of fuel gases, such as CO and CH_4, and can be burned for steam generation and electrical power generation via Rankine cycle or gas turbines.

The product of the catalytic reactor is a mixture of components and often must pass by separation processes, typically distillation, for purification of the liquid fuel or chemical product.

In some situations in which electric energy presents higher profitability than liquid fuels (e.g. peak hours), the generation of synthetic products can be reduced and of electrical energy increased, simply reducing the recycle of gas in the compressor 2 and increasing the purge gas flow in the scheme presented at Figure 2. A similar situation already occurs in the Brazilian sugarcane mills, which can vary the production of sugar and ethanol, depending on their profitability.

An alternative route to the catalytic synthesis is the biological synthesis using bacteria cultures (generally Clostridium Ljungdahlii, as KASTEREN *et al.*, 2005) able to synthesize liquid ethanol from synthesis gas. The advantages of this process is to enable the use of biomass gasification at pressures slightly above the atmospheric, air as gasification agent (since bacteria are not inhibited by the presence of nitrogen in the air) and the bacteria is tolerant to the presence of small quantities of contaminants in the gases, as tars. One of the main limitations of this process is the low solubility of H_2 and CO in water and low ethanol concentration in the solution.

STAGE OF BTL TECHNOLOGY IN THE WORLD AND IN BRAZIL

At moment there is no unity in the world producing liquid fuel from biomass in commercial scale via BTL route, but several pilot scale and demonstration units are in development.

One that is in the most advanced stage is CHOREN, located at Freiberg, Germany, was inaugurated in June 2008. That is a demonstration unit, with design capacity to process 68 000 t/year of dry wood chips and produce 18 million l/year of liquid fuel, that 21% of the total is diesel oil, should be operational in mid Jun 2010. The gasification system, developed initially in pilot scale, is composed of two stages. In the first, biomass is pyrolysed in a reactor at 400 °C to 500 °C, generating a stream of gases and vapors and other of charcoal. The gaseous phase is sent to a second reactor in which reacts with oxygen, reaching high temperatures and where tars are converted in gaseous components. The solid phase, after milling, enters in contact with the gases at high temperature in the middle of the second reactor region, suffering gasification and cooling the gases. The synthesis gas formed is passed through a heat recovery system for steam generation, a filter to remove the particulate matter entrained, a shift reactor to set the molar ratio of H_2/CO around 2, an acid gas absorber and a catalytic reactor, very similar to the flowchart shown in Figure 2. The unit of gasification described can also be used for fuel gas and electricity generation with, in this case, the replacement of oxygen by air. This development began in 1998 and the diesel oil generated at the pilot-scale unit was free of sulfur and aromatic compounds and presented high cetane number.

Another one in an advanced-stage development is CHEMREC, maintained by a Swedish consortium, consisting of black liquor gasification, a waste generated in the cellulose production, in place of biomass, with oxygen. Because black liquor is liquid, it dramatically simplifies the feeding system to pressurized gasifiers, eliminating one of the bottlenecks of biomass gasification. Black liquor gasifier is pressurized and of entrained flow type, similar to those used commercially in petrochemical refineries for petrochemical wastes gasification, with internal coatings resistant to chemical attack of reagents present in the black liquor. The gasifier also enables the recovery of the reagents, similar to the recovery boilers used presently in cellulose factories for steam generation. Once cooled and cleaned, the synthesis gas generated can be used for the production of liquid fuels or chemicals through routes already presented. In September 2008 the construction of a DME production unit with a capacity of 5 t/d was started and that will use the synthesis gas generated at a black liquor gasifier installed in Pitea, Sweden, with financial resources of order 28.4 M € (CHEMREC Press Release 08.Sept.09).

DME is a fuel that can replace diesel oil in diesel engines with minor modifications, and presents a high cetane number with very low emissions of air pollutants. It is not toxic and can even replace LPG in a proportion of up to 20% in LPG barrels used for domestic purposes. In addition, several direct production units of DME from synthesis gases has already been proven in demonstration scale, with high efficiency and reliability (OHNO *et al*., 2007; HEYDORNn *et al*., 2003). In these units, the molar ratio of H_2/CO required in the reactor entry was around 1, near the ratio obtained in biomass gasifiers employing oxygen, which can make unnecessary the "shift" reactor presented in Figure 2, reducing the investment and operational cost.

A third developing project that deserves highlight is of the National Renewable Energy Laboratory – NREL, of USA. The pilot scale gasifier is designed for wood chips with low humidity, and gasification with indirect heating and catalytic reform of tars formed, as described in PHILIPIS *et al*. (2007). The advantage of this process is that it doesn't need an air separation unit – ASU, which can reduce significantly its investment and operational cost. The biomass heating and gasification occur in a bubbling fluidized bed sustained by heated steam, through the contact of biomass with the bed at around 850 °C, composed mainly of olivine (magnesium silicate and iron). The olivine is heated in an attached fluidized bed reactor, trough the combustion of the charcoal formed in the gasifier, with air. The olivine is maintained in circulation between the two fluidized beds and gases generated in the gasifier go through a fines collection system, and are sent after to a catalytic bed, indirectly heated to promote the reform of hydrocarbons present in the gases such as methane, ethylene, aromatic compounds etc. After the gas cleaning and the removal of all contaminants still present, the synthesis gas will be compressed and converted primarily to ethanol, in catalytic reactors with di-molybdenum sulfide (MoS_2).This catalyst has a number of advantages as greater selectivity for ethanol, more tolerance to the presence of H_2S and CO_2 than other catalysts and be able to promote the "shift" of CO to H_2, allowing the use of synthesis gas with a molar ratio H_2/CO near 1.

Brief information about other demonstration units using BTL technologies and their development stages, is presented in Table 1.

In Brazil some research institutes, universities and private companies have been developing biomass gasifiers, targeting mainly fuel gas production and not synthesis gas. To date, only IPT (Institute for Technological Research) has developed biomass gasifiers in pilot scale for synthesis gas generation using oxygen and steam as gasification agent, at pressures slightly higher than atmospheric pressures, as described in USHIMA (2008). From 1999 to 2004 tests for synthesis gas production were conducted in a bubbling fluidized bed, using sugarcane bagasse pellets, and a co-current gasifier employing eucalyptus pellets. The capacity of both gasifiers was around 100 kg pellets/h.

TABLE 1 Others project under development in the world using BTL technology.

Company	Biomass consumption (t/d)	Produced fuel	Capacity	Investment (10^6 US$)	Technology	Country
Range Fuels	1200	Ethanol	38.10^6 l/y	76	Indirect heating	USA
Alico, Inc.	700	Ethanol	27.10^6 l/y	33	Síntese biológica	USA
Enerkem	~45	Ethanol	5.10^6 l/y	***	Biological synthesis	Canada
Chrisgas	~86	Hydrogen	3,500 N, 3/h	~22	Entrained flow gasifier	Sweden

TECHNICAL AND ECONOMICAL FEASIBILITY STUDIES

Due to escalation of petroleum prices, the aggravation of global warming and growing concern with the energy dependency, various studies on technical and economic feasibility of BTL technologies have been submitted, as developed by HAMELINCK *et al*. (2002 and 2003), SPATH and DAUTON (2003) and EKBOM *et al*. (2005).

Because the current development stage of BTL technologies and the lack of a full demonstration-scale unit operation (from biomass treatment to liquid fuel produced), most feasibility studies cited are based only on a series of estimates costs and performance, mainly of equipments in development stages, as pressurized biomass feeding systems, pressurized gasifiers, gas cleaning systems and catalytic reactors.

Any case, in all of them, the required investment cost is the most significant and the factors impacting the fuel cost produced via BTL route were investment rate (40% to 60%) and biomass cost (around 30%) that in Brazil, by being one of the smallest of the World (~1.7 US$/GJ), can represent a huge differential for the deployment of this technology.

The majority of the previous studies cited – before to petroleum price peak in mid 2008 – indicates that the cost of liquid fuels obtained via BTL technology will be greater than that of equivalent fossils fuels, without taking into account the environmental benefits generated, and will be economically viable only with tax exemption.

R&D NEEDS FOR BTL TECHNOLOGY

Despite of the high cost of BTL technology development and the large fluctuations of petroleum and its derivates prices in recent times, there have been significant advances in the BTL technologies development abroad, as reported previously.

In Brazil, however, despite of the enormous potential of biomass generation with low cost (mainly sugarcane bagasse and trash), has done little progress on BTL technology development, as was evidenced in the BTL Workshop held in Institute for Technological Research – IPT, São Paulo, in February 2008.

The need for training a larger number of researchers in this area through scholarships and technical exchange with outside research centers was highlighted as very important in the Workshop. The settlement of fund lines to finance the cooperation with international institutions in gasification also should be fetched.

With the shortage of researchers in this area, dispersion of efforts and a great number of low cost minor works, it has not been possible get advances in this route and offer alternatives to the market.

Another scrappy factor for the development of BTL technology in Brazil, raised in the debate, was intellectual property. The private sector, in general, doesn't has enough resources or lacks sufficient degree of confidence to perform the investments (million US$) required for the development of the BTL technology production chain. In this way, Brazilian industrial sector has only invested in the development of some of the chain links, in isolated and disorganized form, along with universities and research centers, which has hampered and even prevented the exchange of experiences of these centers and universities, on behalf of the industrial property issue. This way may also explain the occurrence of redundancy in various universities and research centers.

In the BTL technology route, many gaps have been identified, since the misunderstanding of important properties of biomass till applied technologies at the end of the production chain of liquid fuels.

As example, in the pretreatment of sugarcane bagasse and trash, the first used intensively for decades, some of their basic properties is unknown, such as the internal structure and composition of fibers, the difference between the structure of sugarcane bagasse and trash from other biomass as eucalyptus etc, that are essential for their recalcitrance reduction, which can enable their direct utilization as solid fuel or as raw material for the second generation technologies, as gasification or hydrolysis. Researches in the pretreatment of biomass, mainly sugarcane bagasse and trash, are very important for the development of industrial processes like combustion, gasification, pellet production, slow and fast pyrolysis (with bio-oil generation), acidic and enzymatic hydrolysis, focusing in the recalcitrance reduction of these materials and equipments wearing.

In the development of biomass feeding systems to pressurized reactors it was found that, for biomass with high densities and granular form (pellets, briquettes, chips) these systems already exist, simply adapting the existing systems for coal. For biomass of low density, as is the case of sugarcane bagasse and trash, it will be necessary to develop equipments capable of maintaining a regular feeding into pressurized environments. Abroad there is some equipment in the development stage, such as solid pump, that must be tested with sugarcane bagasse and trash.

For the development of biomass gasification systems, it must be necessary to provide funding lines for the development of atmospheric and pressurized circulating fluidized bed – CFD and gasifiers with separated pyrolysis and gasification stages, to increase the participation of new researchers in the projects, to arrange events and summer schools specialized in this subject (RENEW and SYNBIOS), to construct pilot scale plants for long-term tests (more than 1,000 h) and technical feasibility proof, and after that the building of a demonstration unit, always seeking the partnership of universities, research centers, governmental funding agencies and private companies.

In the gas treatment step, apparently the difficulty is more in the definition of synthesis gas composition and contaminants present in it, that depends on the biomass and gasification processes adopted, than in the existence of gas cleaning technologies. These systems are already in commercial scale for the treatment of synthesis gas generated from coal, natural gas and petrochemical wastes, and can be adapted for gases generated from biomass. Hot gas cleanup technology is not in commercial scale yet but it can't be necessary, as in cases where wet gas cleaning systems can be adopted. The gas processing industries only will invest in the definition and construction of a specific biomass synthesis gas treatment system when they will have a definition of its composition and contaminants.

In the development of gas catalytic synthesis very little has been done in Brazil. Specific catalysts for the production of ethanol, as has been developed in NREL, and even in commercial scale units for the production of methanol, paraffin etc. must be investigated and developed, in order to build pilot-scale reactors and connect then to biomass gasifiers, enabling the development and performance evaluation of all of the BTL process, not only of isolated parts, as has been done until now.

METHANOL PRODUCTION POTENTIAL IN A STANDARD SUGAR AND ETHANOL MILL BY USING BTL TECHNOLOGY

Most of the Brazilian sugar and ethanol mills present very low energy efficiency. In Figure 3 it is showed the energy framework of a typical sugar and ethanol mill, processing 1,3 million of sugarcane t/a, with a specific steam consumption of 530 kg/t sugarcane, as described in HASSUANI *et al.* (2005).

The energy content of 1 t. sugarcane is equivalent to 0.16 t. of petroleum – TEP and from this mass of sugarcane it has been produced sugar, ethanol and a surplus of bagasse in the quantities indicated in Figure 3. The trash, in general, is being burnt or left in the field, without any improvement of its energy content. The surplus of sugarcane bagasse generated at the mill has been commercialized, mostly as fuel, with improvement of its energy content.

In this way, the energy improvement of this mill has been only 21% of the sugarcane energy content. After its energy optimization, with the installation of equipments with higher energy efficiency like ethanol distillation and sugar concentration units already existing on the market, the mill steam specific consumption can be reduced to only 340 kg/t. sugarcane, as cited in HASSUANI *et al.* (2005). The mill's energy balance, in this new condition, is presented in Figure 4.

In this new situation there is an elevation of the bagasse surplus and 50% of the trash is

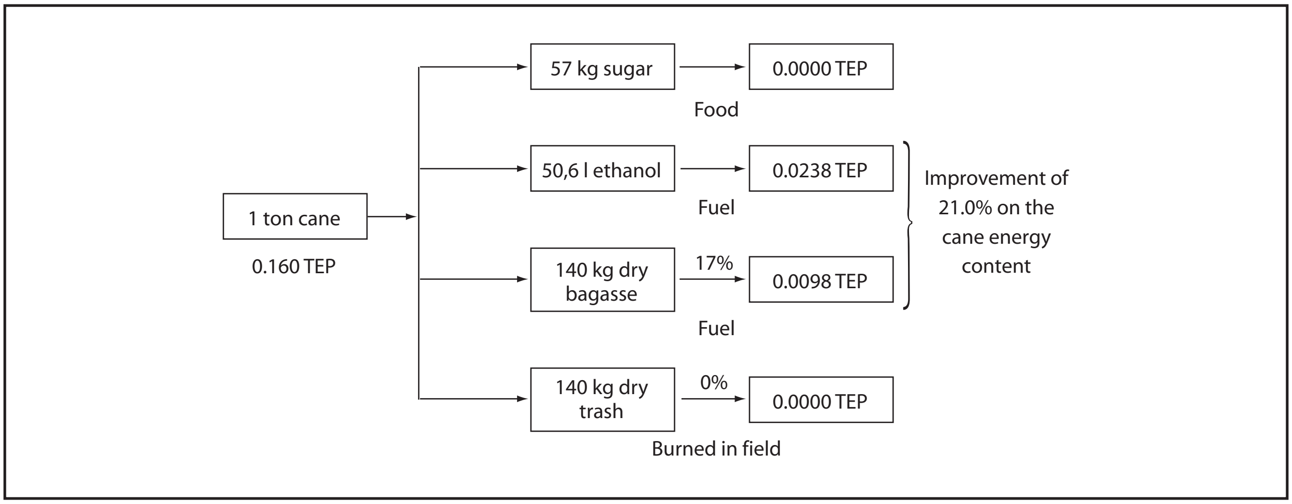


FIGURE 3 Energy improvement of a Brazilian standard sugar and ethanol mill.

brought from the field along with the sugarcane, and separated at the mill. The other half of trash is left in the field for soil protection and weeds control. In this frame, part of the organic material presented in the vinasse is converted to biogas for its energy improvement. After the mill's energy optimization, the potential energy improvement of the mill can reach 50.6%, without any change of sugar and ethanol production capacity.

With the installation of a BTL unit in this optimized mill, the bagasse surplus and trash brought from the field can be converted to methanol, as shown in Figure 5.

The conversion data of biomass to methanol presented in this Figure is based on gas composition and yields obtained on experimental biomass gasification tests performed at IPT (USHIMA, 2008) and on yields of demonstration catalytic reactors (HEYDORN, 2003).

From the gasification of the sugarcane bagasse surplus and the trash brought from the field, it can be produced 58.2 kg of methanol per ton of

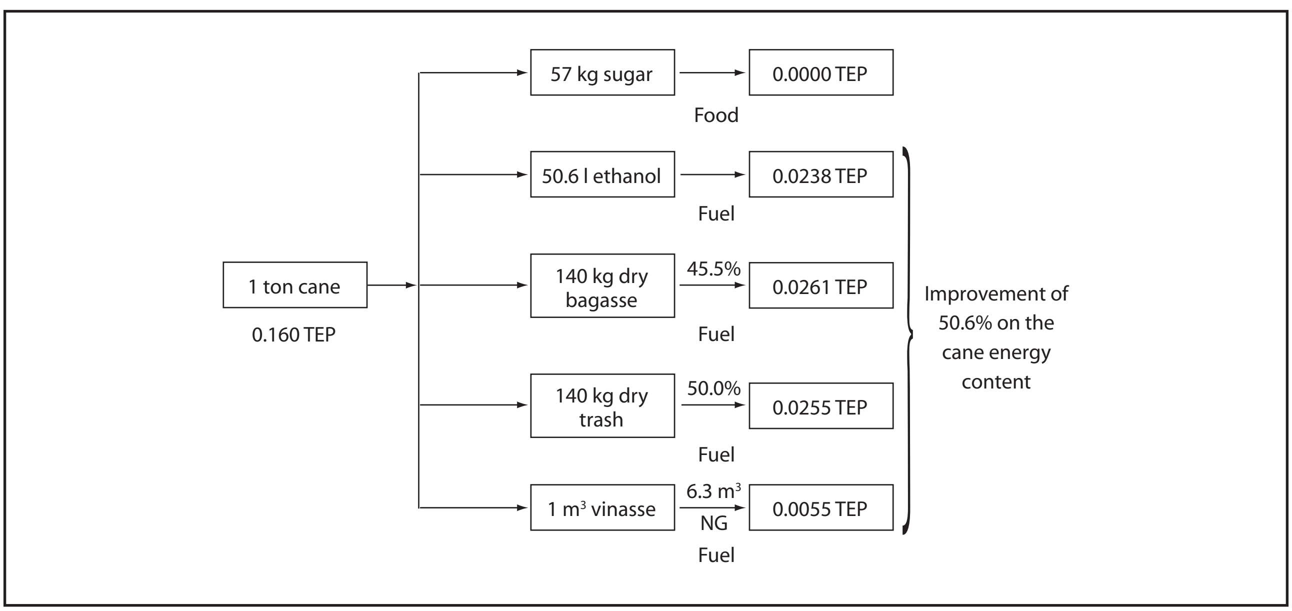


FIGURE 4 Energy profile of the standard mill after its energy optimization.

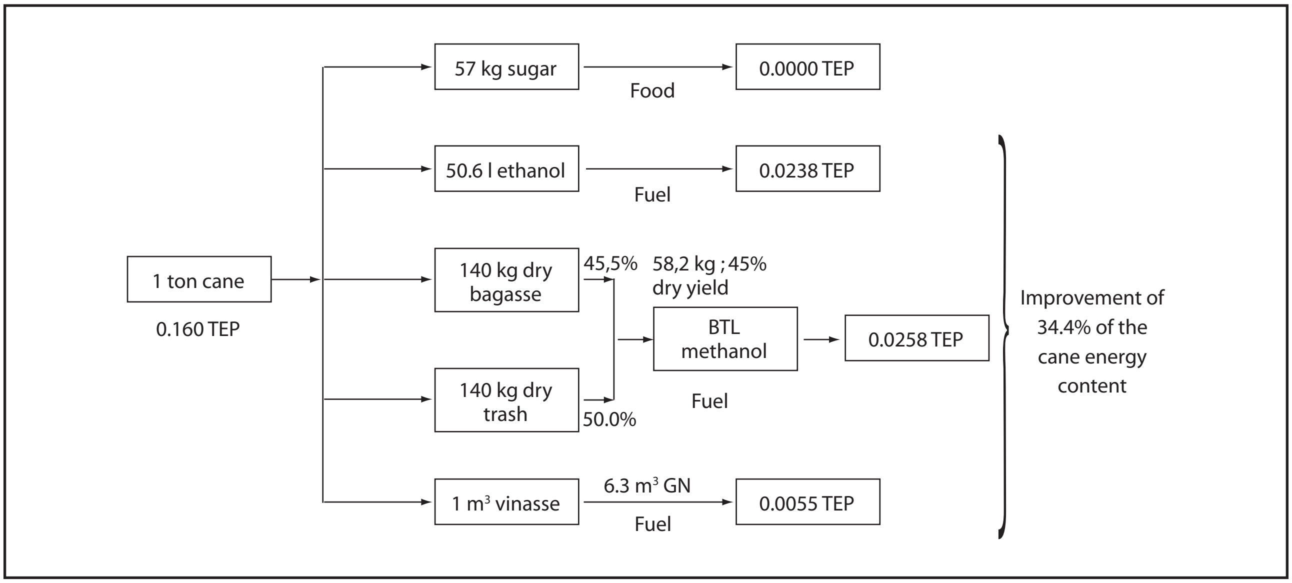


FIGURE 5 Mill's situation after energy optimization and BTL technology implantation for methanol production.

sugarcane, whose energy content is just a little bit more than of the ethanol produced from the sugar fermentation, i.e., it can be possible to double the net fuel production without the need to extend the planted area of sugarcane, only employing the biomass surplus currently wasted. In this evaluation, all energy inputs required for biomass treatment, gasification, gas cleaning, compression and synthesis were considered.

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ENERGY CANE

Manoel Regis Lima Verde Leal

INTRODUCTION

Sugarcane has been developed and cultivated in different parts of the world, through the centuries, always as a source of food with sugar evolving from an expensive spice to become the cheapest source of food calorie. Its basic components, sugars and fibers, are treated quite differently in breeding programs in the world: the sugar components are valued in the selections of cultivars while the fibers of the cane stalk is limited, because of their effect on performance of mills and diffusers dragging sugars in the bagasse, the fiber of straw (leaves and tops) are not even evaluated. In the processing of sugarcane, sugar is the main product and ethanol and surplus electricity are by-products.

In Brazil, this concept of the food industry for sugarcane has been slowly driven by the growing commercial importance of ethanol and, more recently, electricity. Ethanol has been produced consistently in Brazilian plants for more than a century, when it began to be part of the fuel options for the newly introduced car using the Otto cycle engines. Since the 1920s the National Institute of Technology (INT) has worked systematically to develop the technology of the Otto cycle engines operating on ethanol; the interest of the Brazilian Government at this time was to find an alternative to over-production of sugarcane, which constantly depressed sugar prices. Thus, in 1931 the requirement was instituted to blend 5% ethanol in all imported gasoline consumed in the country. This requirement was extended to all gasoline consumed in Brazil from 1938.

However, it was only after the launching of National Alcohol Program – Proalcool in November 1975, that ethanol reached the status of the main product of the mills, along with sugar. It started to emerge then the Brazilian model of mill with the simultaneous production, and increasingly integrated, of sugar and ethanol. This means that no longer the residual alcohol was produced from exhausted molasses (final molasses), but started using the mixture of final molasses partially exhausted and sugarcane juice. The acceleration in production, since 1979, brought the independent distilleries that produce only ethanol; most of these independent distilleries have been converted to sugar mills with annexed distilleries in the 1990s.

In the area of thermal energy and electricity, plants evolved from the situation of external energy consumers in the form of electricity purchased from utility companies, to become fully self-sufficient and bagasse as the only form of primary energy that the industry used in the mid-1990s. With the changes of institutional and regulatory framework for the electricity sector in Brazil it has become feasible for the mills to generate surplus electricity to inject to the grid to sell to third parties. Today the new plants being built are increasingly equipped to generate surplus power and total utilization of bagasse for this purpose. With the increase in cane harvesting without burning the straw appears as a new fiber source for energy that begins, tentatively, to be used to supplement bagasse for extending the period of generation of electricity.

This situation sets the scene of a new era for the sugarcane – to become the feedstock for energy. The technologies called "second generation" to produce biofuels and electricity from lignocellulosic materials are under development for some decades now, starting to reach levels of performance and economy that encourage thinking about its proximity to commercial scale. It is therefore reasonable to begin to rethink the sugarcane from the viewpoint of energy and no more of food, from the breeding to processing and final products. This chapter introduces some aspects to be considered in this difficult and important task of defining the new model of ideal cane.

THE SUGARCANE TODAY

Before thinking about the future sugarcane it is interesting to understand the current state of genetic development of sugarcane, and its processing, and the parameters and driving forces that led to that stage.

At the beginning of Proalcool, about four varieties of sugarcane dominated the Brazilian plantations. Alone, the Argentine variety NA56-79 occupied more than half the planted area. The two main breeding programs of sugarcane were created around 1970, and therefore prior to Proalcool: the one of CTC (Sugarcane Technology Center, until 2004 Copersucar Technology Center), with the varieties SP and CTC, and Ridesa (University Network for the Development for the Sugarcane Sector, former Planalsucar), with the varieties RB. To these two programs should be added the IAC, and the CanaVialis, the most recent. Today there are over 500 commercial varieties, but just about twenty of them cover more than 80% of the area planted with sugarcane in Brazil (Macedo, 2005). And productivity and Pol% of cane grown in the state of São Paulo between 1975 and 2000 increased 33% and 8%, respectively. In addition, were also developed varieties resistant to major diseases known and most appropriate for different production environments; the major pests are controlled or in process to be under control. The breeding programs started to rely on molecular biology and there are already several transgenic varieties in field testing and close trying to reach the commercial stage.

As for the processing of sugarcane, the efficiencies and productivity sectors of the mills have already reached values close to the feasible maximum, which reduces the expectation of further significant gains. Moreover, economies of scale, automation and management improvements have led to significant reductions in production costs making Brazil the most competitive country in the world in the production of sugarcane, ethanol and sugar, dominating the international market for these two products.

This picture of success could lead to an accommodation in breeding programs and in industrial processing steps. However, some changes are appearing in the future scenario threatening the sector's success which has been achieved primarily with a focus on sugarcane as feedstock for food. These changes are guided by the increasing use of sugarcane for energy that made it to become the second largest source of primary energy in the Brazilian energy matrix, behind only to oil. This sugarcane originally developed to maximize the sucrose and later on the content of total reducing sugars (TRS), also became the best feedstock for agro-energy due to its high primary energy content per cultivated area and low production cost. This fact has led the most progressive members of the sugar/ethanol sector and new investors to start to consider about introducing a new model of production and processing of sugarcane, a model focused entirely on energy-ethanol and electricity. In this new model it is clear the importance of the sugarcane fiber in addition to fermentable sugars. It is also obvious to the technical sector that the ideal cane model needs to be redefined, but it is not at all clear what should be the characteristics of this new ideal cane. Moreover, we must continue to develop the sugarcane and processes to the traditional model of production: sugar, ethanol and some surplus electricity.

The main features of the cane grown on the South-Central region are listed below (MACEDO *et al.*, 2004):

- Pol%cane 14.5;
- Fiber%cane 13.5;
- AR%cane 0.56;
- Straw%cane (dry basis) 14.0;

- Productivity (t/ha/year) 68.7 (82.4 t/ha harvested).

This cane has a total of 7,400 MJ primary energy, considering also the straw per tonne of clean stalk, as detailed in Table 1 (LEAL, 2007).

This typical sugarcane, when processed in a modern plant would produce 86 liters of anhydrous ethanol and 60 kWh of electricity surplus, which corresponds to a conversion efficiency of cane primary energy into secondary useful energy – products – of only 30%, as detailed in Table 2, which was developed considering the cane used in Table 1 and an overall efficiency of the distillery of 84%.

Another aspect that is becoming increasingly important is the need for land to produce bioenergy. This is true not only for the economic aspect, because most of the production costs depends only on the acreage, but also in the sustainability aspects (use of natural resources) and the controversial emotional dispute food versus energy. In this aspect the sugarcane is the unbeatable choice, but it can still be improved. The sugarcane described above provides a primary energy of 510 GJ / ha / year (610 GJ / ha harvested) and a total of 150 useful energy GJ / ha / year (185 GJ / ha harvested), considerably higher than the useful energy in the form of biodiesel from castor beans (17 GJ / ha / year). This performance needs and can be improved for the long-term sustainability, as will be seen below.

TABLE 1 Primary energy from sugarcane (for 1 tonne of clean stalk).

Component	Energy (MJ)
150 kg sugars	2,500
135 kg of fibers in the cane stalk	2,400
140 kg of straw	2,500
Total energy per tonne of cane (MJ)	7,400 (0.176 tep)
Total energy per cultivated area (GJ/ha/year)	510

Source: LEAL, 2007.

TABLE 2 Efficiency of energy utilization of sugarcane in a modern distillery.

Item	Energy (MJ/tc)*
Cane	7,400
Products	
Ethanol (86 liters)	2,000
Electricity surplus (60 kWh)**	216
Total	2,216
Conversion eficiency (%)	30.0

* MJ per tonne of clean stalks, based on HHV, dry basis.
** First Law of Thermodynamics.

THE FUTURE

To define the desirable characteristics of the future cane it is first necessary to understand how this cane will be processed and how these features affect the cost and processing efficiencies of the new technologies and also of the conventional process. The first complication is that these second generation technologies are not mature yet and much less commercial, which implies in a low knowledge of the real productivity and efficiencies, and on which technologies will prevail. It's like shooting at a moving target, but does not prevent the making of some preliminary analysis that will be important to gain understanding of the impact of each feature of the new cane; considering the long period required for the development of new varieties, the earlier we start the sooner we will be able to optimize the whole feedstock / process path.

Table 1 above shows the current stage of the sugarcane primary energy, using the values presented by Leal (2007).

It is important to understand that the main reasons for the low current efficiency are not related to energy quality of the cane, but the model cane sugar / food prevailing today:

- The fact that cane trash fibers are not presently used which is either burned before harvest or left to decompose in the field.
- High energy consumption of the production of ethanol, which results in the use of more than 90% of bagasse available.

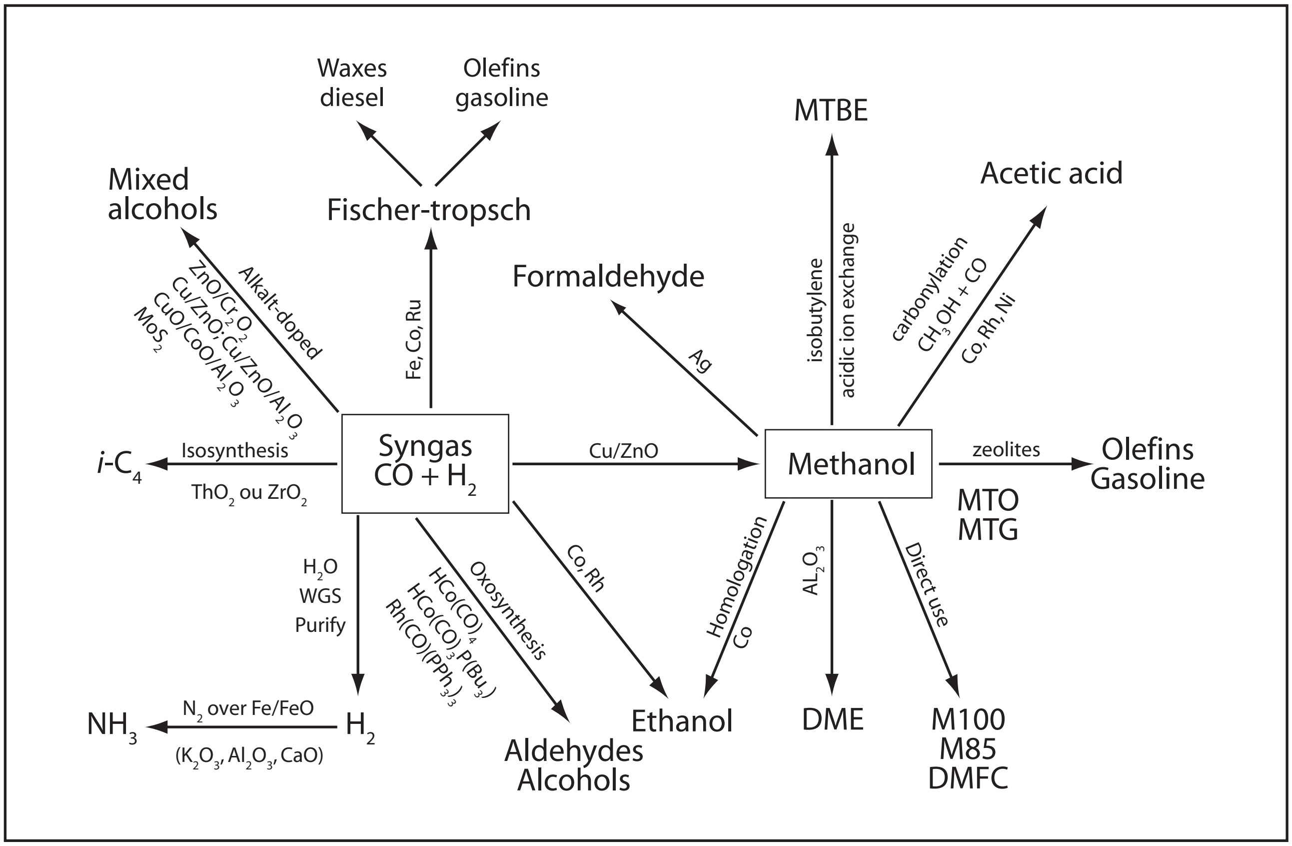
This means that even with the present sugarcane, there is still much that can be done to improve this efficiency. For example, an increase in overall efficiency of the distillery from 84% to 88% and the recovery and use 50% of the straw to supplement bagasse for surplus power generation with boiler pressure of 100 bar and, condensing / extraction turbo-generators this efficiency would rise to 35.6%, a significant gain. It is important to say that the technologies for these improvements are already commercially available (except the recovery and use of straw) and are used in some modern plants. There is not yet the energy crop concept and perhaps lack of economic incentives.

A long-term performance of second generation technologies would help bring some insight to the requirements of future sugarcane for energy use, called from now on energy cane. This type of cane has been studied since the 1980s, initially in Puerto Rico and Cuba, and more recently in Barbados in the West Indies Central Sugarcane Breeding Station (Rao and Albert-Thenet, 2005). But in all these efforts it was sought only the increase in cane biomass production per hectare, while maintaining a minimum of Pol% cane to meet the sugar aspect still on focus. Now we must make an assessment based on the needs of second generation technologies; for this it will be presented below a summary of the main features of these technologies in their long-term projections. The values reported here are taken from the latest literature and reflect expectations that not necessarily will be realized, but it will serve to consolidate the concept of energy cane. Further details on these technologies can be found in the chapters dealing with second generation technologies in this part of this book.

Second generation technologies

It is possible to divide these emerging technologies into two broad categories according to the main feature of each route:

- Biochemical Technologies: characterized by the use of microorganisms to convert cellulosic material into biofuels. They use a process of hydrolysis, chemical or enzymatic, to convert cellulose and hemicellulose into sugars which are then fermented and distilled; the main biofuel obtained is ethanol. The lignin is separated and used, along with other wastes, to produce thermal and electrical energy for the process. Since the cogeneration system is used, it can also generate an amount of surplus electricity to improve the overall efficiency and the technology economic return. The raw material for these processes should preferably have high levels of cellulose and hemicellulose and low lignin (this makes more difficult the access of enzymes to cellulose); low levels of mineral impurities (ash) are highly desirable. The biomass moisture content is not important and it can be tolerated the values found in the biomass freshly harvested. This technology route has had more visibility and therefore appears to be closer to commercial success, which is not necessarily true, since major problems remain to be solved as the definition and consolidation of the pretreatment of biomass, the cost reduction of enzymes and the fermentation of pentoses (five-carbon sugars).
- Thermochemical technologies: these technologies are characterized by the use of heat as a way of turning biomass into liquid or gaseous components which are then converted into biofuels, which can be ethanol, methanol, higher alcohols, gasoline, diesel, dimethyl ether (DME) and other. These routes are benefiting from the substantial investments in technologies CTL (coal to liquids) and GTL (gas to liquids) by the fossil fuels sector. The processes for biomass (BTL – biomass to liquids) are similar, despite some peculiarities mainly in the cleaning of the gases. The level of problems is more related to engineering than to R&D. The biomass most important features are the levels of certain contaminants such as alkali, chlorine, sulfur, ash and moisture contents. This last item is very important in the energy balance, because if the moisture content of the feedstock as received is too



Source: NREL/TP-S10-34929, dez. 2003.

FIGURE 1 Routes for production of biofuels and chemicals from synthesis gas from biomass gasification.

high will translate into energy expenditure to bring it to values compatible with the processes. These technologies are very versatile in terms of final products as shown in Figure 1.

The energy balances in the literature are quite varied, because they depend on routes, characteristics of feedstocks and, especially, the assumptions for the efficiency of energy conversion and integration of the processes. Table 3 shows the results obtained from the conversion efficiencies presented by ZUUBIER and VAN DE VOOREN (2008) and KREUTZ *et al*. (2008) for technologies in the long term.

Despite the efficiencies differ in Table 3, the trend is that they remain close in the case of hy-

TABLE 3 Performance of long-term 2nd Generation technologies

Products (per t of biomass, dry basis)	Hydrolysis	Gasification/F-T	BIG/CC*
Biofuel (l of ethanol eq.)**	408	346	–
Electricity (kWh)	400	500	1,950
Overall efficiency (%)	61	55	39

* Biomass Integrated Gasification/Combined Cycle: only electricity

** Liters of ethanol equivalent: in the Fischer-Tropsch synthesis various biofuels can be produced

Source: ZUUBIER and VOOREN (2008), KREUTZ *et al*. (2008).

drolysis and FT maximized for biofuels, in the case of BIG / GT and FT maximized for the electricity efficiencies suffer the penalty of the 2nd Law of Thermodynamics and will remain slightly lower.

THE ENERGY CANE CONCEPT

It is easy to quantify the primary energy of sugarcane, from its basic components, and also the energy contained in the final products. However, it is not a trivial task to determine the economic value of the primary energy of each component (today, in the cane payment systems more widely used in Brazil, only the total recoverable sugars – ATR – have their economic value derived from the market value of final products and the conversion rate established), because the processing of fibers and sugars has the cost and efficiencies are quite different. To complicate matters further, the fibers of the stalks and leaves have different recovery costs and different impacts on the processing of sugarcane.

In item *The Future* above it was mentioned that the low efficiency of conversion of primary energy from sugarcane into useful energy is not a problem of the feedstock, but the processing of it, mainly due to the concept of sugarcane for food where only the sugars are sought for the maximum recovery. The fibers are still somewhat neglected. To increase the production of primary energy per unit of cultivated area it is necessary to seek varieties with higher biomass, whether it be in the form of sugars and fibers; however, the value of each component would be associated with the values of final energy products and the efficiencies and costs of conversion.

Table 4 shows the comparison, in terms of primary energy, between three types of cane: our reference sugarcane (described in item *The Sugarcane Today*), a clone being tested in the Mauritius Islands (WI 96912) and an energy cane (or fuel cane) being developed in Barbados.

The primary energy of sugarcane is a strong indication of its potential performance for energy, but can not be regarded as the sole indicator of energy quality sought. The economic value of each component will depend on the conversion efficiencies, costs of conversion and the total value of final products. Thus, the value of each energy variety will depend on the processing technology chosen, a very big complication in the task of creating a model for energy cane. Some considerations are possible, using the data available today to the expectations of performance and cost of processing for the main second-generation technologies, to begin to format the concept of energy cane. Initially will be seen some details of the processing of each component of the cane.

Sugars

Until recently, only sucrose entered the system of cane payment since the reducing sugars

TABLE 4 Energy comparison between three cane varieties.

Characteristic	Reference	Mauritius*	Barbados**
Pol%cane	14.5	19.9	12
Fiber%cane	13.5	17.5	26
Straw%cane	14	N.I.***	25
Productivity (tc/ha/year)	68.7	N.I.	100
Total fiber (t/ha/year)	19.3	N.I.	51
Primary energy GJ/ha/year MJ/tc	 520 7,400	 N.I. N.I.	 1,100 11,200

* Source: Autrey, L. J. C. and Kong Win Chang, K. T. K. F., 2006.
** Source: Rao, S. and Albert-Thenet, J., 2004.
*** N.I.: not informed.

(AR's) are not crystallizable in the mill process. With the recognition of the importance of ethanol, the AR's began to be considered and the sucrose is converted numerically in AR and added to them to obtain the Total Reducing Sugars (TRS). The stoichiometric conversion rate in ethanol is today, on average, around 84% and possibly reaching in the medium term, 88% or maybe even 90%. The distillery processes consume in average 28 to 30 kWh of electromechanical energy and 330 kWh of thermal energy per tonne of cane processed. This energy is entirely supplied from about 90% of the bagasse produced in the juice extraction process. As the energy system of the mills and distilleries operate in cogeneration mode (two or more forms of energy are produced from the burning of a single fuel), a little surplus power is increasingly being produced by mills. With conventional technology the power surplus can be maximized in an economically viable way through the use of steam at 100 bar/520 ºC and condensing/extraction turbo-generators (or separate condensing and back pressure turbo-generators).

Considering only the process of converting sugars into ethanol, we can consider two situations (see Appendix for details):

Today: 0.544 liters of ethanol are obtained from each kilogram of TRS (including sucrose converted to RS) processed, and 0.35 kWh / liter of ethanol are consumed (0.64 kWh / kg processed TRS) as electromechanical energy and 3.84 kWh / liter of ethanol (7.05 kWh / kg processed TRS) as thermal energy in the form of process steam. 90% of bagasse is consumed, leaving then 0.157 kilograms of bagasse (dry basis) / liter of ethanol (0.288 kg of bagasse, dry basis / kg of processed TRS).

The processing cost for ethanol is approximately R$ 0.175 per liter of ethanol.

Long term: 0.583 liters of ethanol will be produced for each kilogram of TRS by conventional technology (first generation). This process will consume 0.30 kWh / liter of ethanol (0.51 kWh / kg TRS) of electricity and 2.00 kWh / liter of ethanol of thermal energy (3.43 kWh / kg TRS).

The processing cost will be around R$ 0.145 / liter of ethanol (R$ 0,249 / kg TRS).

Fiber from cane stalk (bagasse):

The bagasse, which is the residue of the industrial process of extracting the juice, is now the only source of energy for all the processing of sugarcane – electromechanical and thermal energies. Because it is a waste, it has no production nor transport cost, but has a value as fuel and therefore an opportunity cost. Also, since there are not many opportunities to be sold to third parties due to the high cost of transportation and requiring boilers and furnaces specifically designed to operate with a fuel with high moisture content and low density. Mills have evolved to get to the point of self-sufficiency in energy consuming almost all the bagasse. With the increased generation of surplus energy for sale the bagasse has become more valued, though not yet to the point of seeking energy sugarcane varieties with higher fiber content.. This is due to two main reasons: 1) the capacity of the milling tandem is related to the fiber, the higher the fiber content the lower the capacity of the mill in tc / h (tons per hour) or tons of sugar / h, resulting in a lengthening of the season in most cases, 2) the bagasse carries a certain amount of sugar (1 to 2% of wet weight of bagasse), thus reducing industrial efficiency (recovery of sugars). For these two reasons, cane fiber above a certain value is penalized in the cane payment systems, and cane breeders have produced varieties with fiber content ever lower. The lower limit is dictated only by the capacity of sugarcane to remain upright, and bagasse to be sufficient just to meet the energy needs of the mills.

Bagasse presents some interesting features as raw material for the second generation technologies: appropriate particle size, low ash (~ 2%) and alkali contents, and low amount of other contaminants. As negative characteristics has low density (physical and energy) and high moisture content (disadvantage only for the thermochemical route).

In the economic aspect, the value of bagasse as an energy feedstock must be deducted from losses caused by the reduction of milling capacity and by the sugar carryover. There are already commercial technologies in the market to dramatically reduce energy consumption in the mills, resulting in a surplus of bagasse above 50%, but at a cost of additional investment. It is necessary to start economic studies involving aspects of the fiber content putting on one side the benefits – increased generation of surplus energy and second generation fuel production – and the other side the negative points – a loss of sugar, the greater number of days of milling, investment in reducing energy consumption. Unlike the component sugars, where the value, conversion efficiency and costs of conversion are well known, the fiber component of the stalk does not have these parameters clearly defined and depend heavily on the choice of end-use and performance of technologies still under development.

Fiber of cane leaves (straw)

The fiber from the leaves of sugarcane presents some additional challenges compared to bagasse for its use. First, the technology for its collection, transport to the mill, processing and storing is not developed enough to be considered commercial. However, several field tests involving multiple routes of trash collection as, for example, the work of the CTC, the Sugarcane Technology Center Project BRA/96/G31 (HASSUANI *et al.*, 2005) from 1997 to 2005. In this project were carried out the quantification and characterization of straw, studies of the agronomic impacts of sugarcane straw in the cane fields, routes of straw recovery and estimated costs of collection and transportation, and processing test. Samples of bagasse and straw were sent to Sweden, where they were tested in a pilot plant of 2 MWt by the TPS-Termiska Processer AB. In some field tests it has been proven the beneficial features of straw as protection against erosion, retaining soil moisture, decrease of temperature fluctuation in the soil, recycle of nutrients and herbicide effect of the straw blanket. Some of these benefits have been preliminarily quantified, but additional studies and field tests will be needed to better understand the agronomic impacts of the straw blanket and to better estimate the economic value or cost thereof.

More recent studies are indicating the importance of the straw to enable the no or minimum tillage systems for sugarcane. All this shows the convenience of leaving an amount of straw in the field to obtain these benefits and the percentage of straw that should be in the field seems to be something around 50%. It is expected a dispute over the use of straw for its agronomic benefits and its value for energy.

The costs of collection raised by the CTC (Hassuani, 2005) are shown in Table 5.

According to Hassuani (2005), in the assessment of costs it is necessary to consider the integration of operations of straw recovery in the sugarcane production process, the agronomic impacts, the impacts on the mill and also the aspects relating to the quality of straw, which are the impurities, moisture content, processing needs and the amount to be collected. From Table 5 it is possible to assess that a fraction of 50% is feasible and reasonable to be collected.

From the standpoint of conversion of sugarcane components in final products there are three

TABLE 5 Costs of Straw Collection.

Harvester condition	Recovery system	Recovery efficiency (%)*	Cost at the mill (US$/t, db)**
Conventional	Baling	67	18.5
Conventional	Hay harvester	53	22.5
No cleaning	Cleaning station	67	31.1
Partial cleaning	Cleaning station	46	13.7

* Average values of field tests.
** Including the agronomic impacts; db – dry basis.

Source: HASSUANI, J. S., 2005.

key points: value of final products, efficiency of conversion and conversion costs. Some of these have already been mentioned earlier but are repeated here in a different way and others will be introduced in order to have a more global view of potential use of the fibers of the cane.

- Economic value of final products

The two final products used in comparisons are anhydrous ethanol and surplus electricity.
Ethanol: U.S. $ 0.80 / L = R$ 38/GJ
Electricity: R$ 140/MWh = R$ 39/GJ

Thus, the values of the two products are practically the same when using the value of the energy content. So efficiencies and the costs of conversion will prevail.

- Efficiencies of conversion

The conversion efficiencies of the two main second generation processes are shown in Table 6 for the expected performance in the long run when these technologies are fully mature in terms of technological and commercial point of view (after 2020).

Under the aspect of conversion efficiencies of the two competing technologies are very similar, and the gasification / FT favors a little more the generation of electricity and has some flexibility in this regard.

- Costs of conversion

At this point the uncertainties are even greater in view of the low stage of maturity of these technologies today. There is the issue of scale that has a strong effect on production costs and unit investment, the cost or price of feedstocks and the performance of each technology. To illustrate this point, we present the projected values for the long-term investment, cost of operation / maintenance (O&M) and the cost of production of biofuel in Table 7.

Energy cane would be a group of varieties with high primary energy per hectare, and their components – sugar and fiber – should be suitable for processing by emerging technologies for second generation or the integration of conventional technology (first generation) with one of the second generation alternatives. As there is not, as yet, a clear picture of performance and production costs of these technologies, it is difficult to define what the optimal characteristics of sugarcane for energy should be.

TABLE 6 Long term conversion efficiencies of second generation processes.

Technology	Conversion efficiency (%)		
	Biofuels	Electricity	Total
Gaseification/F-T	45	10	55
Hydrolysis	53	8	61

Source: ZUUBIER and VOOREN, 2008.

TABLE 7 Values of long-term investments, O & M costs and production of second generation biofuels.

Technology	Investiment	O&M	Production cost
	(Euro/kWt)*	% Invest./year	Euro/GJ_f**
Gaseificação/F-T	540	4	7-9
Hydrolysis	180	6	5-7

Source: ZUUBIER and VOOREN, 2008.

* Euro per kW thermal of biomass entering the gasifier.
** Euro per GJ of fuel.

FINAL CONSIDERATIONS

The intention of this chapter was to present a range of energy aspects of the cane to enable researchers interested in this subject to start simulations and assessments with different values of TRS% cane, fiber% cane and straw. Only with a sequence of simulations and analysis of results and monitoring of development of technologies that enable better use of the cane fibers it will be possible to gain feeling and confidence to help when time comes that we will need to decide between more fiber in exchange for less TRS, since there will be a basis for discussions. It is more or less obvious that the energy cane should have a high value of primary energy, both per ton of cane and, especially, per unit of cultivated area. In a more refined form already, the discussion should extend to the composition of the fibers in their main components and their elements considered contaminants.

For now, we need to start rethinking the fiber content of the cane and put more effort in understanding the agronomic impacts of straw in the field. The collection, processing and storage of straw is far from a solved problem and we begin the journey towards optimizing energy cane for use in first-generation technology, which will continue in use for decades to come, even after consolidation of second generation technologies.

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APPENDIX

A. Basis of calculation

A1 Energetic values: Higher Heating Value (HHV) and Lower Heating Value (LHV)

Material HHV (MJ/kg, dry basis)

Fiber 18

Sucrose 16.5

Reducing sugars (RS) 15.6

A2 Anhydrous ethanol

HHV= 23.4 MJ/l

LHV = 21.2 MJ/l

A3 Conversion (Fernandes, A.C., 2003)

TRS= sucrose/0.95 + RS

Stoichiometric yield

1 kg TRS results in 0.6475 l absolute ethanol, 0.6503 l anhydrous ethanol or 0.6776 l hydrous ethanol.

Actual production of ethanol = (TRS in the sugarcane) X (stoichiometric yield) X (industrial efficiency)

17

NEW BUSINESS OPPORTUNITIES IN THE SUGAR-ALCOHOL INDUSTRY:

ALCOHOL CHEMISTRY AND BIOREFINERIES

Telma Teixeira Franco and *Camilo López Garzón*

BIOREFINERIES: DESCRIPTION AND PRINCIPLES

Biorefinery is an integrated process in which biomass is converted to higher added value products with zero or near zero net CO_2 emissions. The biorefinery concept is based on the similar concept behind traditional petrochemical refineries and partially uses related transformation processes. However, the main value-adding technologies associated with biorefineries are more complex, offering a greatest potential given the huge variety and quantity of renewable biomass and derived products. In addition, the biorefinery provides the possibility to develop non-polluting and sustainable industries with low environmental impact.

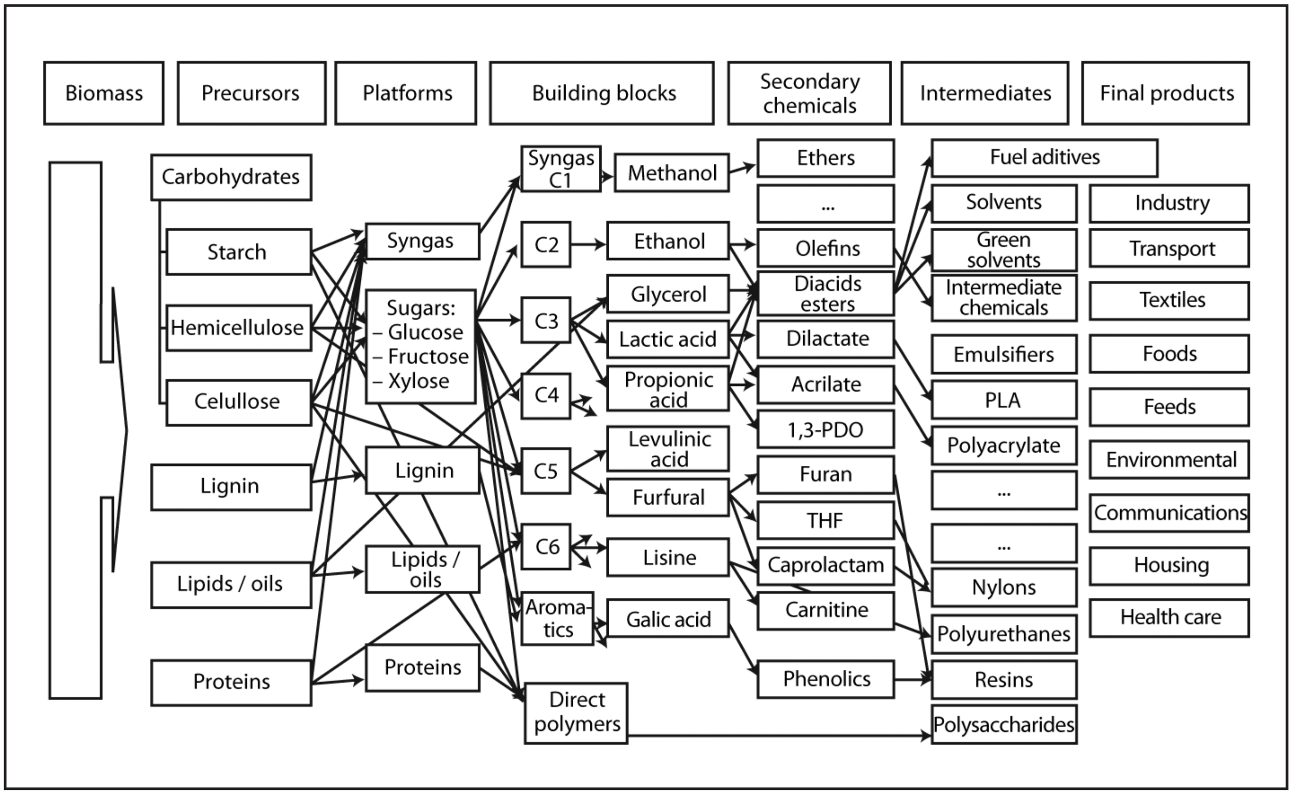
Historically, it is known that several processes, today included in the area of biorefinery, were already known since the 19th century, such as the saccharification of wood, solubilization of cellulose, sugar refinery, starch and maltodextrins for industrial purposes, vegetal oil and chlorophyll extraction, furfural production from bran distillation, isolation of vanillin from lignin (already developed in 1874) and lactic acid production by fermentation (KAMM *et al*., 2006).

Different types of biomass are currently being used for the production of molecules for subsequent use in industrial processes, which can lead to gradual replacement of the petrochemical platform. Among them, building blocks had gained big interest; these are molecules with multiple functional groups, which can be converted into other molecular groups (Figure 1).

In order to obtain chemical building blocks, basically two essential biomass processes need to be developed: a) hydrolysis of polysaccharides originated from lignocellulosic materials with sugar releasing and b) fermentation of this sugars to products of interest. Enzymatic or chemical reactions may be part of the step sequence to obtain the building blocks. Thus, the above mentioned processes must be into a biorefinery facility and lead to several conceptual definitions. Various concepts of biorefinery are associated to ideas about how the biomass should be sustainably converted into chemicals, materials, fuels and energy, satisfying the current economic constraints (KAMM *et al*., 2006). Another concept of biorefinery is directed to maximize the economic value of biomass, improving business and industrial models (STUART, 2006) (Figure 2).

Different technologies need to be integrated in order to achieve widespread and efficient potential of biorefinery, as metabolic design of biochemical pathways (i.e. metabolic engineering), use of raw material (biomass knowledge) and production of chemical intermediates and final products (industrial processes) (Figure 3).

Biorefineries using biochemical routes, should be able to operate based on biomass precursors (mainly carbohydrates in the case of lignocellulose); obtain those requires a number of separation/fractionation steps, usually by means of physical transformation processes. Once the fractions of biomass are obtained they can be chemical and/or microbiologically processed and fed to conventional industries. This approach was described



Source: Based on KAMM *et al.,* 2006.

FIGURE 1 Biomass-based platform.

(KAMM B. and KAMM M., 2004) and summarized by the following expression:

Raw material (non fractionated) + Combination of processes → Miscellaneous products

Therefore, in order achieve an integrated production of food, animal feed, chemicals, materials and fuels an important key concept is to develop and establish the above described industrial com-

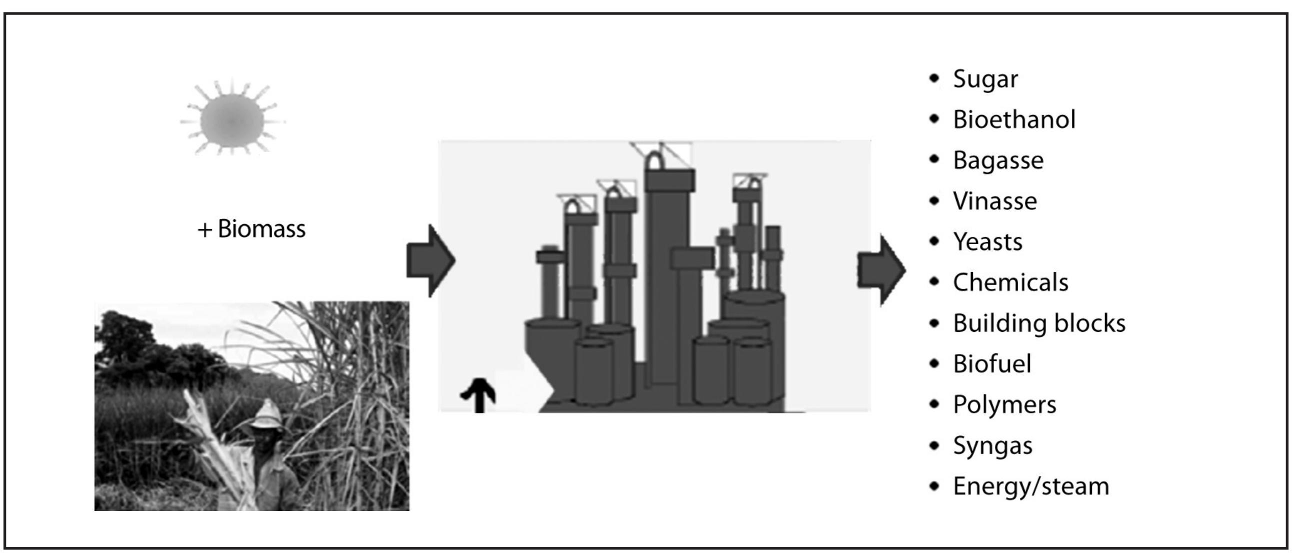


FIGURE 2 Schematic of sugarcane refinery.

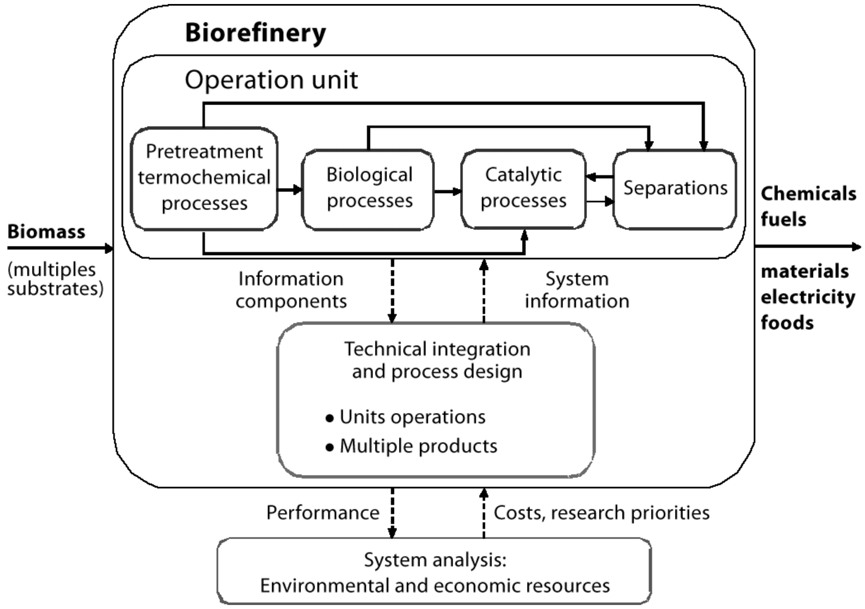


FIGURE 3 Schematic of biorefinery concept.

plex facilities instead of individual isolated ones (U.S. NRC, 2000).

THE FULL EXPLOITATION OF BIOMASS

The strong global economic growth has accelerated the demand for sustainable resources used in industrial production; energy resources may originate from different sources such as wind, water, biomass, nuclear fission and fusion, however material resources mainly depend on biomass in particular vegetal biomass. In 2001 it was estimated that only $6x10^9$ tons/year of biomass were used within $170x10^9$ T/year produced by nature, and only 3% are used for industrial purposes (ZOEBELIN, 2001). Current literature report that between 9% to 13% of biomass is already used in some regions for energy purposes (KRAUSMANN *et al.*, 2008). These resources can be more efficiently used; nevertheless, the increased efficiency is hampered by the inherent characteristics of the vegetal biomass. The separation (fractionation) of biomass into its major components for subsequent processing is a major obstacle to the establishment of biorefineries. One of the research priorities outlined by the U.S. National Research Council (U.S. NRC, 2000) is the development of efficient procedures for processing lignocellulosic materials in order to obtain materials susceptible of transformation by means of biotechnological and/or traditional chemistry. In the case of biomass from sugarcane, efficient processes of pretreatment, aimed on separating the cellulose from hemicellulose and lignin, and the different types of hydrolysis (acid, enzyme or combined) will soon be available on an industrial scale, ensuring the almost complete utilization of biomass.

As soon as the processes for biomass depolymerization have been established, the main precursors available as raw materials in the bio-based sugarcane industry are the two most abundant simple carbohydrates in nature, glucose and xylose (LYND *et al.*, 1999; PANDEY *et al.*, 2000). A new bioproduct platform based on these precursors should be developed.

THE RAW MATERIAL AS DRIVING FORCE IN THE DEFINITION OF TECHNOLOGIES

Since the end of the last decade, has been recognized that the greatest impediment for a global application in large-scale of the biorefinery concept is the lack of low-cost biomass processing technologies (LYND *et al.*, 1999). According to HAHN-HAGERDAL and colleagues (2008), the efficiency and cost of technologies currently used to produce sugar syrup with good fermentation quality could be improved, despite recent progress. The cost distribution of these processes depends on the type of raw material, availability and even more of their required pretreatment.

For a long time has been an objective the development of microorganisms with the ability to convert the biomass components in various products with associated good yields at high final concentrations, thus trying to improve the economy of bioprocesses. Two routes have appeared naturally, the first one focused on improve the selectivity of native microorganisms capable of use given substrates (product-centered development). The latest one aims the inclusion of certain substrate consumption features in microorganisms with good production capacity of target compounds (substrate-centered development) (LYND *et al.*, 1989). The first route is currently being used to obtain high-value bioproducts, where the raw material costs has little impact on the overall production cost.

In the case of commodities production in biorefineries, processes and biocatalysts involved should be designed based on the characteristics of biomass (substrate) used as feedstock, and should make the best use of it in each step. Thus, the development to be achieved depends on the type of biomass available for processing. Hence, the biorefineries have been classified according to the biomass used; the most frequently cited classification refers to lignocellulosic (considered the most important given the abundance of lignocellulosic feedstocks), grains and grass-based biorefineries (KAMM B., KAMM M., 2004).

Another classification has arisen for the biorefineries destined to fuel production; such classification denotes a technological differentiation among them ranked by *generations*: those based on precursors commonly used as food (vegetable oil, sugar and starch) can be typified as first generation biorefineries. Second generation facilities uses biomass feedstock not commonly regarded for food purposes. Recent studies show that the use of biomass not dedicated to food purposes, i.e. from trees (wood and their subproducts), grass and lignocellulosic materials will be greatly improved since the transformation processes hold better energy balance in comparison with the first generation (TAYLOR, 2008).

THE LIGNOCELLULOSIC BIOREFINERY: ALTERNATIVE TO THE SECTOR

In an industry where the main byproducts, bagasse and straw, are lignocellulosic materials it is straightforward the establishment of a biorefinery based on this biomass. The lignocellulosic material is composed of three precursors, lignin (a phenolic polymer or macromolecule according to some authors), hemicellulose (polymer composed of pentose, mainly xylose) and cellulose (glucose polymer). According to KAMM and KAMM (2004) these three precursors are transformed using the equations:

$$\text{Lignocellulose} + H_2O \rightarrow \text{Lignin} + \text{Cellulose} + \text{Hemicellulose} \quad (1)$$

$$\text{Hemicellulose} + H_2O \rightarrow \text{Xylose} \quad (2)$$

$$\text{Xylose } (C_5H_{10}O_5) \xrightarrow{\text{catalist}} \text{Furfural } (C_5H_4O_2) + 3H_2O \quad (3)$$

$$\text{Cellulose } (-C_6H_{10}O_5-) + H_2O \rightarrow \text{Glucose } (C_6H_{12}O_6) \quad (4)$$

Equation 1 represents the fractionation of these three polymers, but not exactly the hydrolysis, nevertheless the separation of these fractions is still only achieved by wet pretreatment.

The process lines of the above mentioned precursors are shown in Figure 4.

A huge amount of microbial conversions based on glucose can be used in these biorefineries; those have been studied since the beginning of the industrial microbiology, are very well documented and, in general, favorable energetically. Therefore the line of production from glucose has the most potential, being ethanol the main product currently. This alcohol can be chemically transformed into ethylene, which could be supplied directly to petrochemical refineries in order to produce polyethylene and polivinilacetate. Other well-known products from glucose are hydrogen, methane, propanol, acetone, butanol, butanediol, succinic and itaconic acid (ZEIKUS *et al.*, 1999).

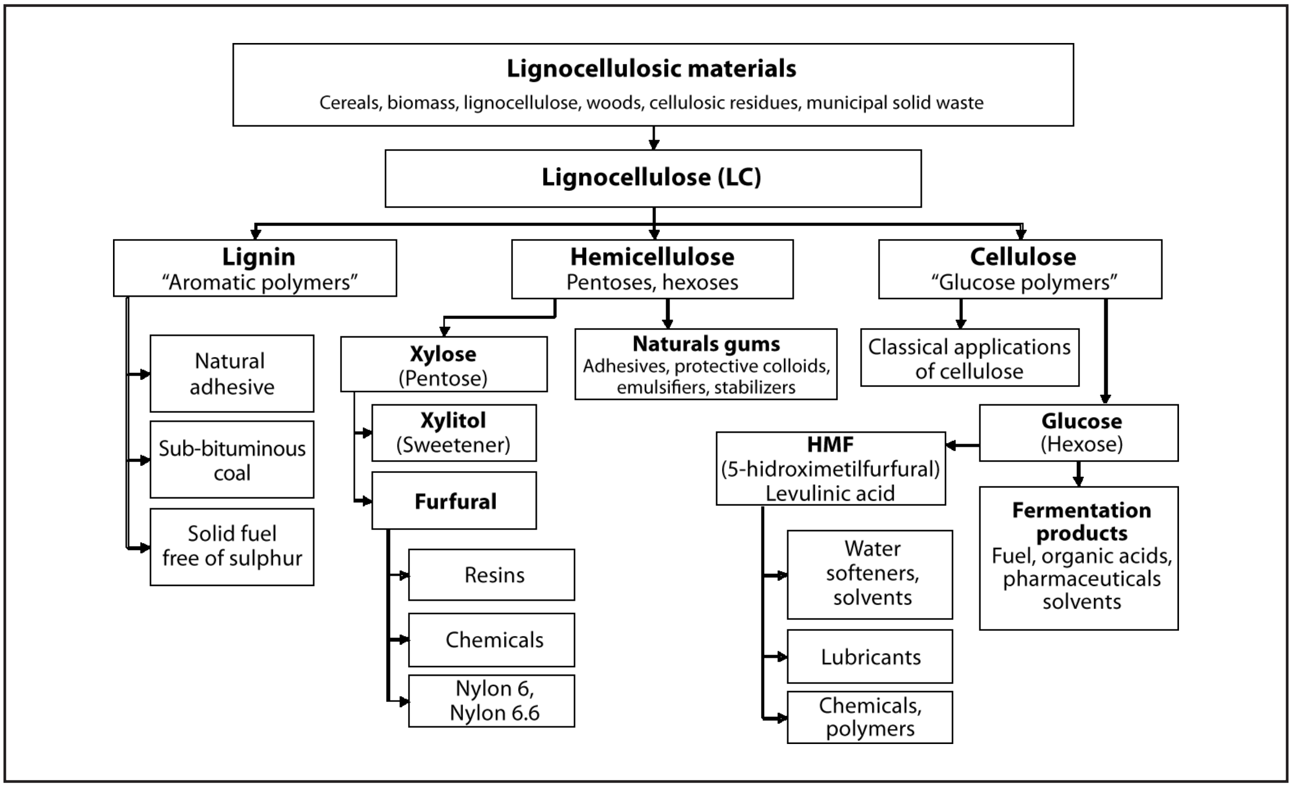


FIGURE 4 Biorefinery based on lignocellulosic residues from straw and sugarcane.

In the case of the production line based on xylose as precursor, was found a shortage of processes developed intending using this feedstock in the generation of bioproducts. Cases such as production of xylitol (sweetener), offers only a marginal advantage of this abundant source of carbon. Recently processes are being developed having as main goal the production of ethanol from xylose using recombinant microorganisms, since there are barriers on the xylose metabolism towards ethanol (JEFFRIES, 2006), these processes so far have been unsuccessful. A product with exciting potential is furfural, which can be used in the production of nylon, returning then to the original process established long time ago, but not in production nowadays. In summary new alternatives for the utilization of xylose should be developed.

Regarding to the lignin as precursor, there are many issues to be solved, the potential is well understood considering the nature of compounds that could be produced, like mono-aromatic hydrocarbons which high value on the market. However, the recovery of those bioproducts is difficult and their applications are limited.

THE NEW BIOCOMMODITIES PLATFORM

In 2004 was published a joint study between the Pacific Northwest National Laboratory U.S. – PNNL and the National Renewable Energy Laboratory – NREL a selected list of chemicals potentially obtained from biomass that would be essential for the gradual replacement of the petrochemical platform (WERP and PETERSEN, 2004). Since it was recognized these compounds could lead to a partial replacement of the known chemical platform, was assigned to those the name of *building blocks*, whereas their multiple functional groups could then be used to obtain other compounds. This preliminary study suggested initially 300 molecules having the characteristics of building blocks, this first selection was quickly reduced to 30 and then to a final 12, which can be produced from sugars and subsequently converted to materials and high

– value chemicals. At the end of the study, the list of building blocks consisted of: 1,4-dicarboxylic acids (succinic, fumaric, malic), 2,5-furandicarboxylic acid, 3-hydroxypropionic acid, aspartic acid, glucaric acid, glutamic acid, itaconic acid, levulinic acid, 3-hydroxybutyrolactone, glycerol, sorbitol, and xylitol/arabinitol.

The current literature describes the planning and construction of some production plants for the development of industries based on renewable resources, such as the production of 1,3-propanediol (DUPONT, USA), polylactic acid (CARGILL, USA), PHB (by the Metabolix consortium formed by ADM from USA and PHB from Brazil), amino acids (Ajinomoto), succinic acid (DSM) and polyethylene (pilot plant in Triunfo, RS; industrial plant under construction by Braskem from Brazil). The production of polypropylene has also been announced by the brazilian Braskem, in addition Amyris-Votorantim, in partnership with Cristalsev and Santaelisa Vale had installed a pilot plant in Sertãosinho (State of São Paulo) for a diesel-like fuel production from sugarcane sucrose, using genetically engineered yeast of the genre *Saccharomyces*.

SUGARCANE BAGASSE AS RAW MATERIAL IN BIOREFINERIES

One of the biggest byproducts of the ethanol industry is the sugarcane bagasse, a cellulosic residue obtained after extracting the sugarcane juice. Currently the bagasse is used as a primary source of energy in most Brazilian mills and as raw material in paper production in some countries (PANDEY *et al.*, 2000). Recently was identified the need of utilize better and more efficiently this material and use it as a source for precursors in the lignocellulosic biorefinery.

The bagasse from sugarcane is the fraction of biomass left after the cleaning procedures, preparation and extraction of the juice (by grinding or using diffusers), it is a heterogeneous biomass that varies in its composition as well as in their morphological structure depending on the procedures for cutting and processing (ROSSEL, 2006).

The production of bagasse is inherent to this industry, it is produced at high rates in Brazil, has a relative low cost (between US$ 30 to 40/T) (SATYANARAYANA *et al.*, 2007) and a composition full of precursors (Table 1).

The usage of sugarcane bagasse has been the main topic in many brazilian studies, used in the form of hydrolyzed in various biotechnological routes for production of ethanol, xylitol, microbial protein, flavorings and enzymes (cellulases, xylanases and ligninases) among others (PANDEY *et al.*, 2000) and even as a biomaterial for the immobilization of cells (SANTOS *et al.*, 2008).

ETHANOL AND ALCOHOL CHEMISTRY

In Brazil, the biobased platform intended to replace the petrochemical technology is pioneer, being one of the world countries leading the production of ethanol, despite this other bioproducts are still in a very early stage of development. Since Brazil is technologically advanced in the produc-

TABLE 1 Typical composition of Brazilian sugarcane bagasse.

Fraction	% (dry base)
Cellulose	32-48
Hemicellulose	27-32
Lignin	19-24
Silica	0.7-3.5
Ash	1.5-5

Source: FINGUERUT, 2006.

TABLE 2 Estimated replacement for the U.S. aromatic derivatives.

<table>
<tr><th>Aromatic derivative</th><th>Current production (109 lb)</th><th>Required lignin (109 lb)</th></tr>
<tr><td>Benzene</td><td>20.4</td><td rowspan="3">90.7*</td></tr>
<tr><td>Toluene</td><td>11.1</td></tr>
<tr><td>Xylene</td><td>13.8</td></tr>
<tr><td>Terephthalic acid</td><td>11.1</td><td>12.7</td></tr>
<tr><td>Phenol</td><td>5.1</td><td>9.8</td></tr>
<tr><td>Total</td><td>61.5</td><td>113</td></tr>
</table>

* In order to substitute the requirements of benzene, toluene and xylene. Values in USA.

tion of ethanol, an alcohol chemistry derived platform can be installed in the country without major disruptions due to the easy access to raw materials, mostly in São Paulo state (Figure 5).

The products generated from ethanol are based on well-established ethanol chemistry, inherited from current refineries, processes like reforming, catalytic cracking and hydrocraking can be used to produce syngas that used in Fischer-Tropsch process or other catalytic process can generate a complete platform of derivatives. Recently there have been studies done in Brazil concerning the synthesis of heterogeneous catalysts using ethylene from ethanol and ethylene oxide, thereby producing a complete range of products such as plastic – PET, solvents, resins, paints, automotive fluids and other (MARTINS and CARDOSO, 2005).

THE THREE LINES OF BUSINESS IN BRAZIL

Lignin derivatives

The lignin (Figure 6) is a complex chemical compound that is an integral part of lignocellulosic materials, is a heterogeneous polymer with the structural function of maintain together chains of cellulose and hemicellulose.

The extensive use of lignin as a chemical precursor is still far from being achieved mainly due to the difficulties on their isolation. There are two problems to be solved in the recovery processes: maintaining the natural structure of lignin and get it at high yields. The processes developed to the date change in some degree the structure of lignin limiting their processing. Different methodologies for lignin isolation were developed, but in general, make extensive use of chemicals (which can react and degrade the lignin) hampering the desired recovery and quality.

Due to its aromatic characteristics, the lignin has been studied as a source of phenolic derivatives. In the United States projections about the total replacement of the phenolic derivatives for lignin derivatives were made (BOZELLI, 2004). These estimates showed that this substitution is feasible because all the chemical processes involved are in the actual state of the art; however the separation and purification of lignin remains

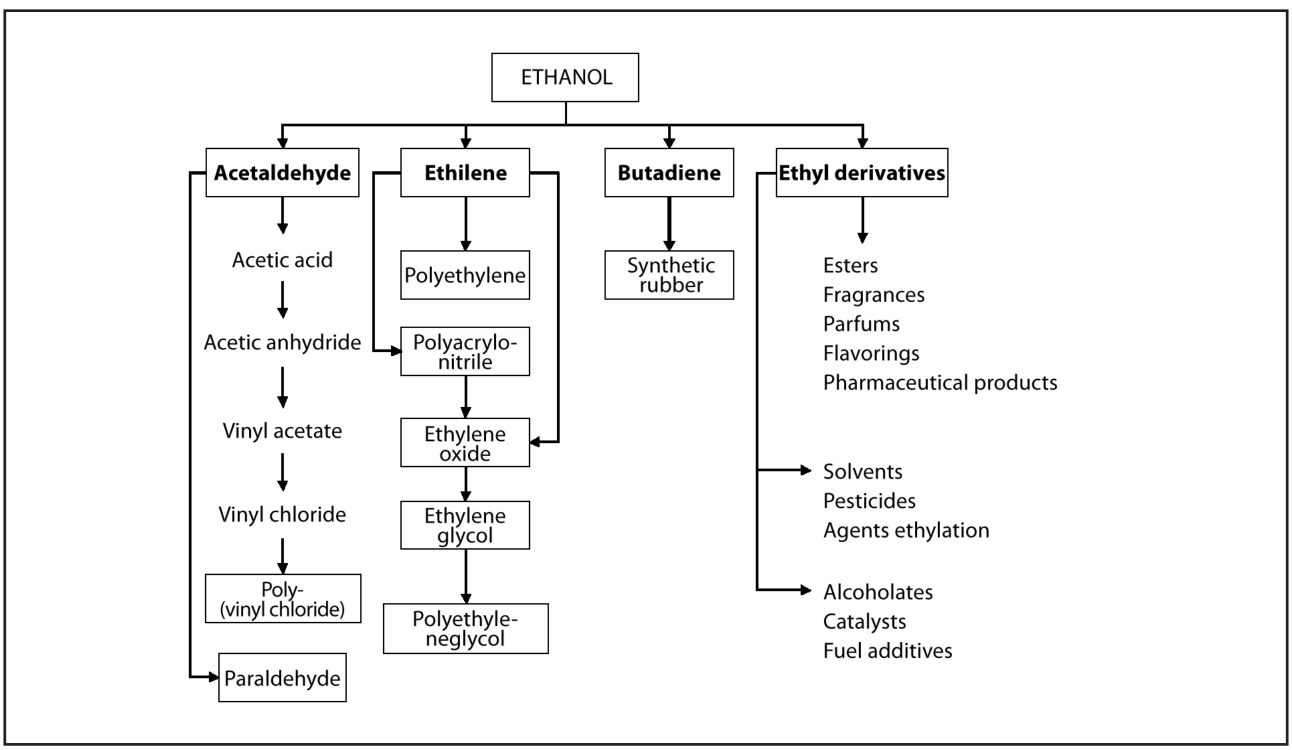


FIGURE 5 Platform chemical derived ethanol.

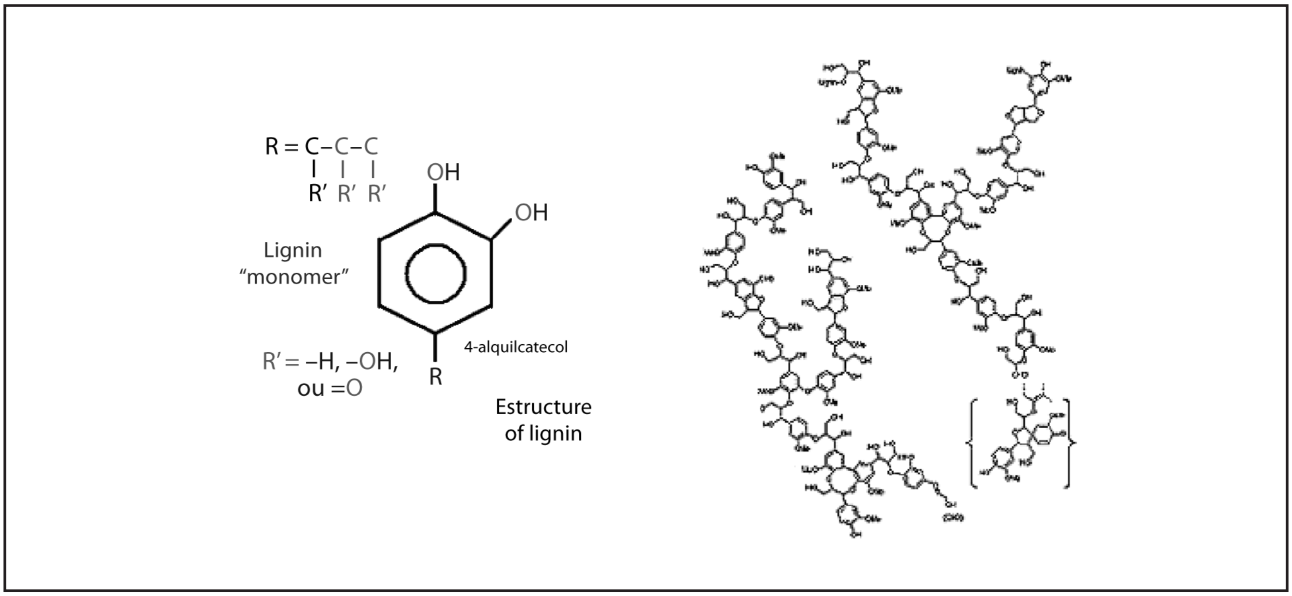


FIGURE 6 Structure of lignin.

as the main difficulties to overcome in order to achieve this goal.

The utilization of lignin can be classified into four groups according to the form of use: polymeric, monomeric or oligomeric (KAMM *et al.*, 2006):

- Polymeric form: as an adhesive for wood, cement additives etc.
- Oligomeric form: as co-reagent in the synthesis of polymers and resins.
- Molecules of low molecular weight monomers: mainly for the synthesis of vanillin and dimethyl sulfoxide.
- Fully degraded to gas, oil or coal via pyrolysis.

The use of lignin has been developed in Brazil in 2007 (mainly IN the monomeric form) to obtain catalytic oxidation products (aldehydes) as vanillin, syringaldehyde and p-hydroxybenzaldehyde, using as a source of lignin a product fraction from DFH – Dedini Fast Hydrolysis process. Certainly these products can add value to the process of separation and hydrolysis of sugarcane bagasse (SALES, 2007).

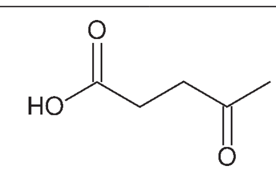
Utilization of cellulose (glucose)

Information about some of the building blocks not so well known in the country, suggested by the study of NREL and obtained from glucose are described below.

Levulinic acid – AL

The levulinic acid (Figure 7) is considered one of the most promising building blocks for chemical synthesis (WERP T., G. PETERSEN, 2004), is also known as acid-oxopentanoic 4, 5-carbon molecule with a ketone group and a carboxylic. The presence of both groups increases the reactivity of the same for the synthesis of a wide range of other chemicals.

The preparation of the AL means controlled degradation of glucose, using the reaction when acids produced from lignocellulosic materials (GIRISUTA B., 2007) (Figure 8).



IUPAC name	4-oxopentanoic acid
CAS	(123-76-2)
Formula	$C_5H_8O_3$
Density	1.1447 g/cm^3
Boiling Point	245 ºC a 246 ºC
Melting point	33 ºC a 35 ºC

FIGURE 7 Properties and structure of acid Levulinic.

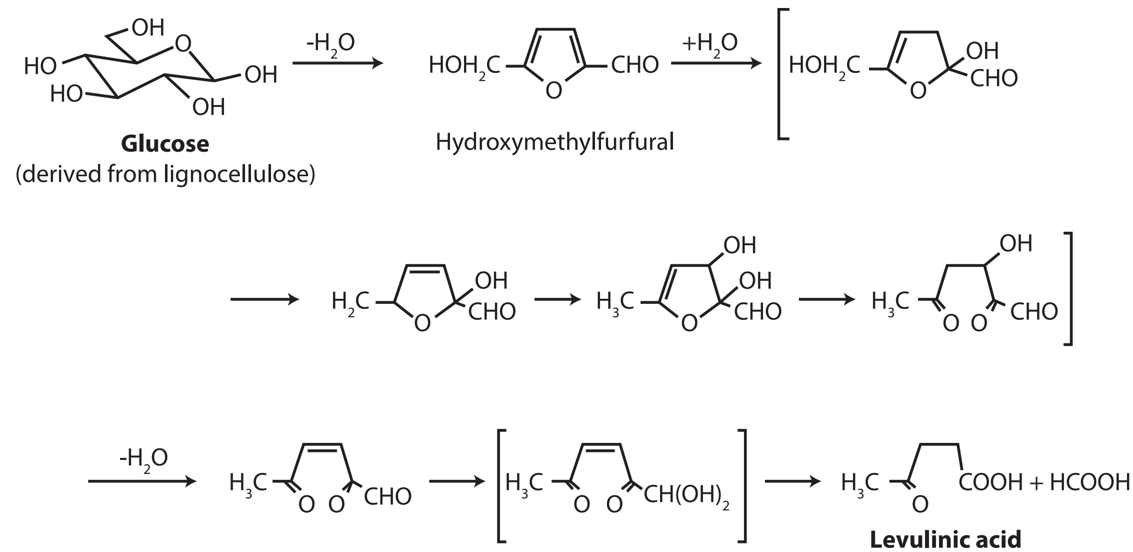


FIGURE 8 Sinthesys of levulinic acid.

According to NREL using this acid as a precursor chemical advantages, as it is a simple preparation, fast and with high yield and low production cost (U.S. $ 4-6/lb). Other authors pointed out the reaction low incomes (close to 70% of theoretical yield) and difficulty in separation. Another difficulty could be the lack of chemical operations from AL, necessitating the development of new chemical routes for the replacement of aromatic compounds and cyclic.

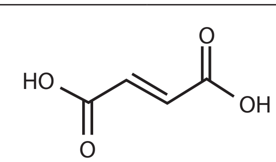
Dicarboxylic acids: fumaric acid

The fumaric acid (Figure 9), as well as succinic and malic acids are diacids that serve as precursors of several routes to obtain other specialized materials and commodities. Reduction reactions of fumaric provide butanediol, tetrahydrofuran and gamma-butyrolactone. The potential of diacids as building blocks is huge, studies suggest that effort should be made to obtain fermentation with minimum productivity of 2.5 g/Lh for the process economically feasible (WERP T., G. PETERSEN, 2004).

Studies were carried out in Brazil from hydrolyzed cassava (LETTER FS *et al*., 1999), resulting in final concentrations of 21.3 g/L. It is possible to expect that similar results can be obtained from lignocellulosic hydrolysates of sugarcane (fraction rich in glucose).

Lactic

The lactic acid can be found in two isomeric forms D-and L-or DL-racemic mixture (this is obtained by chemical synthesis). When produced by fermentation is possible to produce the desired stereoisomer according to the organism and culture conditions used. Its production has been known since the nineteenth century, reaching production in the past decade close to 40.000 ton/



IUPAC name	Levulinic acid
CAS	(110-17-8)
Formula	$C_4H_4O_4$
Density	1.635 g/cm^3
Melting point	287 ºC

FIGURE 9 Structure and properties of fumaric acid.

year (DATTA R., HENRY M., 2006). Fermentation technology in the production of acid is well developed and uses a wide variety of substrates such as molasses, hydrolysed starch and glucose. In general the processes are anaerobic, with yields of 90 mass% and reaching final concentrations of 10% to 13% (LUO J. *et al.*, 2006).

In 2005, he filed a patent on the production of D-lactic acid from hexoses and pentoses derived from lignocellulosic hydrolysates. It was described in this patent production by a bacillus wild (non-recombinant) able to grow and ferment different carbon sources (sucrose, fructose, glucose, xylose, arabinose, mannose, galactose and cellobiose) (SHANMUGAN *et al.*, 2005).

The lactic acid market is booming thanks to its recent applications in the polymer industry, hence the need to develop processes based on abundant raw materials derived from lignocellulose. In Brazil, studies have been developed production from lignocellulosic hydrolysates of malting (MUSSATI SI *et al.*, 2008).

Acrylic Acid

Studies on the feasibility of the biotechnological production of acrylic acid from sugar were described by STRAATHOF, AJ *et al.*, 2005 in the work group ttfranco (Unicamp). These authors suggested that metabolic and genetic engineering should be used to establish the real achievement of acrylic acid on an industrial scale from renewable resources.

Utilization of hemicellulose (xylose)

One of the derivatives of xylose with the greatest potential furfural is produced by acid dehydration of xylose and subsequent closure of the ring, the furfural and three water molecules are produced in this process (Figure 10).

The chemistry of furfural is well known, which in the period of post-war was widely used in the production of derivatives such as furan, THF and adipic acid. Its greatest application in that period was the production of nylon 6.6 (Figure 10) procedure that could return to the bio but with raw material from renewable sources.

Functional foods

Xylooligosaccharides can potentially be used for the prevention of dental caries, reduction of serum cholesterol and stimulating the growth of probiotics (*lactobacillus* and *bifidobacterium*) in the intestinal tract (MENEZES and DURRANT,

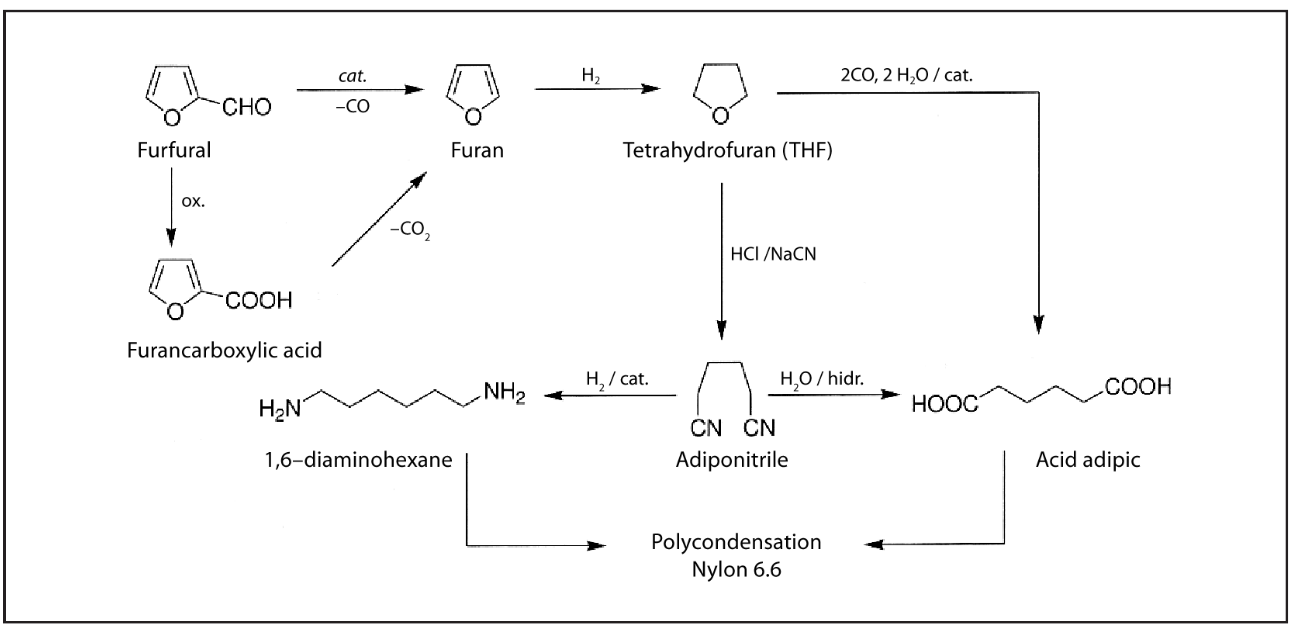


FIGURE 10 Derivatives of furfural.

2008). These compounds can be produced by enzymatic hydrolysis of lignocellulosic materials.

Xylitol

Xylitol is an alcohol-sugar sweetener with capacity similar to sucrose and lower caloric content (2.4 kcal/g compared with 4 kcal/g of sucrose). This sweetener has interesting features due to their commercial properties anticariogenic and metabolism independent of insulin. The production of xylitol can be done through two ways, through a chemical catalytic hydrogenation of xylose using nickel catalyst and high pressure. The second route, the biotech industry, using microorganisms of the genus Pichia sp. is now a reality. Processes based on hemicellulosic hydrolyzate of sugarcane bagasse have been described by the group of the Engineering School of Lorena (WHITE RF *et al.*, 2007).

CONSIDERATIONS AND SUGGESTIONS

The separation (fractionation) of biomass into its major components for subsequent processing is a major obstacle to the establishment of refineries and their development should be encouraged.

In the case of biomass from sugarcane, efficient processes for pretreatment, aimed at separating the cellulose from hemicellulose and lignin, and the different types of hydrolysis (acid, enzyme or in combination) should be encouraged to maximize the utilization of biomass. The lignin, are the two problems to be solved in the process of recovery: maintaining the natural structure of lignin and get it solubilized in high yields. The processes developed to date change to some degree the structure of lignin hindering the process.

Before the material discussed in this article, to obtain hydrolysates/depolymerized biomass with good quality and rich in hexoses and pentoses still needs to be improved, since many problems are still observed in this material, making the steps of fermentation, chemical and enzymatic catalysis.

Routes from glucose should be encouraged (because of their abundance) whereas other microorganisms known to be able to exploit this substrate well known routes and new routes should be encouraged.

Seen a huge deficit in the utilization of xylose, operating the routes that use it and the other pathway should be developed and encouraged as only known microorganisms that can metabolize this route. Other types of catalysts should also be encouraged.

Tools of genetic engineering and analysis of metabolic fluxes should be strongly encouraged to obtain a viable and economical route for obtaining chemicals from renewable sources. Development of fermentation processes, catalytic and chemical needs to be developed to achieve high concentrations and yields of desired biomolecules in line with the economic needs of industry. Integration of different tools will certainly be needed.

Routes to obtain biopolymers from building blocks (existing or brand new) need to be developed, given the huge deficit of polymers from renewable resources in industrial production. Simulation tools for metabolic processes and industrial processes, optimization techniques, modeling decision-making, exploration of "process systems engineering" should also be encouraged to reduce the development time of obtaining the necessary knowledge.

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18

TECHNOLOGY OPTIONS FOR THE FUTURE SUGARCANE BIOREFINERIES

Joaquim E. A. Seabra and *Isaías Carvalho Macedo*

INTRODUCTION

A biorefinery can be defined as an integrated complex that makes a variety of products (liquid fuels, chemicals, electricity or steam) from a variety of feedstocks (Ondrey, 2006); it may be more efficient regarding thermodynamics, economics and the environmental aspects. Ragauskas *et al.* (2006) present a comprehensive discussion on the concepts and possibilities involving biorefineries, focused on the optimized options for biomass utilization for the sustainable production of energy, fuels and materials in both short and long term. With such goal, considerable governmental and private investments have been made in the last year (Genencor, 2003; Oils and Fats International, 2005; Ondrey, 2006), rising the expectation for commercial competitive plants in a short time horizon.

Some analyses of hypothetical biorefineries have been presented, considering the employment of advanced technologies in their mature context. Lynd *et al.* (2005), based on ligno-cellulosic biomass, considered the future co-production of electricity, Fischer-Tropsch (FT) fuels and hydrogen, as well as scenarios for co-production of ethanol-electricity, ethanol-electricity-FT fuels, ethanol-hydrogen, and other combinations of products and protein. In this analysis, some scenarios presented energy efficiencies greater than 70%, and economical competitiveness with conventional process based on oil prices of recent years.

This is an area of great interest. The two key technologies are gasification (conversion to syngas) and the conversion of ligno-cellulose to sugars (Werpy *et al.*, 2005). When the latter becomes commercially competitive, all biochemical processes from sugar to plastics, organic acids, solvents, and others, would not be restricted to the conventional sugar industry, while the gasification technology involves the possibility producing power and also chemicals and fuels via synthesis.

These technologies are not commercial for biomass today, but current sugarcane based ethanol production (with sugar, ethanol and some other chemicals co-produced, as well as power and heat from the residual biomass), is an important precursor of future biorefineries using commercial technologies, though the use of the ligno-cellulosic material is still inefficient. In the near future, with the complete elimination of cane burning practices, huge amounts of cane trash will be available, and its use as energy source along with bagasse will be, possibly, an attractive business option for cane mills. This is already happening in some units of Brazil Center-South.

A recent analysis (Seabra, 2008) investigated the future technology options that might lead to a better use of sugarcane biomass and their possible implications in the mill's context. In addition to the possibilities involving the diversified use of cane's sugars, this study evaluated the use of bagasse and cane trash considering four technologies:

- power generation with conventional steam cycles (current options);
- ethanol production through biomass hydrolysis (options for short, middle and long term);

- power generation through biomass gasification integrated to combined cycles (BIG/GT-CC) (options for middle-long term);
- production of synthetic fuels through biomass gasification (options for middle-long term).

Here we present a comparative resume of the main results of this work, pointing out the effects on the mill's overall performance. In this comparison it is also discussed the value of the bagasse, the influence of feedstock characteristics and the environmental benefits (GHG emissions mitigation) associated to each technology route. In all cases involving advanced-non commercial technologies, it was considered the use of cane trash (40% recovery from the field, i.e. 56 kg_{dry}/t cane) as supplementary fuel to bagasse, recovered at 30 R\$/t_{dry}.

The results presented here must be seen as caution, bearing in mind the different time horizons expected for each alternative to be commercially available, as illustrated in Figure 1. In this analysis we considered that one configuration would be commercially "mature" only after it has been tested in laboratory, pilot and demonstration plant stages, involving the successful operation for more than one year of at least two different plants.

TECHNOLOGY OPTIONS

Sucrose use

The main products of cane industry in Brazil are sugar, which is destined to the food market, and hydrous and anhydrous ethanol, which are mainly used as fuel. Nowadays about 60% of cane's sugars are used for ethanol production (MAPA, 2009). Despite possible variations, sugar and ethanol are, and will probably continue to be, the main products of cane industry in Brazil, though there are innumerous attractive alternatives for the cane's sugars utilization. Amino acids, yeasts and acidulants are only few examples of products with higher added value that could be produced from sucrose and could yield higher revenues to the cane mills. Actually, many of these products are currently commercial in Brazil.

Macedo and Macedo (2005) evaluated the production of dozens of sucrose-derived products that could be produced from sugarcane in a competitive way, thanks to low sugar cost and high availability of energy through the bagasse. Considering market aspects and the interest to evaluate the impacts of such products in the mills' energy balance, four of these products were selected by Seabra (2008)

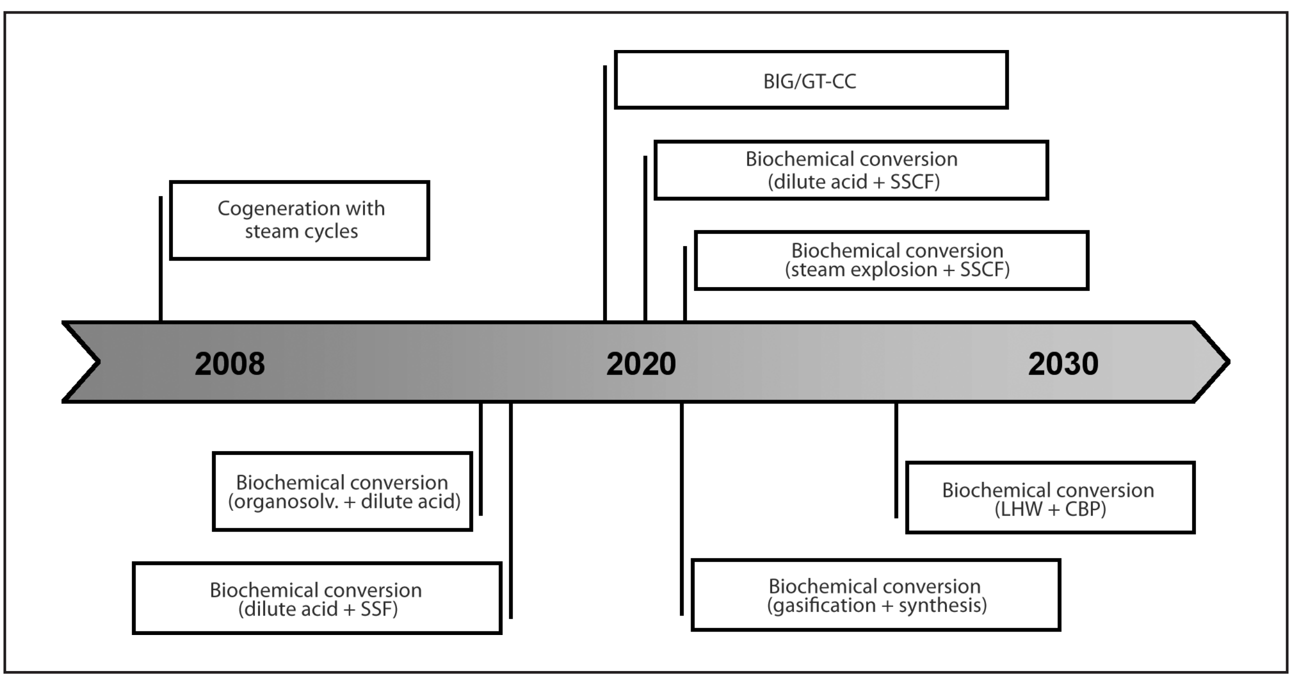

FIGURE 1 Expected evolution of the availability of commercially mature technologies for sugarcane residual biomass use.

for further analysis for the overall performance of an industrial complex producing sugar, ethanol, electricity and a third sucrose-derived product. Considering the assumptions made in the study, except for MSG, the adjacent production of all other products (lysine, yeast and citric acid) lead to more attractive alternatives than the usual option for only sugar and ethanol.

Actually, the diversification of mills' products is the current trend of the cane sector in Brazil, and some groups (e.g., Grupo Zillo, São Martinho, Santo Antônio) have installed plants adjacent to the mills to produce alternative products from sugar. Besides food products, the production of biodegradable plastics from cane's sugars has been tested in a facility adjacent to a mill. For years the PHB Industrial S.A. has operated a pilot plant (60 t/y of polyhydroxybutyrate), adjacent to the Usina da Pedra, which supplies all the sugar, steam and electricity required by the plant. In this case, the biodegradable plastic presents the additional advantage of being produced from renewable sources.

Power generation

The cane processing into sugar and ethanol is an energy intensive process, especially regarding the thermal energy fraction. However, the interest in increasing the biomass surplus in the mills is growing (either for power or other purposes), leading to technology options that enable lower process energy demand. Furthermore, mills are investing in high pressure cogeneration systems (65-90 bar) with condensing-extraction turbines and utilization of totally electrified drivers. And for the short term it is expected that part of the cane trash will be recovered from the field, which would enable the power generation throughout the year. Considering these commercial steam cycles cogeneration systems, the mills' electricity surplus could leap from the current 0-10 kWh/t cane level (pure cogeneration at 22 bar/300 °C) to more than 140 kWh/t cane (CEST, 90 bar/520 °C, using bagasse and trash), and with competitive costs for the current electricity market.

For the future, gasification technology integrated to combined cycles (BIG/GT-CC) is expected to increase considerably the electricity generation efficiency. Despite the demonstration efforts, it is expect that such technology might be commercially available only in the middle to long term. Among the alternatives that have been tested, the near atmospheric gasification with indirect heat and pressurized gasification with oxygen injection attracts special attention. In the case of cane mills with reduced steam consumption (340 kg/t cane) and using cane trash (40% recovery) as supplementary fuel to bagasse, these configurations would lead to electricity surpluses of 194 and 203 kWh/t cane, for near atmospheric and pressurized systems, respectively. In general, the former is indicated to lower scales, while the pressurized gasification is more appropriate for larger scale units. Even though the sizes involved in the mills context justify the adoption of pressurized systems, the electricity costs would not be competitive with current prices in Brazil, despite the low biomass cost. Table 1 summarizes the main results presented by Seabra (2008).

TABLE 1 Electricity generation and costs[a].

Configuration	Electricity surplus (kWh/t cane)	Cost (R$/MWh)
Steam cycles[b]	—	—
65 bar/480 °C	133	97
90 bar/520 °C	145	99
BIG/GT-CC[c]	—	—
BIG-ATM(CO)	184	142
BIG-ATM(AG)	194	149
BIG-PR(CO)	192	144
BIG-PR(AG)	203	149

[a] Costs were estimated considering retrofit projects in existing mills (originally operating with 22 bar/300 °C cogeneration cycle; only backpressure turbines; mill's energy demand – steam: 500 kg/t; electricity: 12 kWh/t cane; mechanical power: 16 kWh/t cane). In all cases it was considered: reduction of steam consumption to 340 kg/t cane; electric drivers; use of trash (40% collection from the field) in addition to bagasse; electricity generation during 11 months per year. See details in Seabra (2008).

[b] Current commercial options.

[c] It was considered atmospheric (BIG-ATM) and pressurized (BIG-PR) gasification systems, as presented in Jin *et al*. (2006) and Consonni and Larson (1996a and b). For both cases two configurations were evaluated: one conservative (CO, in which process steam demand is supplied by 90 bar/520 °C boilers) and another aggressive (AG, aimed at the maximum electricity generation, in which part of the process steam demand being supplied by the HRSG of the gas turbine cycle).

Fuels production

Except for sugarcane, the commercially available technologies for ethanol production today (from starch and sugars) present narrow energy and environmental benefits. Despite its advantages, sugarcane is not a feasible crop for all regions of the world, what has encouraged many countries of the North Hemisphere to pursue technology routes to produce an efficient biofuel, for both environmental and economic reasons. Nowadays the predominant idea is that, for the near term (5 to 10 years), ethanol production from the hydrolysis of ligno-cellulosic materials is the best option.

The production of cellulosic ethanol through biochemical conversion is not a mature technology today, and different stages must yet be verified in the development of more efficient and less capital intensive processes. In the short term, processes based on organosolv treatment with acid hydrolysis and enzymatic processes with dilute acid pretreatment are expected to be commercially available. These options would enable, respectively, yields of 20 and 32 L of cellulosic ethanol per tonne of cane. For the medium term, the SSCF configuration combined with the dilute acid pretreatment or steam explosion may be available, which could present yields around 37 L of cellulosic ethanol per tonne of cane. Finally, in the long run, the consolidated bioprocessing is expected to be available, which could enable the production of almost 40 L of cellulosic ethanol per tonne of cane. Again, it is important to point out that these estimations consider the use of cane trash (40%) as supplementary fuel to bagasse. As for costs, significant evolution is also expected, but even for the short-term configurations, the values would be competitive with current cane ethanol costs, due to low biomass cost the credits derived from the electricity surplus.

Alternatively to the biochemical route, different biofuels can be produced via thermochemical conversion, through biomass gasification and conversion of syngas. As well as for the BIG/GT-CC technology, this option is also expected to be commercially available only in medium-long term, and demonstration efforts are still needed. Among the several alternatives, Seabra (2008) compared the production of Fischer-Tropsch gasoline and diesel, DME and ethanol. Based on pressurized gasification with oxygen injection, the yield for FT liquids production would be around 490 MJ/t cane, while for DME the yields would be 350 MJ/t cane and 750 MJ/t can, respectively for *once-through* and unconverted gas recycling configuration alternatives. For ethanol production, based on an atmospheric gasification with indirect heat, the yield would be 570 MJ/t cane. Except for DME, the costs of these biofuels, as well as for the biochemical conversion technology, would also be competitive with the current values due to the low biomass cost and the credits associated to electricity surplus. Table 2 presents a summary of the results.

TABLE 2 Estimated yields and costs of biofuels derived from cane residual biomass[a].

Configuration	Fuel yield (L/t cane)	Cost[b] (R$/m³)
Biochemical conversion (ethanol)		
Organosolv + dilute acid	20	680
Dilute acid + SSF	32	480
Dilute acid + SSCF	37	390
Steam explosion + SSCF	37	300
LHW + CBP	40	270
Themochemical conversion[c]		
FT liquids	5.9 (gasoline) 8.6 (diesel)	~1,075
DME-OT	12.3 kg/t cane	820 R$/t
DME-RC	26.5 kg/t cane	980 R$/t
Ethanol	25.6 (ethanol)	455
	4.4 (other alcohols)	

[a] In all cases it was considered conversion process integrated to mill with reduced steam consumption (340 kg/t cane), electric drivers, and that uses trash (40% collection from the field) in addition to bagasse. See details in Seabra (2008).
[b] Cost relative to the fuel derived from the ligno-cellulosic material. The study considered that the costs of cane juice derived products would not be affected, and all the revenue related to the sales of electricity surplus would be attributed as credit to the cellulosic fuel.
[c] The analyses were based on conversion processes presented in Larson *et al.* (2006) and Phillips *et al.* (2007).

Even for configurations aimed at the production of fuels, it is interesting for the mills to be able to produce some electricity surplus, because of the characteristics of the Brazilian power sector. Furthermore, electricity is an important co-product, which is largely responsible for the competitiveness of the biofuels/processes considered. As indicated in Figure 2, even for cases with high fuel yields, the electricity surplus is considerably high. In the "worst" case, the electricity surplus would be around 30 kWh/t cane, which is about three times greater than the current levels. This stresses the importance that the sugarcane mills may have in the Brazilian power sector in the future.

ECONOMIC ASPECTS

The improvement of cane energy use does not necessarily lead to higher profits, even though the better use of the ligno-cellulosic material represents an attractive business option for most of the configurations presented here. In extreme cases, the profit associated to the ligno-cellulosic products could represent the largest share of the total mill's profit, while some configurations would not be economically attractive at all. This result, however, is strongly dependent on the products price considered, so that small combined changes may lead to totally different conclusions. Regardless, it is clear that the ligno-cellulosic derived products will play an important role in context of the future sugarcane mills.

In this case, the definition of the value of the sugarcane residual biomass is therefore relevant. Today, bagasse is treated as an industrial residue of cane juice processing, and its costs is generally assumed as zero. However, as different alternatives (with different profitability) for its use rise, it is important to know the value of this biomass. Figures 3, 4 and 5 show the results of such analysis for the technologies considered here. The bagasse value was calculated as the gross profit of the mill (before income taxes) related to the ligno-cellulosic products divided by the total bagasse available at the mill.

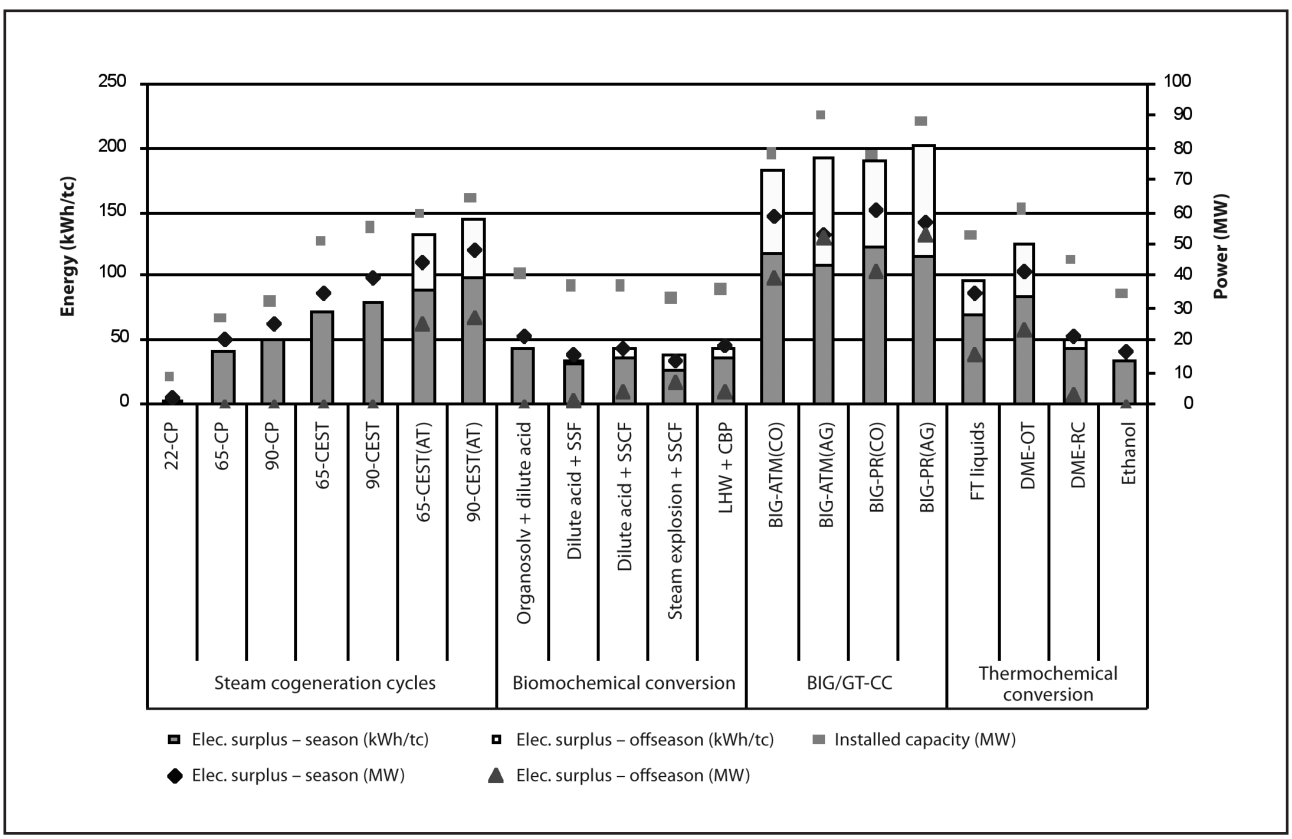

FIGURE 2 Mill electricity generation for different technology alternatives for biomass use (reference scale: 2 Mt cane/year mill)

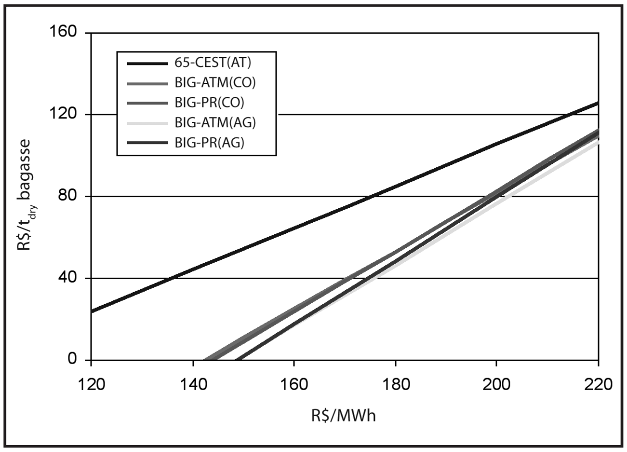

FIGURE 3 Bagasse value for electricity generation.

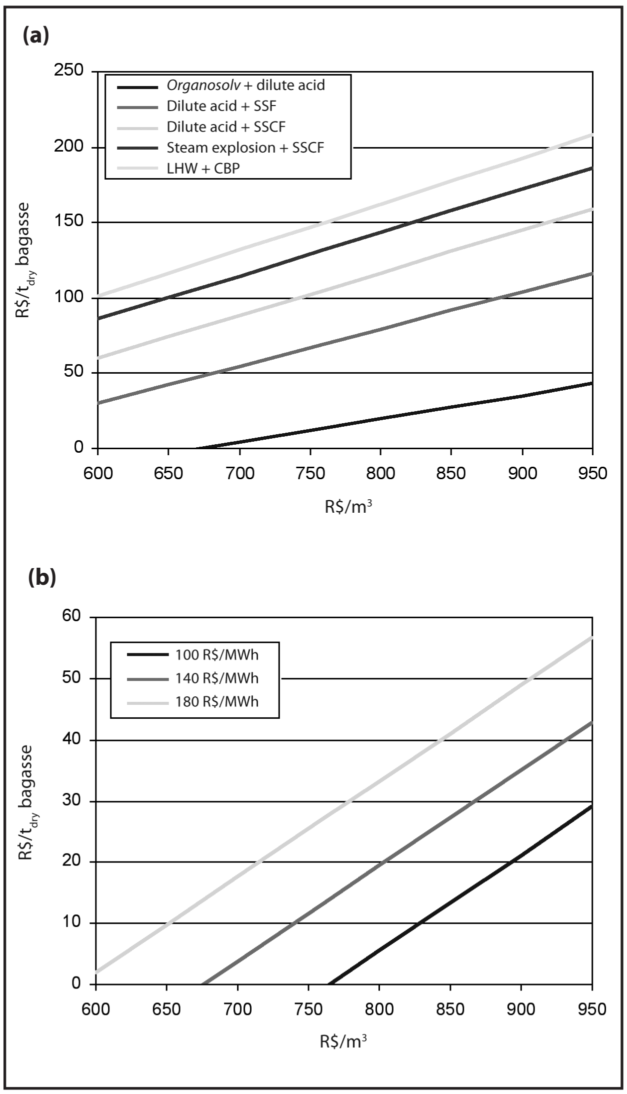

FIGURE 4 (a) Bagasse value for ethanol production via biochemical conversion, and (b) influence of electricity price for the short-term configuration (Organosolv + dilute acid).

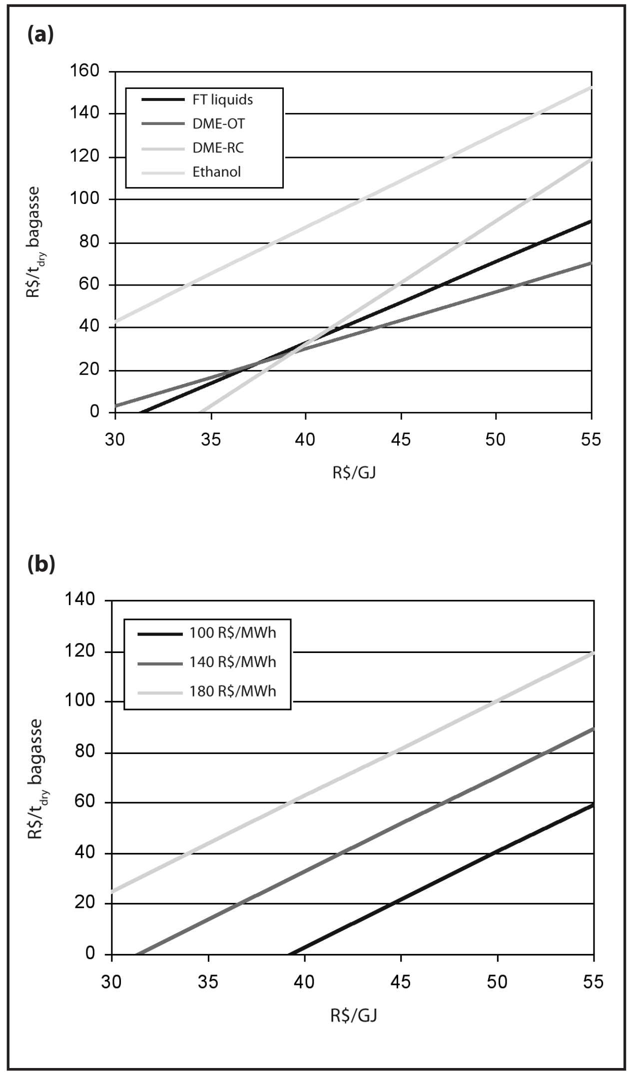

FIGURE 5 (a) Bagasse value for fuels production via thermochemical conversion, and (b) influence of electricity price for FT liquids production.

These results must be compared with caution, since they involve technology options that would be available in different time horizons. For the short term, the options for biomass use lie on ethanol production via biochemical conversion and electricity cogeneration with steam cycles. Such alternatives would lead, respectively, to bagasse values of 15 and 45 R$/t$_{dry}$, considering the current electricity and ethanol prices. But for the enzymatic route, the bagasse value would reach 70 R$/t$_{dry}$, if the yields expected for this configuration were actually achieved. In the long run, when all alternatives would be commercially available, the ethanol production via biochemical conversion would present the higher bagasse value, estimated as 150 R$/$t_{dry}$.

For electricity generation, despite the greater efficiencies, the high costs associated to the BIG/GT-CC technology impose an important barrier for the adoption of this option in the mills context. The biomass gasification for fuels synthesis, however, represents an interesting option for the medium-long term, especially considering the expectation for higher oil prices in the future. Furthermore, it is expected that the technological hurdles associated to this route could be overcome more easily than those related to the biochemical route, once previous gasification demonstration efforts have been conducted, and the remaining challenges of the thermochemical conversion are mostly associated to process engineering. For the biochemical route, on the other hand, current conversion yields and residence times are far from the projected values for the future, and many science level issues must be addressed yet.

For both cases, it is important to remark the sensitivity of their competitiveness to electricity sales, as illustrated in Figures 4b and 5b. The influence of cane trash costs in this analysis must be stressed as well. Those bagasse values can only be achieved if cane trash is recovered from the field at low costs and with appropriate characteristics to be used as fuel or raw material in the mill. This is still a technological challenge today, but it is expected that for the short term the most suitable route for trash recovery and processing will be fully developed. Despite the uncertainties regarding trash costs, for the range of values expected (normally less than 80 R$/$t_{dry}$), the final products costs would not be very sensitive to the trash cost, as it represents only about 30% (in this analysis) of the total ligno-cellulosic material processed.

INFLUENCE OF THE CHARACTERISTICS OF THE RAW MATERIAL

In the last 20 years, the development of new cane varieties more adapted to specific soil and climate conditions, associated to better agricultural practices, has progressively enhanced cane productivity and quality (sugar content). During this period, the development of new varieties was essentially aimed at the enhancement of pest resistance and sugars productivity per hectare. However, as technology progresses and ligno-cellulosic products become more attractive, the development of high fiber content varieties may be also attractive. Today, varieties with high fiber content are still not desired, as they compromise the cane crushing capacity and lead to higher sugar losses in the juice extraction step. But the better use of the ligno-cellulosic material through advanced technologies may change this logic.

A sensitivity analysis presented in Seabra (2008) compares the impact of different cane's sugar and fiber contents on mill's performance, considering three different uses for bagasse (electricity cogeneration with steam cycles, biochemical conversion and FT synthesis). The analysis shows that, regarding the economics, the additional sugar loss due to the higher fiber content would be offset by the additional revenue related to electricity generation through the steam cogeneration cycle in the short term. In the long run, the high ethanol yield of the biochemical conversion technology would also make the production of ligno-cellulosic products more advantageous, while for the FT synthesis the preference for sugar instead of fiber prevails.

Despite that, reaching high fiber commercial varieties is not likely in the short term, although it is clear the interest for their utilization in the pool of varieties of the future sugarcane biorefineries. Independently, the average cane fiber content at the mill will probably rise in the next years, due to the higher impurity levels associated with the unburned cane harvesting. In this case, increasing the cane trash recovery level is one option to delivery more ligno-cellulosic material to the mill; but it is important to stress the additional logistic costs and higher mineral impurity levels associated to this alternative.

ENVIRONMENTAL ASPECTS: GHG EMISSIONS

The environmental benefits of sugarcane ethanol, considering the replacement of oil gasoline and greenhouse gases (GHG) emissions mitigation, are already acknowledged since the publication of the first studies involving the energy balance and GHG emissions in the ethanol lifecycle (Silva *et al.*, 1978; Macedo and Nogueira, 1985; Macedo, 1992). These balances were recently updated (Seabra, 2008; Macedo *et al*. 2008), using 2005/2006 average values related to 44 mills of Brazilian Center-South Region. Besides methodology and database update, the study also assessed a projected 2020 scenario, considering the trends for the sugarcane sector and the availability of advanced technologies for biomass use.

For 2005/2006 values, the energy ratio in ethanol production was 9.4, which is considerably greater than the value verified with 2002 data (Macedo *et al.*, 2004). The ethanol lifecycle emissions were evaluated at 269 kg CO_2eq/m^3 anhydrous, including the emission credits of ethanol co-products (bagasse and electricity). For the future, the complete elimination of burning practices during cane pre-harvesting will lead to considerably lower emission levels (see Tables 3, 4 and 5). Actually, it is expected that the emission credits related to co-products will match (or even surpass) the emissions in the ethanol production and distribution. In the 2020 Steam cycle Scenario (based on conventional cogeneration, which is recognized as the most likely scenario), for instance, the employment of only today's commercial technologies would lead to ethanol lifecycle emissions of -409 kg CO_2eq/m^3 anhydrous.

The potential for emissions mitigation of sugarcane ethanol is even higher in the future. For the 2020 Steam cycle Scenario, the net avoided emission associated with the utilization of 1 m^3 of ethanol as E25 blend would be 2.5 t CO_2eq. In terms of sugarcane biomass, it means that the products derived from 1 tonne of cane (plus some trash) would lead to an emission reduction of 233 kg CO_2eq. In the same way, 1 hectare of cane would be responsible for the mitigation of 18.4 tonnes of CO_2eq per year, considering the utilization of the different sugarcane products assumed in the study.

It must be stressed that, in this analysis, the direct and indirect emissions related to land use change were assumed as zero. For the particular

TABLE 3 Energy balance for different technology options (MJ/t cane).

	2005/2006	2020 Scenarios[a]			
		Steam cycle[b]	Biochemical conversion[c]	BIG/GT-CC[d]	Thermochemical conversion[e]
Fossil energy ***Input***	234.2	262.6	267.8	264.1	264.3
Cane production	210.6	238.5	237.3	238.5	238.5
Cane processing	23.6	24	30.6	25.5	25.8
Renewable energy ***Output***	2,198.4	3,171.1	3,247	3,755.8	3,367
Ethanol	1,926.4	2,060.3	2,879.5	2,060.3	2,060.3
Electricity surplus[f]	96	1,110.8	367.5	1,695.5	814.3
Bagasse surplus	176	0	0	0	0
Synthetic fuels					492.3
Energy ratio	9.4	12.1	12.1	14.2	12.7

[a] Scenarios refer to different options for cane residual biomass use.

[b] 65 bar/480 ºC.

[c] Dilute acid + SSCF.

[d] Pressurized gasification in aggressive configuration (BIG-PR(AG)).

[e] FT liquids.

[f] Values are equivalent to the primary energy required by a Natural Gas thermoelectric plant to produce the same electricity surplus.

Source: Seabra (2008).

TABLE 4 GHG emissions associated to ethanol production for different technology options (kg CO_2eq/m^3 anhydrous)[a].

	2005/2006	2020 Scenarios			
		Steam cycle	Biochemical conversion	BIG/GT-CC	Thermochemical conversion
Emissions					
Fossil fuels	263	264	205	265	265
Trash burning	84	0	0	0	0
Soil emissions	146	129	92	129	129
Sub-total	**493**	**393**	**297**	**395**	**395**
Credits[b]					
Electricity surplus	-74	-803	-190	-1,225	-588
Bagasse surplus	-150	0	0	0	0
Synthetic fuels					-451
Subtotal	**-224**	**-803**	**-190**	**-1,225**	**-1,039**
Total	**269**	**-409**	**107**	**-831**	**-645**

[a] Emissions for hydrous ethanol are about 5% less than the values for anhydrous ethanol.
[b] In the future, considering the consolidation of sugarcane biorefineries, it will more appropriate to use allocation methods for the evaluation of ethanol co-products credits. Emissions mitigation associated to ethanol use considering an allocation methodology is presented in Macedo and Seabra (2008).

Source: Seabra (2008).

TABLE 5 Avoided emissions (t CO_2eq/m^3 hydrous or anhydrous ethanol).

	Ethanol use[a]	Avoided emissions[b]	Net emissions[c,d]
2006	HDE	-2	**-1.7**
	E25	-2.1	**-1.8**
2020 – Steam cycle	HDE	-2	**-2.4**
	FFV	-1.8	**-2.2**
	E25	-2.1	**-2.5**
2020 – Biochemical conversion	HDE	-2	**-1.9**
	FFV	-1.8	**-1.7**
	E25	-2.1	**-2**
2020 – BIG/GT-CC	HDE	-2	**-2.8**
	FFV	-1.8	**-2.6**
	E25	-2.1	**-2.9**
2020 – Themochemical conversion	HDE	-2	**-2.6**
	FFV	-1.8	**-2.4**
	E25	-2.1	**-2.8**

[a] HDE: hydrous-dedicated engines; E25: ethanol-gasoline blend with 25% anhydrous ethanol; FFV: flexible fuel vehicles (ethanol-gasoline), in Brazil.
[b] Avoided emissions (negative values) due to ethanol substitution for gasoline, considering fuel equivalences in Brazil (see Macedo *et al*., 2008).
[c] Net emissions = (Avoided emissions) + (Ethanol production emissions). Note that negative values indicate emissions mitigation.
[d] See note "a" in Table 4.

Source: Seabra (2008)

conditions of cane ethanol expansion in Brazil in the last years and the projections for 2020, this hypothesis is justified (Zuurbier and van de Vooren, 2008).

FINAL CONSIDERATIONS

Today we can say that the current Brazilian sugarcane mills are important precursors of the future biorefineries, using sugarcane biomass to produce different products, but with a still inefficient use of the ligno-cellulosic material. Besides sugar and ethanol, several other products with higher added value (e.g., amino acids and food additives) can be produced from cane's sugars in a competitive way, due to the low cost of sugar and large energy availability.

As for the ligno-cellulosic fraction, current advanced cogeneration systems can lead to a better energy use, and also represent an attractive business option for cane mills. In the middle-long term, the biochemical conversion and gasification technologies will enable even higher efficiencies, but not necessarily with as good economic performances. For the options and conditions assumed here, the ethanol production via biochemical conversion is the most attractive alternative, though it is also the one that possibly presents the largest technical challenges to reach the complete mature level. In general, we can say that all these alternatives have an interesting potential to be adopted in the Brazilian sugarcane mills thanks to the large biomass availability at relatively low cost. It is also important to point out that even greater performances could be achieved through the full integration of these technologies with the mill.

Finally it must be remarked the great environmental contribution that the optimized use of cane biomass can represent. Nowadays, cane ethanol is one of the best alternatives to mitigate GHG emissions, and its environmental benefits shall improve, as mills use more efficiently the residual cane biomass. This, added to the social-economic benefits promoted by the sugarcane sector activity, underlines the contribution of this sector for the sustainable development.

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19

LOGISTICS FOR ETHANOL TRANSPORT

Mirna Ivonne Gaya Scandiffio

INTRODUCTION

Brazil holds a competitive advantage when the issue is cost of ethanol production, due to favorable climate conditions and technological advances as result of over thirty years experience since the National Program for Ethanol, the Proálcool.

This competitiveness, however, faces a growing threat as far as cost of logistics for transportation is concerned, mainly due to lack of investments in infrastructure, harming the transportation of ethanol in the country, aggravated when it comes to exporting the renewable fuel.

Recently, the production of ethanol from sugarcane is receiving considerable attention from national and international investors, for two main reasons: the competitive price of ethanol when confronted with the increasing, and uncertainties, of oil prices, and secondly to the growing perception with its environmental benefits. Still, the growing demand for hydrated ethanol since the introduction of flex fuel vehicles in Brazil in 2003, which already represents a similar volume of commercialization to those of gasoline, together with advances in research on second generation ethanol, are relevant factors to bring back investments for expanding the production of sugarcane ethanol.

And the decision for investing to expand supply of ethanol needs to be thought considering other important aspects, not only based on supply and demand analysis. For example, new production units should certainly consider the proximity or access to the consumer markets, that is, the existing infrastructure allowing better use of different modes of transport for delivering the ethanol, such as pipelines, waterways, railways and roads. Also, the proximity of electrical power substations is an important variable to be considered as the mills present a growing potential for commercialization of bioelectricity surplus from manufacturing process, besides sugar and ethanol, which demands a better use of bagasse and trash.

One of the scenarios recently evaluated in a study carried out by Nipe[1] considered the possibility of substituting 10% of world demand of gasoline by sugarcane ethanol produced in Brazil, showing the potential that the country has to produce, annually, of 205 million of cubic meters (mln m^3) of ethanol by 2025. This expansion would take place in areas more distant to the consumer market increasing the need for better infrastructure and logistics in order to guarantee the delivery of ethanol to distribution hubs and exporting ports.

To define better alternatives and more efficient use of modes of transportation for ethanol, giving priority to pipelines, waterways and railways, studies must be conducted with aid of computerized tools in order to bring out quantitative data to the process of decision taking. Mathematical modelings should be developed to analyze the behavior of the diverse variables present in the logistics for ethanol transportation. The socio-economic impacts, as well as the environmental ones, should be contemplated in the developed models.

[1] Nipe: Interdisciplinary Center for Energy Planning. Study sponsored by the Center for Management and Strategic Studies (CGEE).

ETHANOL PRODUCTION AND STORAGE

Brazilian sugarcane sector is characterized by the existence of two types of distilleries, the autonomous (dedicated only to ethanol production), and the annexed or mixed units, producing both sugar and ethanol. There are also some few mills dedicated exclusively to sugar production. Currently, sixty two percent of the existing mills are mixed and only 38% produce only ethanol (MAPA, 2008).

It was with the launch of the Proálcool, in 1975, that distilleries emerged to produce fuel ethanol from sugarcane juice. Before the Proalcool, ethanol was produced from molasses, a byproduct derived from the sugar production process. To these existing mills, distilleries were annexed to produce ethanol. This was particularly the case in São Paulo, where Copersucar, a leading cooperative of mills, defended that ethanol production should be thought in terms of energy security, while the then Institute of Sugar and Alcohol (IAA) was concerned that use of the same sugarcane for producing ethanol might harm the exports of sugar and the profits, mainly in the Northeast region of the country (SCANDIFFIO, 2005).

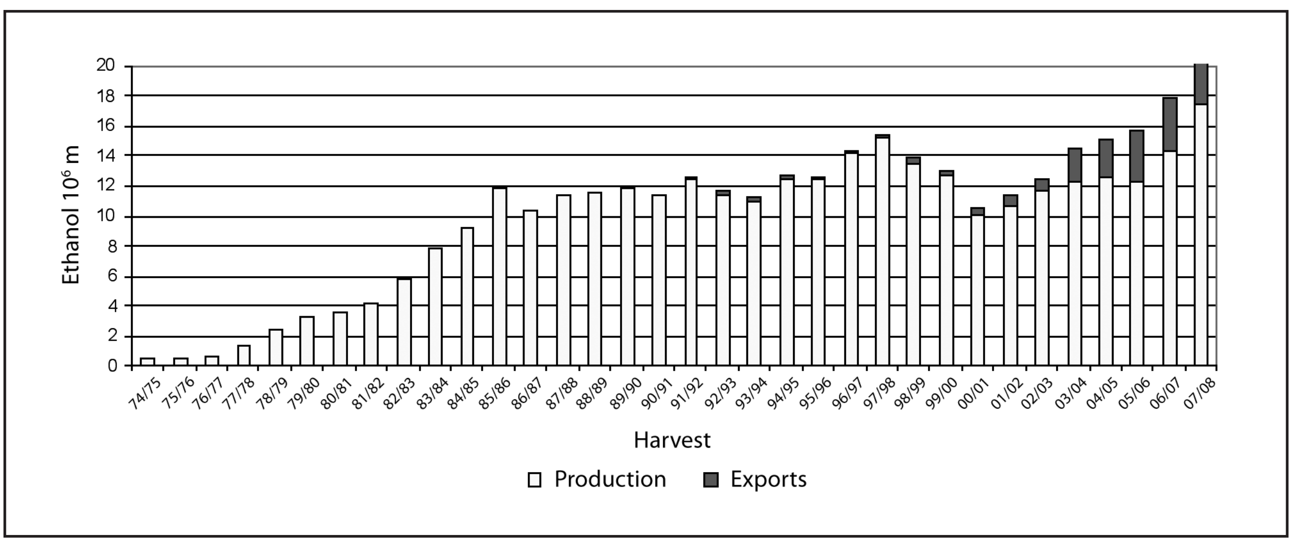
To have an idea of the Proálcool impact, in its first phase, the production of ethanol increased from 664,000 m^3 in the 1976/1977 harvest to 3.7 mln m^3 in the harvest of 1980/1981. This raise made possible to offer enough anhydrous ethanol to be mixed to gasoline, in the proportion of 15 to 20% (FURTADO and SCANDIFFIO, 2006).

The success of the Proálcool's first phase and the rising of the second oil crisis forced the Federal Government to adopt a set of measures such as the configuration of an institutional arrangement, subsidized financing for new units to produce ethanol, creation of an storage system, transportation and distribution of hydrated ethanol to fuel dedicated ethanol vehicles, and giving to Petrobras – the Brazilian Oil Company – a leading roll.

The automobile industry was also called to offer vehicles fueled with hydrated ethanol. As consequence, in 1985, the country produced 11.5 mln m^3 (Figure 1) and the dedicated ethanol vehicles represented 37.8% of total fleet of the country in 1989.

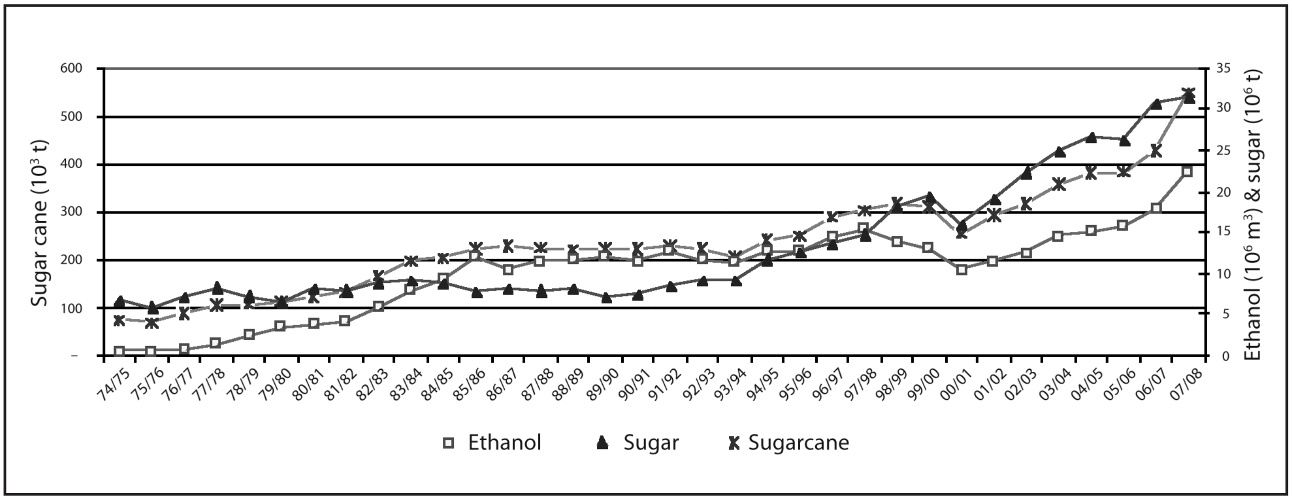
Logistics distribution and transportation, by then, had as the prime objective to supply the domestic market rather than the export market. It should be pointed that the Government set, through the IAA, quotes for production and selling prices for the sector's products.

The production of ethanol remained stagnated to around 12 mln m^3 from the half of the decade of 1985 to 1995 (Figure 2) and dropped to 10.4 mln m^3 at the beginning of the current century.



Source: Elaborated from MAPA (2008) and SECEX (2008).

FIGURE 1 Evolution of production and exports of fuel ethanol in Brazil (harvests 1974/75 to 2007/08).



Source: Elaborated from MAPA (2008).

FIGURE 2 Brazilian evolution of sugarcane, sugar and ethanol production (harvests 1974/75 to 2007/08).

Early in 1990's, the 1000 cylinders vehicles fueled with gasoline were introduced in Brazil and most of the ethanol production would be anhydrous to be mixed to gasoline (FURTADO and SCANDIFFIO, 2006).

After the market opening, established by government Collor in 1990, production of sugarcane grew significantly and between 1992 and 1999 sugar exports increased placing Brazil as worldwide leading position of sugar supplier. Only from the beginning of the current decade that ethanol has recovered its production, as shown in Figure 2.

Sixty five percent of Brazilian sugarcane is produced by the mills owners, who own the land or rent it. The other 35% are delivered to the mills by approximately 70.000 independent sugarcane producers.

The industrial unit, the mill, is composed by the sugarcane reception area, preparation, milling, juice treatment, sugar production, ethanol distillery, effluent disposal and storage of products.

Ethanol is then stored in tanks inside the mills – approximately 60% of total production. The mills produce ethanol seven months of the year but can deliver ethanol over twelve months, depending on the storage capacity (CGEE, 2006).

Considering a scenario of a large increase of ethanol demand, in a competitive environment, storage becomes a strategic issue for its competitiveness. Thus the cost of storage must be considered while, at the same time supply guarantee is also a key issue for the buyer.

BRAZILIAN EXPORTS OF ETHANOL

The Ethanol Prospective Study (CGEE, 2007), previously mentioned, had the objective to analyze, in Phase 2, the Brazilian potential to substitute, in 2025, 10% of world gasoline demand by ethanol from sugarcane, which means, projecting accordingly, a production of 205 mln m^3 to supply the external market.

The Project evaluated the most adequate climate and soil conditions and selected seventeen areas to increase the production of sugarcane without irrigation. First, all environmentally sensitive areas, such as Amazon, Pantanal and Atlantic Forest, were eliminated. Further, forests, military and Indian reserves, and areas with slopes greater than 12% which difficult mechanized cane harvesting, were also excluded. Finally, all permanent and temporary crops within the 623 counties considered in the 17 selected areas, were also analyzed in detail. The evolution of those crops was projected by 2025, so that growing sugarcane for ethanol production would not substitute other crops.

As the best option for transportation of ethanol is pipelines, the Ethanol Prospective Study selected areas which would be able to include a group of distilleries, a *cluster*, capable of producing a significant volume of ethanol to justify the construction of pipelines based in economics.

These *clusters* would aggregate about 210,000 people, who will need housing, education, health etc., and other amenities such as bakeries, drugstores etc.

One of the main concerns of the Ethanol Prospective Study was the minimization of regional differences for producing ethanol. In the first stage, the Northeast would increase its producing share of less than 10% in the harvest 2006/2007 to 34% in 2015, and then reach around 50% of the country's ethanol production by 2025. This means that the North-Northeast region has an ethanol export capacity of 92 mln m^3 and the Center-South region, 113 mln m^3.

To bring all this volume to the ports for exporting the renewable fuel, Brazil needs to implement a new logistics structure.

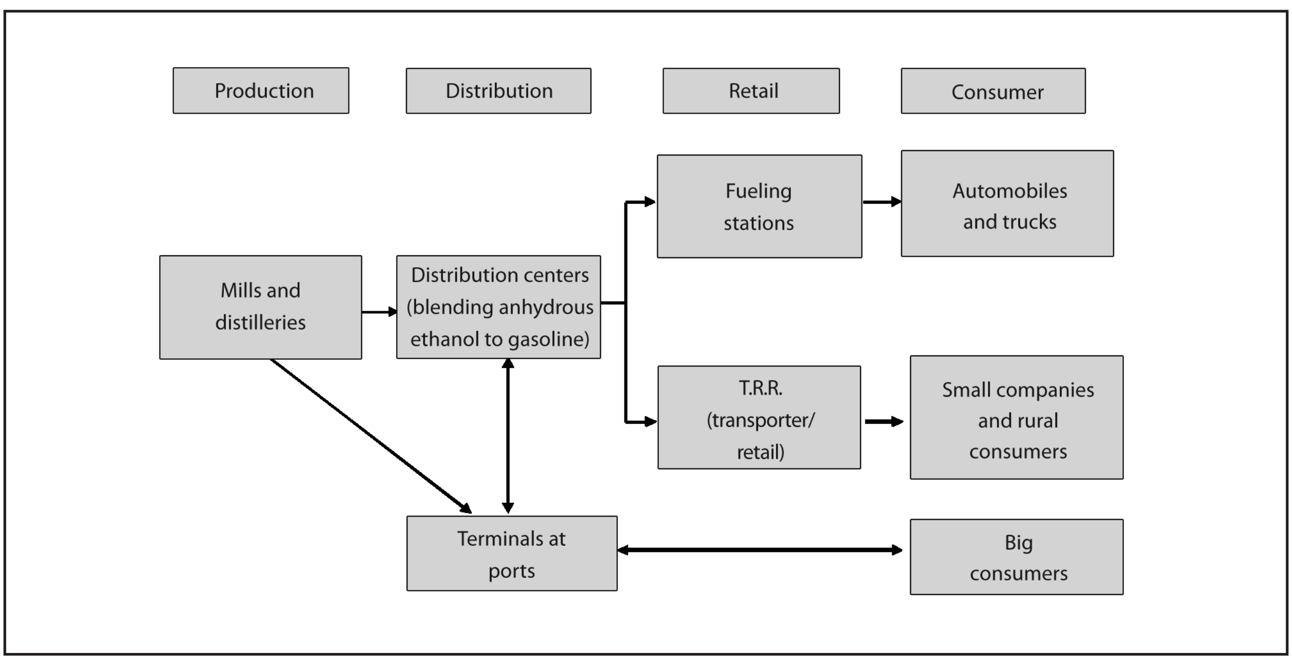
DISTRIBUTION OF ETHANOL

Distribution of Brazilian ethanol begins at the producing mills, both in annexed or independent distilleries. The mills deliver the fuel to the Distribution Bases or, in the case of exports, to the exporting Ports (Figure 3).

The National Agency for Petroleum, Natural Gas and Biofuels (ANP) states in its Article 8, Decree n. 116, dated July 05 2000, that only Distributors are to supply Fuel Stations (Retail). Subsequently, Distribution companies have an important role in the supply chain of fuels, being responsible for supplying gasoline and ethanol, storage, blending anhydrous ethanol to gasoline, transportation and commercialization, and even the ethanol quality control.

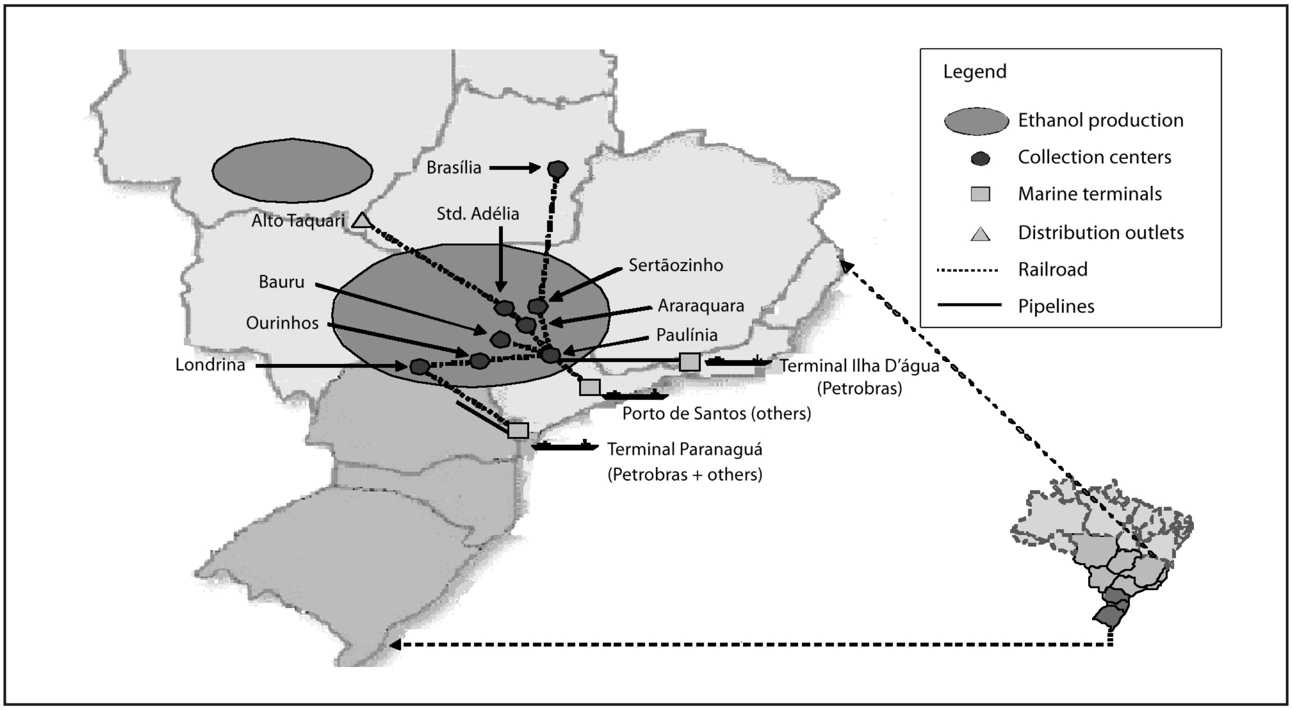
The localization of the distribution bases is strategic. From this point on, ethanol will be placed in the best from of transportation to reach the consumer. Today, approximately 90% of ethanol transport is by trucks-tanks, not because it is the best form, but because of lack of efficient alternatives to transfer ethanol from one mode of transport to the other, considering the time needed in each stage for transferring and transporting bioethanol.

As stated by ANP, the Distributors need to have large storage capacity e.g. in oil derivates, ethanol and biodiesel, and with flexibility to use their storage tanks. Regarding logistics, according to SINDICOM (2008), distributors bring ethanol to primary centers for blending anhydrous ethanol into gasoline, which tehn becomes "gasoline C".



Source: Adapted from SINDICOM (2008).

FIGURE 3 Brazilian Distribution and Logistics for ethanol.



Source: TRANSPETRO (2008).

FIGURE 4 Logistics for ethanol exports at the Center-South-Southeast region of Brazil.

Blending can also be done in the tanker trucks, the so called *splash blending*. Gasoline C and hydrated ethanol are then transferred to secondary distribution facilities or delivered directly to Fuel Stations (retail) and final consumers (Figure 3). Ethanol can also be delivered directly from the mills and distilleries to the terminals at ports when final destination is the external market or cabotage[2].

It is important to keep in mind that ethanol production in Brazil is widespread, distributed in 285 counties. There are over 400 producing units, from which 155 are independent distilleries producing only ethanol (MAPA, 2008). As a comparison, the country has 14 oil refineries producing oil derivates, mainly gasoline and diesel.

Figure 4 shows the current logistics for ethanol exports in the Center-South-Southeast region of Brazil, which is responsible for approximately 85% of total ethanol production.

Brazilian transportation system is heavily based on road, and highly dependent on diesel. The last five years, road transportation represented over 60% of total cargo in the country, followed by railroad with 25%. Waterways are under utilized in Brazil with 14%, when compared to other countries with similar physical dimension (MINISTRY OF TRANSPORTATION, 2008).

For example, in Mexico 34% of its cargo goes uses the waterway, while public roads and railways account for 55% and 11% respectively. The United States has even transportation system with railroads representing 44%, followed by roads with 30% and waterways with 26%. Railroads are widely used in Russia, 81%, with small shares of roads and waterways, 8% and 11%, respectively.

The supremacy of road transportation in Brazil is completely incompatible with the volumes for ethanol projected to supply to the external market, according to the study prepared by the Ethanol Prospective Study (CGEE, 2006 and 2007; CERQUEIRA LEITE *et al.*, 2009).

In January 2007, the Brazilian Federal government enacted Decree n. 6 025 which introduced the Growth Acceleration Package (PAC). Aware of the need to have a more balanced transportation

[2] Cabotage: the carriage performed between ports or points of the country, using the sea and / or inland waterways.

system given its huge impact on economic development, particularly in the most remote areas of the country, the PAC included Logistics in its national infrastructure projects.

Initially, estimated funds to carry out the Program were R$ 503 billion and lately a further R$ 143 billion were added, totalizing R$ 646 billion. This amount, to accomplish the infrastructure projects between 2007 and 2010, will be provided by the Government, states and private companies (Federal Government, 2009). From this total, only 10% is designated to projects on transportation, and from this 57% is to be used in the road transportation mode.

The Plan (PAC) consists of 69 sites for construction and maintenance of 45,337 km of road and 2,518 km of railroads. It includes the modernization of 12 maritime ports, 20 airports, and construction of 13,826 km of electric power transmission to the grid. It also includes the installation of four new petrochemical refineries, construction of 4,526 km of natural gas pipelines, 67 waterway ports and two sluices (floodgates) in Tucuruí/Pará, in the river Tocantins.

During the PAC's second year evaluation, at the beginning of 2008, it was confirmed a further expenditure of R$ 502 billion over the previous amount, totaling R$ 1,148 trillion. Nevertheless, the Federal Government had invested, in 2006, only 0.64% of GDP in infrastructure, 0.73% in 2007 and 1% in 2008. The WORLD BANK Report (2007) states that Brazil needs to invest 3.2% of its GDP in infrastructure to follow the economic growth of the country. The Government recognizes its limitation, though 41% of total investment needed for PAC will come from private companies.

INFRASTRUCTURE

Brazil has 7,400 km of maritime coast and 80% of its population live up to 200 km from the coat. The country has 32 seaports although only 2% of containerized cargo is transported by its sea coast, or cabotage.

Brazilian transportation system comprises 1.6 million km of public roads, 42,000 km of waterways and 29,283 kilometers of railroads. There are 12,000 km pipelines, including multipurpose fuel pipes, crude oil and natural gas pipelines, as shown in Figure 5.

Despite having a considerable waterways capacity, the widespread mode of transportation is road, responsible for over 60% of cargo haul, followed by railways, with share of 25%, as previously mentioned. A study conducted by the Ministry of Transports (CENTRAN, 2007), the National Program for Logistics and Transportation (PNLT) shows a more balanced projection for transport by 2025.

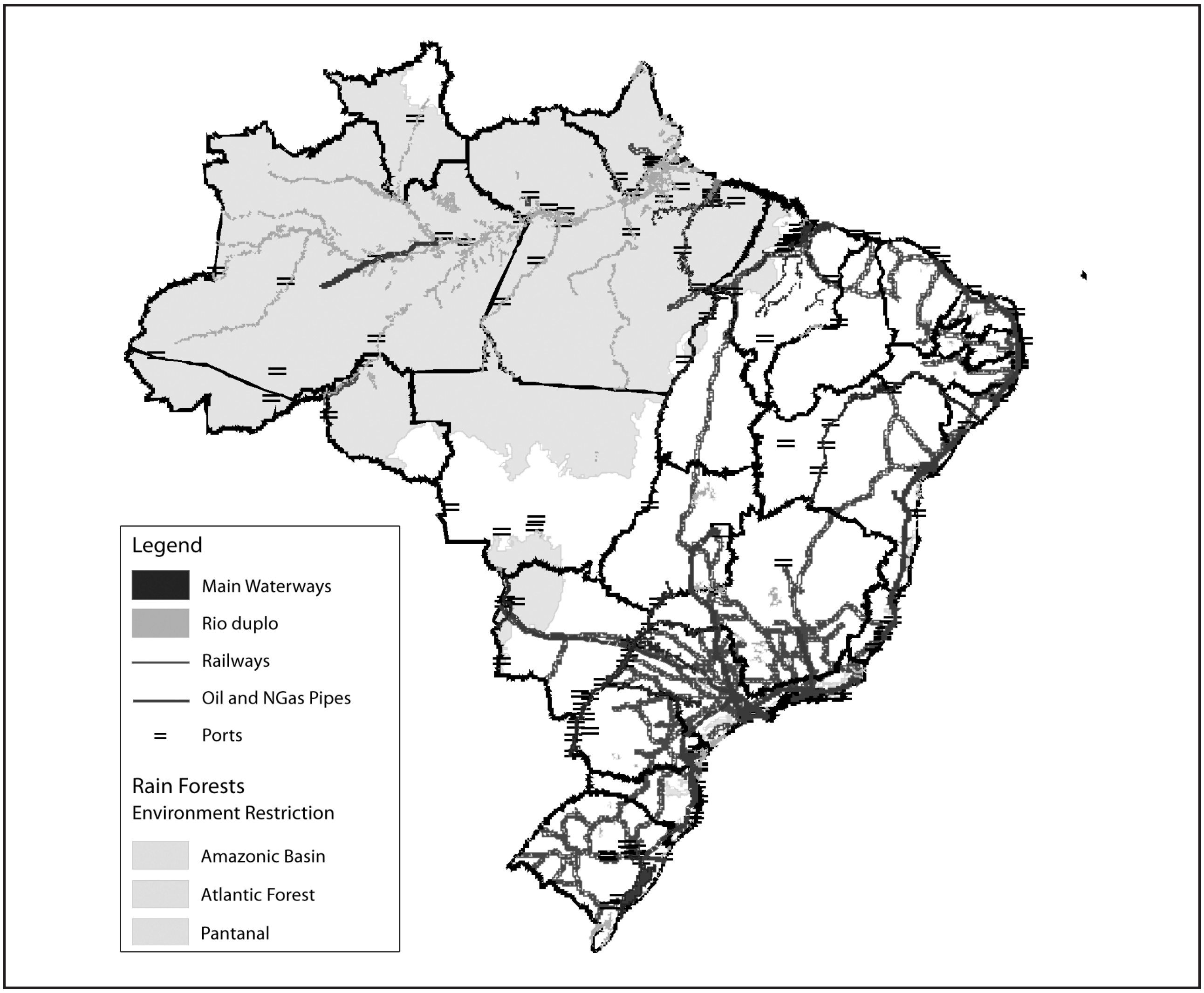
According to the study, road transport by truck will represents 33% of national transport, down from the current 62%. Railroads will be responsible for 32% while waterways will increase its share from 13% to 29% in 2025; over the same period, pipelines will increase the share more timidly, from 3% to 5%.

Railroads

The most important projects for railroad construction in the North/Northeast of the country are: Railroad of Northeast, the *Transnordestina*, *North-South* railroad, the *Midwest* and *Ferroanel*, in São Paulo. *Transnordestina* links three states: Pernambuco-PE, Ceará-CE and Piauí-PI starting in the county of Salgueiro-PE, allowing access to the seaports of Pecém-CE, Recife and Suape in Pernambuco.

The *North-South* railroad, with 1980 km, will link the North/Northeast region to the Center West region of Brazil, Goiás-GO. This railroad is projected to be expanded, starting in the West part of São Paulo-SP, passing through Mato Grosso do Sul-MS and reaching Goiás-GO. The North-South railroad will cross in longitude the whole state of Tocantins-TO.

Some parts of the *North-South* railroad are included in the PAC, Part 2, infrastructure and logistics (FEDERAL GOVERNMENT, 2009). From the North side, 103 out of 116 kilometers were built, from Colinas do Tocantins to Guaraí-TO, plus 20% of 148 km from Guaraí to Palmas. In the South side, 84 km out of 280 from Uruaçú to Anápolis-GO have ready been built and 4% of 575 km from Palmas-TO to Uruaçú-GO.



Source: Elaborated from geographic spatial information from IBGE.

FIGURE 5 Brazilian Infrastructure (except Roadways).

As for the *Transnordestina* railroad, 89% of 96 km are concluded, linking Missão Velha-CE to the West of Pernambuco, in Salgueiro, and also 368 km out of 550 from Cabo, East of PE, to Porto Real, Alagoas-AL.

The project in the Center-West of Brazil, the *Ferronorte* railroad, links São Paulo-SP to Cuiabá-MT. In São Paulo, the *Ferroanel North* railroad project will connect the North of São Paulo city to Sepetiba, Rio de Janeiro-RJ. The state of São Paulo is responsible for about 60% of total ethanol production in the country. It is also leader in ethanol consumption and in volume exported from the port of Santos. Still, ethanol reaches the port by road, which leads to long traffic lines of tanker trucks with diesel burning and release of greenhouse gases (GHG).

Although most railroads were privatized, the sector suffered a stagnation period and it was only after the Government injected new investment that the modernization of projects and extension of some railroads came to reality e.g. 2,000 kilometers, totalizing a network of 31,000 km. In spite of this stagnation, the railroads transportation increased its haul capacity, growing from 1.5 ton to 4.0 ton pushed by modern trains, which also increased the average speed up to 35 km per hour (VILAÇA, 2008).

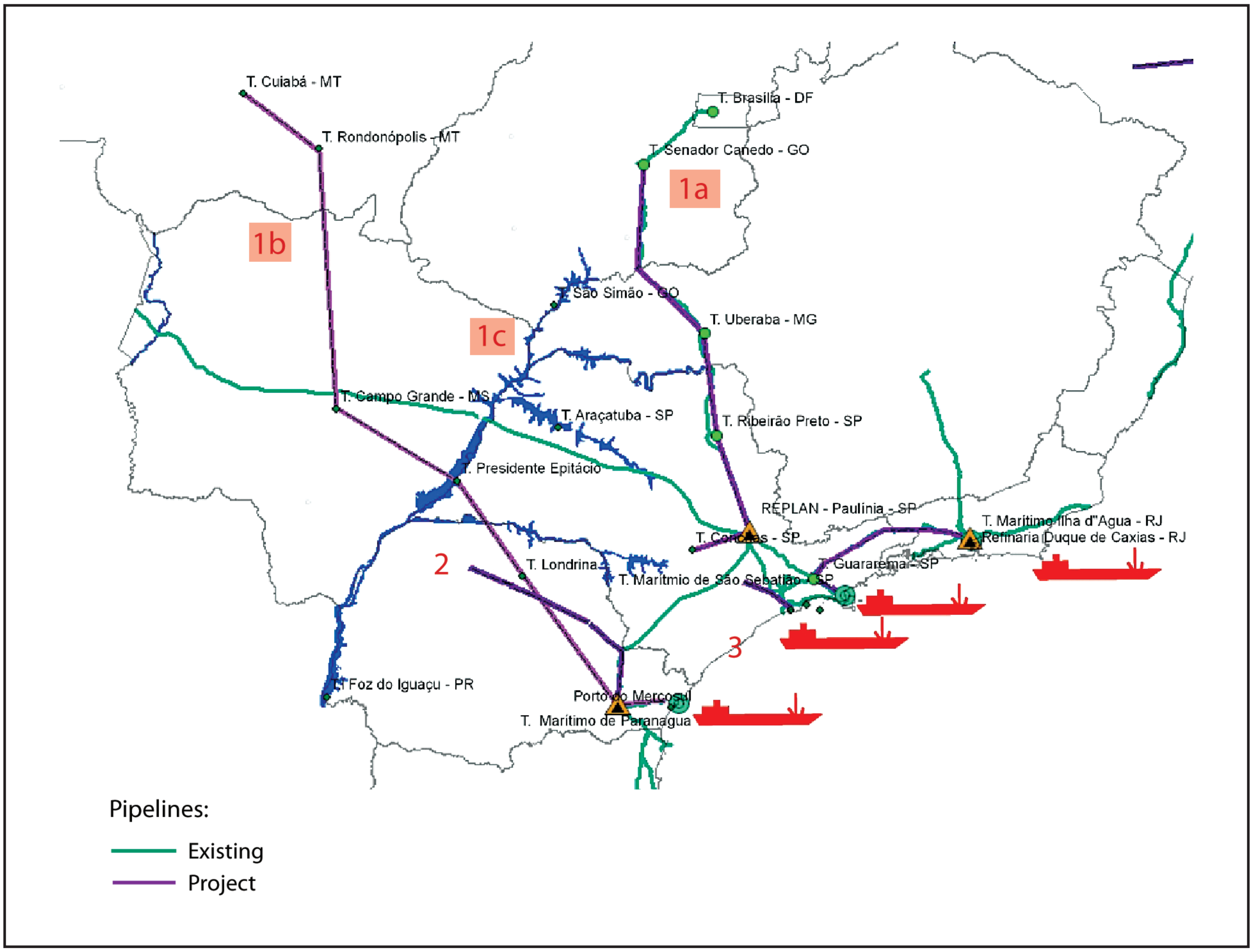


FIGURE 6 Existing pipelines and pipelines projects for the Center-South of Brazil.

Pipelines

Brazilian ethanol transportation via pipelines is insignificant at present, close to 2%. Road trucks are responsible for approximately 90% of ethanol delivery. In 1981, in the Proálcool peak, road mode of transportation participated only with 37% of ethanol's transportation and pipelines, with 13%. Railroads and waterways accounted for 31% and 20%, respectively (CGEE, 2006).

There are several projects currently under study to increase pipelines transportation of ethanol, mainly because of economic and environmental benefits. Major players of those projects are the Government, through Petrobras/Transpetro, the ethanol producers sectors from Goiás-GO, Mato Grosso-MT, Mato Grosso do Sul-MS, Paraná-PR and São Paulo-SP. Figure 6 shows the main projects: 1a, 1b, 1c, 2 and 3, for the Center-South region of Brazil.

In the short and medium term, when these projects become operational, the Center-South region could transport 12 mln m^3 a year of ethanol, with an estimated investment of approximately US$ 2.0 billion, in partnership with the private sector. Fuel ethanol export capacity of Brazil is, at present, close to 5 mln m^3, which was the volume exported in 2008 (MAPA, 2009).

It is important to point out that there are still some Institutional regulation disagreements from the ANP concerning the construction and operation of pipelines and also with respect to the Open Access to transport ethanol (Art. 58, Decree n. 9478/97). A Review of the present Legislation is needed to guarantee the supply to the final consumer and the operational safety for ethanol transportation (ANP, 2007).

Project 1a consists of the construction of dedicated ethanol pipelines from the refinery Replan, located in São Paulo, to the Maritime Terminal Ilha d'Água, in Rio de Janeiro, with total capacity of four mln m^3 a year. The same project includes a pipeline from Ribeirão Preto-SP to Uberaba – MG and another, with 90 km extension from Guararema to the port of São Sebastião, both in São Paulo Sate. It also considers the construction of a 525 km ethanol-only pipeline parallel to the existing one, a multipurpose pipeline, from Guararema to Terminal Ilha d'Água-RJ.

Project 1c, also with annual transporting capacity of four mln m^3, has as the objective to ship ethanol produced in the West region of São Paulo using the Tietê-Paraná waterway to Conchas. From Conchas to Replan/Paulínia-SP, the project includes a 90 km pipeline and the construction of three storage terminals along the waterway. From Replan/Paulínia, ethanol would be shipped by pipeline to the port of São Sebastião or Terminal Ilha d'Água-RJ, following the previous project, 1a.

Project 3, with major contribution from the sugarcane ethanol sector, refers to the transportation of ethanol from the Araçatuba Terminal, West of São Paulo, to Mairinque, Southeast of São Paulo, by railway. A dedicated pipeline would be constructed to transport ethanol from Mairinque to the port of Santos-SP.

Project 1b is an ethanol-only pipeline from Paranagua port, in Paraná, to the terminal in Cuiabá, Mato Grosso, passing through ethanol production regions in the North of Paraná and Mato Grosso do Sul.

Project 2, in Paraná, South region of Brazil, consists of 528 km of a dedicated ethanol pipeline with estimated cost of R$ 630 mln. The pipeline would pass through Copel's safety area of electricity transmission, about 250 km between Maringá and Jaguariaíva. Another 83 km pipeline would go in parallel to the road PR-092 reaching the city of Doutor Ulysses. For the following 100 km the pipeline will follow Gasbol route (a natural gas-dedicated pipe) to Araucária and finally, the last 95 km to the port of Paranaguá, will go alongside an existing oil pipe operated by Petrobras.

Maritime terminals for ethanol exports

The present infrastructure of Brazil to transport ethanol does not differ significantly from the initial proposal presented when Proálcool was launched, though the Program main objective was to supply the domestic market.

For an exporting scenario, the country has few ports with adequate infrastructure for the growing needs of a international fuel ethanol, although some investment initiatives in terminals had been done, as example of TEAS, Stolthaven and others in the port of Santos-SP, Pasa in the port of Paraná, and enlargement of terminal's capacity for liquid fuel in other ports in Brazil.

TEAS (Terminal para Exportação de Álcool Santos) is the result of a partnership between Cosan, Crystalsev, Nova America group and Cargill. This was an important initiative which a 40,000 m^3 capacity, currently being expanded to 80,000 m^3.

The Port of Paranaguá (PR), has recently completed its first public terminal dedicated to ethanol. There are seven tanks with storage capacity of 35,000 m^3 each, able to unload within 48 hours the ethanol to the ship and at the same time to load ethanol to the tanks; it has a monthly capacity for 15 ships. The cost was covered by the Administration of Paranagua and Antonina Ports (APPA).

Other storage initiatives for ethanol are in progress in the Northeast region of the country, mostly by Petrobras, in the ports of Cabedelo-PB, Recife-PE and Maceió-AL.

In 2007, eighty five percent of ethanol exports in the country were through the ports of Santos-SP, Paranaguá-PR and Rio de Janeiro-RJ, located in the South/Southeast region of Brazil, while the Northeast ports represented 14.2% of total exports, as shown in Table 1.

An additional factor to take into consideration is the the ports´ capacity to receive ships, tanks or vessels with significant capacity (DWT: dead weight ton), which is directly linked to the depth of drafts at the ports (Table 2), as the cost of transport is directly correlated to the size of ship or vessel.

The first two ports, Vila do Conde, and Itaqui, located in the states of Pará and Maranhão, respec-

TABLE 1 Participation of brazilian ports for ethanol exports (2007).

Ethanol exports by port (%) 2007	
Santos	69.6%
Paranaguá	14.3%
Maceió	8.0%
Recife	4.5%
Rio de Janeiro	1.7%
Cabedelo	1.7%
Others	0.2%

Source: SECEX/SDP (2008).

TABLE 2 Principal ports with ethanol export capacity in Brazil.

Most importants ports	Deepth	
	Maximum	Minimum
Santos – SP	13.5	5
Paranaguá – PR	7.2	5.9
Cabadelo – PB	9.5	5
Maceió – AL	10	7
Vitória – ES	10.6	2.4
Vila do Conde – PA	15	13
Itaqui – MA	19	13
Salvador – BA	18	12
São Sebastião – SP	18	12
Ilhéus – BA	10	10
Angra dos Reis – RJ	12	6
La Plata – Argentina	8.5	8.5

Source: COPPEAD (2008).

tively, are included in the planned investment in the PAC (2008) and thus it is expected that both ports will be prepared to receive large vessels, with capacity from 150,000 m^3 to 280,000 m^3 of fuel.

Brazilian waterways

Since 1799 many ideas and project had been proposed to integrate the Brazilian territory via waterways. The first registered idea came from Alexander von Humbolt, a German scientist, who visited South America and foresaw that the continent could be linked from North to South with a "Great Waterway", linking the basins of Prata, Amazonas and Orinoco, this last one located in Venezuela, through the Cassiquiare channel, a natural waterway between the rivers Negro and Orinoco (CGEE, 2007).

In 1869, the military engineer Eduardo José de Moraes, presented to the emperor Dom Pedro II, a plan showing how a net of fluvial navigation could be built using only the existing waterway and some low cost structure, integrating all the regions of Brazil.

The linkage between the Prata and Amazonas basins would be done by a 12 kilometers waterway at the Pantanal border, called Serra do Aguapeí, the source of the rivers Aguapeí and Alegre. Those two basins already connect themselves in periods of heavy rain. Integration among the three basins, Prata, Amazonas and Orinoco, with a total extension of 9,818 kilometers, would shape the "Great Waterway" which also would integrate all countries of South America, except for Chile. The strategic meaning of this waterway in terms of regional economic development is compared to the Reno-Danube Waterway, initiated by Carlos Magno and concluded few years ago, in terms of development for the European continent.

Major waterways

Brazil has 7,400 kilometers of navigable Atlantic coastline and thousands of kilometers of rivers. The main navigable rivers are located in the Amazon region, reaching the most remote and less developed areas in the North/Northeast of the country. However, this waterway does not constitute any significant cost-effective solution because of the low population density in those regions.

The more important navigable rivers, from the economic point of view, are located in the Southeast and South of Brazil. The full benefit of other waterways depends on the construction of sluices and floodgates, dredging works and suitable ports to allow intermodal transport integration. A briefly description of main Brazilian waterways follows.

- *Waterway of Araguaia-Tocantins:* Tocantins has the major basin entirely located in Brazil. Its major river, the Tocantins, is 1,900 km navigable between the cities of Belém do Pará and Peixed, in Goiás. Araguaia river crosses North to South the state of Tocantins and it is navigable in 1,100 km.

- *Waterway Hidrovia São Francisco:* between Serra da Canastra, in Minas Gerais, and its fall, in the border of Sergipe and Alagoas, the major river known as "Old Chico" entirely located in Brazil, is the great supplier of water to the Northeast, a semi arid region. The river is navigable in 1,300 km, between Pirapora, Minas Gerais, and Juazeiro, in Bahia.
- *Waterway Madeira:* Madeira River is a major tributary of right margin arm of the Amazonas River. This waterway, with new works carried out to allow navigation at night has been in operation since 1997. The structure will reduce transportation costs from the North and Midwest regions of the country.
- *Waterway Tietê-Paraná:* the importance of this waterway lays in economics, allowing the transportation of grains and other goods from three Brazilian states: Mato Grosso do Sul, Paraná and São Paulo and with two other South American countries: Paraguay and Argentina. The waterway comprises 1,250 km of navigable river, being 450 km in the Tietê river, São Paulo, and 800 km in the Paraná River, at the border of São Paulo and Mato Grosso do Sul, continuing South to the border of Paraná with Paraguay and Argentina.
- *Waterway Taquari-Jacuí:* located in the South region of Brazil, has a length of 621 kilometers and connects with the Rio Grande river, transporting mostly grains and oils. One important characteristic of this waterway is its intermodal terminals to facilitate the transfer of goods.

Waterway as transportation system

The Brazilian waterway transportation network can be consider as partial, since less than one third of its rivers are exploited. The total extension of the waterway network is 42,827 km, from which 27,420 are navigable and a further 15,507 can be made navigable (GARCIA, 2008). Goods transported by waterways represent a mere 13% of total, a small fraction when compared to countries of similar size (CENTRAN, 2007).

The waterway network in Brazil comprises navigable rivers, lakes and man-made channels which, with proper structure and suitable for transportation. With exception of the Amazon river, the Rio Grande do Sul fluvial and lagoon's network, and the Paraguay river, Brazilian waterway network contains waterfalls and cascades, separating rivers navigable and non navigable parts. That is why there is the need to correct those obstacles by building sluices and floodgates, which will require considerable amounts of capital.

To have an idea, to overcome 123 meters of elevation slope between Barra Bonita and Ilha Solteira, in São Paulo, six dams along the Tietê River have to be built: Barra Bonita, Baririm Ibitinga, Promissão, Nova Avanhandava and Três Irmãos. There are 580 kilometers of navigable waters consisting of six sluices and floodgates.

Further investments to exploit navigable waters can be justified by its low cost for transportation of goods. The transport of sugarcane and other products by the *ethanol waterway* linking Jaú – Pederneiras – Barra Bonita, in São Paulo, started in 1981, increasing from 1.1 to 3.8 mln ton in 2006 (MINISTRY OF TRANSPORTATION, 2007). Ethanol coming from Araçatuba (Nova Avanhandava dam) uses the waterway to reach the road SP-191, near to Piracicaba. From there, ethanol is transported by road trucks to Paulínia.

The Union of Ship owners and River Navigation of the State of São Paulo (SINDASP, 2007), confirms that waterway transportation is three times cheaper and eight times less polluting than road transport. Moreover, when using intermodal transportation (road-water-railway) the cost could be up to 40% lower when compared only with the costs of road transport.

Transportation via waterways represents the lowest fuel consumption carried per tonnage. It is half the consumption of the railway, and ap-

TABLE 3 Cost comparison of transportation modes.

Mode of transport	Construction average cost (US$/Km)	Maintenance cost	Fuel consumption (liters/t/1,000 km)	Freight cost (US$/t/1,000 km)
Roadway	440,000	High	96	34
Railway	1,400,000	High	10	21
Waterway	34,000	Low	5	12

Source: SECRETARY OF TRANSPORTS OF SÃO PAULO (2007).

proximately twenty times lower than road transport, as shown in Table 3. Waterway freight cost represents about one third of the cost compared to road trucks.

To make possible the navigation network, São Paulo state invested R$ 565 mln from 1995 to 2005 in works e.g. protection of the pillars of bridges, widening of openings, deepening navigation channels, construction of sluices and floodgates. This results in loading more products and faster transportation.

Such work has guaranteed a minimum water level of 2.90 meters for the entire year. This allows the navigation of ships with 2.70 meters draft. Thus, each barge type "Tietê double", consisting of 2 barges tied together and one towboat, can carry 4,400 tons, the equivalent load of 176 trucks of 25 tons each. The barges have an average speed of 15 km/h.

Some advantages for waterway transport mode would be:

- Efficient fuel consumption. Waterway´s consumption is 5 liters per ton/1,000 kilometers. At railways the figure increases to 10 liters and in the road, jumps to 96 liters (Table 3).
- Avoidance of traffic.
- More security.
- Reduction of pollutant emissions. While waterway transportation emits 0.056 kg/ton/1,000 km Carbon Monoxide, railways emit nearly three times more, 0.18 kg/ton/1,000 km, and roads release almost ten times as much when compared to waterways, 0.536 kg/ton/1,000 km (DINIZ, 2007).
- Life time of a barge is 50 years.

The issues mentioned above would explain the increase of 12% a year of cargo transportation by waterways since 1999. However, waterway transportation has also some negative issues:

- It is barely known, not widely disseminated.
- Depends on other mode of transportation to get to its final destination.
- Incorrect image that waterways transport damages the environment.
- Needs adaptation to ensure fuel transportation is safe.

It is Important to point out that, although pipelines seem to be the best option to transport ethanol, a multimode transportation network with priority to waterways and railways should be used in productive areas with easier access to those modes of transportation, or even while pipelines construction are concluded.

Associated costs related to ethanol exports, according to the information provided by the local Ethanol Broker Society (SCA), in September 2007 and confirmed by visits to the mills, would be as follows: 45-47 US$ per cubic meter (m^3) for consolidated ethanol transport, FOB to Port of Santos, including storage, supervision, taxes and roadway expenses:

- US$/$m^3$ 15-17: Terminal in the Port of Santos: storage costs;
- US$/$m^3$ 2.00: Supervision of Certification Agencies and Port taxes;
- US$/$m^3$ 26-28: Road Transport from Ribeirão Preto to Santos, about 420 km.

If ethanol for exports originates in the state of Goiás, Midwest region, the amount charged for the consolidated transportation to the port of Santos increases to 70-75 US$/m^3. Costs would be approximately 55 US$/m^3 if the origin is Araçatuba, Northwest of São Paulo, and 38 US$/m^3 if ethanol comes from Piracicaba, about 220 km from the Port of Santos.

Costs related to international transportation for the Mexican Gulf, United States, is about 50-55 US$/m^3. If destination is the American East or West Coast, the amount goes to 60-65 US$/m^3. Those quotations can change depending on the season and the availability of larger ships.

One can conclude that with a new logistics design for ethanol transportation, new terminals to enlarge storage capacity and modernization of domestic ports to receive bigger vessels, Brazil is able to export large volumes of ethanol, at a competitive price and based on strategic planning.

According to the Ethanol Prospective Study (CGEE, 2007), if pipelines were used, cost of domestic transportation of ethanol could be reduced from current 45-70 US$/m^3 to 29.60 US$/m^3, from São Paulo and Goiás, respectively, to the port of Santos.

Electricity power stations and substations

Investments to increase ethanol production should consider trading electricity, either as surplus electricity generated from ethanol production process or specifically produced to this end. Therefore, the logistic study should include the best location of the units for ethanol production, considering, among other things, the distances from the distillery to the power station or substation to deliver and trade electricity.

THE NEED FOR MATHEMATICAL MODELING STUDIES

To increase production in such a large volume, there is the need for deeper studies with quantitative data. Mathematical modeling seems to be a useful tool for decision taking when the problem involves diverse variables.

The proposal for this study would be to identify the ideal trajectory (design) and the ideal mode of transportation, considering that ethanol fuel depends on:

- seasonal nature of raw material production, with different harvest seasons between North-Northeast of Brazil, from September to March, and the Center-South region, from April to November;
- difference on fuel pricing among Brazilian states due to different taxation and transportation costs from distributor to final consumer;
- use of a multimode transportation system.

With respect to the transport of ethanol, it is important to develop models considering:

- life cycle studies including ethanol maritime transport to the importing countries;
- timing for transfer of ethanol taking into account the alternatives among modes of transport (roadways/railways/waterways) that ethanol could travel to get to the port, for example:
  - i) trucks to barges(waterway);
  - ii) trucks to railways;
  - iii) trucks to pipeline;
  - iv) barges to railway;
  - v) barges to pipeline;
  - vi) barges to trucks;
  - vii) railway to pipeline;
  - viii) railway to barges;
  - ix) railway to trucks;
  - x) pipeline to railway;
  - xi) pipeline to trucks;
  - xii) pipeline to barges.

Also, for modeling, studies could consider the production of ethanol transport from regions such as Mato Grosso do Sul, South of Mato Grosso and West of São Paulo, using barges through the Tietê-Paraná hydroway, leaving from Três Lagoas to Conchas, as stated in example (i).

After the waterway, the renewable fuel could get to Paulínia by pipeline (v) and by railway or truck to the ports of Santos or Ilha d´Água-RJ (x) or (xi). Another option could use the railway from Conchas to Mairinque (iv) and then to Santos by pipeline (vii) or Conchas – Mairinque by trucks (vi) and then reach the Port of Santos by pipeline (iii).

Studies should consider the availability transportation modes or the projects in progress to build the needed infrastructure. It is understood that the waterway Tiete-Paraná will be more used in the scenario for larger production of ethanol. On that waterway six sluices were already built in the Tiete River plus four in the Paraná River.

Therefore, the model to be constructed should include, among others: the type of barges – barges power; towboat power; utilization of tank-barges and structure to receive ethanol; transfer security between modes; security into the barges and towboats; transport mode speed (travel timing); time needed at sluices and bridges; depth of river or canal.

To transport the projected volume of ethanol, new equipment for transportation would be needed mainly barges and containers for the railway mode. Mathematical modeling should consider the analysis of the environmental impacts for not using trucks, as well as social and economic ones: increase of employment because of new maritime construction (barges, towboats) and professional training for specialized personnel.

FINAL CONSIDERATIONS

Brazilian expansion of ethanol production should be well planned to minimize costs of transport as well as social and environmental impacts. The present moment is extremely favorable to the implementation of a solid, bold and sustainable Project.

The best mode to transport fuel ethanol, considering environmental and economic aspects, seems to be pipelines. However, to make feasible the construction of dedicated ethanol pipelines, it is important to guarantee a minimum volume of ethanol flow, whether for the domestic market or for exports.

Projections for expanding sugarcane production and ethanol supply indicate that this will take place outside traditional and/or more distant areas e.g. the Midwest region of Brazil or Norwest of São Paulo state. Therefore, multimode transport, such as waterways and railways stand out to transport ethanol to the ports of Santos or São Sebastião, both located in São Paulo. Ethanol transport, whether for domestic market or exports, should be compatible with environmental benefits and should aim to identify and minimize undesirable impacts. Therefore, specific studies, such as life cycle analysis for fuel ethanol and optimization mathematical modeling, among others, need to be carried out.

Studies on mathematical modeling for ethanol logistics and distribution searching for the best mode of transport to be used from mills to the ports and the multimode use for ethanol transportation are critical for decision taking. Some examples of studies that used mathematical modeling in compatible research can be found in OJIMA (2005) and XAVIER (2007).

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20

ETHANOL QUALITY REGULATION

Antonio Bonomi

INTRODUCTION

Historically, a new configuration of the sugarcane agro industrial system, that supports the most important biofuel – fuel ethanol, started in Brazil with the deregulation of the sector, the commercial globalization of the Brazilian economy and the perspective of increasing international demand for ethanol.

The deregulation process of the sugar-alcohol industry during the 1990s was due to the Brazilian State withdrawing control caused by the stagnation of the sector at that moment. Nevertheless, the state departure was only partial, because of its importance in the dynamics of the sector.

In order to maintain the leading position in the production and commercialization of biofuels, it was very important for the Brazilian biofuel sector to have official support. Law n. 11 097 of January 13, 2005 formally introduced biofuels in the Brazilian Energy Matrix and the Brazilian Petroleum, Natural Gas and Biofuels Agency – ANP was responsible for the regulation of the sector.

In this context, there is a regulatory and methodological framework that maintains the Brazilian leading position in the biofuel area.

In this chapter, the fundamental aspects required to guarantee the ethanol quality will be presented in detail – essential for internal market consumption and to facilitate its commercialization in the international market. In addition, different fuel ethanol specifications that exist today in the world, strategies and mechanisms to be implemented in a bioenergy policy, to ensure the quality of the biofuels, will also be evaluated. The requirement for the harmonization of the Brazilian fuel ethanol specification with that of other countries will be discussed. This is because ethanol will be commercialized in a highly competitive and globalised market, in which quality and price are the major differentials. Besides discussing ethanol specification, the present chapter presents major aspects related to the quality and control and suggests mechanisms, that can be implemented by the State of São Paulo.

THE REGULATORY FRAMEWORK

The regulatory framework that exists today in Brazil provides support to the production and commercialization of ethanol, seen as a global commodity. Three federal entities are the basis for this regulatory framework:

- ANP – Brazilian Petroleum, Natural Gas and Biofuels Agency, set up by Decree n. 2 455, of January 14, 1998. It is the regulatory organism for activities related to oil, natural gas and biofuels industries in Brazil (ANP, 2008a); and responsible for the definitions and specifications of biofuels (ethanol in this case) and for quality control, in all the stages of the production and commercialization chain.
- INMETRO – Brazil's National Institute of Metrology, Standardization and Industrial Quality, created by Law n. 5 966 of December 11, 1973. It is responsible for metrology field, formulation, coordination and super-

vision of the national metrology, standardization and industrial quality policy (DIAS, 1998). INMETRO is therefore, responsible for the metrology standards of the country and is the leading Brazilian technical organism in ensuring that biofuels meet the metrological requirements in Brazil, European Unit and United States of America tripartite task force (WHITE PAPER..., 2007).

- ABNT – Brazilian Association for Technical Norms, founded in 1940, is the organism responsible for the technical standardization in the country. It supplies the required basis for the Brazilian technological development (ABNT, 2008a) – and is therefore responsible for up to date technical norms tuned to effective national specifications and regulations.

The supply of biofuels (as well as other fuels) is considered of public interest and deserves some state intervention which in the case of the fuel ethanol including production, commercialization, distribution, sale and quality control. It is the responsibility of the State of São Paulo, the country leader of ethanol production, to give technical support and to create institutional conditions for the three federal regulatory entities to operate in a coordinated and effective way.

FUEL ETHANOL SPECIFICATION

The fuel specification is defined through a set of characteristics required for a good performance of the engine, evaluated through internationally standardized agreed methods. ANP, as well as all the international organisms responsible for fuel specifications, do not regulate the chemical composition of the fuels, but establish, through Resolutions and Technical Regulations, specifications that define the minimum quality requirements for the proposed utilization. The proposals of the fuels specifications elaborated by specialized technicians are consolidated by the regulatory organism based on discussions, looking for a consensus among the agents responsible for the production and use of the fuels and the environmental organisms responsible for emissions control, trying always to satisfy the consumer's requirements. Such specifications are periodically revised to meet the new engine technologies, the environmental requirements and, finally, the supply of products to society.

As an example of the continuous improvement of the specifications, a revision of the Brazilian ethanol specification (ANP Decree n. 2/2002) was performed in December 2005, regulating the addition of dye to anhydrous ethanol – ANP Resolution n. 36/2005 (ANP, 2005), that started to be commercialized with an orange color, without interfering in the physicochemical characteristics of the product. The addition of dye was best alternative to solve the problem of addition of water to anhydrous ethanol (used only in the mixture with gasoline) commercialized as hydrated ethanol.

The specification of a product, besides insuring its quality, is also a reference standard for the consumer market. For ethanol, the international market points to a growing demand, stimulated by public policies through the use of renewable energies that will lead to a reduction of CO_2 net emissions.

Brazil and the United States of America (USA) are discussing ways to increase ethanol utilization in the world. The idea is to transform ethanol in a world commodity such as petroleum, corn or and coffee. The US is planning to increase internal ethanol consumption by more than six fold in the next few years for environmental and social reasons, and is looking for greater cooperation with Brazil in this area.

Presently, there are important differences between Brazilian and international specifications for biofuels, in general, and for fuel ethanol, in particular. For international trade of these fuels their harmonization is essential.

In 2007, a Tripartite Task Force was created, comprising specialists from the European Union, Brazil and the USA, aiming at harmonizing ethanol and biodiesel specifications. On the Brazilian side, the group of specialists is coordinated by Itamaraty (Brazilian Ministry of External Affairs), with the participation of ANP, Petrobras, INMETRO, ABNT and UNICA (WHITE PAPER..., 2007).

Table 1 compares the ethanol specifications (characteristics and limitations) adopted in Brazil – ANP Resolution n. 36/2005 (ANP, 2005), The European Union – prEN 15376/2007 (CEN, 2007) and USA – D4806-07a (ASTM, 2008).

Table 2 (WHITE PAPER..., 2007) classifies the differences found in fuel ethanol specifications in 3 categories: (A) similar characteristics, (B) characteristics with significant differences and (C) characteristics with fundamental differences.

The three current specifications are very similar, mainly because all of them were derived from a unique specification (the Brazilian one). Differences reflect different markets, climate conditions in each country and region, and variations in raw materials used for production. A significant difference among the three sets of standards is water content, which is set at different levels, primarily due to the varying ethanol concentrations allowed in gasoline mixture and also to gasoline distribution differences (WHITE PAPER..., 2007).

TABLE 1 Brazilian, European and North American specifications for fuel anhydrous ethanol.

Property	ANP n. 36/2005 (ANP, 2005)	prEN 15376/2007 (CEN, 2007)	ASTM D 4806 – 07a (ASTM, 2008)
Appearance	Clear & no impurities	Clear & bright	Clear & bright
Color	Colorless[a]	–	–
Acidity[b] – max	30 mg/l	0.007% m	56 mg/l
Electrical Conductivity – max	500 S/m	–	–
Residue by Evaporation – max	–	10 mg/100 ml	–
Density at 20 ºC – max	791.5 kg/m^3	–	–
Ethanol content – min.	99.3 ºINPM[c]	98.7%m	92.1%v
Ethanol content – min.[d]	99.6%v	–	–
C3-C5 sat. alcohols – max.	–	2%m	–
Methanol content – max	–	1%m	0.5%v
Hydrocarbons content – max	3%v	–	–
Denaturant – min-max	–	–	1.96% a 5%v
Water content – max	–	0.3%m	1%v
Copper content – max	0.07 mg/kg	0.1 mg/kg	0.1 mg/kg
Sulfur content – max	–	10 mg/kg	30 ppm
Sulfate content – max	–	–	4 ppm
Phosphorus content – max	–	0.5% mg/kg	–
Inorganic Chloride content – max	–	20 mg/l	32 mg/l
Washed Gum content – max	–	–	5 mg/100 ml
pHe	–	–	6.5 a 9

[a] Colorless before dye addition; a 15 mg/l dye content should be added, giving the product an orange color.
[b] Defined as acetic acid.
[c] ºINPM = %m.
[d] Limit only applies to ethanol not produced by fermentation from sugarcane or ethanol contaminated by other types of alcohol.

Source: ANP, 2005; CEN, 2007; ASTM, 2007.

TABLE 2 Classification of the differences of the various bioethanol specifications.

Category (A)	Category (B)	Category (C)
Appearance	Ethanol content	Water content
Color	Acidity	
Density	Phosphorus content	
Sulfate content	pHe	
Súlfur content	Gum/Evaporation residue	
Copper content		
Iron content		
Sodium content		

Source: WHITE PAPER..., 2007.

For bioethanol, the Task Force concluded that there is no technical specification characteristic that constitutes a barrier to trade given the current situation. However, it is recognized that additional drying and testing will be required by Brazil and USA exporters willing to supply the EU market. The impact and costs associated with these additional processes have not been evaluated by the Task Force (WHITE PAPER..., 2007). It is also important to know the composition of the anhydrous ethanol before denaturation in different countries, in order to establish the quality limits, considering the different raw-materials (sugarcane, corn, sugar beet and others) and the processes employed in production.

TECHNICAL NORMS FOR FUEL ETHANOL

The technical norms are documents produced by nationally and internationally recognized organizations that establish guidelines and restrictions for the execution of an activity, service or product. In general, technical norms are required for the standardization or to make uniform the procedures and actions of the different interested parties. In Brazil, the official organization in charge of technical norms for emission is the ABNT. Each country has one or more entities equivalent to ABNT and these entities discuss and harmonize related matters through the International Organization for Standardization – ISO. ABNT was given the responsibility to the secretary of the ISO's Normalization Committee for the biofuels (WHITE PAPER..., 2007).

The national ethanol normalization is currently make up from 18 Brazilian norms for the characteristics of ethanol and water mixtures, 6 for the distribution logistics, 3 for the characteristics of superior alcohols; 2 for the characteristics of ethanol for industrial use, 9 for the use in engines and 2 for the production of fuel ethanol. Table 3 presents a complete list of the Brazilian ethanol norms currently in use. In the context, besides the national norms, the US norms produced by the American Society for Testing Materials – ASTM are also largely used (ANP, 2005; ABNT, 2008b).

The application of technical norms is strongly connected to the technology and regulatory framework. For this reason, it is necessary to update regularly in order to make them compatible with the present technological changes of the country. Therefore, the organizations responsible for normalization set up technical committees with the objective to keep up with technical changes specifications and regulations. An example is PROCONVE – the national program for the control of the air pollution by automotive industry, coordinated by Ibama/MMA (Ministry of Environment), that requires a continuous update of the norms for measuring the sulfur content in gasoline and diesel oil.

In relation to ethanol norms, there is an ABNT commission, named ABNT/CEET-00:001.61 – A Temporary Special Commission on Fuel Ethanol, that revises old norms as well as develops new ones (ABNT, 2008c).

CERTIFIED REFERENCE MATERIALS FOR FUEL ETHANOL

There is a strong need to guarantee and control the quality of the chemical analysis, reducing costs, avoidance of analysis duplication, use of Certified Reference Materials – CRMs. The CRMs are specific materials produced in a certain amount

TABLE 3 Brazilian ethanol norms in use.

Code	Title	Publication	Reference
NBR10260	Ethyl alcohol – Determination of acetal, acetaldehyde, ethyl acetate, acetone, methyl alcohol, superior alcohols and benzene contents by gas chromatography	01.04.1988	**Quality**
NBR10266	Alcohols – Determination of the brome number	01.04.1988	**Quality**
NBR10422	Ethyl alcohol – Determination of the sodium concentration – Method of flame photometry	30.04.2007	**Quality**
NBR10425	Alcohols (establish characteristics required for alcohol reception)	01.08.1988	Distribution Logistics
NBR10429	Superior alcohols – Determination of total alcohol content	30.08.1988	Superior Alcohols
NBR10430	Superior alcohols – Color stability assay with sulfuric acid	01.08.1988	Superior Alcohols
NBR10517	Corrosion inhibitor additive for fuel hydrated ethyl alcohol – Efficiency evaluation as a function of the storage period	01.10.1988	Distribution Logistics
NBR10547	Ethyl alcohol – Determination of the electrical conductivity	11.12.2006	**Quality**
NBR10649	Ethyl alcohol – Determination of benzene by ultraviolet spectrophotometry	30.04.1989	**Quality**
NBR10891	Hydrated ethyl alcohol – Determination of the pH – Potentiometric method	11.12.2006	**Quality**
NBR10892	Hydrated ethyl alcohol for the alcohol chemistry industry	01.01.1990	Industrial Use
NBR10894	Ethyl alcohol – Determination of chloride and sulfate concentration – Ions chromatography method	27.08.2007	**Quality**
NBR10896	Anhydrous ethyl alcohol for the alcohol chemistry industry	01.01.1990	Industrial Use
NBR11331	Ethyl alcohol – Determination of iron and cupper concentration – Atomic absorption spectrophotometry method	27.08.2007	**Quality**
NBR11481	Light road automobile vehicles – Measurement of evaporative emissions	01.11.2002	Engines Use
NBR11483	Alcohols – Determination of the relative density	01.06.1990	Quality
NBR12026	Light road automobile vehicles – Determination of emissions of aldehydes and acetone in the exhaust gas by liquid chromatography – DNPH method	30.03.2002	Engines Use
NBR12781	Wagon tank – Degasification	01.02.1993	Distribution Logistics
NBR12782	Wagon tank – Tank cleaning	01.01.1993	Distribution Logistics
NBR13992	Automotive gasoline – Determination of the fuel anhydrous ethyl alcohol content	01.10.1997	**Quality**
NBR13993	Fuel ethyl alcohol – Determination of the gasoline content	01.02.2002	**Quality**
NBR14052	Sugarcane spirit – Determination of superior alcohols	01.04.1998	Superior Alcohols
NBR14525	Fuels – Determination of gum by evaporation	24.07.2006	Engines Use
NBR14752	Auto motor road vehicles – Fuel electric pump – Maintenance assays	01.10.2001	Engines Use

continues

Code	Title	Publication	Reference
NBR14753	Auto motor road vehicles – Injection valve – Maintenance assays	01.10.2001	Engines Use
NBR15531	Ethyl alcohol – Determination of water content – Karl Fischer volumetric method	08.10.2007	**Quality**
NBR15559	Ethyl alcohol – Determination of non-volatile material content by evaporation	28.01.2008	**Quality**
NBR5824	Acetone, ethyl and methyl alcohols – Determination of permanganate reduction time – Barbet Method	01.07.1986	**Quality**
NBR5991	Plastic packages for alcohol – Requirements and assay methods	30.07.1997	Distribution Logistics
NBR5992	Determination of density and alcohol content of ethyl alcohol and its mixtures with water	01.03.1980	**Quality**
NBR7485	Color use for piping identification in sugar plants and refineries and alcohol distilleries	02.10.1994	Alcohol Production
NBR7820	Safety on installations for production, storage, handling and transport of ethanol (ethyl alcohol)	01.04.1983	Alcohol Production/ Distribution Logistic
NBR8644	Fuel ethyl alcohol – Determination of evaporation residue	17.03.2008	**Quality**
NBR8645	Corrosion inhibitor additives for fuel hydrated ethyl alcohol – Efficiency evaluation in carburetors without coating	30.10.1984	Engines Use
NBR8689	Light road automobile vehicles – Fuels for test – Requirements	30.04.2006	Engines Use
NBR9184	Gasoline and alcohol filter – Determination of characteristics	01.12.1985	Engines Use
NBR9297	Alternative internal combustion engines for vehicles using fuel hydrated ethyl alcohol – Verification of calibration requirements	01.03.1986	Engines Use
NBR9866	Ethyl alcohol – Determination of acidity	11.12.2006	**Quality**
NBR9868	Ethyl alcohol – Determination of formaldehyde content	30.05.1987	**Quality**

Source: ABNT, 2008b.

and certified afterwards. They are prepared with the highest metrological quality and focus on three major functions:

- to help develop better analytical methods (reference methods);
- to calibrate measuring systems used to improve the commerce of goods, to establish a quality control and to determine performance characteristics or properties measurement;
- to insure the adequacy and integrity of the quality control programs in long-term measurements.

Despite the fact that Brazil has been, for a long time, one of the largest world producers of ethanol and that the federal government has adopted many actions to implement a biodiesel production program, there are only 4 CRMs available in Brazil. They are for bioethanol (water content, density, pH and ethanol content for anhydrous and hydrated fuel ethanol) and none for biodiesel (INMETRO, 2008).

QUALITY CONTROL OF FUEL ETHANOL

Nowadays, in order to guarantee the quality of fuels commercialized in the State of São Paulo, there are monitoring and sample inspection programs, promoted by ANP and the São Paulo Finance

Secretariat, as well as some verifications/controls performed by the Public Ministry and the Public Safety Commission – generally based on complaints.

Since 1999 the ANP, through agreements established with research institutes and universities, has evaluated the quality of the fuels commercialized in Brazil, including the State of São Paulo, mapping the and directing the enforcement actions of the agency.

The quality of ethanol (anhydrous and hydrated) produced in the country is presently directly controlled by ANP through Quality Certificates provided by the producers.

Through these monitoring and enforcing actions, a reduction was observed (Figure 1) in the non-conformity index of the fuels commercialized all over Brazil (ANP, 2008b).

Since 2004, the Finance Secretariat of the State of São Paulo, together with ANP, is controlling the quality of gasoline and hydrated ethanol commercialized in the state, as well as the fiscal situation of the gas (petrol) stations in several urban areas. This action has improved the gasoline station enforcement in the State of São Paulo.

In order to inhibit fuel adulteration and also to guarantee their quality, besides the monitoring and enforcing programs, there is a Fuel Tracing Program. ANP's Regulation n. 274/2001 establishes the requirement of adding a tracer to solvents and petroleum derivatives selected by the Agency, as well as the prohibition of the presence of the tracer in gasoline.

EXISTENT BARRIERS TO BIOFUELS COMMERCE

Although Brazil is the world largest exporter of ethanol, markets suffer from large bottlenecks. Despite the fact that the US and the EU Community have established ambitious targets for ethanol use, the alignment of the Brazilian specification with the ones practiced in these countries is extremely important.

Worldwide, the technical specifications of fuel ethanol are not centralized in any international normalizing organization, with each country adopting a different specification. Thus, the requirements vary depending on the importing country; in the Brazilian case the ANP is the national organism responsible for setting the specifications of the ethanol produced and commercialized internally.

Nowadays, the Brazilian norms not always present experimental methods similar or equivalent to the tests defined by the majority of the international countries that, in the future, can represent large commercial partners, importing Brazilian biofuels.

Many of the available ethanol norms have been effective for more than 5 years and some of them have been used for 20 years as mentioned (Table 3), violating ABNT's own recommendation. This situation, alone, increases the probability of having its validity questioned by buyers.

On the other hand, some of the Brazilian norms recently updated define quite simple and

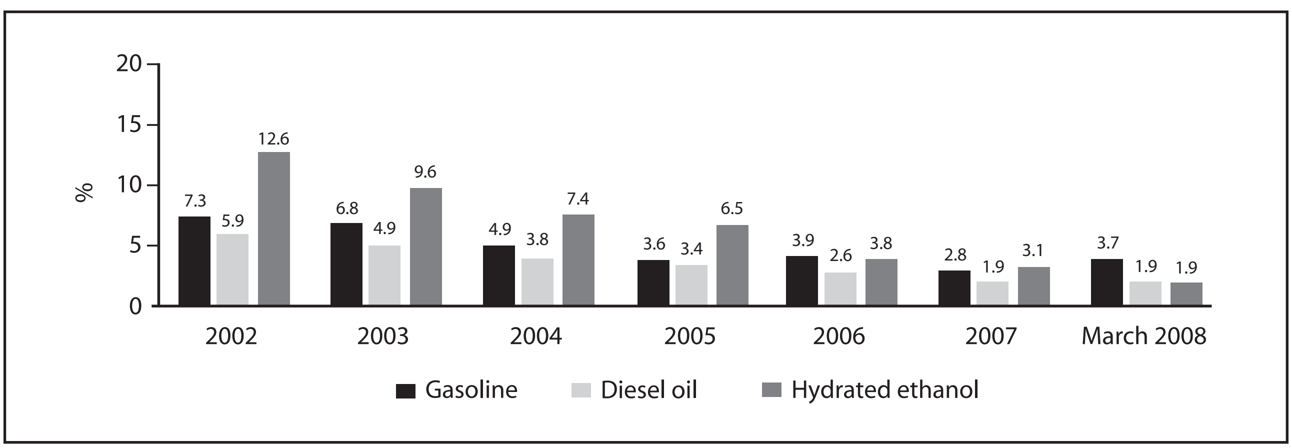

FIGURE 1 Non-conformity index of fuels in Brazil.

low cost methods. This, from one side, facilitates the operation of laboratories in the production units, as they do not require additional investment, but, on the other side, they do not consider more sophisticated methodologies indicated in several international specifications, reducing its acceptance by the importers.

It is true that one of the major bottleneck to be overcome related to the technical norms is the reduced availability of specialists working in the technical committees. This fact is due to several reasons, such as the reduced dissemination of the normalization culture among the administration of the enterprises, the traditional overload of professionals in their activities, the cost represented by an effective participation and, sometimes, the lack of appropriate technical committees.

As already mentioned, these technical barriers to the commerce of biofuels, in general, and specially of fuel ethanol are been analyzed and discussed by an international Working Group, that is trying to eliminate them (WHITE PAPER..., 2007).

In the context of the international market, countries are aware against the creation of technical barriers based on biased regulations that hamper free commerce. The World Commerce Organization – WCO keeps a notification panel of cases of technical barriers sent by the international community, aiming at a fair handling of the disputes (PERINA; MACHADO; MIRANDA, 2003).

Besides the technical barriers on the biofuels quality, there are several other barriers that can be created. Presently, it is clear that there is a tendency to create new barriers related to aspects of biofuels production, associated to the requirement of demonstration of good labor relations in the production units and lack of environment damage. These aspects will be fundamental to make business in biofuels international trade viable. The problem related to these requirements is the fact that a position has not been negotiated at WCO. Brazil has tried, through its regulation organisms, biofuels producers associations and researchers working in the area, to demonstrate the sustainability of the fuel ethanol production from sugarcane (GOLDEMBERG; COELHO; GUARDABASSI, 2008).

In the case of ethanol, Brazil can be notified regarding the production process, due to the burning operation used in sugarcane harvesting, besides problems with labor relations. Since these are aspects not regulated by WCO, Brazil should give special attention to solve them, mainly because biofuels commerce is associated to environment preservation.

Recently, the new attack of the international community against biofuels has focused the following claim: "biofuels are using land that should be used to produce food". In Brazil, food production increased 6.8% in the last harvesting season in spite of the ethanol production growth. Still this year, the Federal Government informs, that the sugarcane zoning will be complited. This document will tell where it is possible to plant sugarcane and where should be avoided and even forbidden (SELO..., 2008).

CONTRIBUTIONS TO POLICIES PROPOSITION

Specification and normalization of biofuels

In this quality context, the major demand is the requirement of technical support of the existing Working Groups including the regulatory organizations (ANP, INMETRO, ABNT), producers, automakers, research institutes and universities. These groups aim at specifying the quality required by the biofuels in order to meet the national and international demands, looking for harmonization with the different world specifications. In spite the fact that specification regulation is an ANP assignment, the State of São Paulo can contribute to the process as an inductor, reinforced by the position of the largest ethanol producer and consumer.

The evolution of the sector normalization has not started naturally with this focus, but the present context makes it more critical that the national norms include, without prejudice of the methods traditionally employed, the modern methods, which are used in the developed countries that are potential importers of biofuels.

As a general conclusion, the requirement will be to stimulate and support an effort to elaborate Brazilian norms with analytical methods comparable with their equivalents reported in the international specifications. It is obvious that there will be questions related to the cost of implementing these new methodologies, since some of the old Brazilian norms include low cost methods, that did not require high investments by the producers, mainly in training and instrumentation operation.

A policy of the state of São Paulo should foresee, in a first stage, the support for the instrumentation update of the laboratories of the Research Institutes that support the producers and, in a second stage, a policy of incentives to the laboratories of the producers that envision exporting the biofuels. A way to support this industrial sector in updating their infrastructure would be by opening special lines of credit in State Banks.

Another favorable action in this context would be the promotion of a Training Program, including updating courses and conferences, for Brazilian personnel responsible for the tests and analysis of the biofuels, covering up to date normalization, if possible with the participation of members of the international normalization committees and specialists of the major biofuels testing centers.

The certified reference materials for the biofuels could be prepared from the moment that the specifications and the norms are consolidated, that some national primary standards are available and that the required specific specialized knowledge is defined and available in the academic and technical sector. The Government of the State of São Paulo would be responsible to create incentives for the utilization of the certified reference materials by the biofuels producers, including their use as an evaluation item for receiving a state quality certificate.

Quality control

It seems important to increase the investment in the present working model (fuels quality monitoring, aiming at directing the enforcement actions), since it has produced positive results, improving even the quality of the new biofuels.

The Government of the State of São Paulo should establish a policy to create and keep up to date reference laboratories, for monitoring and controlling the quality of the fuels commercialized in the State, being responsible for the logistic aspects.

An additional aspect of the biofuels quality control policy is the incentive to strengthen a national production chain in the State of São Paulo of the required instrumentation for the analysis of biofuels, decreasing the dependence of the traditional foreign producers, as well as creating new labor posts.

Considering the aspect of using tracers to control the quality of biofuels, it is strategic that the Government of the State of São Paulo supports the development of new tracers that will allow the monitoring laboratories to identify possible frauds practiced in the production and distribution of the biofuels. Still in this area, the Government of the State of São Paulo should, through organisms that deal with legal matters, discuss with ANP a technical alternative to answer the legal questioning of the impossibility of a complete defense of those accused of fraud, due to the secrecy involved in the use of tracers.

Quality certificate

The creation of a state quality certificate for the sector or the active participation of the state in a national certification scheme, being constructed by Inmetro (INMETRO, 2008b) would be important policies to indicate the quality of the biofuels produced in the State of São Paulo. The introduction of a quality certificate implies not only the adoption of standards for the product, but also the implementation of a tracking procedure in order to make the control of the production links that are to be certified viable. In this way, in the case that some portion of the product does not meet the required specifications for commercialization, it would be easy to identify and analyze the source of the problem and work it out in order to minimize its effects.

The tracking of the chain can be total or partial, considering the economic cost of a tracking system compared with the benefits. Nevertheless, in the case of compulsory tracking, the scope of the process covered is defined by the quality standards that should be reached (MACHADO, 2000).

The Social Environmental Certification of the Sugar-alcohol Sector, designed by Imaflora, Embrapa – Meio Ambiente and Fase (FERRAZ; PRADA; PAIXÃO, 2000), establishes several standards for evaluating and monitoring for the certificate grant:

- Conformity with the international legislation and pacts and treaties.
- Right and responsibility of property and use of land.
- Fair relationship with the workers.
- Relationship with the community.
- Planning, monitoring and evaluation of the agro industrial activity, considering technical, economic, social and environmental aspects.
- Ecosystems conservation and biodiversity protection.
- Soil and hydro sources conservation.
- Control of the use of agro-chemicals.
- Management and utilization of residues and other chemical substances.
- Interaction with the landscape.
- Promotion of the optimization of the use of multiple sources and products of the agricultural production system, in order to guarantee the economic sustainability of the activity.
- Accomplishment of the pertinent legislation and promotion of the natural sources conservation and workers and community security in the industrial processing of the sugarcane.

In the case of the biofuels, the challenge, after the definition of the scope of the certificate, i.e., on which process it will focus (only final quality, or production process, workers conditions, environment respect, among others), is to coordinate the different agents, making the process homogeneous and the data available.

Actually, even with the benefits of a quality certificate scheme, reducing the risks in the commercialization of the products, a resistance towards its adoption can be observed, both from the entrepreneur sector and the technical teams. In order to minimize this resistance, it is essential to disseminate the largest amount possible of information regarding the implementation procedure and the benefits and risks in case it is not adopted completely. In the case of the technical team, the adoption of a training program is essential as a way to support and motivate the implementation of quality certificates schemes.

The implementation of a quality system, although costly, will bring large benefits to the sector and its cost can be minimized if the benefits to be achieved are clear and there is a strong coordination and cooperation among the agents involved.

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FUEL ETHANOL QUALITY:

METHODS OF ANALYSIS AND REFERENCE MATERIALS

Nelson Ramos Stradiotto, Maria Valnice Boldrin Zanoni, Isabel Cristina Serta Fraga and *Paulo Paschoal Borges*

INTRODUCTION

Biofuels constitute a viable alternative in relation to fuel derived from petrol and can be considered as important source of energy in the future. The participation of biofuel in the energetic matrix depends of a complex array of factors involving many production aspects (raw material and technology) and from the sustainability (social, economic and environmental), of this energy source. Since the start of Proalcool program the quality of ethanol was always connected with performance of engine working with hydrated alcohol and playing an important role in its sustainability economic.

Afterwards, ethanol quality was considered a priority factor for environmental sustainability, mainly when it compared with other vehicles working with other fuels. More recently, ethanol quality plays a decisive role on the possibility of becoming a commodity in the international market.

The validation of biofuels is markedly dependent of three basic factors: normalized specifications; official methods of analysis, and certified reference materials. The normalized specifications are a set of characteristics required to secure that the biofuel has the final destination as previously defined. The official methods are the tools necessary to construct a correct evaluation of the normalized specification of the fuel. The credited reference materials are tools utilized in the validation and official method control of fuel analysis.

Taking into consideration that the ethanol specifications are normalized by national (ANP e ABNT) and international (ASTM e CEN) agencies, the present work has the aim to contribute with a critical analysis of the state-of-the-art (research and development) using the main analytical methods and to compile norms about reference materials certified for ethanol analysis.

METHODS OF ANALYSIS

The methods of analysis utilized for evaluation of fuel ethanol quality can be classified in two main groups: officials and alternatives methods. In both cases, there are a preponderancy of instrumental methods in relation to classic methods based on gravimetric and volumetric analysis. From the instrumental methods of ethanol analysis there is predominance of three classes: chromatographic, spectroscopic and electrochemical methods.

Official methods

The official methods destined to ethanol analysis and adopted by ANP have presented small changes since the first regulatory rules established to certify biofuel quality. The technical regulations emitted for CNP (n. 17/1985), DNC (23/1991), ANP (1/2001) and ANP (36/2005) shows that there is methodological evolution only for determined species.

This evolution was mainly based on the transference process occurring from classical to instrumental methods. As instance, the sulfate determination in ethanol was initially based on gravimetric method, afterwards was proposed a volumetric method and more recently the main analytical method for sulfate determination is ionic chromatography. Also, the methodological evolution for chloride determination in fuel ethanol was from the volumetric methods, potentiometric analysis and finally by using ionic chromatography method.

On the other hand, some times the evolution occurred using own instrumental methods. For example, initial determination of copper and iron emigrated from UV-Vis spectrophotometric methods to atomic absorption spectroscopic methods. Paradoxically, for example, determination of hydrocarbons, esters and superior alcohols that were usually carried out by gas chromatography are not required in the actual specifications. In addition, there is introduction of regulations for new species, too. For example, it was introduced the necessity to determine some species that in the past was not required, such as hydrocarbons determination in fuel ethanol destined to importation, distribution and commercialization, by using gas chromatography.

Other official methods of analysis are proposed to assess the quality of fuel ethanol by international organisms, such as, American Society for Testing and Materials (ASTM) e Comité European de Normalisation (CEN). In general, the analytical methods utilized by these organisms present some differences with that adopted by the Agencia Nacional de Petróleo, Gás Natural and Biocombustíveis in Brazil (ANP).

In most cases these differences are centralized by the utilization of more specific method of analysis. Sometimes this difference involves the change of classical methods to instrumental methods or the specific type of instrumental method adopted. For example, the determination of water content in ethanol is carried out utilizing the karl Fisher method, but can be done by both volumetric (NBR 15531) and coulometric (EN 15489) methodology.

In summary, the official methods for fuel ethanol analysis have been the subject of several evolution over the years , which involves classical methods and simple instrumental methods but sometimes still demands modern and sophisticated methods, too. Thus, it is observed the disappearance of some analytical methods that are obsolete and the raising of others to attempt the new specificities dealing with fuel ethanol. This dynamic involving the utilization of methods of analysis is due mainly the concern with environmental and economic factors. The environmental concerns determine the source for new species of importance in the environmental equilibrium; meanwhile the economic aspects are oriented to attempt the requirement of cost, speed and accuracy of the analysis.

Alternative methods of analysis

The main characteristics of the alternative methods for ethanol analysis are that they are essentially instrumental analysis. This occurs because most of them present high detectability and high selective of interest species.

Chromatographic methods

The chromatographic methods are predominant in organic species determination present in fuel ethanol, such as alcohols, aldehyde and acetones (Table 1). Among all these methods, predominates gas phase chromatography (GC) with fire ionization detection (FID). For determination of organic species are also utilized high performance liquid chomatography (HPLC) with spectroscopic (UV/Vis) and electrochemical detectors (DC).

From several chromatographic methods found in the literature [1] for fuel ethanol analysis we would like show some examples, such as the work carried out by Vilar *et al*. [7] that used gas chromatography with mass spectroscopy (GC-MS) for determining several organic compounds in fuel ethanol. The sample was submitted to solid phase extraction using XAD-4 resin and fractioned subsequently in a preparative liquid chromatographic column containing activated silica gel. It was detected linear saturated hydrocarbons and aromatic hydrocarbons in the first fraction and oxygenated compounds, such aldehydes, acetones and alcohol in the second fraction.

Pereira *et al*. [3] describes a useful analytical method for determining organic and inorganic contaminants in fuel ethanol sample utilizing capilar eletrophoresis technique. Chloride and

TABLE 1 Chomatographic methods proposed for ethanol fuel analysis.

Methods	Species	Useful work interval		Reference
		Minimum	Maximum	
GC	Acetaldehyde, Methanol, Propanaldehyde, Ethyl Formiate, Ethyl Propionate, Methyl acetate, Isopropyl Acetate, Dimethylcetone, Dimethyl Ether, Diethyl Ether, Superior Alcohols, Formaldehyde	1 ppm	N/S	[2]
CE	Acetaldehyde, Dimethylcetone	1.3 ppm	25 ppm	[3]
	Ammonium	0.15 ppm	N/S	[4]
	Calcium, Magnesium	0.17 ppm	N/S	[4]
	Potassium	0.22 ppm	N/S	[4]
	Sodium	0.16 ppm	N/S	[4]
	Chloride	0.065 ppm	0.65 ppm	[8]
		0.02 ppm	0.1 ppm	[20]
		0.08 ppm	N/S	[4]
	Nitrate	0.1 ppm	N/S	[4]
	Sulfate	0.25 ppm	4 ppm	[8]
		0.2 ppm	4 ppm	[3]
HPLC-ED	Acetaldehyde	3.8 ppm	379 ppm	[5]
	2-Furfuraldehyde, 5-Hidroximethylfurfural, Buthyraldehyde, Dimethylcetone, Methyl-ethylcetone	6 ppb	500 ppb	[6]

sulfate anions were analized using indirect detection at UV irradiation of 210 nm. The analysis of aldehyde was based on detection of adducts 3-metil-2-benzotiazole hydrated at 216 nm. Both methodologies were successful applied in real samples of fuel ethanol indicating inorganic ion concentration level from 0.15 to 6.64 mg L^{-1} and aldehydes from 32.0 to 91.3 mg L^{-1}.

Munoz *et al.* [4] developed a method for determination of inorganic ions in fuel ethanol using capilar eletrophorese technique. The method was used to Na, K,Ca, Mg e NH_4 cation and sulfate, chloride and nitrate anions. The limit detections for these ions are in a concentration interval from 0.06 to 0.18 mg L^{-1}. Inferior detection limit can be reached by increasing of injection time and/or injection pressure.

Okumura *et al.* [5] describes an analytical method for acetaldehyde determination in fuel ethanol by using high performance liquid chromatography (HPLC) with UV-vis detection. The acetaldehyde was dissolved with 2.4-dinitrophenilhydrazine. The calibration graphs are linear from concentrations of 3 to 300 mg L^{-1} by injection of 20 μL sample. The limit detection was estimated to 2.03 μg L^{-1}. The method was successful applied in analysis of acetaldehyde in fuel ethanol sample.

Bruning *et al.* [2] developed a method for identification and quantification of organic contaminants presents in fuel ethanol utilizing the gas phase chromatographic technique (GC) couple to fire ionization detector (FID). The analysis carried out in ethanol presented relative standard deviation around 10%. The main organic contaminants found were ethyl acetate, n-propanol, isobutyl acetate and isoamyl acetate.

SACKZ *et al.* [6] describes the determination of aldehydes and several acetones in fuel ethanol by high performance liquid chromatography (HPLC) with electrochemical detection (ED). The compounds 5-hydroximethylfurfural, 2-furfuraldehyde, butyraldehyde, acetone and methyl-ethyl-acetone, were derizatized with 2.4 – dinitrophenilhydrazine (DNPH). The analytical curves present linear relationship for concentration from 5.0 to 400.0 ng L^{-1}, and detection limit from 1.7 to 2.0 ng L^{-1} (20 μL). The proposed methodology is simple, rapid (15 min/analysis) and present high recovery (> 95%).

Spectroscopic methods

The spectroscopic methods are utilized in fuel ethanol analysis for determining inorganic species, mainly metallic ions, such as, copper, iron and sodium (Table 2). In the set there is predominance of methods involving atomic absorption spectroscopy with fire (Faas) and graphite oven (GFaas). In the determination of metallic ions species are also utilized plasma methods induced by mass detectors (ICP-MS).

From the spectroscopic methods for ethanol analysis found in literature [1] a relevant contribution was shown by SAINT'PIERRE *et al.* [10]. The authors describe the development of a method for metal determination in fuel ethanol utilizing ICP-MS. A solution of 10% v/v ethanol was introduced directly in the ultrasonic nebulizer formed with carbon deposit in the cones. The detection limits for each analyzed metal were: Ag: 0.08; Cd: 0.12; Co: 0.04; Cu: 0.4; Fe: 27; Mn: 0.7; Ni: 0.4 e Pb: 0.2 μg L^{-1}. The results illustrated that the proposed method present rapidity, accuracy and enough sensibility when compared with that obtained by ETV-ICP-MS.

Oliveira *et al.* [11] developed a simultaneous determination method of Al, As, Cu, Fe, Mn e Ni in fuel ethanol utilizing atomic absorption spectrometry with electro thermal source (ETAAS) using permanent modifier of W-Rh and conventional modifier of $Pd(NO_3)_2$ + $Mg(NO_3)_2$. The detection limit was 1.9 μg L^{-1} Al; 2.9 μg L^{-1} As; 0.57 μg L^{-1} Cu; 1.3 μg L^{-1} Fe; 0.40 μg L^{-1} Mn e 1.3 μg L^{-1} Ni. The relative standard deviation between the measurements was 4%; 4%; 3%; 1.5%; 1.2% e 2.2% for Al, As, Cu, Fe, Mn e Ni respectively. The proposed method was applied for metal determination and ten samples of fuel ethanol showing a good accuracy.

Roldan *et al.* [12] describes an analytical method for determining Cu, Ni e Zn in fuel ethanol utilizing the atomic absorption spectroscopy with fire (Faas) subsequently to a pre-concentration step containing silica gel modified with 2-aminotiazole (Siat). The results shown recovery around 100% for all metallic ions adsorbed in the column containing 500 mg of Siat. The adsorption and desorption studies of studied metallic ions contributed to the development of a sensible method of these metals at trace levels in fuel ethanol using FAAS for its quantification.

Teixeira *et al.* [13] developed a spectrophotometric method for simultaneous determination of copper and iron in fuel ethanol using ferroine as derivatizing reagent. 1.10-fenantroline can be used to detect both compounds after controlled reaction up to limit detection of 7 and 8 μg L^{-1} and variation coefficient between measurements of 1.8 and 2.3% for iron and copper, respectively. The 2.2-bipyrine reagent can also be utilized for simultaneous determination of iron and copper and the method reaches limit detection of 11 and 32 μg L^{-1} and variation coefficients of 1.9 and 2.5 for iron and copper, respectively.

Santos *et al.* [14] also developed a spectrophometric method for sulfate determination in fuel ethanol using previous reaction with dimethylsulphonazo reagent. The analytical method was based on absorbance of the product monitored at 665 nm. The method was used for determination of sulfate up to 10 mg L^{-1} with a relative standard deviation less than 2.5% between measurements and limit detection of 0.27 mg L^{-1}. The proposed method was successful used in determination of sulfate in real samples of fuel ethanol.

Teixeira *et al.* [15] describes a simple method for determination of formadehyde in fuel ethanol utilizing the spectrophotometric technique.

TABLE 2 Spectroscopic methods proposed for fuel ethanol analysis.

Methods	Species	Useful work interval		Reference
		Minimum	Maximum	
FIA-UV/Vis	Formaldehyde	0.063 ppm	1.9 ppm	[15]
	Sulfate	12 ppm	N/S	[14]
Colorimetry	Cyanide	100 ppb	N/S	[2]
FTIR	Methanol	N/S	N/S	[11]
GFAAS	Arsenic, Aluminum, Iron, Manganese, Nickel	3 ppb	63 ppb	[16]
		0.004 ppb	N/S	[16]
	Aluminum	3 ppb	N/S	[16]
	Copper	2.5 ppb	63 ppb	[11]
		0.72 ppb	N/S	[16]
	Iron	1.6 ppb	N/S	[16]
	Manganese, Nickel	0.5 ppb	N/S	[16]
FAAS	Nickel	1.6 ppb	N/S	[16]
	Cadmium	35 ppm	141 ppm	[17]
		28 ppm	359 ppm	[18]
		0.3 ppb	N/S	[19]
	Chromium, Copper, Iron, Nickel, Potassium, Sodium	1.3 ppb	N/S	[2]
	Chromium	16.4 ppm	65.8 ppm	[17]
FAAS	Cobalt	14.8 ppm	185 ppm	[18]
		1.8 ppb	N/S	[19]
	Copper	20 ppm	80 ppm	[17]
		16 ppm	200 ppm	[18]
		19 ppm	252 ppm	[12]
		1.8 ppb	N/S	[19]
		2.9 ppb	N/S	[20]
		11 ppb	N/S	[21]
		8.9 ppb	N/S	[22]
	Iron	18 ppm	70 ppm	[17]
		14 ppm	140 ppm	[18]
		6.3 ppb	N/S	[20]
		11 ppb	N/S	[21]
		5 ppb	N/S	[22]

continues

Methods	Species	Useful work interval		Reference
		Minimum	Maximum	
FAAS	Lead	14 ppm	176 ppm	[18]
	Manganese	2.5 ppb	N/S	[22]
	Nickel	18 ppm	74 ppm	[17]
		15 ppm	182 ppm	[18]
		19 ppb	253 ppb	[12]
		10 ppb	N/S	[20]
		4 ppb	N/S	[21]
		5 ppb	N/S	[22]
	Sodium	N/S	0.375 ppm	[23]
	Zinc	20 ppm	205 ppm	[17]
		16 ppm	$2.5x10^{-3}$ mol L^{-1}	[18]
		13 ppb	126 ppb	[12]
		1.3 ppb	N/S	[19]
		0.1 ppb	N/S	[20]
		2.5 ppb	N/S	[21]
		2.5 ppb	N/S	[22]
ET-AAS	Arsenic	3 ppb	N/S	[24]
	Cadmium	0.06 ppb	N/S	[24]
	Lead	1.4 ppb	N/S	[24]
ETV-ICP-MS	Cadmium	0.1 ppb	N/S	[25]
	Copper	0.12 ppb	N/S	[25]
	Lead	0.06 ppb	N/S	[25]
	Silver	0.03 ppb	N/S	[25]
	Thallium	0.001 ppb	N/S	[25]
	Cadmium	0.15 ppb	N/S	[10]
	Copper, Nickel	0.5 ppb	N/S	[10]
	Cobalt	0.05 ppb	N/S	[10]
	Iron	34 ppb	N/S	[10]
	Lead	0.25 ppb	N/S	[10]
	Manganese	0.9 ppb	N/S	[10]
	Silver	0.10 ppb	N/S	[10]
UV/Vis	Copper	40 ppb	N/S	[13]
	Iron	14 ppb	N/S	[13]

The product assigned as 3.5-diacetyl-1,4-dihydrolutidine generated after reaction between formaldehyde and fluoral P was kept in the solid phase cartridge (C18) and the spectrophotometric detection carried out at 412 nm. The proposed method presents linear response for concentration interval from 0.05 to 1.5 mg L^{-1}. The detection limit obtained was 30 μg L^{-1} and the relative standard deviation was 2.2% (625 μL). The method was successful applied in determination of formaldehyde in fuel ethanol samples.

Electrochemical methods

The electrochemical methods utilized for determination of inorganic species in fuel ethanol, are preponderantly metallic ions, such as copper, lead and zinc (Table 3). From these methods are predominance of them based anodic stripping voltammetric techniques (ASV) coupled to differential pulse (DP) and square wave (SW) as scan mode. The potentiometric and conductometric methods are also utilized for species no metallic determination as, chloride and sulfate.

From the several electrochemical methods describes in the literature [1] for fuel ethanol analysis, there is relevant contribution from work developed for Godinho *et al*. [27]. The authors developed a methodology for sulfur determination in fuel ethanol using Raney nickel base don cathodic stripping voltammetric coupled to differential pulse scan. The calibration curve present linear relationship for concentration of sulfur from 1-40 ppb and the method was successful applied in ethanol samples containing 15 ng g^{-1} to 20 μg g^{-1}. The values of precision and accuracy obtained with

TABLE 3 Electrochemical methods proposed for ethanol fuel analysis.

Methods	Species	Useful work interval		Reference
		Minimum	Maximum	
Voltammetry	Acetaldehyde	0.05 ppm	5 ppm	[31]
		0.05 ppm	0.5 ppm	[33]
	2-Furfuraldehyde	115 ppm	704 ppm	[34]
	Solvent Orange 7	1.4 mg L^{-1}	6.3 mg L^{-1}	[32]
ASV	Cadmium	0.14 ppb	70 ppb	[30]
DPV	Nickel	$5.0x10^{-9}$ mol L^{-1}	$5.0x10^{-7}$ mol L^{-1}	[35]
		$7.5x10^{-9}$ mol L^{-1}	$1.0x10^{-6}$ mol L^{-1}	[36]
DP-ASV	Copper, Zinc	0.08 ppb	40 ppb	[30]
	Copper	6 ppb	200 ppb	[37]
	Lead	2.5 ppb	312 ppb	[28]
		0.26 ppb	130 ppb	[30]
	Zinc	40 ppb	411 ppb	[38]
SW-ASV	Copper	0.15 ppb	N/S	[39]
	Iron	0.42 ppm	1.4 ppm	[40]
	Lead	0.297 ppb	N/S	[39]
DP-CSV	Sulfur	1 ppb	40 ppb	[27]
Potentiometry	Copper	12 ppb	N/S	[41]
	Chloride, Sulfate	1 ppm	N/S	[2]
Conductometry	Chloride	1.1 ppm	N/S	[29]

the proposed method present values comparable with that previously described in the literature.

Takeuchi *et al*. [28] described a method for determining copper in fuel ethanol utilizing paraffin containing impregnated graphite powder with the 2-aminotiazole as modifier. The technique for detection was anodic stripping voltammetry with differential pulse mode. The analytical curve presents linearity from 7.5 x 10^{-8} to 2.5 x 10^{-6} mol L^{-1} copper concentration and detection limit of 3.1 x 10^{-8} mol l^{-1}. The method was successful applied in the determination of copper in fuel ethanol sample.

Avelar *et al*. [29] developed a determination method for chloride and total acidity in fuel ethanol sample using conductometric titulation method. The proposed methodology is simple and rapid and can be applied with good repeatability and detectability of total acidity and also chloride content when compared with the official methods of analysis.

Oliveira *et al*. [30] describes the development of a method for simultaneous determination of zinc, copper, lead and cadmium in fuel ethanol using a mercury film on vitreous carbon electrode by stripping voltammetric technique (ASV). The measurements were carried out using linear scan (LSV), differential pulse (DPV) and square wave (SWV) modes. The obtained detection limit for all metals was in the interval from 10^{-9} to 10^{-8} mol L^{-1}. The proposed method was tested for quantification of zinc, copper, lead and in commercial samples of fuel ethanol.

Rodgher *et al*. [31] proposed a method for acetaldehyde determination in fuel ethanol utilizing previous mixed reaction with hydrazine by using square wave voltammetry. The analytical curves were linear for concentrations changing from $1.0x10^{-6}$ to $10x10^{-6}$ mol L^{-1}, with a detection limit of $2.38x10^{-7}$ mol L^{-1}. The method was satisfactory applied in determination of total aldehydes in ethanol samples without any pretreatment step.

Romanini *et al*. [32] describes the development of a method for determination of solvent orange 7 dye used as dye marker in fuel ethanol using linear scan voltammetry (LSV) and square wave voltammetry (SWV. The SWV technique presents lower detection limit and linear calibration curve from $4.0x10^{-6}$ to 18 $x10^{-6}$ mol L^{-1}. The method was successful applied in direct quantification of this marker in fuel ethanol sample without any pretreatment step.

THE IMPORTANCE OF THE REFERENCE MATERIAL ON QUALITY CONTROL OF ETHANOL

The current usage of biofuels is global concern with environmental sustainability. Therefore the quality of Brazilian bioethanol due to its origin from renewable sugarcane becomes even more important [42-44]. Since well-characterized reference values are essential to the development and validation of measurement methods, the usage of Certified Reference Material (CRM) will contribute to the quality of the measurement around the world, giving support to international trade.

In 2007, experts and government representatives from the United States of America (USA), European Union (EU) and Brazil agreed that there are different standards for biofuels which were known to be an obstacle to the free circulation of biofuels among the three regions. On a White Paper [45] issued by the tripartite task force, they identified areas where greater compatibility could be achieved in the short to long term. Bioethanol was classified into category B. It has specifications with significant differences between parameters and methods.

Because of the importance of bioethanol to the Brazilian economy [46], and considering that the international trade in biofuels will increase significantly [47, 48], Inmetro, the Brazilian Metrology Institute, has focused its attention on the need for accurate and reliable measurements in a variety of parameters, through the work for developing and producing CRM of bioethanol [49] in order to establish quality and comparable measurements in bioethanol matrix. However, the use of a CRM of bioethanol will also contribute to Brazilian producers, to avoid possible technical barriers imposed by bioethanol importers in the near future.

Reference Material (RM) and Certified Reference Material (CRM)

Reference material is a material sufficiently homogeneous and stable with reference to specified properties, which has been established to be fit for its intended use in measurement or in examination of nominal properties [50-54]. On the other hand, a CRM is a reference material accompanied by documentation issued by an authoritative body and providing one or more specified property values with associated uncertainties and traceability, using valid procedures. To summarize, the RMs and CRMs, as defined above, are widely used for the calibration of measuring apparatus, evaluation or validation of methods of analysis or test and for long-term quality assurance of measurements. All kinds of RMs and CRMs are playing an increasingly important role in national and international standardizations activities, for the trade, in proficiency testing and in the accreditation of laboratories.

In the chemical area, to establish the traceability to the measurement, the use of the so considered primary measurement methods or certified reference materials is needed. The Consultative Committee for Amount of Substance — Metrology in Chemistry (CCQM) has identified several methods with the potential of being a primary method of measurement, which in the field of chemical measurement, such a method is defined by CCQM as "a method having the highest metrological properties, whose operation can be completely described and understood, for which a complete uncertainty statement can be written down in terms of the units of SI (International System of Units)". However, they are as yet very few [55, 56], thus, the CRMs are strongly used to guarantee the quality of chemistry measurements.

Although the importance of the use of CRMs is known, however, the great variety of chemical substances and diverse matrices in which the analytes can be encountered limit the number of the CRMs available. Thus, there are not sufficient CRMs to all measurements. To this difficulty can be added the high cost for acquisition and importation of this materials, to the bureaucracy and the long time spent in the transport and liberation of the imported materials in the Brazilian customs [57].

Hence, Inmetro has been developing CRMs which can be used by the laboratories in the country from different areas such as industrial, research & development and environment. The high metrological level of the measurements performed by the laboratories of Inmetro is mainly due to its participation in key comparisons with the supervision of the *International Committee for Weights and Measures* (CIPM)/CCQM. On the other hand, the CRMs prepared by Inmetro follow the requisites established in the ISO Guides 30 [58], 31, 32 [59], 33 [60], 34 e 35 [54]. The ISO guides from 30 to 34 have already been translated to Portuguese by ABNT, the Brazilian forum for standardization.

Some countries have already had an accreditation system for producers of reference materials. The accreditation is based on the ISO Guides 30, 31, 34, 35 and on the standard ISO/IEC 17025 [61], as well as the standards or guides which are related to the area to be accredited. Thus, Inmetro is structuring a similar system in Brazil. This system of accreditation will contribute to increase the production of CRMs as well as the quality of the chemical measurements in the country.

Development of a certified reference material

In the development of a CRM, the producer must take into account the requisites and the recommendations stated in the ISO Guides above mentioned.

The ISO Guide 35 can be seen as an application of the *Guide to the Expression of Uncertainty in Measurement (GUM)* [62] specifically for the production of CRMs. ISO Guide 35 complements the GUM because it provides additional guidance with respect to the inclusion of the uncertainties due to the batch in homogeneity and instability of the CRM in the uncertainty of the property values, and the determination of these uncertainty contributions.

Homogeneity and stability are two important characteristics of any CRM. Hence care must be taken during preparation to produce materials as homogeneous and stable as possible. However, careful preparation by itself is not enough. Demonstration of homogeneity and stability is required by taking into account the uncertainty calculation [63]. According to the GUM, the uncertainty of a CRM should consider all the uncertainty sources relevant to the user. This not only includes the uncertainty of the batch characterization (u_{char}), but also all uncertainties relating the possible between-bottle variation (u_{bb}), instability upon long-term storage (u_{lts}) and instability during transport to the customer (u_{sts}). The combined standard uncertainty for a CRM can thus be expressed as in Equation 1 [64].

$$u_{CRM} = \left(u_{char}^2 + u_{bb}^2 + u_{lts}^2 + u_{sts}^2 +\right)^{1/2} \qquad (1)$$

It is important to highlight the difference between characterization and certification. Characterization of a reference material is a process of determining the property values of a reference material, as part of the certification process. The characterization process provides the values for the properties to be quantified. In batch certification, the characterization refers to the property values of the batch. Certification is the whole process of obtaining the property values and their uncertainty, which includes homogeneity testing, stability testing, and characterization [65].

Homogeneity study

A homogeneity study is necessary in batch certification to demonstrate that the batch of bottles (units) is sufficiently homogeneous. It also finds application in the preparation and checking of proficiency testing material [66]. Even when a material is expected to be homogeneous, as in the case of solutions, an assessment of the between-bottle inhomogeneity is required. When dealing with solid-state reference materials, a within-bottle homogeneity study should be foreseen to determine the minimum sample intake.

The results of a between-bottle homogeneity test should be evaluated in accordance with the design of the study. In most cases, however, an approach based on a fully-nested analysis of variance, as described in ISO Guide 35 and in [66, 67] can be used for the purpose.

Stability testing

Stability testing aims to determine the remaining degree of instability of the reference material after preparation, or to confirm the stability of the material. A distinction is made between the stability under specified storage conditions (long-term stability) and transport conditions (short-term stability).

The long-term stability concerns the remaining instability of property values of the CRM. A reference temperature should be chosen so that it is practically certain that the material is stable at that temperature.

The short-term stability study is typically carried out at different temperatures, to study the effect of different temperatures on the properties of the material. A short-term stability study takes typically 1 to 2 months. On the other hand, a long-term stability studies last between 24 and 36 months [68, 69].

A flow diagram for evaluation of measurement uncertainty in a complete process for certifying a reference material [65] can be seen in Figure 1. The measurements of the homogeneity, stability and the characterization studies of the material should be combined in order to obtain a proper estimate for the property value and its standard uncertainty.

Choice of measurement methods

For the characterization of the reference material, especially in the case of matrix reference materials, it is often highly desirable to use multiple methods, and often also multiple laboratories. Both the methods and the performance of the laboratories should represent "state-of-art", and they should be able to make their measurements traceable to the references specified in the design of the project to develop a CRM. This approach is known as a collaborative study. This underpins the joint effort of the coordinator and participants to characterize the reference material.

The method used in a certification project should be properly validated, and it should be demonstrable that any result obtained with the measurement method meets the specifications established during the validation of the method.

The property values of a CRM need to be traceable to appropriate units and/or references due to its role as a measurement standard. Ensuring the

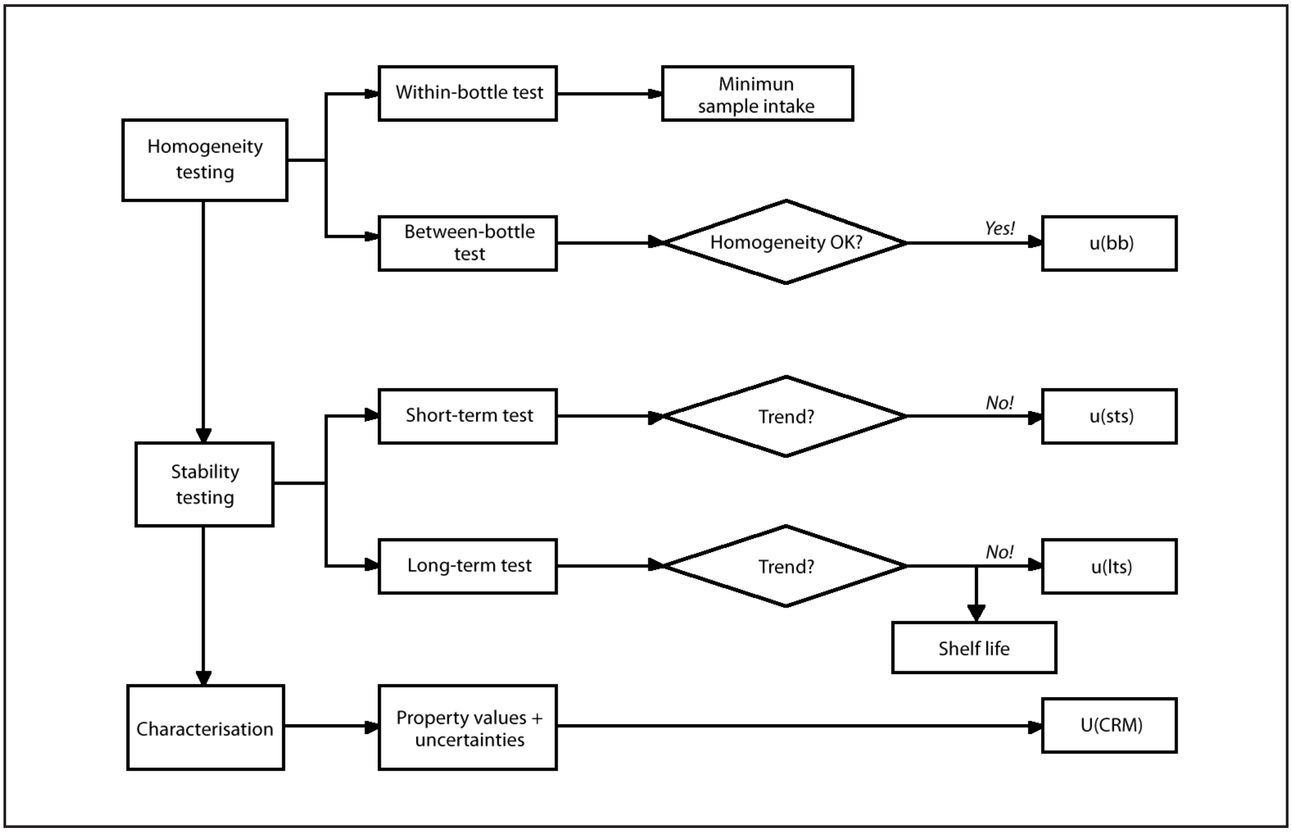

FIGURE 1 Flow diagram of a complete process for certification of a reference material.

traceability of all measurements in a certification of a reference material is an important requirement [53, 70, 71].

The CRM of bioethanol

The necessity of developing CRM of bioethanol has been claimed by the producers of this kind of product for a long time in order to guarantee its quality and to increase the exportation of their products, since the specific parameters for bioethanol could be measured with traceability and reliability and accepted by the international trade.

The development of reference materials and commercial barriers are two of the most sensitive areas needing proper Chemical Metrology support. Therefore, the first step, as stated above, would be to define the traceability chain for the measurement of these parameters. A side bonus derived from this effort would be the proposal of which parameters should be considered in the specifications of bioethanol as a fuel. This is something that would naturally come from the scientific background that will be associated with the proposed metrological work.

Since 2003, Inmetro has been studying different parameters which are established in the specifications of the National Agency of Petroleum, Natural Gas and Biofuels (ANP). This agency is responsible for the control of quality of biofuels in Brazil. It regulates the limits for several parameters in biofuels [72], according to the Brazilian Standards.

The parameters that are being studied for certification and the reasons of their relevance are given below. They are common for both anhydrous bioethanol and hydrated bioethanol.

Alcoholic content and density: for the stability and quality of the product, since the original alcoholic content as well as evaporation may affect calorific power and motor performance.

Acidity: for avoiding corrosion in the fuel chain, since it contributes to the corrosion of the metallic parts present in the production process, transport and motors.

Electrolytic conductivity: conductivity values above 500 μS×m^{-1} contribute to corrosion.

Water content: high water content may increase the conductivity and therefore corrosion, as well as decreases the calorific power.

pH: range from 6.0-8.0 for hydrated bioethanol to avoid corrosion in the fuel chain, as well as it contributes to the corrosion of metallic parts in the production process, transport and use (motors).

Copper and iron content: these metals in contact with gasoline may cause polymerization (probably gum formation) in automotive motors. ASTM Standard [73] recommends copper content values below 0.1 mg×kg^{-1}.

Chloride and sulphate: the presence of chlorides by external contamination and sulphates which cause deposits in the electronic injection systems can also contribute for increasing the corrosion.

Since 2008, the USA and Brazil have established a partnership attending to American and Brazilian government throughout of their National Metrology Institutes, National Institute of Standards and Technology (NIST) and Inmetro, respectively. In this partnership, the development of CRM for bioethanol was proposed because of the great visibility which the bioethanol has today, mainly in the environmental issues. Besides, both countries are the major biofuel producers in the world. Nowadays the studies of this CRM are in progress.

European Union has been focusing on working with Brazil also in the relevant task of comparing and searching for the harmonization of the analytical methods for the biofuel. The main objective of this partnership is to coordinate a proficiency testing (PT) in order to measure different parameters of bioethanol. In this PT the participation of various countries which has interest in providing the quality management in the trade of their products will be possible.

At Inmetro, the studies of these several parameters in anhydrous and hydrated bioethanol from Brazilian producers have become possible because this work has the support of different laboratories from Mechanical and Chemical Division from Inmetro in this challenge. Each of them carries out the measurements which are needed in the homogeneity, characterization and short-term and long-term stability studies. All the studies relating to the CRM production and development have been done according to ISO Guide 35.

The studies of homogeneity of each parameter were carried out with random measurements. If the results present homogeneity, the characterization study is carried out with the best method available for each parameter.

The short-term and long-term stability studies were done in two different temperatures simulating transport and storage conditions. Both temperatures were at 50 °C and 20 °C, respectively.

The total time of the stability study for CRM for anhydrous and hydrated bioethanol was done during one year and all parameters showed stable, then the shelf-life (validity) of this CRM was established by one year.

It is very important to highlight that the period of validity of the CRM for bioethanol can be increased if the stability is maintained during the stability studies which will continue for all the certified parameters.

FUTURE PERSPECTIVES

Nowadays, despite the high evolution that can be seen in the used methods for analyzing the fuel ethanol, there is a constant need for new specifications that require analytical methods even more precise and accurate for determination of great numbers of species. Therefore, the development of new methods of analysis might find great challenges in order to guarantee the quality of this biofuel.

From this perspective, one can designate them as: i) development of analytical methods with very low detection limits for diverse species responsible for the quality of the fuel ethanol; ii) development of analytical methods with very great selectivity to guarantee the quality of the fuel ethanol from different matrices; iii) development of analytical methods for determination of new important species for the environmental sustainability; iv) development of analytical methods for on line monitoring of the quality of the biofuel; v) development of low cost analytical methods joined with operational simplicity to guarantee the quality of the fuel ethanol.

From the perspective of the research and development of CRM for bioethanol, it has showed great importance to Brazil, since there was an extreme urgency to produce it. The Brazilian producers, in order to prove accuracy of the measured parameters for the trade, needed a reference material which could be used as a standard reference to chemical measurements. Therefore, this CRM of bioethanol, which is in development by means of a collaborative study from NIST and Inmetro, will guarantee the traceability and quality of the measurement results from quality parameters of the bioethanol in order to contribute for a reliable and fair trade; moreover, it will help to increase the trade for bioethanol from sugarcane.

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ISSUES RELATED TO THE FINAL USE OF ETHANOL (FUEL AND CHEMICAL)

THE ALCOHOL – POWERED MOTOR: PAST, PRESENT AND FUTURE

Henry Joseph Jr.

Veja, a national weekly magazine, had the following news on its June 13th, 1979 issue:

"This time we won: CDE closed the case and Proalcool is now irreversible", as a close friend heard it from the Minister of Industry and Commerce, João Camilo Penna, ecstatic, upon exiting the meeting. In fact, CDE[1] decided to invest 5 billion dollars in Proalcool[2] until the end of President Figueiredo's term, in exchange for an equally grand figure: 10 billion liters of alcohol per year. With this volume, government expects to fulfill the additional demand for gasoline in the future, as well as completely fuel 475,000 vehicles with adapted engines plus 1.225 million of originally alcohol-fueled ones for the next six years.

The minister's euphoria on that moment was explainable for Proalcool – albeit having been created four years before by the previous General Ernesto Geisel government, by means of Federal Decree n. 76 593 of 1975 – not having yet, according to the magazine, *"left the realm of vague promises, far away from the path that could free Brazil from the petroleum nightmare"*.

Among the various problems that the program faced to replace gasoline with ethyl alcohol[3], maybe the most significant one was to adapt engines to this new fuel with a minimum level of quality to ensure performance and durability comparable to conventional gasoline-powered engines. Corrosion, high fuel consumption, impaired drivability and difficult cold starts were some of the factors that made mechanics frown with distrust upon vehicles converted to use alcohol.

Until then, only fleets in government and state-owned companies or taxicabs were authorized to convert their vehicles' engines to use fuel alcohol and results were not always satisfactory. The most numerous alcohol-powered fleet then belonged to one single company: the state-owned São Paulo telephone company (Telesp), which had 400 Volkswagen Sedan 1300 cars converted by Motorit, a firm specialized in engine reconditioning. These vehicles suffered from operational and durability problems, which required intense maintenance to be stubbornly used. Some other fleets were also being converted, however most vehicles converted for alcohol were taxicabs, which benefited from the allowance granted to buy alcohol at a 65% reduced price in comparison to gasoline at the so-called "licensed gas stations".

The alcohol fuel itself was, until then, from a technical specifications standpoint, reasonably unknown. Produced by different processes, in attached (connected to sugar mills) or independent distilleries (not attached), with variable chemical composition, it contained various contaminants from the processing, storage or transportation processes, plus an absurdly variable water content, that could range from 5% to 12% in volume, even considering only the so-called hydrated ethyl alcohol fuel. The issue then was whether the ideal ethyl alcohol

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[1] CDE (Conselho de Desenvolvimento Econômico) – Economic Development Council.

[2] Proálcool (Programa Nacional do Álcool) – National Alcohol Program.

[3] Ethanol and ethyl alcohol are synonyms; it is an alcohol with two carbon atoms in its molecule.

for fuel should be produced according to specifications for pharmaceutical alcohol, food alcohol (used in the liquor industry) or sanitation alcohol (sold in supermarkets for household cleaning).

In fact, it should be remembered that the Department of Engines of the Aerospace Technical Center (Centro Técnico Aeroespacial – CTA), then led by the Air Force Coronel and Aviation Engineer Urbano Ernesto Stumpf (1916 – 1998), had been, since 1947, researching and developing the use of ethyl alcohol in internal combustion engines, with some success. Witnesses tell that, upon being presented a vehicle converted by CTA to use alcohol, President Geisel believed and decided that the program to use ethanol as an alternative fuel to gasoline was viable. Nevertheless, the works developed at CTA, while clustering the efforts of several engineers and technicians on some engines, only showed the technical feasibility of such conversion; they didn't take into account all the minor details that, in practice, would have to be considered, such as large-scale conversion of motors of different makes and brands, with different technical standards, plus varying conservation and maintenance conditions.

The reason for this difficulty in adapting engines to use alcohol for fuel was very simple: at that time, engine design resulted from decades of development in one technology (the internal combustion engine) for one specific fuel (gasoline); and vice-versa.

THE DEVELOPMENT OF GASOLINE-POWERED ENGINES

The motors-fuels match was one of the most important factors in the evolution and affirmation of the internal combustion engines market. In the first engines, still used for driving industrial machinery from the 19th century, the fuel used was the same as in gas lighting[4]. The availability of this fuel, thanks to the public lighting systems of those days, made it very convenient for use in stationary engines[5]. Differently from the cumbersome steam engines with their furnaces, the reduced weight and size of the internal combustion engine made it quite attractive for application in small vehicles that would serve for individual transportation. In this case, the use of lighting gas for fuel was inadequate.

The vision of the opportunity of its application to light vehicles led several entrepreneurs to work on adapting the internal combustion engines to liquid fuels. Their higher energy density and ease of transportation made evident the advantages of using this fuel in small vehicles.

The discovery of oil fields in the US, around 1854, with ample supply and relatively easy exploitation was another driving factor for this development. John D. Rockefeller, an American born in 1839, was one of the first visionaries to notice the business importance oil products would have as liquid fuels for those motorized vehicles that were beginning to appear. At the age of 22 he bought a small company, which got him into oil products refining, transportation and sales. In 1863, he founded his first refinery and the second one in 1866. He quickly secured the virtual monopoly of the business, building his own pipelines, buying several companies, developing distribution networks and using quick negotiation methods. In 1879, his Standard Oil Company controlled 95% of the petroleum market. However, his efforts to enter the world of politics were not welcomed and, in 1892, with the Anti-Trust Law, his company was forced to divide into smaller enterprises.

The Austrian Siegfried Marcus is considered as the inventor of the carburetor, an essential part for using liquid fuels in internal combustion engines. Due to the natural difficulty to promote a good mix between liquids and air, the invention of the carburetor, by improving this mixture, brought an enormous advance to the use of gasoline as fuel.

Nevertheless, the final step in establishing the gasoline engine only came in 1883 with the work of Gottlieb Daimler and Wilhelm Maybach, who built a convincing operation carburetor and associated it to a fuel injection system they had also developed. The result was a tremendous leap in the evolution of internal combustion engines. Daimler's engine reached 900 RPM, while gas-powered motors of those days barely took on 200 RPM. This made the match between internal combustion engines and petroleum products, at the same time that it created conditions

4 Lighting gas was produced from coal gasification.

5 Industrial application engines, used to drive machines or electric generators.

for developing the automobile, to which internal combustion engines became unavoidably attached.

However, the automobile would only be affordable to a few overly wealthy people, were it not for the entrepreneurial spirit of the American Henry Ford. Born in 1863, Henry Ford, an engineer, saw that the automobile could interest everyone, if only it could be bought for a reasonable price. In order to achieve a cheaper product, Ford invented the famous “assembly line”, where all the production steps were spread along a belt conveyor, where each employee would mount a standard component. The idea was to gain in scale and avoid hesitation and time wasted by employees while building vehicles. Launched in 1908, and sold for 850 dollars apiece, the T-Model Ford was a hit and 15 million units were sold over some 20 years. Contrary to products offered by other manufacturers, Ford cars were not like handcrafted toys for the wealthy to show off; instead they were mass produced, to be used every day by plain citizens.

With the progress made by Ford and his many competitors, parts suppliers, resellers, repair shops, fuel stations and roads multiplied. Having a car, people were able to travel more and to live farther away from downtown areas. Pollution, noise, accidents and traffic jams replaced other urban problems and became thus associated to the image of urbanization and development.

So, at the outset of the 20th century, from the introduction of the assembly lines and serial production concepts brought by Henry Ford, the automotive industry began growing immensely, not only in America, but also in England, Germany, Italy, and France. The year of 1919 reported the amazing figure of 186 roadworthy automotive manufacturers worldwide, which produced 11 million units in that year alone. The outbreak of World War I in Europe raised two very strong factors for this industry. On the one hand, it halted the growth this industry had been enjoying in terms of production volume, mostly in Europe, however, on the other hand, thanks to the war efforts and the widespread use of the internal combustion engine fueled with petroleum products in military cars and trucks, as well as in motorcycles, airplanes, boats, ships and any self-propelled contrivance, it caused tremendous technology leaps that allowed to improve their efficiency and performance, reduce their size and lower their cost.

In the period between the two World Wars, the number of vehicle manufacturers diminished, but the quantity of acquisitions and incorporations strengthened the surviving companies which, adopting more advanced technologies, resumed large scale production, rendering the automobile even more popular and taking this product to every corner of the planet. Intensely publicized by the movie industry, literature and press, the individual use of the automobile took on in every continent and country, transforming cities, opening highways, fostering oil prospecting, the construction of refineries and the distribution of products.

THE DEVELOPMENT OF GASOLINE

Contrary to the development of the internal combustion engine, whose major characters and dates are well known and documented, the development of features and specifications of gasoline as automotive fuel does not have the same accurate records and names. This is probably a result of countless minor empirical changes effected by hundreds of companies and technical associations throughout the past 100 years.

What can be said is that most of the early research into the adaptation of the physicochemical characteristics of gasoline to the requirements of internal combustion engines began in the US in 1900, due to the pressure exerted by vehicle manufacturers against the incredible variety of fuels offered to American consumers as proper for their vehicles. In 1982, when Standard Oil Company split into smaller companies and tens of other oil companies started out, the American oil refining industry began growing in such a haphazard manner, that each producer had their own criteria for fractioning petroleum into its various components. As petroleum is a mixture of tens of compounds (hydrocarbons) with different molecular sizes, separated by distillation in groups, the definition of where one group ends and another begins is essential, as each group will be named gasoline, diesel, kerosene, naphta, fuel oil, lubricating oil, grease or asphalt. For vehicle manufacturers, the variation in the mix of hydrocarbons present in the various "gasolines" available in the market was a huge problem, as such variation completely changes the physicochemical characteristics of the fuel, altering its combustion properties and compatibility with materials.

The outbreak of World War I (1914-1918) turned the need for setting quality standards and technical specifications for the most varied industrial products into an urgent issue and, within the action taken and nurtured by the US government, several technical associations were created. One such association was the *National Petroleum War Service Committee*[6], which led to the creation of the *American Petroleum Institute*[7] – API in 1919. In parallel, other existing technical standards associations became involved with developing norms for parts and components for the automotive industry, among them the *American Society of Testing Materials*[8] – ASTM.

Also in Europe, the beginning of the 20th century was a time for intense research and standardization of fuels and lubricants, with the involvement and creation of various standardization organizations, mostly in France, Germany, England and Italy. Just as in the United States, the two World Wars, both the First (1914-1918) and the Second (1938-1945) caused significant progress in the study of fuel properties and their specifications.

Therefore, within a 50-year interval that began circa 1900 and continued until the 1950s, engine, vehicle and gasoline were developed, each one to match the others, reaching excellent quality and compatibility levels, rendering the automobile the most suitable means of individual transportation, as well as an object of desire for any human being in the world.

THE SEARCH FOR ALTERNATIVE FUELS

When World War II burst, the automobile and vehicles of the same kind were already present in the four corners of the world and the demand for fuel, components and replacement parts was quite significant. Interrupted supply of these products in non-manufacturing countries, due to transportation difficulties and rationing caused by the war, became a serious problem, leading to the search for alternative fuels and the rise of a new industry, the production of non-original parts, which later became the seed for new vehicle manufacturing centers in countries in Asia, Oceania and South America that until that moment did not have local manufacturing.

As the war ended, with the efforts to rebuild affected countries' economy, the United States taking the role of a new world power and the plans for rebuilding defeated nations, the automotive industry had its apogee. The automotive manufacturing park became international. Automobile, truck and parts manufacturing plants were implemented in dozens of countries, making the world fleet reach 200 million vehicles in 1960. Consequently, as all these vehicles were powered with gasoline or diesel, petroleum consumption hit 8 million barrels per day on that same year of 1960, at an average price around US$ 2 per barrel at that time. Fuel was very cheap for those wonderful vehicles, which gave status, freedom and progress.

Conflicts in the Middle East, which began with the Suez War (1956) and that were deeply aggravated with the Six Day War (1967) were the first warning signs that oil-consuming countries saw about the possibility of shortage and price increases, making them think about their dependency on this energy source. On the other hand, oil-producing countries in that troubled area quickly realized they held a most valuable trading asset to impose their political interests on the international economic community. At that time, holding over 70% of the international oil trade, as the US production was short of supplying its own demand, the North Atlantic oil was outrageously expensive due to extraction in deep waters, Russia, the leader of the Soviet Union at that time, did not trade their oil with Western countries on account of the Cold War, Mexico and Venezuela were happy to fulfill part of the American oil production gap. As other countries had very little relevance in the existing oil trade, the Middle Eastern countries realized they held most of the supply for Western Europe, Asia, Oceania and a considerable part

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[6] War Effort Committee for National Petroleum (Comitê de Esforço de Guerra para o Petróleo Nacional).

[7] American Petroleum Institute.

[8] American Society for Testing and Materials.

of the Americas in their hands. Taking power positions in the Organization of the Petroleum Exporting Countries – Opec, until then an existing but rather inexpressive international organization, they managed to compromise the producing countries into quotas and joint price setting. The results of this strategic union did not take long to be felt. In 1973, as a response to the international support given to Israel in the Yom Kippur War, the world was subject to what became known as the "First Oil Shock". The oil producing countries jointly cut their production volume and raised the price of the oil barrel to absurdly high values. In three months, oil price jumped from US$ 2.90 to US$ 11.65 per barrel. Such action shattered the world economy and led to severe recession in the US and Europe, with large international repercussion. Owning two-thirds of the petroleum reserves in the world, countries like Saudi Arabia, Iraq and Kuwait controlled production volume and prices.

The second petroleum shock occurred in 1979, caused by the Iranian Revolution that ousted Shah Reza Pahlevi and installed an Islamic republic in that country. Oil production in Iran was seriously affected and the nation was unable to supply even its own domestic needs. Iran, which had been the second largest Opec exporter, below Saudi Arabia, was practically out of the market. In short supply, oil price skyrocketed and increased the world economic recession in the early 1980s. Exception made to Iron Curtain countries (the Soviet Union and allies), which had the abundant Russian oil, all other countries, both developed and developing, were seriously affected by this shock.

The new oil price level after these two shocks and the joint action of the Opec countries, however, brought some unexpected consequences. Pressured by high prices, consuming countries sought new suppliers or resumed their extraction in known – but so far not economically viable – oil fields. Oil extraction in deep waters, in the North Sea, Gulf of Mexico, the Caribbean and the Brazilian coast, or inland extraction in Africa, Alaska and South America was then resumed and considerably increased the supply of petroleum.

On the other hand, this made it clear to the international community that the use of petroleum as a sole source of energy or raw material for producing vehicular fuel had to be reconsidered. Several experiments began to be carried out then in different countries. Methanol[9], ethanol, vegetal oils, natural gas, MTBE[10], ETBE[11], Fame[12], FAEE[13], DME[14] and various other substances started being mentioned and tried.

THE USE OF THE GASOLINE – ALCOHOL MIXTURE

Like gasoline, ethyl alcohol is also a light, flammable and easily obtainable liquid, so it also aroused interest as a possible fuel for vehicles by several early manufacturers. Were it not for the strong campaign against drinking in the US, in the early 20th century (that culminated with the Prohibition Law, on January 16th, 1919), ethanol would probably have been used more often, or at least would have been further researched as fuel for vehicles. Henry Ford himself did experiments with an alcohol-powered T-model car in 1911, and several car races in the US Midwest between 1910 and 1915 used alcohol for fuel.

In Brazil, as ethyl alcohol was a lesser-valued product in sugar production, its informal use as fuel was quickly adopted for the first automobiles that arrived here, as a way to reduce the high cost of imported gasoline. On February 20th, 1931, through Federal Decree n. 19 717, the government made it mandatory to add 5% ethanol to imported gasoline and seven years later (Decree Law n. 737 of September 23rd, 1938) – as the imported gasoline and alcohol mix results had been positive, and World War II had erupted in Europe – the government extended the mandatory addition of 5% ethanol to all gasoline sold in Brazil, regardless of its being domestic (local production had just begun) or imported.

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9 Methanol and methyl alcohol are synonyms; it is an alcohol with one carbon atom in its molecule.

10 MTBE – Methyl tert-butyl ether.

11 ETBE – Ethyl tert-butyl ether.

12 Fame – Fatty acid methyl ester (biodiesel made from trans-esterified methyl fat).

13 FAEE – Fatty acid ethyl ester (biodiesel made from trans-esterified ethyl fat).

14 DME – di-methyl ether.

However, the introduction of ethyl alcohol into our energy matrix in a responsible, standardized, consistent and systematic manner only began in the 1970s, by means of the National Alcohol Program (Programa Nacional do Álcool – Proálcool), which was implemented in two phases, named Proálcool I (Federal Decree n. 76 593, 1975) and Proálcool II (Federal Decree n. 83 700, 1979). Pressured by the strong impact on the Treasury caused by successive raises in international petroleum prices, the Brazilian government chose to make it official and add to our energy matrix the use of alcohol as automotive fuel. Though all the alcohol produced so far was ethylic, made from sugarcane, Proalcool's first idea was that other alcohols and other sources of raw material should also be fostered, such as methanol from natural gas or wood and ethanol from cassava.

At the same time and for the same reasons, other countries also focused on the implementation of research programs for alternative fuels, among them methanol (United States, South Africa, Germany, Japan etc.) and ethanol (Sweden, India, China, Australia etc.). Like Brazil, these countries also saw in alcohols a cheap and adequate alternative to petroleum products.

In its first phase, Proálcool did not have a clear goal on how alcohol should be used, if only as an admixture to gasoline or if it should also be used pure in converted engines like the one shown by CTA to President Geisel. It was known that, as an admixture to gasoline, ethanol should be of the anhydrous type[15], since the presence of water impaired miscibility, especially in colder environments, causing the two fuels to divide into two phases. On the other hand, to be used pure in adapted engines, it was understood that hydrated alcohol[16] – for its being cheaper and more abundant (few distilleries then had the second tower, required to produce anhydrous ethanol from hydrated ethanol) – was more adequate.

At that time, the National Petroleum Council (Conselho Nacional do Petróleo – CNP), was the agency in charge of technical specifications for fuels, so it was also assigned the task of specifying methanol, anhydrous ethanol and hydrated ethanol. Since the production of methanol was not significant and its use for fuel had been under international criticism (fire hazards due to its invisible flame and the risk of intoxication if ingested), the specification of this product was postponed to a second stage. Regarding ethyl alcohol, lacking a deeper knowledge on its automotive applications, CNP initially adopted the prevailing specifications for other uses, as pharmaceutical alcohol, alcohol for beverage production or sanitation (cleaning) alcohol.

CNP also adopted regional limits for adding alcohol to gasoline, raising the content to 10%-15% in the alcohol-producing states (10% to 11% in Pernambuco, 11% to 12% in São Paulo, 11% to 15% in Alagoas, 10% to 15% in Paraná and 10% to 12% in Rio de Janeiro, Ceará, Rio Grande do Norte and Paraíba), keeping a minimum of 5% for all others.

The presence of ethyl alcohol in gasoline changes several of the latter's physicochemical characteristics, such changes being somewhat more significant, the more alcohol content in the final mix. Up to certain limits in this mix, vehicles that were not developed and designed for alcohol-bearing gasoline will function without any major trouble, as safety margins used in their design, plus manufacturing and tune-up adjustments will tolerate minor deviations in the characteristics of the fuel used. However, when these deviations escalate, proper functioning of the vehicle may be compromised, and performance, drivability and durability failures may occur. There is no set limit between one situation and the other, as it depends a lot on the type, model, brand, technology level, use and maintenance condition of the vehicle in question. It also depends on the quality and specifications of both the gasoline and alcohol used, as well as occasional contamination (accidental or deliberate) that either one or both may have. In some cases, environmental conditions (temperature, humidity and pressure) during use may also influence functional outcomes.

Generally, upon specifying the physicochemical features of a fuel, regulatory agencies focus on three different sets of characteristics:

[15] Anhydrous ethanol is obtained from hydrated ethanol, by a second distillation after the addition of a co-solvent, which helps remove remaining water.

[16] Hydrated ethanol is the result of the first distillation of the fermented sugarcane juice, which contains 6% to 9% of water remaining from the fermentation process.

1. The first set covers those properties that ensure quality as a fuel *per se* and which are also considered by vehicle manufacturers' engineers upon designing and developing engines. In the case of gasoline, some examples of these characteristics are density, octane rating, distillation curve, vapor pressure, oxygenated compounds content and heating value – important items to define vehicle performance and engine parameters, such as compression rate, fuel/air ratio, cooling, lubrication, as well as starting systems rating, fuel injection systems calibration, ignition system mapping, valve opening control definition, metal load on the catalytic converter, lubricating oil specification and so on.
2. The second set deals with properties that ensure the origin and quality of the fuel production process, important for defining metallic parts, possible metallic parts coating protection; polymers, elastomers and adhesives used in the fuel tank, filters, and pumps, injection system, hoses, sealing rings, exhaust system and any parts that may come in contact with the fuel. These are also important to prevent buildup of residues that may obstruct the fuel line, or cause sedimentation in tanks, filters or combustion chambers, as well as to avoid poisoning the catalytic converter. For gasoline, examples of these characteristics are lead content, sulphur content, copper strip corrosion, stability to oxidation, gum content (washed and unwashed), hydrocarbons content (benzene, aromatic, olephinic, naphthenic), end point and residue of distillation and the presence of detergent additives.
3. The third set focuses on the need for fuel inspection to control its distribution and sale, important to enable authorities responsible for the final fuel quality to prevent occasional deviation, fraud, contamination and improper usage. On the other hand, these characteristics (within proper limits) do not influence vehicle performance, operation nor durability. In the case of gasoline, this class includes the definition of color and appearance.

Due to lack of further knowledge, upon adopting the first specifications for ethanol fuel (both for hydrated ethyl alcohol fuel – AEHC and for anhydrous ethyl alcohol fuel – AEAC) and for the alcohol-gasoline mixture, CNP failed to assess the consequences of introducing this new fuel and, therefore, did not set limits that could inhibit significant changes to the final quality of the gasoline sold.

Even considering that automotive engines in those days – due to the available technology and less stringent requirements on fuel consumption and pollutant emissions – had coarser calibration and tuning than present ones and that they could cope with wider variations in fuel characteristics, the use of gasoline containing up to 15% anhydrous ethanol caused the occurrence of several problems. Difficult start, loss of power, torque and drivability, clogged nozzles, sediment buildup and erratic idling speed were the most persistent initial complaints. After a while, more serious grievances began to come up, including sudden failure, hydrolock[17] and parts corrosion. At this time government realized the seriousness of the situation and began suggesting vehicle owners and manufacturers to adjust engine tuning to take into account the presence of ethanol.

After many trials and errors, CNP began adopting more adequate specifications for the ethanol admixture to gasoline, setting minimum and maximum ethanol content levels in the gasoline admixture[18], as well as considering the influence of the ethanol present in specifying other characteristics for gasoline, and adopting a specification for pure gasoline before anhydrous gasoline were added (A-type gasoline), and a new one for gasoline already containing ethanol (C-type gasoline).

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[17] Hydrolock is caused by flooding the combustion chamber with liquid fuel, due to its directly passing through the fuel feeding system; due to the effort caused by the attempt to compress a liquid, pistons, rods, crankshaft and head are damaged.

[18] Several ranges were successively adopted (18% to 20%, 20% to 23%, 23% to 25%, 18% to 22%, 10% to 12%, 13% to 17%, 17% to 23% and 21% to 23%) until an adequate balance was found between specification, ethanol supply, and calibration range.

On another front, based on better understanding of the physicochemical characteristics required to use ethanol as fuel, both AEAC and AEHC were specified in a more adequate way. Limits for density, alcohol content, total acidity, fixed residues and copper content were included or modified, to improve compatibility with gasoline and the vehicles.

Several institutions collaborated in this work, some of them being Cepat[19], IPT[20], INT[21], CTC[22], Cenpes[23], Abiquim[24], ABNT[25], Abraco[26], Anfavea[27], Sindipeças[28], Sindicom[29], Sopral[30] and various producers of fuel, lubricants, automotive vehicles, auto parts, laboratory instruments etc.

As specifications for gasoline were progressively improved, embodying the necessary changes due to the presence of alcohol, it became possible to develop more adequate auto parts, as well as calibration and tune-up concepts. The domestic automotive industry itself gradually began to implement these modifications, making their cars leave their plants already suited to the fuel available in the marketplace. On the other hand, auto parts manufacturers began to make available, for the replacement market, components already including the modifications auto makers were implementing. Many auto repair shops began to get qualified for altering and tuning vehicles in use with the necessary changes for using the new fuel. It can be said that over a three to five-year period most of the Brazilian fleet of gasoline-powered vehicles had been enabled to use C-type gasoline.

ALCOHOL-FUELED ENGINES

Beyond the increase of the alcohol content in gasoline, one of the Proálcool goals in 1975 was to stimulate the use of ethanol alone as fuel, i.e, cars running on 100% ethanol.

Enthusiastic over the demonstration by engineer Urbano Stumpf to President Ernesto Geisel, the Brazilian government felt that it was possible to stimulate the population to convert their cars to run on 100% alcohol, if this fuel were priced lower than gasoline and if the conversion were made by licensed shops at an affordable cost. This would increase the replacement of gasoline by ethanol, saving more money for the country.

The conversion of an engine from gasoline to ethanol, as it had been done in the CTA, was based on theoretical concepts already available in the international academic literature, many of them originally from experiments carried out by Henry Ford back in 1911. Actually, the work developed at CTA conceived the major modifications to be made to a gasoline-powered Otto cycle engine, required to use ethyl alcohol for fuel: air-fuel ratio changed to a new stoichiometric level (from 14.5:1 for pure gasoline to 8.5:1 for hydrated ethanol), ignition spark advanced further, use of spark plugs with wider thermal range, increased flow rate from the fuel pump and gasoline spray injection to aid cold starting.

Such modifications, when performed on an engine by qualified technicians, by means of accurate calculations and measurements done with engineering resources, led to very satisfactory results, in both operational and dynamic performance terms.

[19] Technology Research and Analyses Center of the National Petroleum Council (Centro de Pesquisas e Análises Tecnológicas do Conselho Nacional do Petróleo).

[20] Technology Research Institute of the São Paulo State University (Instituto de Pesquisas Tecnológicas da Universidade de São Paulo).

[21] National Technology Institute of the Ministry of Science and Technology (Instituto Nacional de Tecnologia do Ministério de Ciências e Tecnologia).

[22] Copersucar Technology Center (Centro de Tecnologia da Copersucar – today, Centro de Tecnologia Canavieira).

[23] Petrobras Research Center (Centro de Pesquisas da Petrobras).

[24] Brazilian Chemical Industries Association (Associação Brasileira das Indústrias Químicas).

[25] Brazilian Technical Standards Association (Associação Brasileira de Normas Técnicas).

[26] Brazilian Association of Studies in Corrosion (Associação Brasileira de Estudos da Corrosão).

[27] National Association of Automotive Vehicles Manufacturers (Associação Nacional dos Fabricantes de Veículos Automotores).

[28] National Syndicate of Automotive Vehicle Parts Industry (Sindicato Nacional da Indústria de Componentes para Veículos Automotores).

[29] National Syndicate of Fuel and Lubricant Distributing Companies (Sindicato Nacional das Empresas Distribuidoras de Combustíveis e Lubrificantes).

[30] São Paulo State Alcohol Producers Association (Sociedade dos Produtores de Álcool do Estado de São Paulo).

However, the Brazilian government's intent was to have engine conversions widely performed by auto shops that, in spite of being certified and staffed with good technicians, did not have the resources needed to treat each engine individually. Therefore, no means were available to make an initial assessment of a vehicle to be converted, considering the technical features and the maintenance condition of its components to allow, by means of calculations, the definition of new settings for the carburetor, distributor and fuel pump. Consequently, as customized handling of each vehicle was impossible, modifications were made on a general basis and results were not always satisfactory.

On the other hand, conversion research made by the CTA focused only on the engine's functional and performance aspects, which were certainly the most important at the outset. However, little, if any, attention was given to fuel quality aspects or engine parts durability, which has a huge mid – and long-range impact and this may negatively affect the way the conversion is perceived.

Furthermore, specifications that had been adopted for both anhydrous and hydrated ethanol were still insufficiently adequate, which allowed for tremendous variations in the content of several contaminants that were later identified as the cause of ethanol's corrosive attack.

Hence, the initial image of 100% hydrated ethanol as a fuel was not very positive in the eyes of the public and the press. On one side, we had poorly converted vehicles, with bad performance and parts unsuitable for contact with ethanol. On the other side, we had a quite aggressive fuel with very inconsistent quality. The result was some vehicles displaying absurdly high fuel consumption, despicable drivability, clamorous starting problems especially in cold weather, that issued a pervasive odor and that required constant repairs to the fuel feed system, due to corrosion and sediment buildup.

The period between Proálcool I (1975) and Proálcool II (1979) was decisive for the success this fuel had in the next years.

During this period, several studies were carried out to determine the reasons for the corrosiveness of ethanol, which allowed new specifications to control some major features. Therefore, to comply with the new specifications, ethanol producers had to alter their industrial processes, resulting in improved and more consistent quality.

To improve the program image, the government understood that it was necessary to convince auto manufacturers, which had been adapting their cars to use the gasoline-alcohol mix, to offer original factory alcohol powered vehicles. Their belief was that consumers would feel more secure using this fuel, mostly because of the manufacturers' warranty. They also believed that car manufacturer engineers would be able to solve several of the existing technical problems. For this purpose, government representatives had meetings with the Vehicle Manufacturers' Association (Associação dos Fabricantes de Veículos Automotores – Anfavea) and, in 1979, a covenant was signed setting a production commitment[31] regarding wholly-alcohol fueled vehicles to be launched on the following year.

The entrance of auto manufacturers in the development of engines specifically for alcohol drew the line that divided the technology used until then by conversion shops from the one that was thereon built into the new vehicles.

The main changes made to the new vehicles built for the new fuel were:

a. In the carburetor (at that time there were no Brazilian-made vehicles with electronic fuel injection), the lid received surface treatment (phosphatization, chrome plating, nickelization, chemical nickel plating or anodization) to avoid direct contact of the base metal (aluminum or Zamak[32]) with ethanol, the float hinge was replaced (changed from carbon steel to brass or nickel plated brass), the float material was changed (from Ebonite[33] to polyamide 11), plastic inserts were replaced with metallic ones (from polyamide 6.6, to copper or

[31] 250,000 vehicles in 1980, 300,000 vehicles in 1981 and 350,000 vehicles in 1982.

[32] Metallic alloy of aluminum, zinc and manganese.

[33] Ebonite® – Vulcanized spongy rubber with high sulphur content.

bronze) and the high-speed valve menbrane was changed (from nitrile rubber to Viton[34]).

b. The air-fuel mixture was adjusted to a leaner[35] ratio by replacing the nozzles[36] in the carburetor.
c. The fuel tank (at that time tanks were made from phosphatized or galvanized iron plates, sealed with epoxy resin) thereon received an internal surface treatment (brass or lead plated) and had its volume capacity enlarged, to be more compatible with the increased fuel consumption inherent to ethanol.
d. The fuel pump received similar treatment to that made to the internal surfaces of the carburetor, carbon steel clamps were replaced with brass ones, and the natural rubber menbrane was replaced with a nitrile rubber one.
e. The fuel filter had to host a new filtering element, sealed with synthetic glue, not soluble in ethanol.
f. The intake manifold was redesigned into a profile that allowed increased flow and internal walls were treated for lower rugosity.
g. Compression ratio in the combustion chamber was significantly increased, from 7~8:1 to 9~11:1; consequently, the engine block and head reinforcement structures had to be redesigned.
h. Ignition timing had to be advanced further so that spark occurred earlier and spark plugs were replaced with others having lower temperature ranges.
i. The valve command camshaft was given a new cam profile and new phases, changing the timing of opening and closing of admission and exhaust valves; the valves themselves and their seats received new harder surface materials.
j. The exhaust pipe and muffler assembly received internal surface protection and its design was altered to prevent the accumulation of condensed water from the exhaust gases, produced in larger quantity when burning ethanol.
k. Lubricating oil was changed to a new additive package, more compatible with ethanol usage.
l. The vehicle was fitted with a cold start aid system, which sprays a small quantity of gasoline vapor directly into the intake manifold, fitted with a temperature probe, a small gasoline tank and its own electric pump and fuel injector.

It can be said that the outcome of these changes was very positive, even considering that they were not simultaneously adopted in all of the aforementioned components, nor by all vehicle manufacturers. However, the negative image converted cars had gradually faded and consumers became interested in alcohol-powered cars.

Even with the adoption of a Fuel Saving Program (Programa de Economia de Combustível – Peco) in 1981, emission limits set by Proconve (in 1986) and with the incorporation of new automotive technologies such as electronic fuel injection (in 1987), the EGR exhaust gas recirculation (in 1992), plastic fuel tanks (in 1994), and catalytic converters (in 1997), the technical concepts adopted for using ethanol were maintained and improved.

After several successful years, with over five million alcohol-powered vehicles manufactured from 1979 through 1993, considering that in 1986 the sales of 700,000 alcohol vehicles represented 89% of the light vehicles sold, consumers interest for this fuel declined. In 1995 less than 50,000 units were sold and in 1997 only 0.1% of the total light vehicles sold were alcohol-fueled.

There was not one single cause alone. Various factors got together to reduce consumers' interest in alcohol vehicles: the international price of petroleum went down, allowing a reduction in the price of its products; the international price of

[34] Viton® – fluorinated rubber.

[35] "Lean" is the designation given to an air-fuel ratio where there is excess oxygen for the quantity of fuel introduced as vapor in the combustion chamber.

[36] Metallic parts fitted with a precision hole, that work like mini-venturis, i.e., they impose a restricted maximum flow rate for a fluid going through.

sugar went up, leading producers to prefer exporting sugar; Brazilian government offered incentives to the production of popular vehicles without any incentive to their engines being alcohol-fueled, which led manufacturers to launch gasoline-fueled popular cars only.

Nevertheless, the launch of flex-fuel vehicles, in March 2003, was a historic milestone and a turning point in the Brazilian alternative fuels market.

After the launch of the flex-fuel car, popularly known as bi-fuels, the Brazilian automotive industry manufactured in little over five years (from March 2003 through December 2008) 6.95 million of flex-fuel cars. Nowadays, 11 manufacturers offer over 70 different models of flex-fuel cars in the Brazilian market, their price being equivalent to conventional models.

Actually, flex-fuel vehicles were not invented in Brazil. The first vehicles fitted with technology for different fuels were introduced in the United States in the 1980s. However, the technology used by US manufacturers is based on a fuel identification probe, which analyses the fuel being used, and then gives an input signal to the onboard computer to adjust the injection and ignition systems to the best burning conditions for that fuel. In spite of its efficiency, this technology is expensive, and completely dependent on the useful life of the probe. Due to its cost, this technology can only be implemented in expensive vehicles, so as not to increase significantly the cost to the end user. In the US, this technological concept's success was only due to the interest of manufacturers in offering a vehicle powered by an alternative fuel so they could benefit from tax incentives.

As the Brazilian market is dominated by low-cost compact vehicles, it is unthinkable to adopt the expensive American flex-fuel technology in Brazil. Therefore, when Brazilian car manufacturers began discussing the possibility of launching such vehicles locally, the basic requirement was to develop a new concept that avoided the need for a fuel sensing probe.

At this point, Brazilian creativity and the vast experience brought together over 25 years manufacturing 100% alcohol-fueled vehicles came out loud and clear.

Based on the existing differences in two physicochemical characteristics of alcohol and gasoline (octane rating and stoichiometric ratio) and using the same diversified probes that all modern vehicles already have (pressure and air temperature, fuel flow rate, load, rotation speed, engine firing and oxygen content in the exhaust gas), Brazilian engineers developed a completely new flex-fuel system. In the Brazilian system, fuel is first burnt in the ignition chamber and, a split of a second later, evaluating the consequences of that explosion via the existing sensors and comparing it to a resident database in the onboard computer memory, it is possible to analyze the fuel and adjust the engine settings, without the need for a fuel identification probe. This renders a flex-fuel vehicle for the same price as an alcohol vehicle, which we had learned to manufacture so well.

Thanks to the overwhelming acceptance of flex-fuel engines and to the competitive price of hydrated alcohol, the declining Brazilian production of alcohol took a tremendous thrust and thereon began growing at a rate above 10% per year.

THE FUTURE OF ALCOHOL ENGINES

The expression "renewable fuel" is used to define fuels made from agricultural products or from organic matter fermentation. Contrary to fossil fuels (petroleum and natural gas) that will be over when reserves are exhausted, mankind will always be able to produce more renewable fuel as needed.

However, there is yet another peculiarity that adds meaning to renewable and that has pointed biofuels as the savior solution for global warming. It is the fact that the CO_2 gas emissions from burning any fuel (and being the major cause for atmospheric heating) is reabsorbed via photosynthesis by the same plants used to produce renewable fuels, almost neutralizing their use. Thus, the CO_2 emissions are recycled, leaving no negative effect to the environment.

Due to features such as their easy application to existing automotive technologies, by replacing the ailing and expensive petroleum and by their lower environmental impact, renewable fuels made from biomass have been conquering space and leading other countries into becoming interested in their use.

Just as there are countries interested in using renewable fuels, there are countries eager to produce them for export, as their climate and geography favors agriculture and they see such production as an economic opportunity.

Therefore, one can envisage a forthcoming international market for renewable fuels, creating socio-economic opportunities for many countries and energy options for others, at least until a new vehicle concept is developed – cleaner, more affordable and more reliable – to be mass-produced and eventually replaces the current internal combustion engine cars.

So what are the most promising technologies under development?

Basically, ongoing studies point in the same direction, which is the use of electric motors, as they are efficient, silent, powerful, non-polluting and simple. However, there are still two pending issues: how electricity can be generated to power these motors in a safe and non-polluting way and how this energy can be taken on board in a sufficient quantity to offer some good autonomy. Generating energy in a safe and non-polluting way goes through the risk analysis over thermal or nuclear power plants and taking enough stored energy on board means anything other than carrying the well-known and heavy battery using lead or other heavy metals.

Current beliefs consider that the most adequate way to generate electric power would be through the ion exchange obtained by passing hydrogen though an array of electrolytic membranes (the so-called fuel cell), coupled with a catalytic transformer able to extract hydrogen from a substance with a high content of this gas, such as natural gas (methane rich), or, preferably, due to the ease of supply and transportation, from a liquid, such as an alcohol (methanol or ethanol). Due to its extremely low density and high explosion power, the idea of transporting cylinders filled with hydrogen gas on the vehicle is being avoided.

As it may have been noticed, Brazil continues to be a privileged country in the vehicle technology future, since the use of alcohol to generate hydrogen, which in other countries is methanol, obtained from natural gas (hence fossil and finite) or wood (low yield), in our case will be ethanol from sugarcane, which we know how to make like nobody else.

Putting it all together, there is a very promising big picture. We are replacing our fleet with flex-fuel cars, which can use gasoline or alcohol, so we can shift from one fuel to the other depending on price and availability. We are also introducing vegetal oil admixtured to diesel, which will reduce our dependency on petroleum, as soon as biodiesel production attains sufficient scale. Albeit being technologically behind, other countries are following a similar path, which will lead to an international market of renewable fuels, giving Brazil more energy security and opening space for further developments. Due to its sustainability features and for pooling together solutions for economic, social and environmental issues, as well as reducing emissions that cause global warming, the renewable fuels market will be quite attractive to international investors. There is an immense application potential for renewable fuels in the future vehicle technologies. We became self-sufficient in petroleum production and yet we have natural gas available to be included in our energy matrix.

Contrary to those countries that fear an energywise complex future, Brazil has the opportunity to make better use of its energy matrix, both for itself and for export.

23

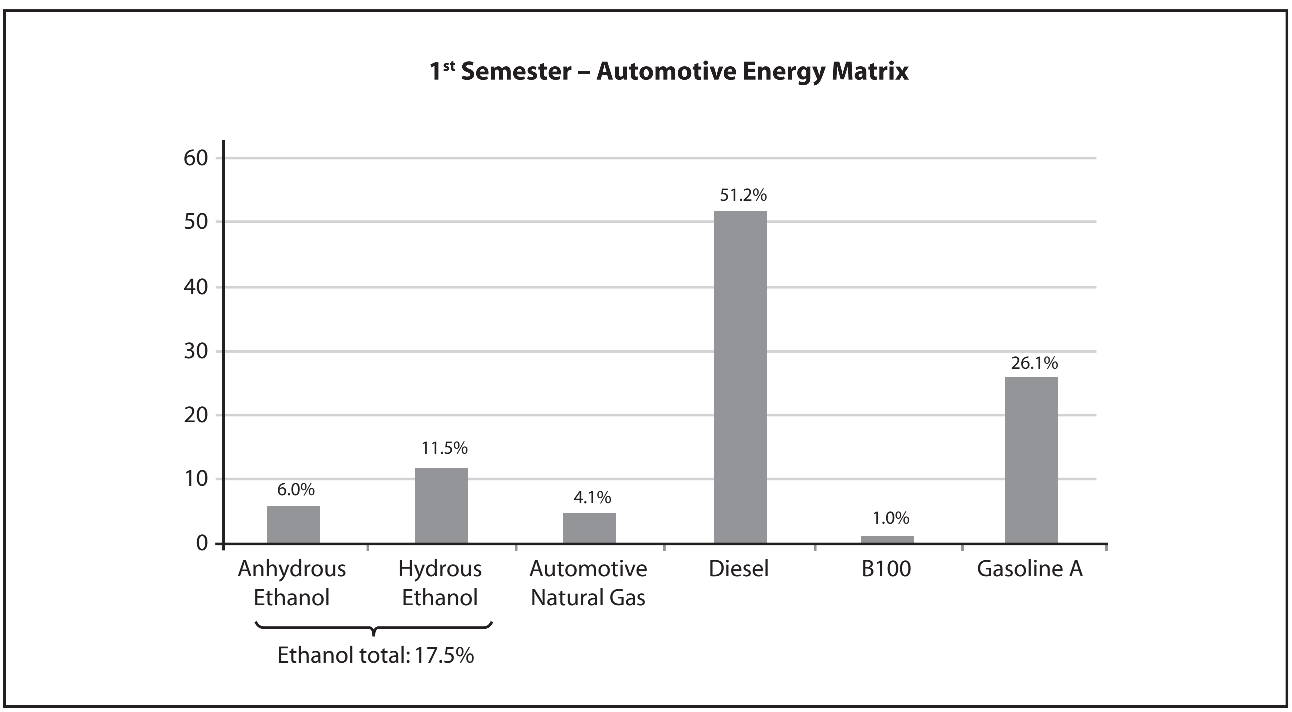
USE OF ETHANOL IN DIESEL – CYCLE ENGINES

Jose Roberto Moreira, Sílvia M. S. G. Velázquez and *Euler Hoffmann Melo*

INTRODUCTION

The global fuel option for urban public transport is diesel, a fossil source of energy which is produced from the fractional distillation of petroleum. The diesel fuel is the most important fuel in the Brazilian Automotive Energy Matrix, accounting for 51.2% of the total volume of fuel consumed in 2008, as shown in Figure 1.

Other type of fuels, such as gasoline or ethanol, have not been commonly used in the urban public transport. However, some initiatives have been taken in order to search for new technologies with lower environmental impact. One of the initiatives in order to diversify the automotive energy portfolio and partially replace the diesel is the production of biodiesel (B100). However, this option cannot meet the total diesel demand based in the available known technology. On the other hand, ethanol fuel from biomass, a renewable fuel with low emission of pollutants if compared to diesel or gasoline, has only been used in spark ignition engines (Otto



Source: ANP (2008).

FIGURE 1 Brazilian Automotive Energy Portfolio.

cycle), due to technical limitation prohibiting the use of ethanol in Diesel cycle engines. Beyond that, Brazil already has an infrastructure for large-scale production of ethanol that could supply a significant diesel demand in the shorter term.

Technological improvements have provided, in the last decade, a Diesel cycle engine which runs on ethanol blended with a clean additive, whose applicability is the same as conventional diesel engine and, therefore, the automotive energy portfolio can be diversified with ethanol, which is a renewable fuel and less polluting than the diesel.

The Diesel cycle engine adapted to operate with ethanol has been developed and it is already commercially available. In Brazil, this technology has been transferred through the BEST Project – BioEthanol for Sustainable Transport (BEST, 2006)[1]. The project is an initiative of the European Union, coordinated by the city of Stockholm, which aims to encourage the use of ethanol as a fuel for urban public transport and as a replacement for diesel in Brazil and in the world.

São Paulo, the pioneer city in the America, has demonstrated the technical and economical performance of buses which are fuelled with ethanol in order to seek an alternative for reduction in the consumption of fossil fuels and, therefore, a reduction in emission of pollutants from the transport sector.

This concern is due to the fact that the city of São Paulo, with 10.8 million[2] inhabitants, is the greatest urban center of São Paulo Metropolitan Region, which has more than 19.4 million inhabitants. São Paulo Metropolitan Region is the fourth greatest urban center of the world[3]. This center is responsible for 18% of the Brazilian GDP[4] (US$ 247 billions per year) and where roughly 3.2 million[5] people are transported every day through 13,726 urban buses[6], almost all of them fuelled by diesel oil. These Figures generate stakeholders concern regarding pollutants emissions due the use of diesel, which is harmful to the environment as well as to the health of the people who live in São Paulo.

HISTORICAL REVIEW

In the early 1980's, there was a Brazilian initiative to replace diesel with ethanol, which consisted in the adaptation of a Diesel cycle engine, originally designed to run on diesel oil, installed in buses and trucks for the transport of sugarcane.

Swedish Scania started researching Diesel cycle engines powered by ethanol blended to additives in 1985; finally, in 1989, the first Scania buses fuelled by ethanol additive were officially incorporated to the Stockholm's bus fleet as a replacement of the diesel buses which previously circulated in the urban center. The objective of the Swedish program was to reduce the pollution generated in the city center, where there was high concentration of pollutants. In 2007, about 500 buses circulated in eight cities in Sweden, 400 of those in Stockholm Municipality (MILJOBILAR. STOCKHOLM, 2007).

As a result of the operation of the ethanol buses in Stockholm, for the past fifteen years, about 140,000 tonnes of carbon dioxide (CO_2) are no longer released in the atmosphere (SCANIA, 2007). The equivalent emission reduction is compared to 5 thousand cars withdrawn from the roads.

Due to demands of the Swedish environmental legislation, Swedish Scania has developed the engine and Sekab (<www.sekab.com>) developed the additive. In Sweden ethanol imported from Brazil has been used and there are tax incentives

[1] See Report BioEthanol for Sustainable Transport – Results and Recommendations from the European BEST Project, January 2010 (www.best-europe.org)

[2] Source: São Paulo's City Hall Site. Data referred to 2005. Available in: <www9.prefeitura.sp.gov.br/sempla/md/mostra_tabela.php?cod_subtema=ger&nome_tab=geral1&partes=1>.

[3] Source: São Paulo's City Hall Site. Data referred to 2005. Available in: <www9.prefeitura.sp.gov.br/sempla/md/mostra_tabela.php?cod_subtema=ger&nome_tab=geral1&partes=1>. Access in: 2008.

[4] Source: Seade. Data referred to 2003. Available in: <http://www.seade.gov.br/negocios/snpct-v2.html>. Access in: January 2008.

[5] Source: São Paulo' s City Hall. Data referred to 2005. Available in: <www9.prefeitura.sp.gov.br/sempla/md/mostra_tabela.php?cod_subtema=tra&nome_tab=transportes6&partes=1>. Access in: January 2008.

[6] Source: São Paulo's City Hall. Data referred to 2003. Available in: <www9.prefeitura.sp.gov.br/sempla/md/mostra_tabela.php?cod_subtema=tra&nome_tab=transportes4&partes=1>. Accessed in: January 2008.

from the government which makes ethanol be sold at 40% of the price of diesel.

In 1997, the São Paulo Transporte S.A. – SPTrans, acting as Management Company of urban transport of São Paulo city and also the responsible for measures to minimize the levels of pollutants emissions, performed tests for 30 days in actual operating conditions for two buses fuelled by an ethanol additive manufactured by Swedish Scania. SPTrans performed that demonstration in partnership with *Santa Brígida, a* bus concessionaire and also with *Santa Madalena* another bus concessionaire (SPTRANS, 2007).

A comparative study was performed of ethanol-powered vehicles with a diesel and natural gas, in buses lanes operated in the same conditions. Considering only the fuel consumption by buses, the ethanol results were excellent from the environmental point of view, however more costly. This is hoped to be overcome with the new generation engine and also with a lower cost additive.

A more detailed research regarding the benefits of these buses is an important step for the implementation of this ethanol engine technology. That is the reason why Best Project has been initiated.

BEST PROJECT – BIOETHANOL FOR SUSTAINABLE TRANSPORT

In Brazil, the project is coordinated by Cenbio – Brazilian Reference Center on Biomass, IEE/USP – Institute for Electrotechnology and Energy of the University of São Paulo, and project partners are: Scania, Baff/Sekab, Marcopolo, Unica, Copersucar, Petrobras, EMTU and SPTrans. Through the Best project in the São Paulo Metropolitan Region there is one ethanol bus which circulates in the segregated bus lane managed by EMTU (Jabaquara/São Mateus), which passes through municipalities of São Bernardo do Campo, Santo André, Diadema and São Paulo. More recently, November 2009, a second bus with similar characteristics has been in operation through the city center. Beyond São Paulo, eight other cities in Europe and Asia also took part in the Best project, they are: Somerset County Council (United Kingdom), Dublin (Ireland), La Spezia (Italy), Rotterdam (Netherlands), Nanyang (China), Stockholm (Sweden), Madrid and the Basque Country (Spain).

After complete analysis of the results, the European Community and the project coordination will provide blue prints of public policies in order to encourage the use of ethanol in urban public transport.

The current engine powered by ethanol is a third-generation engine which complies the Euro 5 emission standard that will be validated in Europe in October 2009 and it is also certified as an EEV – Enhanced Environmentally Vehicle. EEV emission standard is even stricter than Euro emission standard and do not have any prevision to be validated in Europe. Therefore, this engine technology is advanced even for the current emission standard in Europe (SCANIA, 2007).

In accordance to the engine manufacturer, Swedish Scania, there are no significant differences between a conventional Diesel engine and an Ethanol Diesel engine. Among differences, the higher compression ratio can be mentioned, which achieves 28:1, against 17:1 in conventional Diesel engines, different injector nozzles in order to compensate the lower energy content of the ethanol in comparison to diesel, materials resistant to ethanol in order to avoid the corrosion of the parts such as gaskets, seals, coils and valves, and finally a different fuel pump with higher flow capacity. Other parts of the vehicles, such as breaks, transmission

Source: CENBIO (2008).

FIGURE 2 The ethanol bus in São Paulo City.

gear box, body and chassis, and exactly the same as used in conventional diesel vehicles.

The differences found in the engine are due to the fact that ethanol does not have the property of self-ignition, which is the operating principle of a diesel engine. Therefore, for the diesel engine running on ethanol, it is necessary the high compression ratio of 28:1, as well as the fuel must have a 5% additive by volume, with an additive in order to promote the fuel self-ignition. The fuel is commercially known as E95, in reference to the percentage of ethanol by volume, which is 95%. Sekab is the only company to offer E95 to the fleet of 600 ethanol buses in Stockholm and for the Best project, its fuel E95 is known commercially as Etamax D (BEST, 2006).

Companies Scania and Sekab, both Swedish, have developed their products together since 1985 and are technically ready for the supply of components and fuel ethanol – powered buses additive. Some characteristics of the engine are shown in Table 1.

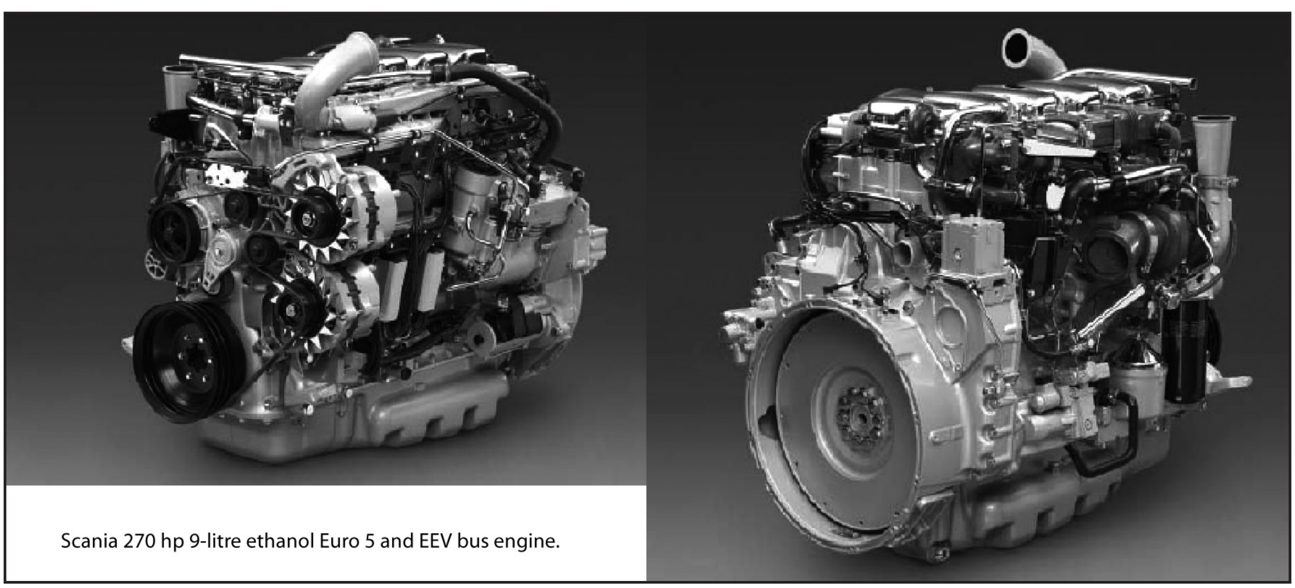
Due to the lower energy content of ethanol in comparison with diesel, the ethanol bus has higher fuel consumption than an equivalent diesel-powered vehicle. As energy contained in one liter of diesel is the same as that contained in 1.7 liters of ethanol, ethanol powered bus requires 70% greater volume of fuel to travel the same distance with the necessity of the vehicle to have a greater fuel tank capacity (400 liters of E95), while a conventional vehicle has a tank capacity of 300 liters of diesel (CENBIO, 2008).

The fuel has been developed and improved since the start of the tests in Sweden. Its composition is presented in Table 2.

TABLE 1 General Specification of the Diesel engine powered by ethanol.

Scania Engine DC9 E02
Compression Ratio – 28:1;
5 cylinders;
Maximum Power – 270 hp (198kW) @ 1,900 rpm;
Maximum torque: 1,200 Nm @ 1100 – 1,400 rpm;
Special Injector Nozzles – UI (Unit Injectors);
Electronic Fuel Injection;
Turbo compressor;
Intercooler: air-cooled;
EGR – Exhaust Gas Recirculation (NO_x emission controller).

Source: CENBIO (2008).



Scania 270 hp 9-litre ethanol Euro 5 and EEV bus engine.

Source: SCANIA (2008).

FIGURE 3 Diesel engine powered by E95.

TABLE 2 Etamax D composition.

Elements	Amount by volume
Hydrous ethanol	95%
Ignition improver	5%
Isobutanol **(denaturant)**	Small amount
Corrosion Inhibitors	Small amount
Identification pigment (red)	Small amount

Source: SEKAB (2008).

The fuel sold in Europe has in its composition methyl-tertiary butyl ether (MTBE). However, according to the manufacturer of the additive, MTBE can be replaced by ethanol or another ethanol derivative in order to adapt the fuel to the Brazilian legislation which does not allow the use of MTBE since September 1991. The additive supplied by Sekab for the Best project in Brazil is composed of derivatives of polyethylene glycol, which is the promoter of ignition, isobutanol, identification pigments, corrosion inhibitors and does not use MTBE.

The main advantage of use of ethanol as fuel in urban public transport is environmental gains regarding the reduction of emissions. São Paulo's captive bus fleet is around 15,000 buses, and almost all of these vehicles are diesel-powered[7]. According to José Roberto Moreira, coordinator of the BEST project in Brazil, if the bus fleet of 15,000 buses were replaced by an ethanol-powered fleet, it would, environmentally, be equivalent ,to operating only 3,000 diesel buses in the city.

Ethanol is a biodegradable fuel, renewable, which implies also in another significant contribution on reducing greenhouse gases responsible for the global warming. Furthermore, it has no sulfur content which, when burned in internal combustion engines, produces SOx responsible for acid rain.

The engine has been already approved in Brazil by *Companhia de Tecnologia de Saneamento Ambiental* – Cetesb. This engine is perfectly adaptable to the Brazilian legislation because its local emissions are well below the limits imposed by the *Controle de poluição do Ar por Veículos Automotores* – Proconve. Table 3 shows the local emissions of this ethanol engine and makes a comparison with the emission limits established by Proconve:

The results of the essay are compared to limits established in Proconve. It can be concluded that results on emission data collected from an ethanol engine are much lower than the limits imposed by phase P-5 and P-6 Proconve. The P-6 Proconve legislation is the strictest emission set, in Brazil, imposed to engine manufacturers, and was designed to be effective by January 2009. Unfortunately, due delays in the supply of low-sulfur diesel by Petrobras, enforcement of P-6 has been postponed by 2 years.

The Brazilian Ethanol bus powered by an engine assembled in Sweden went through one small technical adjustment in order to be adapted to operate in Brazilian climate conditions. Operating in the segregated bus lane of EMTU, the vehicle's engine used to make sudden stops at idle speed. This problem manifested itself most often on hot days and at the end of the long steep path. The original design of buses running on ethanol additive, which was developed in Sweden, provided fuel heating before it flows to the engine for better engine efficiency, through a heating device in the fuel supply line of the engine. Brazilian climatic conditions caused overheating of the fuel and its vaporization caused loss of line pressure and, consequently, sudden stops of the engine. The heating device was removed and no more sudden engine stops have been registered since the technical modification.

More than to encourage the use of ethanol in the urban public transport, the initiative launched by Cenbio, partners companies and the European Community forwarded the discussion of the economic model that Brazil is currently seeking. The present time is very favorable to the deployment of this technology in Brazil, because it is the largest producer of ethanol from sugarcane and has the lowest production cost. Brazil produced 24 billion

[7] On top of diesel powered buses the fleet is composed by a few hundred electric buses, and a few natural gas Otto cycle powered buses.

TABLE 3 Emission of the ethanol engine.

Emission values	CO (g/kWh)	HC (g/kWh)	NO_x (g/kWh)	PM (g/kWh)
Emission Essay*	0	0.05	1.7	0.01
Proconve P-5**	21	0.66	5	0.1
Proconve P-6***	1.5	0.46	3.5	0.02

* Essay performed in September 2007, in RDW laboratory in the Netherlands.
** Established in Conama Resolution 315/02, and in effect since 01.01.2006.
*** Conama Resolution n. 315/02, Art.15, Table 1, line 2, and to be effective by 01.01.2009.

Source: CENBIO (2008).

liters of ethanol in 2008 and there is the prospects to reach 38 billion liters in 2012 (UNICA, 2008).

Given the figures above, added to the competitive and environmental advantages, such as the reduction of emissions of greenhouse gases, the use of ethanol in Diesel engines offers a wide range of benefits and favorable points for Brazil. They are: diversification of energy sources in the transport sector and the proper use of the existing Brazilian infrastructure for production and distribution of ethanol. It is also compatible with the existing interests of various sectors of government which support the product.

However, a model of urban public transport powered by ethanol needs to receive incentives from the Government, since it is a sustainable alternative. Studies and operational data indicate that the bus consumes about 70% more ethanol to travel the same distance, notwithstanding that ethanol is 50% cheaper than Diesel. Thus, fuel expenses are higher and increases slightly more when adding the cost of the additive. Presently, the Swedish Sekab is the only company that produces the additive for the Diesel engine powered by ethanol. One of the challenges for the commercial use of ethanol in public transport in the country is the production of the additive in Brazil and its expected cost reduction.

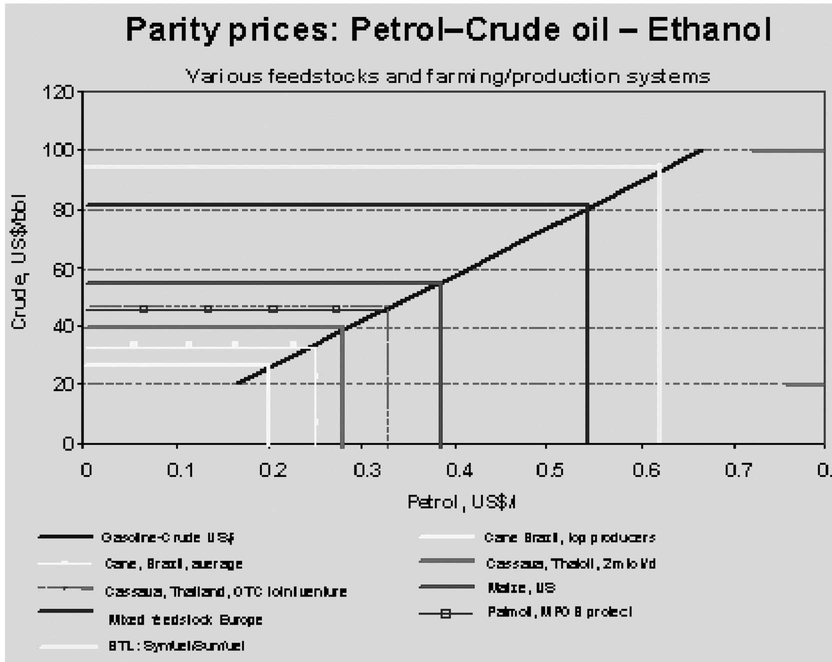
ECONOMIC EVALUATION

Considering that the technology has been sufficiently tested in Sweden by a process of implementation of about 600 ethanol buses, for over 15 years and that the operation of ethanol buses purchased by the Best Project during the years 2007 and 2008 in other countries, the technology has been successful (CENBIO, 2008), it can be concluded that there are no technological barriers for these vehicles.

In order to analyze the economic barriers, it is necessary to examine the particularity of each country; the economic feasibility depends on the price of diesel and ethanol added to the additive in each location.

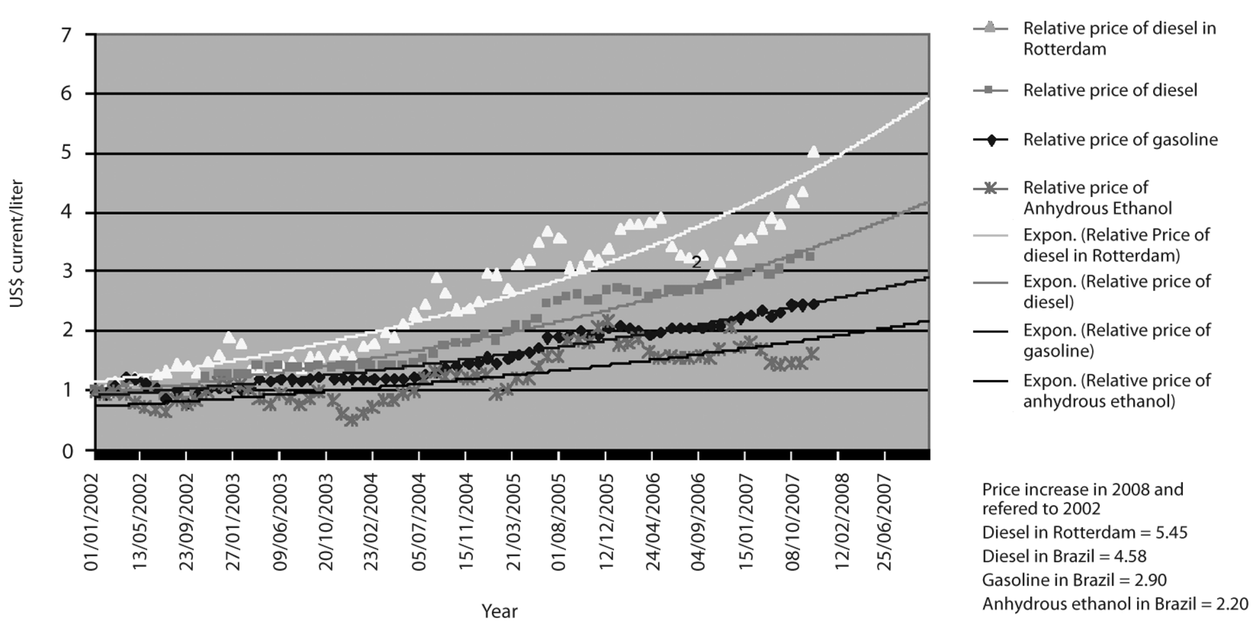
Figure 4 shows that the lowest cost production of ethanol occurs in Brazil, followed by Thailand. Prices are higher in the United States and the European Union. It is also important to analyze the price of diesel fuel. Figure 5 shows the variation of the price of ethanol, diesel and gasoline, in the domestic and international market (Rotterdam Port). It is noted that diesel is more expensive than gasoline as shown in Figure 5. It is seen that in January 2002 and December 2007 (thus ignoring the high prices of oil in 2008), diesel oil in Rotterdam shows a price increase roughly five times while in Brazil the increase was 3.3 times. Even more interesting is to compare the increasing price of gasoline in Brazil, which was 2.5 times.

Given these increases, in June 2008, the price of diesel at gas stations in Brazil were around R$ 2.20 while those of gasoline around R$ 2.50, which means that diesel now costs 88% of the price of gasoline, when at the begin of the century its cost was only 50%. It is also important to note that the price of diesel increased more in the Rotterdam market than in Brazil, 5, and 3.3 times, respectively, which shows that this fuel in Brazil receives special cost treatment and its price is



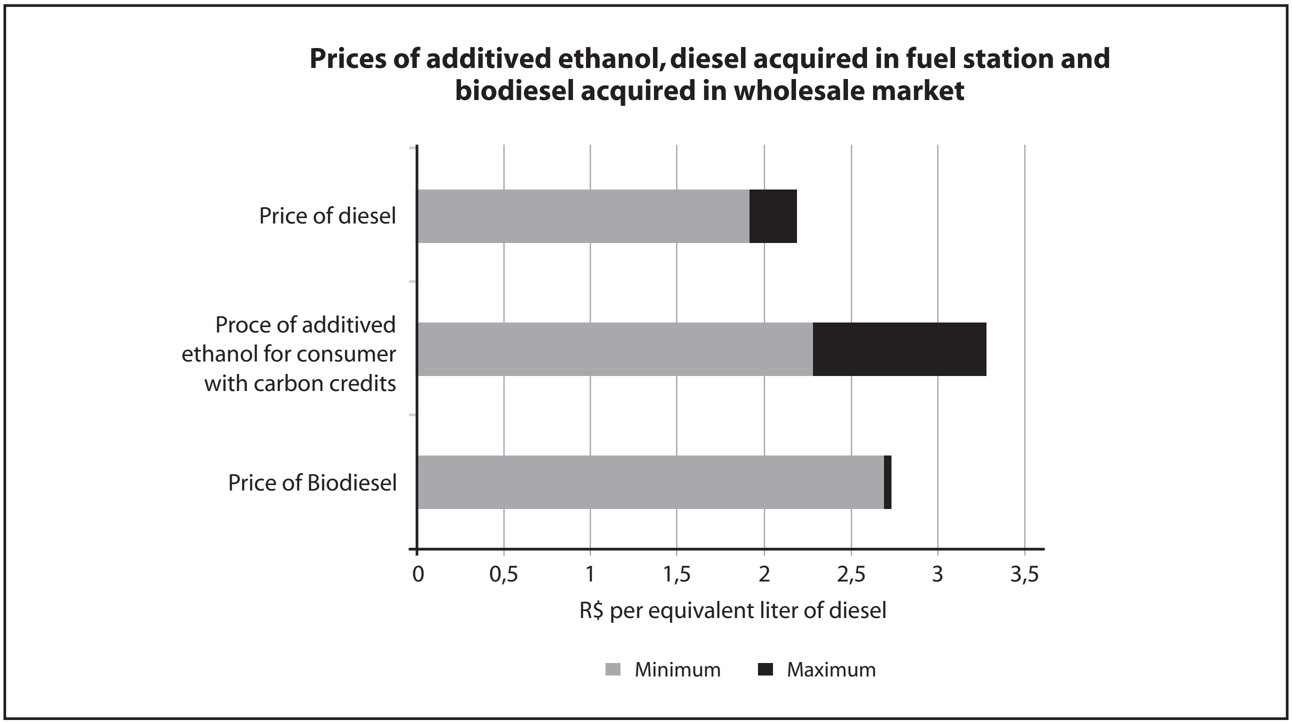
Source: SCHMIDHUBER (2005).

FIGURE 4 Ethanol Production Cost in several regions and countries.



Source: Built with data from EIA (2009) and from ANP (2008).

FIGURE 5 Time variation of the relative prices of diesel oil in Rotterdam and in Brazil, of the ethanol in Brazil and of gasoline in the 2002/2007 time period. For 2008 the values are projected based in econometric data by the authors.



Source: Authors referred to ANP data (2008).

FIGURE 6 Prices of the additived ethanol, diesel and biodiesel in wholesale market.

lower than its international market value. This is part of government's economic policy which claims that the transfer to the final price of diesel of all its true market value is harmful to the economy as its impact is greater than for gasoline. On the other hand, transfer to the gasoline consumers the price increases of petrol is also difficult in Brazil because of the competition with ethanol, a fuel that is well established due to the large-scale production and the large fleet of flex-fuel cars. This explains why Petrobras has not increased the price of gasoline to the extent necessary to compensate for oil prices increase, but tried to expand its revenue increasing diesel price, despite the limitations imposed by economic policy.

It is also important to mention that in addition to greater increase for diesel compared to gasoline, diesel in Brazil is still less costly than gasoline. This is against the trend of the international prices because in most of the countries' diesel oil is more expensive than gasoline. Moreover, that is logical because the energy content of diesel oil is greater in comparison to gasoline. This occurs because the diesel's density is roughly 0.84 kg/liter while gasoline's is 0.74 kg/liter, and there is more carbon in the same mass of diesel than in gasoline ($C_{12}H_{26}$ for diesel and C_8H_{18} for gasoline).

However, examining the situation in Brazil, there are two reasons to expect an increase in the price of diesel in the next few years, regardless of variation in the international price of oil. The first reason has economic origin and is shown in Figure 4, from where it has been observed that in recent years the increase in diesel price has always been higher than gasoline and it might remain so in the future. The second reason is the improvement in the quality of diesel produced in Brazil. According to standards of environmental legislation, the sulfur content in diesel was supposed to be reduced in Brazil to 50 ppm in January 2009. This did not happen due Petrobras inability to comply with this requirement of legislation, which became an uncomfortable issue for the company. Through agreements seeking a compensation for the damage to the environment, Brazil continues to use diesel with 500 ppm in cities and to 2,000 ppm in the less urbanized areas. However, Petrobras is still obliged to comply as soon as possible with the legislation, and produce diesel whose sulfur is 50 ppm. Petrobras will invest up to 2012 about R$ 4 billion in refineries[8] and will increase energy use by 35%[9] in the production of diesel, which eventually will raise its production cost. The expected cost increase mentioned is required to pay for the investments of new production processes and to minimize the environmental impact of oil refineries. Therefore, evidently, cleaner diesel production will demand an increase in the fuel price.

All the discussion above is intended to forecast future prices of diesel and ethanol, which could facilitate the competition of ethanol as an additive with petroleum diesel. This may help the market penetration of additive ethanol, but there is an urgent need, as will be shown below, that niche markets, where competition can occur nowadays, be immediately explored.

Figure 6 demonstrates the cost of the fuel for diesel engines; all figures are quoted in Brazilian currency (R$ per equivalent liter of diesel). The comparison must be on diesel equivalent basis because, as mentioned, ethanol and diesel have different energy content per unit of volume, which means that 1.7 liters of ethanol are necessary in order to substitute a liter of diesel to travel the same distance. Figure 6 reflects data of the average prices published by the Brazilian Oil Agency – ANP. Collected data below are referred to the initial months of 2008 (ANP, 2008):

- Ethanol
  - Minimum price → R$ 1.21
  - Maximum price → R$ 1.82
- Diesel
  - Minimum price → R$ 1.92
  - Maximum price → R$ 2.18

In addition, it is necessary to point out that ethanol blended with additive is composed of 95% of hydrous ethanol and 5% of ignition improver additive.

- Additive

Considering the importation cost of additive is $ 18.2 SEK per kilogram, which means, US$ 2.81/kg (1 US$ → R$ 1.80) and its density 1 kg/liter, the price composition of the minimum and maximum prices of the final fuel are:

Minimum price = [0.95 x (1,21) + 0.05 x (5,06)] x 1.70
Minimum price = R$ 2.38/liter
Maximum price = [0.95 x (1.82) + 0.05 x (506)] x 1..70
Maximum price = R$ 3.37

Considering Carbon Credits:

- Carbon credit – CER → US$ 20/tonne of CO_2

Diesel CO_2 emission = Density (kg/liter) * % mass of carbon in diesel * (CO_2 molecular weigh/ C molecular weigh)

CO_2 Emission of diesel = 0.85 x 0.86 x 44/12 =
CO_2 Emission/liter = 2.68 kg CO_2/liter diesel
Value of Certification Emission Reduction – CER = 2.68 x 20 x 1.80 x 10^{-3}

CER = R$ 0.10/liter

Therefore, considering the Carbon Credits:

Minimum price of the fuel = 2.38 – 0.10 = **R$ 2.28**
Maximum price of the fuel = 3.37 – 0.10 = **R$ 3.27**

These Figures demonstrate that in some regions of the state of São Paulo, where the price of ethanol fuel is the cheapest in Brazil, the price of additivated ethanol overcomes the maximum price of diesel (R$ 2.18) by only R$ 0.10, when considering the carbon credit from the reduction of diesel CO_2 emission. It is important to be observed that ethanol presents a seasonal variation on its price; during the season its price can be reduced by R$ 0.10 or R$ 0.15/liter compared with the value quoted above. The price reduction to R$ 1.11/liter (R$ 1.21 – R$ 0.10) makes possible to bring the price of an equivalent liter of diesel, as additivated ethanol, to R$ 2.12/ liter, as demonstrated in the sequence:

$M_{\text{inimum price of fuel in season}}$ = [0.95 x 1.11 + 0.05 x 5.06] x 1.70
$M_{\text{inimum price of fuel in season}}$ = 2.22 R$/l

Subtracting the carbon credit:

[8] Source: Jornal o Estado de São Paulo. Petrobras investe US$ 4 bi em diesel menos poluente. Accessed in January 2009. Available in: <http://www.estadao.com.br/noticias/economia,petrobras-investe-us-4-bi-em-diesel-menos-poluente, 306572,0.htm>.

[9] Personal Information collected from Supply Board of Petrobras.

$M_{\text{inimum price of fuel in season considering carbon credits}}$ = 2.22 – 0,10
$M_{\text{inimum price of fuel in season considering carbon credits}}$ = 2.12 R$/equivalent liter

Therefore, additivated ethanol may have a price inferior to the maximum price of diesel of R$ 2.18. Beyond that, it is important to observe that fuel stations put over an average profit of R$ 0.15 per liter of diesel sold. Considering that the fuel station would sell 70% more fuel when selling additivated ethanol than diesel, thus, in order to maintain the same gain of R$ 0.15 per liter of diesel sold, it would be sufficient to earn R$ 0.15/1.70 → R$ 0.09 per liter which means a reduction from R$ 2.12/liter to R$ 2.06, which is significant less than the maximum price of the diesel (R$ 2.18/liter). Thus, we conclude that in some regions of the state of São Paulo there are already niches were additivated ethanol is already cost competitive with diesel, mainly if the fuel is acquired during the harvest season and stored for full year use.

Furthermore, other very favorable niche to the use of ethanol fuel as a replacement for diesel is the Brazilian ethanol production sector. The sugarcane mills own a great quantity of trucks to move the sugarcane production. A simple calculation considering that Brazilian ethanol production is around 600 million tones of cane and that:

- Each truck transports 30 tonnes per trip.
- The average travel time, including loading and unloading, takes 2 hours.
- Average distance travelled per trip is 30 km.
- Each truck operates 20 hours per day.
- Annual sugarcane season lasts 200 days.
- Utilization Coefficient of the vehicle is 90%.

Each truck may transport:

- 30 tonnes * 10 trips/day * 200 days * 90% = 54,000 tonnes/year.

Based in these figures sugarcane transportation demands more than 11,000 trucks.

These cost conditions are more interesting for the mills because there is not the presence of the fuel distributor in the production and use chain of ethanol, and there are also tax exemption such as the *imposto de circulação de mercadoria* – ICMS and others, since the ethanol built in additivated ethanol is not commercialized between different producers and users.

As for ICMS, whose rate varies between 12% to 25%, depending on the state of the Brazilian Federation, this may imply in a reduction of 1.21 * 0.12 to 1.21 * 0.25 and 1.82 * 0.12 to 1.82 * 0.25 for the minimum price and the maximum ethanol price listed above, which means minimum prices of the hydrous ethanol of R$ 1.06 to R$ 0.91 and maximum prices of R$ 1.60 to R$ 1.36. In these conditions the average price of the fuel would be:

$P_{\text{min ICMS free}}$ = [0.95 x 0.91 + 0.05 x 5.06] x 1.70 = R$ 1.90
$P_{\text{max ICMS free}}$ = [0.95 x 1.60 + 0.05 x 5.06] x 1.70 = R$ 3.01

Consequently, the additive ethanol would be competitive with diesel in several regions in Brazil, mainly in the state of São Paulo where more than 60% of the mills are located. Prices would be even lower because there would not be any ethanol commercialization outside the mills and other taxes would be also reduced.

Only in this market niche, ethanol would be able to replace diesel in the following amount:

(54,000 tonnes/per year/truck) x 30 km = 1.62 Million tonnes.km/truck/yr.

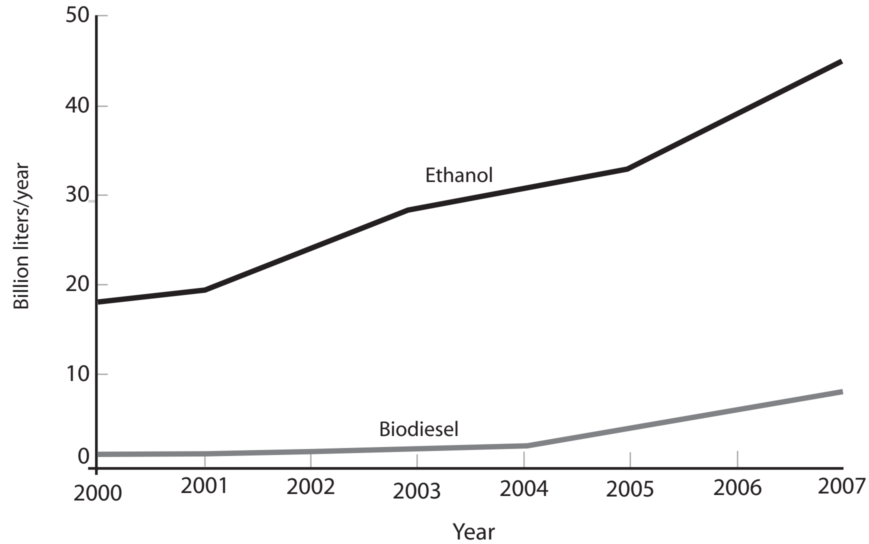
Considering the displacement of the trucks from the source to destiny is about 15 km:

1.62 Million tonnes/km/ 70 tonnes/km/liter[10] = 23,143 liters/truck/yr.

For 11,000 trucks, more than 255 million liters of diesel or 412 million liters of additive ethanol, approximately 1.5% of the ethanol amount produced in Brazil (28 billion liters of ethanol) would be necessary; the relative volume is modest but capable to create a new market of vehicles powered by ethanol blended with additive.

Another fuel developed to diversify the Automotive Energy Portfolio is Biodiesel. However, biodiesel is not able to replace the total demand of diesel in short term since the production of

[10] Average diesel consumption by trucks transporting sugarcane.



Source: MARTINOT (2007).

FIGURE 7 Biodiesel's and ethanol's production capacity.

biodiesel is still very small. On the other hand, ethanol presents advantages if compared to biodiesel because there is a great infrastructure for the production and the distribution of ethanol that may supply the market in the short term.

Besides, as it can be observed from Figure 7, the growing production capacity of ethanol is superior to the production capacity of biodiesel. The increase rate of ethanol production is larger than the increase rate of biodiesel between 2000 and 2007.

The feasibility of the production of biodiesel is related to the cost of the feed-stocks used for its production. There is some variation on costs for processing vegetable oil to biodiesel but the major contribution to the final cost of biodiesel is the cost of feedstock production, which also varies according with the type of vegetable oil.

The energy balance also demonstrates ethanol's competitiveness with biodiesel. For each unit of energy used in biodiesel's production from soybeans, for example, the energy ratio is only 2.5 energy units of the fossil energy used in its production. On the other hand, the energy used in ethanol's production, about 8.06 renewable energy units are obtained for each unit of fossil fuel invested in its production (MARTINOT, 2007).

The final price of the fuel is influenced by this energy efficiency. The average price of biodiesel in the 12th auction, in August 2008, achieved R$ 2.38/liter, which is superior to the maximum price of diesel oil (R$ 2.18/liter). Therefore, any blend proportion of biodiesel in diesel would make the final price of the latter fuel more expensive. This is a good evidence that additive ethanol, based in our previous discussion, has better cost advantage than biodiesel.

FINAL CONSIDERATIONS

The use of ethanol instead of diesel has been a goal pursued for many years. Efforts have been made in Brazil, since the early 1980's, and in Sweden since 1990's. The major difficulty found was economic while technical difficulties were easily overcome. The additive developed in Brazil, in order to increase the cetane number of ethanol fuel to make it feasible to use it in diesel engines, had some technical problems that could be solved in short time. However, the low price of oil in the early 80's discouraged its use. In Sweden, where the cost factor had not been of significant interest when compared with pollution issues and consequently the quality of life of the people, the additive has been successfully developed since 1990's and currently it is widely used in buses running in Stockholm and other nearby cities.

The increase on oil prices noticed over the past two years, the increasing appreciation on quality of life of the population in many countries, including Brazil, and the necessity to reduce the risk in obtaining energy, all make the use of ethanol as an additive more desirable.

The experiences during the buses operation and their good performance as noted by the users in the city of São Paulo have shown that it is technically and economically feasible to use this fuel, since its price is equal or very slightly higher than diesel (June 2008) but, below the price of biodiesel.

Currently, the Brazilian legislation establishes a mandatory addition of biodiesel to diesel up 3% proportion by volume. Due to the merits shown by the use of ethanol, there is no reason why not to develop a political effort in order to encourage the use of ethanol in diesel engines in a compulsory manner similar to biodiesel.

The only drawback is that in the contrary with occurs for biodiesel, ethanol additive cannot be blended in diesel and used in existing diesel engines. It requires that the vehicle's producer prepare an adapted diesel engine especially designed. Thus, the fuel should be used only on new vehicles or on vehicles that have their engines replaced by new engines.

On the positive side we should add that the gains to public health and global environment through mitigation of climate changes mean that the transport sector of heavy urbanized areas should be the first sector for the introduction of this technology.

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USE OF ETHANOL IN TRANSESTERIFICATION

Leticia Ledo Marciniuk, Camila Martins Garcia
and *Ulf Friedrich Schuchardt*

Due to the unrestrained energy consumption associated with growing environmental concern, research is being encouraged in many diverse areas, to search for alternative resources, which were neglected until recently, principally renewable energy resources such as wind, tides and biomass.

Among these energy resources, biomass has received special attention because due to the large number of applications e.g. ethanol and biodiesel, which are the object of great interest in the world economy.

They can be burned directly or used indirectly after chemical, biological or thermochemical transformations. Among these are the transesterification of vegetable oils, fatty acids esterification, pyrolysis, gasification, extractions with supercritical fluid, anaerobic digestion and fermentation. These processes can use various feedstocks such as agricultural wastes, which otherwise would cause serious environmental problems if left in the fields as it is the case of sugarcane bagasse (MARCINIUK, 2007).

In addition, the use of biomass reduces pollution, because its main components are formed from carbon dioxide and water, using sunlight as a source of energy. This gives biomass a strategic position for the solution of problems related to global warming. If you consider that during combustion of biomass, carbonic gas emitted to the atmosphere is absorbed by photosynthesis during growth, the mass balance for CO_2 is more favorable than zero. However, for this becoming a reality, a sustainable consumption of biomass is needed, without reduction of its availability over the years, as it is presently happening in most developing countries (GARCIA, 2006).

As readily available sources, vegetable oils have been gaining in importance in current energy programs. They provide a decentralized energy generation, bringing benefits to more distant locations and less affluent regions. Its production also means supporting family farming and enhancing regional development (RAMOS, 2003).

Several researchers propose the direct use of vegetable oils as alternative fuels for petroleum-based such as diesel oil. However, despite being vegetable oils energetically favorable due to their high calorific value, their direct use may prejudice operations and durability of diesel engines, increasing their maintenance costs (MACEDO, 2004).

This is due to the high viscosity of these oils, approximately 11 to 17 times greater than diesel fuel, low volatility and high molecular weight because of the large chain of triacylglycerides. These factors may prevent their complete combustion, leading to the formation of carbon deposits inside the engine and obstruction of oil filters and injection systems. Furthermore, the thermal decomposition of glycerol, present in vegetable oils, can lead to the release of acrolein, a highly toxic and carcinogenic substance (TEIXEIRA, 2006).

Several processes have been studied which would allow to obtain renewable fuels with physicochemical properties similar to diesel oil, without requiring engine modifications or additional technology investment. An example is the use of biodiesel, which can be obtained from vegetable oils or other sources of fatty materials, such as animal fats or waste oils, by transesterification with short-chain alcohols. The fuel compatibility with conventional diesel has characterized it as the most appropriate alternative which can be used in fleet of most diesel vehicles existing on the market (XIE *et al*., 2006).

When compared to mineral diesel, biodiesel has as major advantages such as the reduction of emissions, biodegradability, higher flash point and increased lubrication.

The term "transesterification" (or alcoholysis) describes an important class of organic reactions in which an ester is transformed into another through the exchange of their alkoxide groups. In this reaction, the triacylglycerides present in vegetable oils, react with an alcohol in the presence of a catalyst producing a mixture of monoalkyl esters of fatty acids and glycerol, as shown in Figure 1.

Various alcohols can be used in such reactions, however, only methanol or ethanol will produce biodiesel. Both can be obtained from renewable sources such as dry distillation of wood and fermentation of sugarcane, respectively.

According to the technical aspects of transesterification, the use of methanol (methanolysis) is advantageous because it allows the spontaneous separation of glycerol and as a consequence the reduction of the number of process steps. Moreover, it gives a high conversions using homogeneous catalysts in basic or acidic conditions. On the other hand, this alcohol has a high toxicity.

The use of ethanol (ethanolysis), even anhydrous, creates problems in the separation of glycerin from the reaction mixture. The power consumption of a plant that produces ethylic biodiesel is higher when compared to methylic biodiesel. However, for Brazil, from the economic point of view, the use of ethanol is more advantageous, since the country is considered to be the second largest producer.

The transesterification of vegetable oils is a reversible reaction, whose kinetics is governed by the principle of Le Chatelier. Thus, the conversion of the reaction depends on shifting the chemical equilibrium towards the formation of products through the optimization of the variables such as temperature, concentration of catalyst, its acidic or basic strength and the amount of reagents.

One of the most important variables that affect the conversion to esters is the vegetable oil to alcohol molar ratio. Using an excess of alcohol, the equilibrium is shifted towards the product, however, an excessive increase will also favor the solubility of glycerol in biodiesel, making its separation difficult (GARCIA, 2006). According to the literature, vegetable oil to alcohol molar ratios are normally in the range of 1:6 to 1:30. In the case of ethanol, ratios of 1:6 and 1:12 show satisfactory results.

ENCINAR *et al*. (2002) have studied the ethanolysis of *Cynara* oil by varying the oil to ethanol molar ratio from 1:3 to 1:15. The best results were obtained for reactions carried out with the molar ratio between 1:9 and 1:12. The reactions employing molar ratios below 1:6 were incomplete and problems in the glycerol separation step were found when using a molar ratio of 1:15. The temperature and reaction time also influence these reactions. High temperatures al-

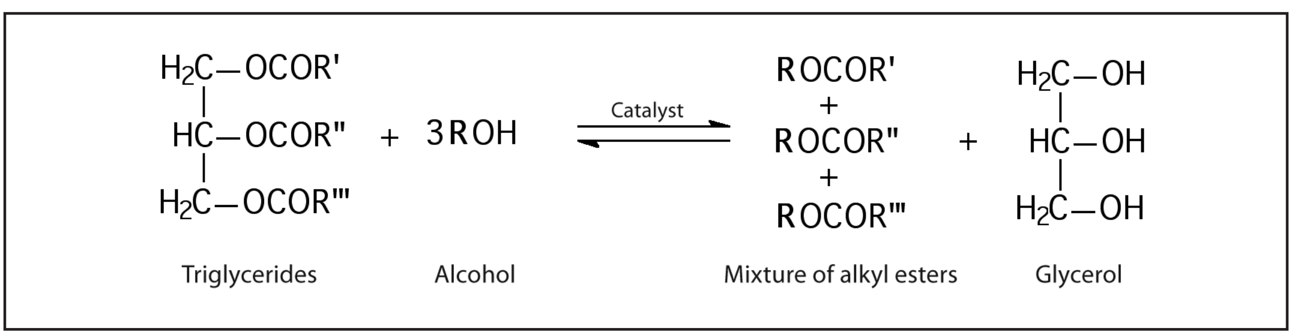

FIGURE 1 Transesterification of a triacylglycerides.

low higher conversions in shorter reaction times. However, it is necessary to evaluate whether the energy expenses used for heating do not exceed the economic gains.

Methanol and ethanol are not miscible with vegetable oils at room temperature. To increase the reagents' miscibility, transesterification reactions are largely promoted at temperatures between 60 °C and 70 °C under vigorous stirring in order to promote the phase transfer. These conditions usually cause the formation of an emulsion which, in the case of methanolysis, is rapidly broken with the interruption of agitation, leading to the separation of glycerol. In ethanolysis, these emulsions are much more stable and sometimes difficult to brake (MEHER *et al.*, 2006).

The emulsions formed during transesterification are partly due to the presence of diacilglycerides (DAG) and monoacilglycerides (MAG), intermediaries in the alcoholysis of triacylglycerides (TAG), which are good surfactants. In the alcoholysis process the base catalyst is dissolved in the alcohol and, after its complete dissolution, is mixed with the triacylglyceride. The reaction is initially controlled by phase transfer, however, in the course of the reaction the concentration of intermediaries decreases, reaching a critical level at which the formation of emulsions is favored. When the concentrations of MAG and DAG in the reaction medium reach very low values, the emulsion is broken. However, the emulsion formed in the course of ethanolysis provides a large contact of glycerol with the ethyl esters, thus making the phase separation more difficult (GARCIA, 2006). The presence of glycerol in the reaction medium shifts the equilibrium of the reaction towards the reactants. Consequently, the conversion is decreased and intermediate surfactants will remain in the system in concentrations that enable their performance as emulsion stabilizers.

Another important aspect for the reaction is the agitation speed. After homogenization of the system, vigorous agitation may cause glycerol droplets to disperse in the reaction medium, making its separation longer. This variable is much more important in ethanolysis, in which the agitation should be vigorous only in the first minutes of reaction; after this period it is preferable that the reaction is conducted under milder agitation. This procedure reduces the dispersion of glycerol droplets and thus shortens the glycerin coalescence at the end of the reaction.

GARCIA (2006) found that the yield of esters in transesterification reactions of soybean oil with ethanol at 70 °C in the presence of potassium hydroxide was directly proportional to the amount of catalyst used, however, the formation of a transparent and thermodynamically stable microemulsion was observed, which does not allow the coalescence of the glycerol, reducing the amount of ethyl esters isolated and increasing the difficulty to purify the product. On the other hand, the alcoholysis at 25 °C, catalyzed by sodium methoxide or by sodium or potassium hydroxide, resulted in systems that allowed the complete separation of glycerin which was observed immediately after switching off the agitation. For all three reactions total conversion was observed.

Since methanolic solutions of sodium or potassium methoxide are now commercially available, the problems of the ethyl esters and glycerin separation are reduced, so that the water content of ethanol is now a major variable causing problems in the separation of the products. This should not be higher than 0.2%. Although the use of these commercial catalysts has bypassed much of the problem of the separation of glycerin, the time required for full separation is larger for the production of biodiesel with ethanol compared to that with methanol.

LIMA *et al.* (2006) reported the production of biodiesel from babassu (Orbingnya species) oil with methanol or ethanol at room temperature for 30 min, using sodium hydroxide as catalyst. The yields were 71.8% and 62.2% (by mass) which was attributed to the formation of soap, since the alcohols used were not anhydrous. FERRARI *et al.* (2005) used the ethylic route in the transesterification of neutral soybean oil in the presence of sodium hydroxide to demonstrate the rapid conversion into ethyl esters after 5 min. at 45 °C. This reaction time is sufficient for the full conversion into esters, as verified by the sudden darkening of the mixture which then returned to the original color (confirmed by gas chromatography). After the reaction, 600 g of glycerin were added to the system in order to accelerate the formation of the lower phase, facilitating the separation of biodiesel and glycerol.

As can be seen, the appearance of the reaction mixture during the reaction is very relevant. The beginning of the transesterification of vegetable oils is characterized by changes in the color of the reaction system. This change of color ceases in methanolysis, regardless of the reaction temperature, and the reaction system becomes opalescent. In ethanolysis, carried out between 60 and 70 °C, the reaction mixture becomes clear and transparent, as if a solution had been formed. In ethanolysis at room temperature, the end of color change is followed by a loss of transparency of the reaction mixture and coalescence of glycerol, which starts immediately after interruption of agitation (GARCIA, 2006).

Most of the implications cited are consequences of the use of homogeneous catalysts in the transesterification of vegetable oils, which requires the steps of washing and purification of the products. The attempt to recover the catalysts that are dissolved in the reaction medium will lead to a series of environmental problems since large amounts of solvents and energy are used (DOSSIN *et al.*, 2006). Furthermore, the use of homogeneous basic catalysts can lead to the production of soap by secondary reactions, such as the neutralization of free fatty acids and saponification of triglycerides and/ or mono-esters formed. These reactions are undesirable because they consume part of the catalyst and make the separation of glycerin more difficult. This means higher costs of ester production and possible damage to the environment (LIU *et al.*, 2007).

However, the basic homogeneous catalysis still prevails as the common technology used by industry, because it is a simple process and the catalysts are more easily manipulated and less corrosive than acid catalysts for industrial plants (BUNYAKIAT *et al.*, 2006). It provides very high conversions to esters, even at room temperature, and allows a faster reaction when compared to acid catalysis. The catalysts used are the hydroxides or alkoxides of sodium or potassium (SCHUCHARDT *et al.*, 1998).

Heterogeneous catalysis, on the other hand, has several advantages over homogeneous catalysis, considering the ease of catalyst recovery and reuse, as long as the catalyst does not leach to the reaction medium. Furthermore, a purer fraction of glycerin and an easy recovery of alcohol are obtained. The catalysts allow a continuous process, using a fixed bed reactor, and thus a decrease in production costs (MARCINIUK, 2007). Moreover, the transformation of a homogeneous catalyst into a heterogeneous catalyst and the development of alternative solid catalysts are of great importance for organic synthesis, because the catalytic activity is closely related to the surface used in the absorption of the reagents (BAZI *et al.*, 2006).

LÓPEZ *et al.* (2008) reported the synthesis of three modified zirconia: SZ, WZ and TiZ (sulfated zirconia, tungstated zirconia and titania zirconia, respectively), calcined at temperatures of 400 °C to 900 °C. The catalytic activity of the different zirconia was evaluated as a function of the calcination temperature in the reaction of tricaprylin with ethanol at 75 °C for 8 h. Although the sulfated zirconia SZ is the most active in this reaction, its catalytic activity is not easily recovered, even when recalcinated at 500 °C. The TiZ was more active than the WZ, due to the presence of basic sites, according to the authors. The yields of ethyl caprylates were, however, only in the order of 10%. The WZ catalyst proved to be most active in the esterification of oleic acid, giving a yield of 100% at 120 °C after 8 h and of 80% at 75 °C after 22 h of reaction (LÓPEZ *et al.*, 2008).

SHIBASAKI-KITAKAWA *et al.* (2007) used a variety of ionic resins in the transesterification of triolein with ethanol. The anionic resins showed greater activity than the cationic. The ethyl oleate was obtained with a conversion of 98.8% using a triolin: ethanol molar ratio of 1:20, 4% (w/w) of catalyst at 50 °C for 1 h of reaction.

MARCINIUK (2007) evaluated the catalytic activity of various phosphates of trivalent metals for the production of esters. The catalysts were shown to be very efficient in the transesterification of vegetable oils and in the esterification of free fatty acids, giving more than 95% yield of methyl and ethyl esters. The reactions conditions were 2 h in methanolysis and 1.5 h in ethanolysis, 175 ºC, molar ratio of oil: methanol of 1:12 and oil: ethanol of 1:9 and 5% (w/w) catalyst.

It was found that these catalysts do not lose their catalytic activity in the presence of water, allowing the use of hydrated ethanol in the reactions. This can be demonstrated by the yield of esters of 90% and 97% for the reactions of soybean oil with ethyl alcohol containing 20% and 5% (w/w) water, respectively. In addition, the solids can be recycled, however, a loss of their catalytic activities from the second re-use is observed, due to leaching of phosphate groups (SCHUCHARDT *et al*., 2006).

GARCIA (2006) synthesized the sulfated zirconia S-ZrO_2, through an alternative route without solvents and precipitation, and SZ, through a different precipitation method. In addition, non-sulfated zirconia (ZrO_2) was used. The catalytic activity of zirconia was evaluated in the methanolysis and ethanolysis of soybean oil at 120 ºC and 1 h reaction time using 5% (w/w) of catalyst. The results show that the non-sulfated zirconia (ZrO2) is not active in the methanolysis of soybean oil. The sulfated zirconia (SZ) showed a low catalytic activity (8.5% conversion), compared to the very active S-ZrO_2 (98.6% yield of methyl ester and 92% yield of ethyl ester).

The performance of the sulfated zirconia (S-ZrO_2) and a commercial niobium catalyst (niobic acid supported on graphite) was compared in the esterification of oleic acid with methanol and transesterification of soybean oil. The sulfated zirconia as well as the niobium catalyst converted oleic acid into methyl oleate, however, the niobium catalyst was not active in the transesterification of soybean oil (GARCIA *et al*., 2008).

RATNASAMY *et al*. (2006) developed bimetallic cyanides (Fe-Zn) which were shown to be highly active in both transesterification of vegetable oils and esterification of free fatty acids. These catalysts have acid sites which are resistant to the presence of water, probably due to the hydrophobic characteristic of their surface, and can be reused several times without significant loss of their activity. Conversion of vegetable oils increased with the amount of catalyst used, resulting in yields of methyl esters of 99% at 170 ºC. As expected, an increase of conversion with increasing oil:ethanol molar ratio was observed, giving 100% yield at a molar ratio of 1:15 (RATNASAMY *et al*., 2006).

The largest biodiesel factory in Latin America, Naturoil Combustíveis Renováveis S.A., is being constructed in Ourinhos (São Paulo) which will produce 227 million liters per year. French technology (Esterfip-H) will be employed, using zinc aluminate ($ZnAl_2O_4$) as a catalyst for the transesterification of different vegetable oils and tallow.

In addition to all the advantages of heterogeneous catalysis, the great difference in using a heterogeneous acid catalyst for transesterification is the easy separation and recovery of the catalyst, the elimination of washing steps and the possibility of using vegetable oils with high levels of free fatty acids which are typically found in the north and northeast of Brazil, in waste oils and animal fats.

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Part 5

TECHNOLOGICAL ROADMAPPING FOR SUGARCANE ETHANOL

André Tosi Furtado
and *Rodrigo Lima Verde Leal*
(organizers)

1

INTRODUCTION

André Tosi Furtado and *Rodrigo Lima Verde Leal*

The ethanol produced from sugarcane is considered as one of the most competitive alternative energy to substitute liquid fuels derived from hydrocarbons. The light and medium oil distillates are more difficult to replace. Its uses are specific, especially in the transportation sector. In this particular niche, biofuels, stand as the only renewable energy option currently feasible without requiring the scrapping and replacement of the fuel distribution infrastructures and of the transport equipments. Among biofuels, ethanol from sugarcane is by far the more attractive alternative in economic and energy terms as well as environmental sustainability is understood, especially energy balance and emission of greenhouse gases. The energy requirements of ethanol industrial processes are all covered by the sugarcane by-products (mainly bagasse). This singularity is the most attractive feature of cane over almost all other agro-energy crops.

The central advantage of sugarcane is the high energy yield of this crop and the high proportion of fermentable sugars directly into ethanol (1/3 of the energy content). The high proportion of sugar ensures the reduction of energy requirements of sugarcane ethanol in relation to the cereals rich in starch ethanol, which is crucial to ensure its competitiveness[1]. The other key advantages of the sugarcane is the use of bagasse in the industrial process and recycling of vinasse, filter cake and ash, a very common practice in Brazilian plants. These wastes become important inputs in the production process that contribute to greater competitiveness of the sugarcane. The technologies, however, in use in the Brazilian agro-industry still rely largely on incremental innovations made on technologies acquired from abroad. There is enormous potential for progress in energy productivity of sugarcane that has yet to be tapped.

The Brazilian sugarcane agro-industry has a long history in the country, and is characterized by the development of technologies with immediate application. However, since Proálcool, in 1975, this complex production system began a virtuous path of expansion, supported to a large extent on the ability to incorporate new technological knowledge and translating it into productive advances. One reason why the sugarcane industry could survive over the long period of low oil and ethanol prices, which followed the counter-oil shock, was its diversification into the international sugar market. The Brazilian sugar exports expanded considerably during the 1990s supported by technological developments started with Proálcool. Thus, the technological system converges to a hybrid ethanol-sugar production model, with a distillery attached to a sugar refinery known as the "Brazilian model".

However, this process of technological learning, which proved effective in the 1990s, is still weak when compared with the potential develop-

[1] In the other hand, it is worth to mention a grain crop: corn. This has 70% starch, which is hydrolyzed to glucose, giving values for sugars even higher than sugarcane. A problem of corn – and other cereals – is the fact that they have no residue, such as sugarcane bagasse, as the waste materials are all left in the field.

ments of the sugarcane agro-industry, with the advent of rising international oil prices and increasing pressure to reduce emissions of greenhouse gases. Indeed, sugarcane bioethanol stands today as an excellent renewable alternative with reduced emission of greenhouse gases compared to fossil fuels. In addition, the state of the art technologies and availability of land for agricultural expansion puts Brazil in a unique leadership position within the global context, as being practically the only country with the ability to expand ethanol production significantly.

This chapter aims is to identify research problems for the team participating in this project (Public Policies for Ethanol), using process Technology Roadmapping. Chapter 2 presents the long-term vision, built by the team for the sugarcane industry of the State of São Paulo. Based on this view, the chapter establishes the goal of Technology Roadmapping, highlighting the scope of the research and the goals to be met by the sugar and ethanol industry. It presents the current status of the industry through the description of its products and services, customers, suppliers and processes. The chapter also indicates market trends that will require adaptations in current processes in order to comply with their respective demands and provides a list of the main limiting factors (e.g. regulatory, stakeholders, budget etc), to establish a long-term vision. Chapters 3 to 6 deal with each of the four components of the Technology Roadmapping – Genetic Improvement, Management, Hydrolysis, and Thermoconversion – presenting a description of these components. Finally, policy options are summarized in the final chapter of this book.

2

CONTEXTUALIZATION AND ASSUMPTIONS FOR THE TECHNOLOGY ROADMAPPING FOR ETHANOL

Rodrigo Lima Verde Leal, Luís Augusto Barbosa Cortez, Maria das Graças de Almeida Felipe, Carlos Eduardo Vaz Rossell, Antonio Bonomi and *Paulo Sérgio Graziano Magalhães*

CONTEXT

Vision

For a new model of the sugarcane industry

The need of the sugarcane agro-industry to increase its production, through increased productivity – agricultural and industrial – or the expansion area is considerable. This sector could meet both the domestic and export ethanol and sugar markets. Previous studies conducted by the members of this project (Public Policies for Ethanol) shows that Brazil would have enough land to meet the expanding needs of the area in two scenarios to produce 5% or 10% of world demand for gasoline in 2025 (UNICAMP, 2005). These are optimistic scenarios for sugarcane drives the need to rethink the paradigm of production the two main markets: sugar and ethanol. In this context the assessment of sugarcane energy was virtually tied up with increased sucrose content and its better use in the industrial process.

The changes occurring in the international energy scenario, with almost constant rise in oil prices since the beginning of the decade, require the need to consider a new model for the technological development of sugarcane. These changes concern the behavior of international technological frontier in the field of biofuels and the potential production and technological development of Brazil as a whole.

Developed countries are investing heavily in technologies for production of raw materials and conversion to biofuels. As the existing cultures are not sufficiently attractive as a raw material for biofuels, in terms of economic, environmental or energy, these countries are focusing on second generation technologies for the production of biofuels. The production of cellulose, hemicellulose and lignin will be crucial for the generation of bioenergy in the near future, especially biofuels. As the production of cellulose is much higher per unit area and opportunities for use of crop residues rich in cellulose are much larger, the production potential of the developed countries could , therefore, be increased. The investment being made in technologies to convert cellulose into ethanol are much higher than in previous decade. Most likely we will have a displacement of the boundary of conversion technologies, and Brazil need to be properly prepared for a new competitive environment.

Brazil, taking into account international developments, should aim at maintaining its leadership in terms of capacity and price competitiveness of bioethanol, which relies exclusively on sugarcane. Sugarcane offers an undeniable competitiveness because its high productivity, high energy yield and sucrose content. Brazil has been able to improve the path of technological learning started with Proálcool, supported by more efficient industrial processes and a capacity of endogenous generation of technologies for second generation biofuels. For thi, the country needs to join a new model, aiming at maximazing the energy utilization of sugarcane.

This new model should not merely be oriented to the production of ethanol, but also to the incorporation of a complex set of energy services that make full use of the sugarcane. One of the biggest challenges is to make better use of all of the energy from sugarcane and not only sucrose. In fact the rest of the energy contained in the sugarcane bagasse and straw would be better valued by the use of new agricultural technologies (e.g. system of sugarcane cultivation and recovery of straw) and industrial (e.g. hydrolysis). Some of these technologies are well developed but not implemented mainly due to economic attractiveness. This is the case of new-generation technologies that would allow a more efficient use of bagasse to drive the mills and production of process heat, and generating surplus electricity.

Another way to use the energy contained in the bagasse and straw would be to convert them into ethanol. This requires overcoming a technological barrier of transforming the lignocellulosic materials into ethanol in an economically and environmentally sustainable way. The development of hydrolysis, especially enzymatic, constitutes an important technological challenge that will allow it to meet this challenge[1].

As pointed out by the Fapesp project PPPP – Ethanol, the Brazilian sugar industry is going through a **technological transition**, from a Brazilian model of sugar and ethanol – based on increased production from the advancing technologies, to reduce cost and improve the overall economic indicators – towards a new paradigm for ethanol production and full use of the sugarcane, decoupled from sugar production. In other words, the view of the participants of this project is that *the sugar-based ethanol is expected to be transformed within 20 years to a new ethanol production chain, in which energy and other bio-products enhance competitiveness in a socially, economically and environmentally sustainable manner and rovide international leadership in production and in technology.*

This new industry will have new players and stronger links oil companies, utilities in addition to the food industry. This transition requires a new technology platform that supports it, whose identification can be facilitated by the work of Technology Roadmapping.

Scope

The Roadmapping objective

This work starts from the premise that if Brazil wants to maintain leadership in ethanol production it needs to be planning the actions of R&D throughout the production chain of sugarcane ethanol, that fully meet the goal of any process of Technology *Roadmapping*.

Thus, the aim of Technology *Roadmapping*, which is part of this document, is to provide improvement proposals covering the whole cycle of production chain – agricultural, manufacturing, products (sugar, alcohol, energy and other) and the environment – through prospective analysis. It is expected that this process will get support from Fapesp to conduct research and the investment needed to develop the sector in all areas: agricultural production, industrial production, product diversity and the environment.

Roadmapping components

Thus, this process Technology *Roadmapping* is divided into several areas during each cycle of the production chain, each focusing on a specific high technology area of the sugarcane industry. Figure 1 illustrates the four components considered in this work: genetic improvement, management, hydrolysis, and thermoconversion.

In the agricultural area, a first component is called **Genetic Improvement** and incorporate new techniques of molecular biology and genetic engineering knowledge areas that are developing rapidly, for the generation of cultivars of sugarcane with improved technology, specific goal of

[1] Although hydrolysis is one of the components to be elaborated in this TRM, one important point to be developed because it is not treated by the rich countries is the integration of second generation technologies – when they are widely available – with the first generation, both the plants, as the new are been implemented. The development of a study in this regard may be the subject of future research and not part of this stage of the TRM

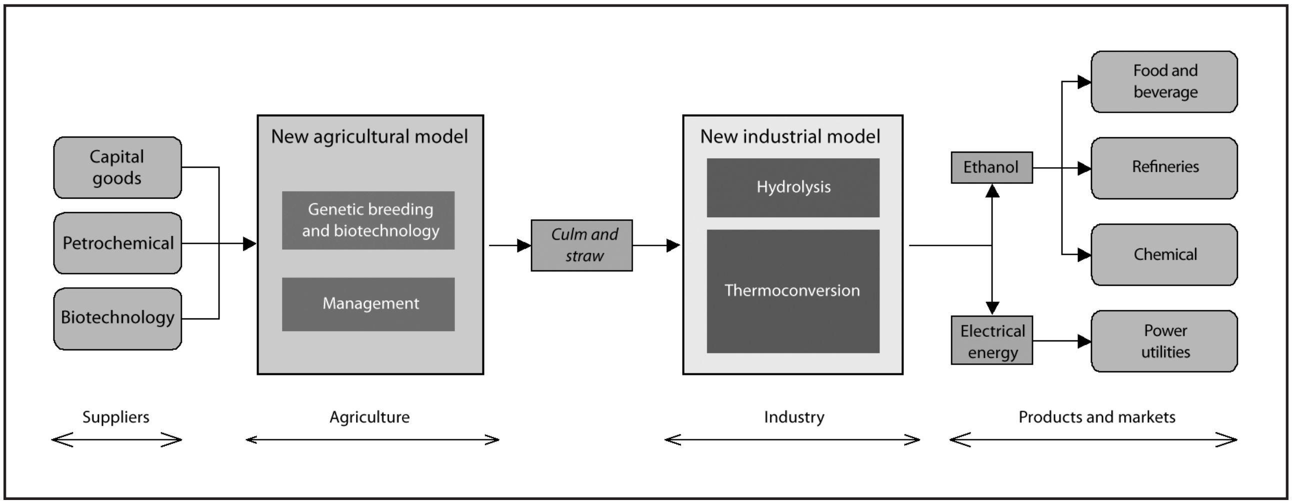


FIGURE 1 The four TRM Components.

production ethanol (energy cane) and electricity, but also incorporates requirements such as high productivity and resistance and tolerance to pests and diseases, and adverse factors, particularly drought, flood, heat shock, salinity, soil acidity, in addition to fixing symbiotic nitrogen and increased pumping capacity and utilization of nutrients.

Even within the agricultural area, a second component considered is the **Management**, which includes no-till, trash recovery, mechanization and farm management alternatives. Here we observe that the first three issues are closely interlinked through the sugarcane trash, which represents about one-third of the biomass that has historically been discarded, needs to be incorporated into the current scenario. To the extent to which the recovery of trash becomes part of the production scenario, may spontaneously used the technology of tillage, which in turn requires a mechanized alternative, based on traffic controlled by information technology.

Looking to the industrial area, another component of the TRM is **Hydrolysis**, the process of transformation of ligno-cellulose for conversion into ethanol. This is one of 2nd generation biofuels technological processes. Hydrolysis include acid, enzymatic and supercritical. The hydrolyzate product, having defined the destination to be given to the hydrolyzate of hemicellulose and lignin, must be subjected to fermentation for the production of ethanol.

The fourth component, thermoconversion, involves Gasification and BTL. The gasification process is related to the thermochemical conversion of ligno-cellulose into fuel gases, which in turn can be used to generate electricity. In this four-step process – drying, pyrolysis, reduction and combustion – biomass in the form of fiber is heated and partially oxidized with atmospheric air to produce fuel gases (typically CO, CO_2, CH_4 e H_2) as well as CO_2, N_2 and water vapor) that can later be burned in gas turbines to generate electricity.

Finally, the Biomass-to-Liquid (BTL) is the thermo-chemical conversion of ligno-cellulose into synthesis gas (CO, CO_2, CH_4 and H_2) – through a gasification process with oxygen – which can then be used to obtain liquid fuels, in reactors with temperature, pressure and appropriate atmospheric conditions. From the synthesis gas, via a catalytic process, hydrocarbons similar to those produced by oil, can be obtained. The best known of catalytic processes is the Fischer-Tropsch process, originally used for the conversion of coal or natural gas into liquid fuels (CTL or GTL).

Moreover, the work also takes into account the external environment, analyzing the economic, social, cultural, international, demographic, environmental, political and legal influence the development of the productive chain. Therefore, the goals to be achieved by the future program

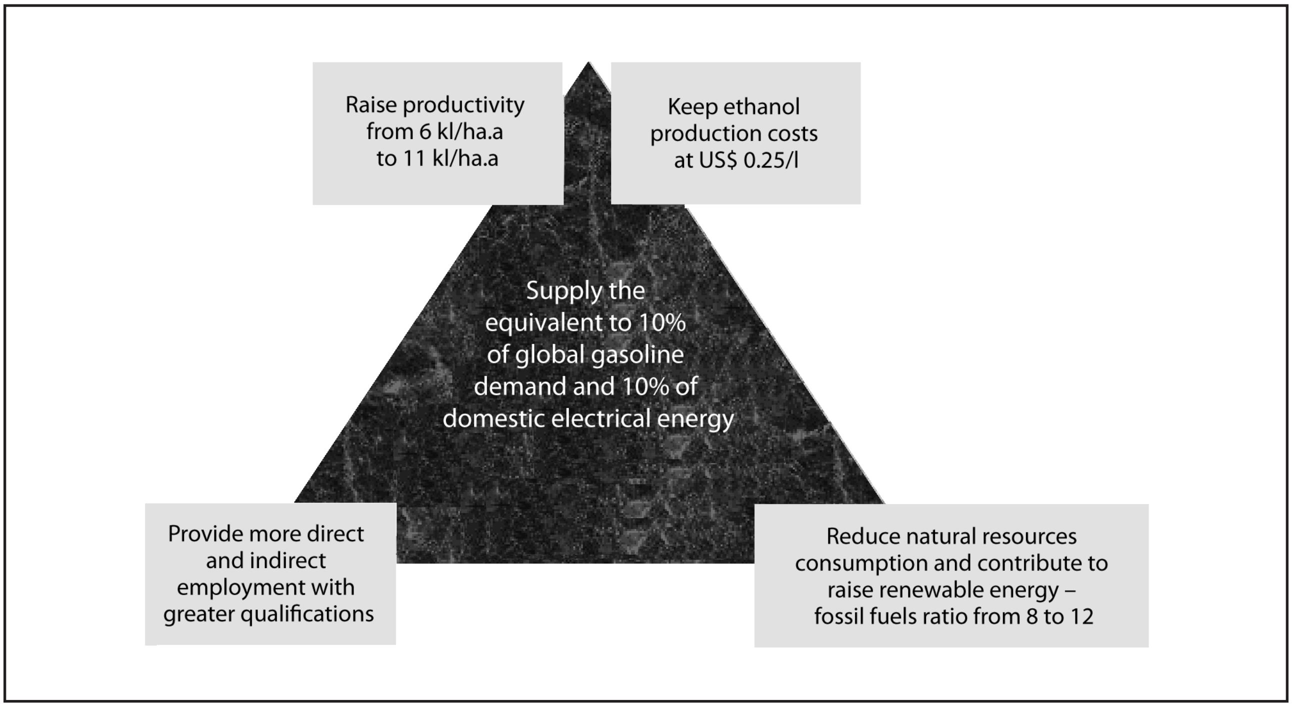


FIGURE 2 Strategic objectives for the next 20 years.

of scientific and technological development of sugar industry should be grouped into categories aligned with the environmental factors in terms of sustainability, emissions, cost of production and socio-economic benefits.

With the establishment of a strategy of technological development in the components above, it is expected that the Vision established can be reached within 20 years.

Unfolding

First, the Vision states that the transition that will pass the sugar-based ethanol will provide international leadership in *production*, and the focus of this work is the production of ethanol and electricity. In the case of ethanol the goal is established in terms of external demand: estimated projection of the potential demand for ethanol – which was regarded here as 10% of world demand for gasoline in 20 years, from previous studies of this project[2]. In the case of electricity, the goal is stipulated by domestic demand: the generation of electricity from biomass residual sugar can contribute 10% of electricity generation in the country in 2025[3].

Secondly, the Vision states that the exploration of new supply chain will be made in a sustainable socially, economically and environmentally way. The first pillar of this triangle that increased job opportunities – direct and indirect – arising from the development industry and its impacts on other sectors of the economy. In the new model, these jobs require higher qualifications, the result of technology advances. The second pillar is crystallized in economic goals in terms of productivity increase ethanol production without increasing production cost per gallon of ethanol. Finally, the third pillar implies in reducing consumption of natural resources and the improvement in the energy production process, and the latter in a broad sense, includes the mitigation of emissions of greenhouse gases (GHGs). It is expected that the energy balance can reach a value around 12, a value estimated by a number of improvements to the cycle, as the use of trash and vinasse.

[2] See Section Ethanol.

[3] See Section Electric Energy.

Strategic goals

The following are the goals to be achieved in order to meet certain economic goals, social and environmental need to view presented (Figure 2).

The objective of this type of document is to summarize the views of project participants in each stage of the supply chain identified in Figure 1. In the new paradigm of "energy cane[4], whole cane (optimization of the crop) would be collected, along with optimization of the energy balance of the plant to increase the amount of biomass available.

Present industry: products, clients, producers, suppliers and processes

To mark out the future course of the sugarcane industry – the subject of a later section – this section defines where the industry is through a summary of current industry that describes its main products, consumers, producers, suppliers, materials and energy sources used.

Products

In Brazil, sugarne was the raw material of a typical food industry where the sugar was clearly the main product and the alcohol just a by-product to utilize the exhausted molasses left over from sugar production. The launch of Proalcohol in 1975 found the situation in Brazil with nearly 100 million tons of sugarcane and 600 million liters of alcohol, this accounts for around 10% of sugarcane.

Currently, the sugar and alcohol also divide cane sugars. However, the first is still in the main product is the cane designed to maximize the production of sucrose (not sugars) and to facilitate their conversion into sugar (high purity of the juice and fiber lower). Additionally, it is important to recognize that the genetic improvement programs can keep the fiber in a standard medium-high, because there needs to be met with the advent of mechanical harvesting and planting. Researchers Rides in UFV has, since 2004, developing sugarcane varieties with the goal of increased biomass for cellulosic ethanol.

In the late 90s, the electric energy began to consolidate itself as a third product from the implementation of public policies[5] that created the position of the Independent Producer and opened using the electricity network to all parties to fulfill the requirements technical resources.

Clients

The production of sugar is the main product of the industry, this product is directed to the food sector.

With the growing awareness of the scientific community and governments of most countries in the world to the problem of global warming, interest in renewable fuel sources has increased significantly. Alcohol was facing a period of disinterest in Brazil, due to low oil prices, received a new lease on life. With the rapid escalation of oil prices since 2001, the alcohol car returned to be sought and encouraged the automobile industry to develop the flexible fuel vehicles (FFV's) leading to the launch of the first commercial model of technology in 2003. Today, the FFV's represent over 70% of new cars sold in the country[6].

Additionally, the first steps towards relaxation of protectionist barriers to imports of alcohol in the U.S. and the European Community have recently been and there is a market expectation for further liberalization, which depends on several factors, including the "commoditization" of ethanol.

With respect to electricity produced by industry, the sugar industry itself is the main customer of this product. As highlighted in MACEDO and CORTEZ (2005), its life cycle (or energy balance), expressed as the ratio of renewable energy pro-

[4] The term "energy cane" is an arbitrary name in order to indicate that technological development will target the total energy produced per hectare.

[5] Here we must mention the Incentive Program for Alternative Sources of Energy (PROINFA) from the Brazilian Ministry of Mines and Energy – MME, which considered a biomass energy source to be encouraged.

[6] According to the Brazilian Automotive Association-ANFAVEA, 74.17% of vehicles produced in the country and 88.58% of vehicles sold domestically in 2008 are Flex Fuel (http://www.anfavea.com.br/tabelas.html).

duced during the life of the system – to produce alcohol – and the energy consumed from its beginning until its decommissioning, is more than 8, while the corn ethanol produced in the U.S. has a life cycle between 1.2 and 1.4. According to the authors, this exceptional value reflects the current condition of the sugarcane plants in Brazil, with low efficiency (for energy) of the cogeneration system, bagasse based steam systems. Almost all the plants are self-sufficient in electricity and meet all the demand for thermal energy (GOLDEMBERG, MONACO and MACEDO, 1993). Soon, almost all the energy contained in the bagasse is consumed inside the mills. Estimates indicate a usage of 5,500 GWh in the generation of electricity and 7,000 GWh for the mechanical work.

Producers

With regard to sugarcane, it is produced in over 100 countries around the world, despite the eight major producers focusing about ¾ of world production, with Brazil and India together account for approximately 50% (Table 1). In all these countries except Brazil, sugarcane is essentially a raw material for the production of sugar in its various forms.

The leadership and global competitiveness are not guaranteed in the medium and long term, as countries such as Australia and Thailand have production costs of sugar, not much larger than the Brazilians, and may grow even more its total production.

TABLE 1 Sugarcane world production.

Country	Cane Production (10^6 ton)
Brazil	411
India	244.8
China	93.2
Thailand	63.7
Pakistan	52
Cuba	24
Mexico	45.1
Australia	36.9
Others	347.1
Total	1,317.9

Source: FAO, 2004 apud UNICAMP, 2005.

As can be seen in Figure 1, ethanol production worldwide is concentrated in Brazil, USA, India and China, and more importantly the first two, according to data from 2004 (DATAGRO/FOLICHT, 2005 *apud* UNICAMP, 2005). It is worth noting that Brazil has the lowest cost of production of alcohol in the world.

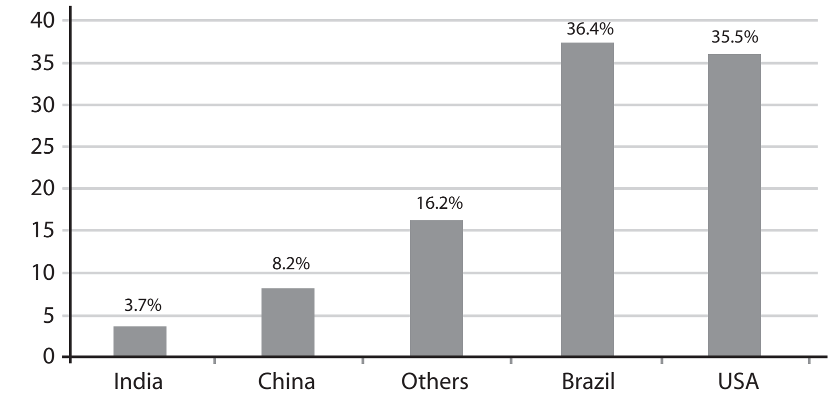
However, developed countries invested heavily in ethanol production from lignocellulosic materials, either by hydrolysis as routes for gasification followed by synthesis (Fischer-Tropsch process and others), with the expectation of achieving production costs in the medium term similar to the current Brazil[7]. It is worth mentioning the current status of the U.S., which share global leadership with Brazil in terms of production and consumption of ethanol.

In Brazil, before Proálcool, ethanol production in Brazil was essentially the so-called residual alcohol, which had the raw molasses or final molasses, a byproduct of sugar factory. After 1975, were installed distilleries annexed to sugar mills exist. Starting in 1979, came the so-called autonomous distilleries, producing only ethanol from sugarcane juice. With the growth of exports of sugar, the autonomous distilleries were mostly converted to sugar mills and alcohol.

The Brazilian sugarcane sector is dominated by local entrepreneurs and also has a strong predominance of the state of São Paulo (BRAUNBECK and CORTEZ, 2005). This second feature is due to a combination of factors such as soils, climate and topography, more organized structure of the entrepreneurs, more intensive use of available technologies in both agriculture and industry (*ibid*) and proximity to the consumer market.

The largest producer in Brazil is the state of São Paulo, which produces around 60% of all cane, sugar and alcohol in the country. The second larg-

[7] According to an expert, the cost of production from lignoselulosic material, tends to be always greater than that from sucrose technology (1 generation), the advantage of new technologies for 2nd generation is the economics of land use.



GRAPH 1 World ethanol production (2004).

est producer is the state of Paraná with 8% of the crushed cane in Brazil.

Suppliers

The ethanol production chain has several agents involved effectively in agricultural processes, industrial and commercial, they are: suppliers of fertilizers and agricultural inputs, suppliers of machinery for the agricultural service providers involved; agricultural producers (sugarcane), chemicals (raw materials and reagents), suppliers of machinery and equipment for industrial production, logistic and transport, fuel distributors, trading companies, colleges and universities (training of labor force), research centers; associations and professional associations, provision of infrastructure (water, energy, access), providers of services (technical, environmental etc.).

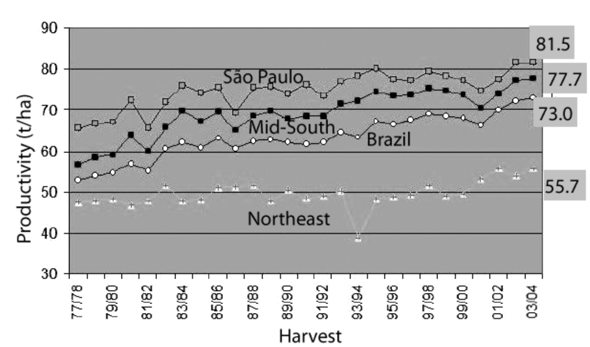
Processes

In Brazil, as previously mentioned, the sugarcane is used for the production of sugar and ethanol. The following is a summary of the sugarcane production process and production of sugar, alcohol and energy.

Production of sugarcane

Sugarcane is a semi-perennial crop, being harvested five times before being replanted, or complete the production cycle in five years. There are two alternatives that are used for the planting season of sugarcane: 12 months to 18 months. After the first cut, which corresponds to the so-called "plant cane", the cane is harvested on average four times ("ratoon cane"), from the regrowth of cut cane (ratoon). Thus, the average yield in the harvested area is 82.4 t/ha and planted area (sections 5, 6 years) 68.7 t/ha year.

Graphic 2 shows the evolution of the yield of sugarcane (IBGE, 2005 apud UNICAMP, 2005). It may be noted that the productivity of Central-South Brazil, and especially the Brazilian average, is higher than the Northeast, much of this difference is explained by differences in soil, climate and topography, but there is a strong technology component once varieties of cane that there have been developed primarily for the Central-South region.



GRAPH 2 Sugarcane productivity evolution by region in Brazil.

Agricultural activities ranging from soil preparation to harvest the cane will be described briefly below.

Sugarcane planting: this phase consists of the following: stool elimination (or weeding if necessary in case of a new area), terracing, sub soiling or plowing, liming, harrowing, furrowing, distribution of filter cake and fertilizer, distribution of billets, cover of billets, herbicide spraying and soil leveling.

Harvesting and transportation: harvesting of sugarcane in Brazil is rapidly advancing. In the traditional system, there is the manual harvesting of sugarcane with prior burn the cane fields. In the system of mechanized harvesting, the cane is chopped without burning the sugarcane field. The main reason for this transition is in the federal and state laws (to São Paulo) establishing timelines (Federal and State) to reduce and end the burning cane fields, but there are no incentives that result in the interest of recovering the trash for economic.

The main types of sugarcane transport used are: truck (double-bin, double-driven axles, 1 trailer), Romeo and Juliet (five axle articulated road train including a truck pulling a trailer); Treminhão (seven axle articulated road train including a truck tractor pulling two trailers) and Rodotrem (nine axle articulated road train including a truck tractor pulling a semitrailer and a trailer). The average distance of transport in Central-South is around 20 km and is increasing in the recent past following the increasing scale of the plants, making room for research related to reducing transportation costs and to adapt to changes in cropping system even to include the partial recovery and transport of trash along with the cane.

Ratoon cultivation: operations of ratoon cultivation depend on the type of cane harvesting and specific conditions of the sugarcane field. The main ones are: trash winrow (in case of cutting burned cane), cultivation and ratoon fertilization and application of herbicides. The application of fertilizers depends on soil conditions, productivity of sugarcane and other factors; the use of stillage (ratoon) and the filter cake (planting/ratoon) reduces the need for chemical fertilizers and improves the organic matter content of soils.

Production of sugar, ethanol, and energy

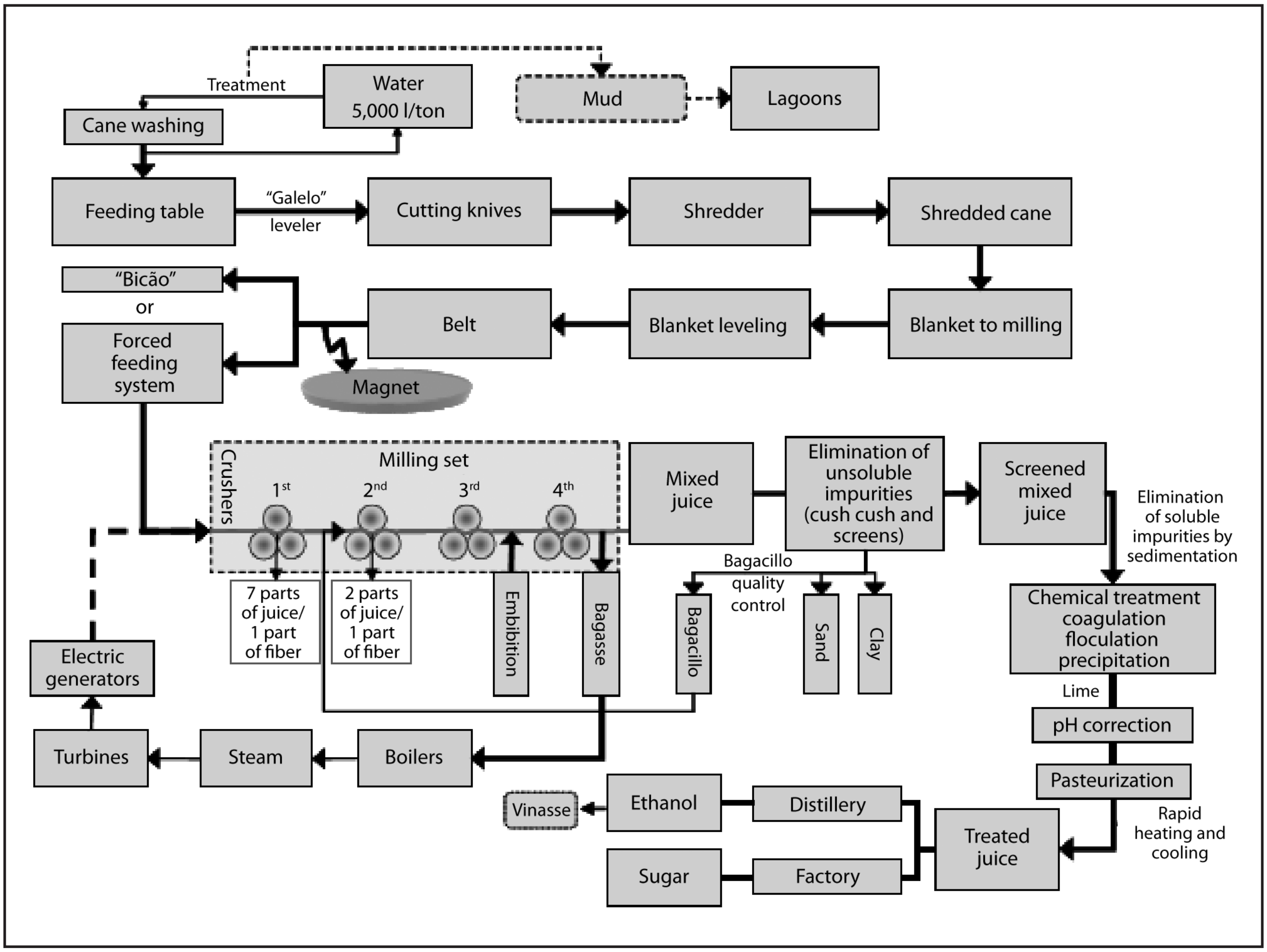
In the 2003/2004 harvest, Brazil had 320 processing plants sugarcane, and 226 installed in the Center-South and other 94 in the north-northeast. The type of production units are divided into plants, mills with distilleries and independent distilleries, the first produce only sugar, the latter producing both sugar and alcohol and alcohol only independent distilleries. Plants producing alcohol amounted to 284 plants.

These cane processing plants grind an average of 1.5 million tons of cane per harvest in the Mid-South and just over 1 million as the national average. That the 2003/2004 harvest, the distilleries, autonomous or annexed, producing an average of about 400 thousand liters of ethanol per day, at the beginning of Proálcool units produced between 120,000 and 180,000 liters/day, and there was therefore a significant economies of scale.

Due to its territorial extension, Brazil has, typically, two distinct periods of harvest. In the Northeast harvest runs from September to March and the Center-South cane is harvested from May to November. Thus, the country produces alcohol throughout the year, despite the North-Northeast harvest produce only about 15% of ethanol in the country. The best distilleries produce approximately 85 liters of anhydrous ethanol per tonne of cane. The plants have attached production around 71kg of sugar and 42 liters of ethanol for each ton of cane processed.

The technology for producing alcohol and sugar is very similar in terms of processes, in all Brazilian plants, there are variations in the types and qualities of equipment, operational controls, and especially in the managerial levels. There is now a good integration between the agricultural and industrial plants, which optimizes the entire production chain units better managed. The payment system of sugar stimulates the independent producer of cane to deliver the raw material in good condition as there are no penalties or rewards depending on the quality of the cane at the plant.

The plant can be divided into the following sections: receiving/preparation/milling, processing of the juice, sugar factory, distillery, utilities, waste



Source: UNICAMP, 2005.

FIGURE 3 Sugarcane processing.

disposal and storage of products. Figure 3 shows a block diagram of the processing of sugarcane.

Reception, preparation and milling: this section is intended to prepare the cane (cleaning and opening of the cells) and extract the juice, with a minimum loss of sugarcane as well as reduce the final moisture content of bagasse.

The received cane is randomly sampled to assess their quality (sucrose content, fiber, pure juice etc.).

Whole sugarcane harvested (manual cutting) is usually washed to reduce impurities that negatively affect the processing of sugarcane, in their own reception table, in the case of chopped cane (mechanized cutting) the cane can not be washed, because the loss of sucrose would be very high, but some plants are beginning to use the system for cleaning, based on jets of air over the cane.

From the feeding table the cane is transported by conveyor to the equipment preparation. There are usually one or two sets of rotating blades that aims to chop the cane (when whole cane) and/or even a layer of sugarcane on the mat, facilitating the work of the grinder. This equipment, consisting of a rotor with swinging hammers and a shredder plate, powdered sugarcane and opens the cells containing sugars, facilitating the extraction process of sugar by crushing (at least 85% of the cells should be opened to achieve a good extraction efficiency in the mill).

On the grinder exit, the height of the cane bed is uniform with equipment called a spreader, located in the discharge of the metal conveyor belt to a rubber high-speed feeding trough for feeding the mill (Donnelly kick); in this channel cane disintegrated form a column with higher density, increasing the power and capacity of the mill. The level of sugar in the channel is used to control the flow of cane to the mill.

The extraction of sugars contained in sugarcane can be made by two processes: milling and diffusion. The diffusion process is still little used in Brazil. Milling is a process of extracting the juice, making the cane through three rolls, with a preset pressure applied to them. The grinding must not only extract the juice, but also produce a residue with a moisture content which allows its use as fuel in boilers. The grinding is usually made up of 6 suits in series. After passing the first of these suits the proportion of stock in relation to the fiber decreases from about seven for between 2 and 2.5, making it difficult to extract this residual broth, and the device used is called imbibition. The imbibition can be made and with water recirculation, and the type made most frequently used. In this case, water is injected into the layer of sugar between the last two suits and stock in each suit is injected before the suit before, until the second suit. Typically, the juice extracted in the first suit is sent to the sugar factory (being better) and the rest of the juice goes into the distillery. The efficiency of extraction of sugar varies from 94% to 97.5% and final moisture content of bagasse is around 50%.

Utilities: after the juice extracted bagasse, consisting of fiber (47%), water (50%) and dissolved solids (3%) is transported by conveyor belts to the boilers and the surplus sent to the storage yard. It is noteworthy also that by not washing the cane, or the little cane-washing, the residue can also contain 1% to 3% of mineral matter insoluble (earth). Bagasse is produced in quantities ranging from 250 to 320 kg per tonne of sugarcane, it is the only fuel used in steam boilers, generating all the energy needed for the processing of sugarcane and also producing a surplus that could reach 15%. In most plants, the steam leaves the boiler at a pressure of 22 bar and temperature of 300 °C. Under these conditions, it is expanded in turbine exhaust to 2.5 bar. The engines power the main power plant mechanical equipment (chippers, shredders, grinders, blowers and water pumps for feedwater), as well as electric power generators, which is provided for the various industry sectors. The steam at 2.5 bar, called vapor pressure, is adjusted for the condition of saturation, and sent to the process, providing all the heat energy needed to produce sugar and alcohol

Juice treatment: the juice, when it comes out of the extraction process, contains a number of impurities that have to be reduced to make the broth in a quality suitable for processing in the sugar factory and distillery. The first phase of treatment is for the removal, by means of sieves, the insoluble solids (sand, clay, bagacilho etc.) Which are at levels between 0%, 5% and 2%. The second phase is the chemical treatment for the manufacture of sugar, which aims to remove insoluble impurities, which were not eliminated in the previous phase, and the soluble and colloidal impurities. This process aims to coagulation, flocculation and precipitation of impurities, which are removed by sedimentation. It is also necessary to correct the pH to prevent inversion and decomposition of sucrose. The broth that is used for manufacturing alcohol is only heated and sent to sedimentation, requiring only the removal of insoluble solids, avoiding the removal of soluble substances such as phosphates and amino acids, which are nutrients for fermentation.

Sugar factory: the broth is treated specifically to be sent to manufacture sugar or alcohol. In the manufacture of sugar is widely used to sulfurizing. Sulfurizing has as main objectives (i) inhibit reactions that cause color formation, (ii) coagulate soluble colloids, (iii) form precipitate CaSO3 (calcium sulfate), and (iv) reduce the viscosity of the broth and, consequently, syrup, massecuites and molasses, facilitating the operations of cooking. After passing the initial treatment, the juice to alcohol must go through heating to at least 105 °C, decanting and cooling.

In general, the cooling of the juice is carried out in two steps:

a) Pass the hot broth for a regenerative heat exchanger in counter with the raw cold juice, where it is heated and the decanted juice to the distillery is cold (60 °C).
b) Final cooling to approximately 30 °C, usually held in plate exchangers in countercurrent with water as cooling liquid.

Ethanol distillery: most of the ethanol produced (~80% of the total) is performed by a fermentation process in batch, fed with yeast recycle. The remainder of the ethanol is produced by multistage continuous fermentation with yeast recycle, the process is based on fermentation continues proposed by Guillaume.

With the increase of milling for the manufacture of sugar and the production of a greater proportion of honey, the continuum has been losing share due to factors such as the difficulty to operate stably with high percentages of final molasses and lack of adequate technical knowledge to operate them.

The characteristic parameters of fermentation are:

- energy conversion of sugar by 90%;
- titles of ethanol in wine reach 8 to 12 of GL;
- times of fermentation from 6 to 11 hours;
- concentration of yeast in the final wine typical 10% v/v;
- stillage final volume after distillation 8 to 13 liters/liter of ethanol.

In the recovery of ethanol in the final wine and getting AEHC (hydrated ethanol fuel), almost all distilleries follow the same pattern using whole column distiller with exhaustion, and concentrates epuration heads, and the rectification of phlegm held in a section exhaustion and a section of concentration (as a whole exhausting, rectifier) or exhaustion at the end of flegmass distiller (Flegstil). These sets are operated at low pressure above the air using the exhaust steam turbines and modern, the steam produced in the evaporation plant juice.

Until today are rare the operation arrangements that increase the efficiency of production AEHC (hydrous ethyl alcohol fuel) above the current values of 3 to 3.5 kg steam per gallon of ethanol, despite the industry have made great progress with new distilleries that reach 2.4 kilograms liter. The production of AEAF (anhydrous ethyl alcohol fuel) is made largely using the azeotropic distillation using cyclohexane (methyl cycle and pentane) and ternary dehydration and no further optimization of energy resources to reduce the current 1 to 1,4 kg of steam per gallon of ethanol. More recently has been introduced the extractive distillation with ethylene glycol mono as an extractant and adsorption process with molecular sieves, both with significantly lower energy consumption. The process of mono ethylene glycol tends to be abandoned due to outbreak of dioxane and also due to the strong corrosion that is produced at the dehydration columns.

The present industry

From what has been presented in this section, the sugar industry now has some features that can be illustrated in the Table 2:

Besides the points above advised, the current state of ethanol production in Brazil can also be summarized by the following observations:

- Brazil has the lowest production cost of ethanol in the world and has exceptional conditions to extend several times the current production in a period of 20 years.
- The ethanol produced from sugarcane has an energy balance much more favorable than that produced from corn. The energy inputs represent 12% of the cane alcohol and 80% of corn ethanol. One of the main arguments that support today to the use of sugarcane ethanol is to reduce emissions of greenhouse gases. According to MACEDO (2005), avoided greenhouse gas emissions is equivalent to 13% of total emissions from the energy sector in Brazil.
- With the growing importance of ethanol, this may no longer be a by-product for sugar.
- The production model of Brazil, based on a simultaneous production of sugar and ethanol in the same plant (plant with distillery attached), is more characteristic than in other countries and its adoption has been growing internationally.
- The breeding programs of sugarcane from Brazil and the rest of the world favor productivity and increase the sugar content.
- In terms of sugarcane primary energy, (1/3) comes from sucrose present in the juice and (2/3) in the fibers present I the stalks and leaves. Today only the third represent-

TABLE 2 Summary of present industry: products, clients, producers and production model.

<table>
<tr><th>Products</th><th>Clients</th><th>Producers</th><th>Production Model</th></tr>
<tr><td>Sugar</td><td>Food industry</td><td>Brazil and India</td><td rowspan="3">• Base don sugarcane model.
• Alcohol is byproduct.
• Joint production of sugar and alcohol in annex distilleries, in its majority.
• Electric energy is consumed internally, but there are plants selling energy.
Land property:
• Plants (65%) and ~70,000 independent producers (35%).
• Production concentration in Central-South Brazil.
Harvest period:
• Central-South: April to November (85% of cane).
• Nort-Northeast: September to March (15% of cane).
Plant capacities:
• < 500,000 to 7,000,000 t cane/harvest.</td></tr>
<tr><td>Alcohol</td><td>Fuel distributors and chemical and beverage industry</td><td>Brazil and USA</td></tr>
<tr><td>Electric Energy</td><td colspan="2">Sugarcane industry, but also utilities and independent consumers</td></tr>
</table>

ed by the sugar is used to produce products (the other 2/3 is recovered partially and inefficiently to generate energy).

- There is a growing interest in the generation of large surpluses of electricity for sale by plants. However, currently little more than 10% of the plants generate significant quantities of surplus, which is still far from having the same economic importance of the sugar and alcohol plants in revenues.
- The conventional technology of processing sugarcane to produce sugar and ethanol has reached a high degree of maturity. There is little room for incremental gains with the exception of the areas of energy savings – where the technology to extract the juice by diffusion applies well – reducing the volume of vinasse, optimization of energy recovery from cane sugar and byproducts.
- The mechanization of cane harvesting and increasing the percentage harvested without burning the trash is an inexorable trend.
- There are in other countries, sugarcane varieties with high fiber content that can double the primary energy supply per unit of area planted. The processing of sugarcane to optimize energy use is not developed.
- The sugarcane is already being looked at as a source of energy instead of raw material for the food industry.

Needs for the future: market trends and projections

This section presents market forecasts that help define what the future consumers will probably demand. In other words, the purpose of this section is to define the market needs to be met by future scientific and technological development. The basic premise of any process of Technology Roadmapping that it is driven by market needs and not the technology itself.

The future scenario is seen is breaking the paradigm of sugarcane production for food and energy (ethanol and electricity) as major products. Also, should prevail in the concept of energy cane, which would be the development of sugarcane varieties in order to maximize energy use and processing of raw materials optimally for the production of useful secondary energies such as transport fuels and electricity.

This section aims to consolidate the results of previous studies in this project and is divided into two parts. The first part presents projections for the demand for ethanol here two decades, while the second shows the potential market for electric power in Brazil in the same period.

Ethanol

Projection for the growth of gasoline demand for 2025

The annual world consumption of gasoline is approximately 1.15 trillion gallons of gasoline that are consumed almost exclusively as fuel for light vehicles. Market trends are governed by two opposing forces. On the one hand the expectations of shortages of oil have been promoting the development of technologies that save fuel. On the other hand, the accelerated economic development of developing countries with large populous as China, India and, to some extent Brazil, has been trying to meet a repressed demand for an increasingly affluent population for light vehicles (LV).

Forecasts of growth become more complex when, in addition to traditional considerations of efficiency, autonomy, performance, economy, cost and practicality, are taken into account specific socio-cultural characteristics. An extreme case is the U.S., where the car is much more than a means of transport, is a symbol of status, a device for personal statement. In this country, after six years of availability, gasoline-electric hybrid that provides an increased efficiency of 30% to 40% in the expenditure of gasoline, did not reach the level of 1% of the compact market.

Despite these difficulties, the National Energy Information Center – NEIC (apud UNICAMP, 2005) from U.S., projected increase in global demand for gasoline by 48% from 2005 to 2025, varying about 5% more or less, depending on the adoption of new technologies. Note that the expectation of increased demand for fuel LVs, according to the NEIC, is much greater than for other oil products. We will adopt, therefore, as a reference to the 2025 demand of 1.7 trillion liters of fuel for light vehicles.

To fulfill 10% of gasoline demand in 2025 will require 205 billion gallons of ethanol per year, which would occupy an area with sugarcane, with productivity of today's around 35 million ha, without irrigation, already included this figure the area of legal reserve of 7 million hectares.

World ethanol production and potential market

According to a study done by F.O. LICHTS (2003), 61% of global ethanol production is sourced from the fermentation of sugars and raw materials such as sugarcane, sugar beet and molasses and the rest comes from grains such as corn.

This industry is, in many countries, supported by protectionist trade barriers such as import tariffs, subsidies for exporting production quotas, fixed producer prices and regulated prices to the consumer.

These supporting measures have important implications for the economies of many developing nations in the Caribbean, Asia and Africa, as these nations have preferential agreements of trade with the U.S. and EU.

The high levels of support for the sugar industries in OECD countries (Organization for Economic Cooperation and Development) result in excess production that is exported at prices below production costs, which limits opportunities for market access. Under these conditions the opportunity cost of ethanol production can be attractive. However, in general the returns from sugar production in domestic markets are larger than those that would be obtained in the manufacture of ethanol.

The prospects for reform and deregulation policies of sugar in the EU and the U.S. may create greater incentives for ethanol production (and other forms of bioenergy as the generation of electricity), even incurring in higher costs, since the returns to preferential sugar trade and the domestic market would then be significantly reduced.

Potential market of fuel ethanol

The world consumes more than 20 million barrels of gasoline per day (1.15 trillion liters in

2004), used mainly as fuel for light vehicles. As seen above, this annual consumption is approximately 1.7 trillion liters in 2025.

The main gas-consuming countries (U.S., Japan and EU) and countries with rapid growth in consumption (China and India) are eagerly seeking alternatives to gasoline. Environmental, economic, political and strategic make ethanol from biomass one of the main options to replace gasoline, either by direct blending or as a feedstock in the production of ETBE (oxygenating gasoline).

That is how many countries are supporting the production and consumption of ethanol from biomass, for use as fuel, through programs and policies to promote biofuels, incentives for the production and domestic consumption and international agreements (Kyoto Protocol).

The international market for ethanol fuel is nascent and is still in the stage of overcoming difficulties such as security of supply, lack of infrastructure and political and commercial barriers in some areas. However, the rapid increase in demand for gasoline and oil prices are helping to increase the flow of international trade in renewable fuel.

In what follows below we seek to project the market potential of fuel ethanol by 2025, the calculation is based on consumption of gasoline (historical consumption trends and projections from the Energy Information Agency), the production of ethanol fuel (history and ability to increase production) and policies to support biofuels.

For the present study included 21 countries representing 71.5% of gasoline consumption and 51% of current production of ethanol.

It is shown the current and projected consumption of gasoline (Table 3), the share of ethanol on the market of 21 countries surveyed according to the policies of each country (Table 4), the current and projected production of fuel ethanol (Table 5) and finally the quantities of fuel ethanol to be imported by these countries by 2025 (Table 6).

The need to import ethanol fuel in these 21 countries is presented as an interesting opportunity for Brazil to become the leading supplier in 2012 and 2025, with a potential market of nearly 20 billion gallons of ethanol by 2025. The main markets are Japan, China and the United States.

At Figure 4 is shown the trade of fuel ethanol in the world in 2010. Brazil, India, Central America, Peru, and South Africa being the main actors in the supply of ethanol fuel in the world. China, Japan, United States, Australia and Europe are the main importers in this market for biofuels.

Although this group of countries representing the largest consumers and producers of ethanol does not rule out the possibility of greater participation of other countries with large potential to produce ethanol from sugarcane and also the emergence of new markets (new customers) for the fuel ethanol, since ethanol is considered a commodity policy and many countries are showing interest to import and mainly produce its own fuel for light vehicles.

It is important to note that Table 6 reflects a very conservative world demand for ethanol in 2025, it is based on the current protectionist policies of the countries surveyed and plans short and medium term these countries, where it is clear the intention of each to consume only what they could produce.

To have a reasonable positive impact on the overall emissions of greenhouse gases, in our opinion, would require that biofuels replace at least 10% to 20% of fossil fuels in the transportation sector. That would raise at least 110 billion liters of ethanol need to import from the countries shown in Table 6 added to the other countries that do not produce ethanol.

Brazil has significant comparative advantages for having experience of more than 30 years with a biofuel program – which is a model for many countries – as the largest producer and consumer of ethanol fuel in the world and has the highest capacity expansion production of renewable fuel, since it has large amounts of land, lower costs and mastery of technology in the agricultural and industrial.

For this liberalized biofuels market is necessary to eliminate barriers to environmental goods and services, it requires the active participation of major players in the market (producers and consumers) to sustainably supply the domestic

TABLE 3 Projected gasoline consumption.

Billion liters per year				
Country	**2004**	**2012**	**2020**	**2025**
United States	530	601	671	7,161
Colombia	4.4	11.4	15.7	22.4
Peru	1.3	1.0	1.5	1.8
Austria	3.4	6.0	11.6	16.4
Denmark	2.7	2.8	2.9	2.9
Finland	2.6	2.7	2.9	3.1
France	17.8	20.2	20.4	21.0
Germany	36.4	38.2	40.1	41.3
Greece	5.0	6.2	7.3	8.0
Italy	22.3	23.4	24.4	25.1
Netherlands	5.5	5.8	6.0	6.1
Spain	11.2	10.7	10.3	10.0
Sweden	5.5	6.2	6.0	6.2
United Kingdom	28.1	29.3	33.6	37.9
Czech Republic	2.8	3.3	3.8	4.1
Hungary	2.3	5.0	5.5	6.3
Australia	19.4	23.7	28.1	30.9
China	55.9	69.7	83.5	92.2
India	11.2	15.8	20.4	23.3
Japan	64.6	78.3	92.0	100.0
Thailand	7.7	8.9	10.1	10.8
Total	**840**	**969**	**1,097**	**1,186**
World	**1,175**	**1,356**	**1,534**	**1,658**

Source: UNICAMP, 2005.

and foreign markets, requiring more investment and eventually, transfer of technology.

Biofuels will not completely replace fossil fuels in the long term, but may have an important role in the transition to a sustainable future of transport fuels.

Electric energy

Electricity generation from bagasse contributed 2% of total electricity generation in Brazil in 2006, and this participation has grown since 2000, when the contribution percentage was 1%. More-

TABLE 4 Participation of fuel ethanol according to policies of countries.

Billion liters per year									
Country	Mix	2004		2012		2020		2025	
		Gasoline	Ethanol	Gasoline	Ethanol	Gasoline	Ethanol	Gasoline	Ethanol
United States	E 7.2	491.8	38.2	557.7	43.3	622.7	48.3	664.4	51.6
Colombia	E 10	4.4	0	10.2	1.1	14.2	1.6	20.2	2.2
Peru	E 7.8	1.3	0	0.9	0.1	1.4	0.1	1.7	0.1
Austria	ETBE	3.4	0	5.8	0.2	11.4	0.2	16.2	0.2
Denmark	Not consume	2.7	0	2.8	0	2.9	0	2.9	0
Finland	Not consume	2.6	0	2.7	0	2.9	0	3.1	0
France	E 5 starting in 2004	16.9	0.9	19.2	1.0	19.4	1.0	19.9	1.0
Germany	ETBE	36.1	0.3	37.3	0.4	39.2	0.9	39.9	1.4
Greece	ETBE	5.0	0	5.6	0.6	6.2	1.1	6.5	1.4
Italy	Not consume	22.1	0.2	23.4	0	24.4	0	25.1	0
Netherlands	Not consume	5.6	0	5.8	0	6.0	0	6.1	0
Spain	Not reported	10.9	0.3	0.9	0.8	8.7	1.6	7.8	2.3
Sweden	Increments 0.6% year	5.3	0.1	5.7	0.4	5.3	0.8	5.2	0.9
United Kingdom	No defined policy	28.1	0	29.3	0	33.6	0	37.9	0
Czech Republic	No defined policy	2.8	0	0.5	2.8	1.0	2.8	1.3	2.8
Hungary	ETBE	2.3	0	4.9	0.1	5.4	0.1	6.2	0.1
Australia	E 10	19.3	0.1	21.3	2.4	25.3	2.8	27.8	3.1
China	E 10	50.3	5.6	62.8	7.0	75.2	8.4	82.9	9.2
India	E 5	10.6	0.6	15.0	0.8	19.4	1.0	22.1	1.2
Japan	E 3-E 10 in 2012	62.6	1.9	70.5	7.8	82.8	9.2	90	10.0
Thailand	E 10	6.9	0.8	8.0	0.9	9.1	1.0	9.7	1.1
Total		**791.1**	**48.8**	**899.8**	**88.7**	**101.61**	**80.9**	**1,097.0**	**88.6**

Source: UNICAMP, 2005.

over, the installed capacity of electricity generation in sugar mills and ethanol is at least 3% of the total existing capacity, and the actual participation must be at least 3.5%, since the database of the National Energy – Aneel is incomplete in respect of cogeneration units in plants.

It is estimated that much of the electricity generated – something like 55% to 60% – is consumed by the plants themselves in their production processes, but it is expected that this portion of decreases depending on the appreciation of the biomass electricity. The rest is sold with the

TABLE 5 Ethanol projected production (billion liters per year).

Billion liters per year				
Country	**2004**	**2012**	**2020**	**2025**
United States	13.4	28.4	43.3	52.7
Colombia	0.4	0.6	0.6	0.6
Peru	0	1.6	1.6	1.6
Austria	0	0.2	0.2	0.2
Denmark	0.1	0.1	0.1	0.1
Finland	0	0	0	0
France	0.8	0.9	0.9	1.0
Germany	0.3	0.4	0.9	1.4
Greece	0	0.6	1.1	1.4
Italy	0.2	0.2	0.2	0.2
Netherlands	0	0	0	0
Spain	0.3	0.8	1.6	2.3
Sweden	0.1	0.1	0.1	0.1
United Kingdom	0.4	0.4	0.4	0.4
Czech Republic	0	2.8	2.8	2.8
Hungary	0.1	0.1	0.1	0.1
Australia	0.1	0.4	0.7	0.9
China	1.9	4.3	4.0	3.9
India	1.8	2.0	2.2	2.3
Japan	0.1	0.1	0.1	0.2
Thailand	0.3	1.0	1.0	1.0
Total	**20.0**	**45.1**	**62.2**	**73.1**

Source: UNICAMP, 2005.

national electricity system (e.g., sales to electricity distributors, selling to large consumers).

Moreover, considering the current level of milling, the availability of technology and only the use of bagasse as fuel, the potential is equivalent to three times the current electricity generation. And if we consider the partial use of trash as fuel, only with technologies available today and available in Brazil, the electricity generation could be 6 to 7 times greater. In addition, the potential associated with technologies still in development, and that can reach commercial stage in 10 to 15 years, the potential for electricity generation would be 10 to 15 times higher compared to the current generation.

TABLE 6 Potential market for fuel ethanol.

Billion liters per year						
Country	**2012**			**2025**		
	Estimated consumption	**Estimated production**	**Need to import**	**Estimated consumption**	**Estimated production**	**Need to import**
United States	29.9	28.4	1.6	55.5	52.7	2.8
Colombia	1.1	0.6	0.5	2.2	0.6	1.6
Peru	0.1	1.6	-1.6	0.1	1.6	-1.5
Austria	0.2	0.2	0	0.2	0.2	0
Denmark	0	0.1	-0.1	0	0.1	-0.1
Finland	0	0	0	0	0	0
France	1.0	0.9	0.1	1.0	1.0	0.1
Germany	0.4	0.4	0	1.4	1.4	0
Greece	0.6	0.6	0	1.4	1.4	0
Italy	0	0.2	-0.2	0	0.2	-0.2
Netherlands	0	0	0	0	0	0
Spain	0.8	0.8	0	2.3	2.3	0
Sweden	0.4	0.1	0.3	0.9	0.1	0.8
United Kingdom	0	0.4	-0.4	0	0.4	-0.4
Czech Republic	2.8	2.8	0	2.8	2.8	0
Hungary	0.1	0.1	0	0.1	0.1	0
Australia	2.4	0.2	2.2	3.1	0.9	2.2
China	7.0	4.3	2.7	9.2	3.9	5.4
India	0.8	2.0	-1.2	1.2	2.3	-1.2
Japan	7.8	0	7.8	10.0	0	10.0
Thailand	0.9	1.0	-0.1	1.1	1.0	0.1
Total	**56.4**	**44.8**	**11.6**	**92.6**	**73.0**	**19.6**

Source: UNICAMP, 2005.

Even considering only the use of technologies already commercial, but if the expansion of the sugar-ethanol sector is significant in the next two decades, the contribution of electricity generation from biomass residue from sugarcane would be even more important. For example, if ethanol production for export reach 100 billion liters in 2025, electricity generation associated with this production could add 12% to 25% of electricity consumption projected for that year in Brazil.

Source: IEA, 2005 apud UNICAMP, 2005.

FIGURE 4 Fuel ethanol trade in 2010.

However, only part of the technical potential can be made feasible in practice due to the high cost of lower capacity systems, the inertia of some investors, technical and economic constraints to access to the grid, delays in development technology etc. Can be estimated that 50% of technical potential would have economic viability in relation to other alternatives for expansion of electric generating capacity.

Thus, the generation of electricity from the sugarcane biomass could provide 6% to 13% of electricity consumption in 2025, when only conventional technologies were employed, and 10% to 20% is still in development technologies are employed in the moderate range.

Thus, the goal of the generation of electricity from residual biomass from sugarcane can contribute 10% of electricity generation in the country in 2025 is quite feasible. The value of this goal should be seen as an order of magnitude and not as a strict target to be achieved. Although feasible, technically and economically, there are still many challenges to overcome and, therefore, you must either invest in research, development and demonstration, and create conditions for investment, from the point of view, economic, financial and regulatory.

Relevant limits

This section presents the most relevant limiting factors of the sugarcane industry progress in the future, covering aspects such as regulation, key stakeholders and budget issues.

The difficulties of the transition discussed in the previous section will be concentrated mainly in:

- Changing a culture, that has several centuries, in a historically conservative sector and resistant to change.
- Raise funds to facilitate the technological development for the future model, since most of the productive sector would prefer to continue investing in the existing conventional process.
- From the above, comes the inherent difficulty of achieving regular income from government sources and public policies to stimulate this transition.
- The process of formulation and management of public policies is a dynamic process and very complex, since said:
  - to occur within a structure that requires continuous financial resources and motivation; and
  - the management of public policy involves many components that communicate and interact in different ways, either explicitly or by hidden channels.

FINAL CONSIDERATIONS

This chapter sought to present the context in which the process of Technology *Roadmapping* (TRM) was performed. It was presented to long-term vision of the sugarcane industry in the State of São Paulo, which provided the basis for establishing the goal of Technology *Roadmapping*, highlighting the scope of the search and the goals to be met by the sugar industry. The chapter also described the current state of the industry in terms of their products and services, customers, suppliers and processes, and indicated the likely market trends that will require adjustments in the processes and the main limiting the formation of long-term vision.

In short, this first stage of the process is of a "general" character, i.e. the process of TRM as a whole and not just one or another component, such as Genetic Improvement, Hydrolysis or any other area to be studied. It establishes the vision and scope (strategic objectives and long-term goals), describes the current state of the industry and determine what the market needs (market demands in the long run) to be satisfied by the result desired by the TRM.

Then, the next chapters deal with each of the four components of the Technology Roadmapping – Genetic Improvement, Management, Hydrolysis and Thermoconversion. These components reflect the vision, scope and needs of the market, previously established in the first step. Thus, each working group has undertaken to provide inputs to the TRM in their area of competence, aiming to show the needs and technological capabilities of each individual constituent the TRM.

In terms of future research, there is room for further technology development strategy set, covering the special features of each component and any synergies that may exist between them. This is because, if certain technological driver of a component of the TRM development requires another component, this should be clarified indicators to be applied to that component. Additionally, it might be identified points of decision making, in which the team who will oversee the future implementation of this roadmap is to decide the continuation or termination of either technological path. Finally, the recommendation of alternative technologies can be further from indicators of various kinds – such as cost, schedule and performance – measured for each alternative.

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3

TRM:

GENETIC BREEDING AND BIOTECHNOLOGY COMPONENT

Marcos Guimarães de Andrade Landell, Luciana Rossini Pinto, Silvana Creste, Sabrina Moutinho Chabregas and *William Lee Burnquist*

INTRODUCTION

Brazil is the major sugarcane producer worldwide with an estimated production around 571 Mt of cane (Conab-MAPA). Such leadership was possible due to the incorporation of management technologies and mainly by the utilization of improved cultivars developed by sugarcane breeding programs.

The raising demand for ethanol as a source of renewable energy, along with the need to ensure Brazilian's competitiveness, mainly about ethanol production facing international market and consequently its leadership on bioenergy, brings a series of new challenges especially for genetic breeding programs. In doing so, besides an increase in productivity, it will be necessary to develop new sugarcane cultivars with a new agroenergetic profile, aiming at biomass production for cellulosic ethanol production.

Developing a new sugarcane cultivar takes about 10 to 15 years. Thus, crossings currently performed will provide cultivars that must be able to answer to the predicted needs for sugar-alcohol sector within at least 10 years. Thus, due to the objected scenarios, it is of fundamentally importance that parental genotypes to be used on further crossings have the genes of interest for breeders, in such a way that they can be incorporated on new cultivars. In turn, genetic breeding aiming to develop cultivars with a higher biomass production will demand appropriated germplasm as a source of genes that confer traits capable of contributing to an increase on biomass and fiber content, as well as other major agronomic traits such as resistance to main diseases, pests and abiotic stresses.

Therefore, molecular technologies such as the prospection of genes of agronomic interest, genetic transformation, molecular markers, among others, will be of considerable importance and will help sugarcane genetic breeding programs.

TECHNOLOGY NEEDS AND CAPABILITIES

In this section, we intend to show the necessities and technology capabilities regarding the Genetic Breeding and Biotechnology component of *Roadmapping* of sugar-alcohol industry.

Products or technologies targeted

Genetic breeding of sugarcane plays a key role on the ethanol productive chain, since it is responsible for providing the basic raw material that drives the whole system, i.e., sugar-alcohol industry. This feedstock is essentially represented by sugarcane cultivars and must comply with a series of pre-requisites, not only the necessary for a shift from the paradigm "sugarcane for sugar and alcohol" to "sugarcane for ethanol and energy generation", but also for those related to the expansion of this crop to restrictive areas, especially drought-prone areas ("cerrado"), where water deficit is the main limiting factor.

However, genetic breeding is not an isolated subject; still, it requires the integration of other areas of knowledge such as pathology, mineral nutrition, physiology, soils and genetics. Recent advances on genomics, genetics, proteomics and metabolomics, suggest that biotechnology must impact sugarcane breeding by making it more efficient. Molecular-assisted breeding holds the potential to speed up varietal development, while transgeny may be able to alter great paradigms in a short period of time. Though, the biggest challenge is how to overcome the technological gap resulting from the huge quantity of information obtained through genetics and genomics, where the capacity of comprehension and development of resources has exceeded the capacity to apply them in a practical manner on the genetic breeding of sugarcane.

Thus, the aimed technologies for the Genetic Breeding and Biotechnology component of sugarcane refer to a set of strategies either from conventional genetic breeding or from biotechnology, which play important roles on the development of new sugarcane cultivars, whether it be for ethanol production (1st and 2nd generation), sugar or biomass. Yet, they still have bottlenecks that need to be solved. Furthermore, these technologies were focused on the development of cultivars to achieved two different scenarios:

Scenario 1: higher yield cultivars with higher sucrose content that can meet the demand of industries that use conventional system of ethanol production.

Scenario 2: sugarcane cultivars focused on higher energy yield, resulting from higher fiber content, whether it be from bagasse or straw (leaf sheath and lamina, including the sum of all sugars which will respond for a lower percent of this primary energy (PE) in the future.

Quantification of the PE may be calculated by the expression suggested by REGIS (personal communication, 2007): MJ/tc = 18 x kg fiber (dry matter) + 16 x kg sucrose + 15.6 x kg RS (reductor sugars). These new cultivars should improve the current potential either for biomass production destined to electricity production ("Energy Mills"), or to cellulosic ethanol production, depending on the market demand.

Basically, genetic breeding can be divided into two stages that involves the generation of

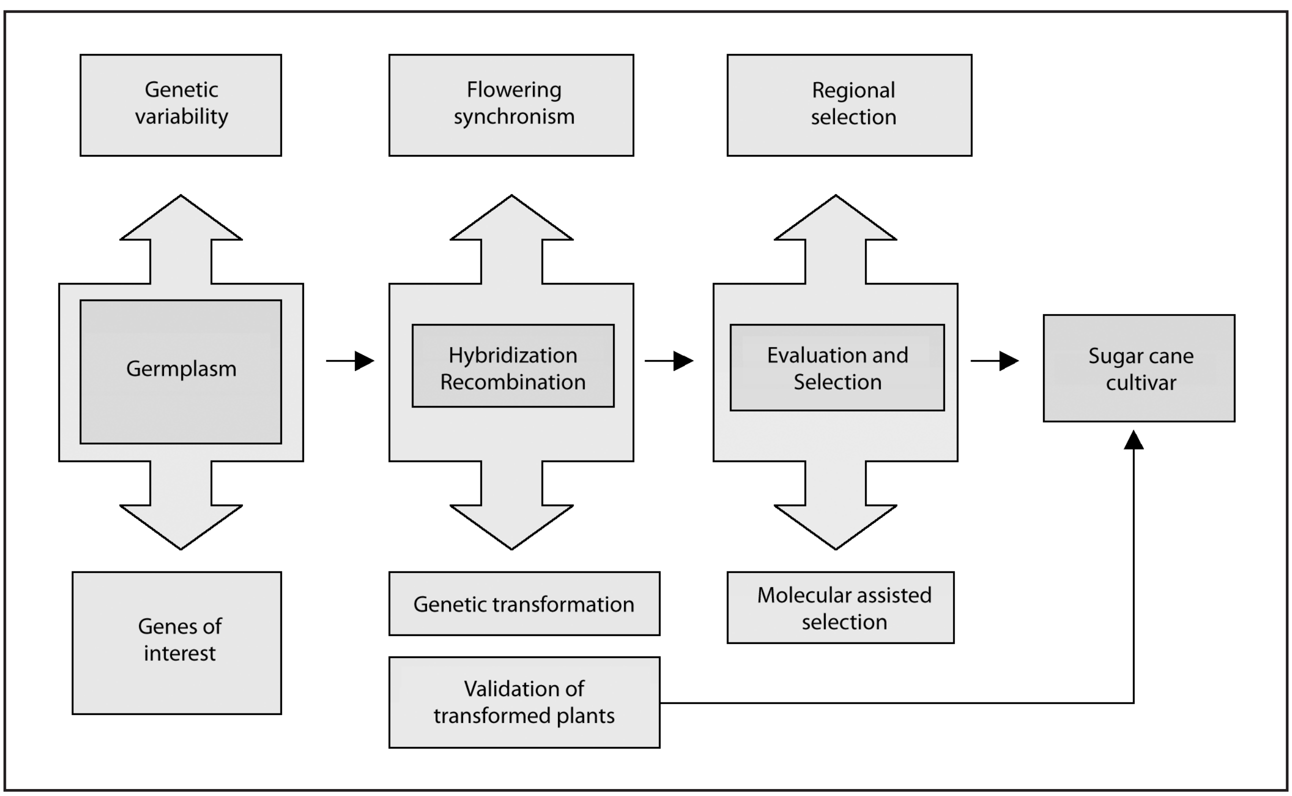

FIGURE 1 Developing process of a sugarcane cultivar and incorporation of molecular technologies.

variability through recombination (hybridization), and selection, that also includes the process of characterization of new clones. Both scenarios 1 and 2 go through these stages, although they have particularities concerning their critical requisites, since their main goals are different. Figure 1 shows a diagram of the developing process of a new cultivar, where critical steps that limit development are shown in red, as much as for conventional breeding or for biotechnology.

Critical stages for scenarios presented herein are:

1. characterization and use of germplasm;
2. regional selection strategies on expansion areas;
3. selection for drought tolerance;
4. molecular markers, genetic mapping and marker-assisted selection;
5. prospecting novel genes of interest for breeding and genetic transformation.

The identification of these stages drives the need for performing in depth basic studies in order to enable a diagnosis of the problem and identify solutions and areas of competence to solve the bottlenecks, ensuring the development of cultivars for both scenarios shown herein.

Critical system requirements – CSR

The development of sugarcane cultivars regarding to the scenarios mentioned above must meet a set of strategic goals in terms of:

- increase on biomass productivity;
- increase on sugar content (Pol%);
- increase on fiber content;
- increase of straw percent.

Sugarcane currently occupies an area of about 7.5 millions of ha. It is estimated that by 2020 the sugarcane plantation area will be at least twice as it is nowadays, and by 2025 it will probably reach an area of about 17 millions hectares. Crop expansion will occupy drought-prone areas where the main limitation is water deficit. Within this context, the development of drought tolerant cultivars, as well as their correct allocation on production environments, is imperative for increasing yield.

Current sugarcane productivity is about 81 t/ha and is predicted to reach nearly 98 t/ha in 2030 (Scenario 1). This average productivity is still much lower than the biological potential of sugarcane, and is and is limited mainly by severe drought, especially on fields managed for spring harvesting. Management strategies should be implemented to exploit *genotype x environment* to ensure optimize annual productivity.

Selection of new cultivars adapted to *cerrado* areas, is another important procedure when considering upland sugarcane cultivation, which is the most predominant type in Brazil. Sugar content (Pol%) of modern cultivars is about 15%, and it is predicted that this number may reach 16,5% in 2030, to attend demand of mills using conventional system for ethanol production (1st Scenario). So, for developing sugarcane destined for the 2nd Scenario, the main focus of genetic breeding is not sugar production, but higher content of fibers and biomass for electricity production (Energy Mills) and/or for cellulosic ethanol production. This would allow to achieve an increase of about twice of present biomass and fiber production within 20 years, starting from current 81 t/ha biomass and 12% fiber content to future 130 t/ha and 23%, respectively, or and additional 24 t/ha of trash as residues produced from cultivars with 17% or higher trash level (lamina and bundle sheath). This new situation will impact, undoubtedly, on the utilization of new sources of germplasm, different from the currently used by conventional breeding. In this case, a significant shift on the industrial profile of bioenergy cultivars will come about. Such transition period should take place during the next twenty years, as a result of current genetic breeding work.

Another interesting topic is the evolution of primary energy productivity on both scenarios. In the first one, if one projected gains of genetic breeding within the next two decades for cultivars with current non- bioenergy biotypes, it could be able to obtain gains of about 22%. On the second scenario, with the inclusion of new sources of germplasms, these gains are projected to reach up to 95.6%. Naturally, the velocity of scenario

TABLE 1 Critical System requirements (CSR) during the development of sugarcane cultivars under Scenarios 1 and 2, respectively.

CSR Scenario 1	Present (2010)	5 years (2015)	10 years (2020)	20 years (2030)
Culm biomass (t/ha)	81	83	89	98
Straw biomass (t/ha) – 14%	11.34	11.62	12.46	13.72
Total biomass (t/ha)	92.34	94.62	101.46	111.72
Sugar content (Pol%)	15	15	15.5	16.5
Fiber content	12	12	11.5	11
PE fiber (Giga Joules)	175	179.3	184.2	194
PE straw (Giga Joules)	204.1	209.2	224.3	247
PE sugar (Giga Joules)	201	205.9	228.1	267.3
Total PE (Giga Joules)	580.1	594.4	636.6	708.3
*Cost (RV)	100	96	80	69
**Energetic balance	8	9	12	14
Environmental impact	High/medium	Medium/low	Medium/low	Low

Note: estimates are based on upland cane.
* Referent to TCH (Pol and Fiber content are included on yield, since, in practice, they are associated to yield).
** Biofuel energy/invested fossil energy. PE: Primary energy.

CSR Scenario 2	Present (2010)	5 years (2015)	10 years (2020)	20 years (2030)
Culm biomass (t/ha)	81	91	111	130
Straw biomass (t/ha) – 17%	14	16	19	24
Total biomass (t/ha)	95	107	130	154
Sugar content (Pol%)	15	14	13	12
Fiber content	12	14	18	23
PE fiber (Giga Joules)	175	229.3	359.6	538.2
PE straw (Giga Joules)	252	288	342	432
PE sugar (Giga Joules)	201	210.7	238.6	257.9
PE total (Giga Joules)	627.9	728	940.2	1,228.1
*Cost	100	96	80	69
**Energetic balance	8	9	12	14
Environmental impacts	High/medium	Medium/low	Medium/low	Low

* Referent to TCH (Pol and Fiber content are included on yield, since, in practice, they are associated to yield).
** Biofuel energy/invested fossil energy. PE: Primary Energy.

two may be intensified or not, depending on the transformation dynamics of modern industry.

In relation to yield costs, we expect a decrease of about 31% within twenty years for both scenarios.

About environmental goals to be achieved by the yield component, it has to be pointed out that, generally, on qualitative terms (high, medium and low), both scenarios will change from a high/medium to a medium/low situation in twenty years. Elimination of sugarcane burning (predicted to the year of 2014) and, consequently the replacement with mechanical harvesting, will have a positive environmental impact, especially on the second scenario (production of biomass/cellulosic ethanol). In parallel, mechanical harvesting, together with the development of cultivars with better water and nutrients use efficiency will also contribute to preserve natural resources.

Major technology areas

On this section, a synthesis for each of the main technological areas from the Genetic Breeding and Biotechnology component is presented, in which scientific and technological developments are required to achieve the development of sugarcane cultivars for both scenarios.

Germplasm characterization and utilization

Germplasm is the base of all breeding programs, playing a key role in developing new cultivars. World sugarcane cultivation is based on few genotypes, which have intensively been intercrossed, originating hundreds of modern cultivars, determining a narrow genetic basis for this crop. Although some gains were achieved, the increase on productivity is each time more and more restricted, and increments that have been reached may no longer be sufficient to meet sugar and ethanol demand predicted for next decades. For this reason, it is imperative for sugarcane breeding programs to carry out strategies focusing on broadening the genetic base of sugarcane cultivars.

Genetic variability for sugarcane breeding relies on species of the so-called "*Saccharum* complex OR genus)", which includes *Saccharum officinarum*, *S. barberi*, *S. sinensis*, *S. spontaneum*, *S. robustum*, *S. edule* and genera *Narenga*, *Erianthus*, *Sclerostachya* and *Miscanthus.* Through recombination, it is possible to incorporate genetic variability from these genera on breeding programs, promoting a broadening of the genetic base. *Saccharum officinarum* and *S. spontaneum* are the main source of gene for breeding, whereas they were involved in sugarcane origin. *Saccharum spontaneum* represents the major species for breeding on Brazilian conditions, because it has a high biomass production potential, adaptation to several environments and tolerance to pests and diseases. Furthermore, genes can also be introduced from other species of *Saccharum* and related genera, through genic recombination (introgression) or genetic transformation. *Erianthus* shows high potential of producing biomass as a way to overcome restrictions from wild environments; therefore, it may have great potential for energy production. Recently, it has been confirmed the possibility of inter-crossings between *Erianthus* and *S. officinarum*.

A diagnosis of factors that has limited the utilization of new germplasms sources by sugarcane breeding programs identified the following bottlenecks:

- Low representativeness of species from the "*Saccharum* complex" on germplasms collections held by public institutions (IAC and RIDESA). In Brazil, collections well represented are kept by National private institutions (as is the case of CTC) and by multi national companies (i.e., MONSANTO), and therefore, have restricted access.
- Although there is a great variability inside the "*Saccharum* complex", there is little or no possibility of immediate use of new accessions in an introgression genetic program due to a deficient characterization of materials maintained on the collections. Therefore, genetic variability present on germplasm collections is not exploited for generation of new cultivars.
- The major limitation of an introgression program is the loss on the genetic potential of the material.

- Sugarcane germplasm collections have a relatively high maintenance cost, since they are kept in field. Moreover, many accessions show problems with adaptability, and are vulnerable to a series of biotic and abiotic stresses. Thus, it has been proposed that public programs should join efforts to establish a public germplasm collection, representative of genetic variability existing on the "*Saccharum* complex". Also, they must establish a program of wide characterization of accessions that they already have, using a robust system where it will be possible to integrate molecular, phenotypic and morphological data. *In vitro* sugarcane germplasm conservation must have special attention, ensuring the replacement of materials that may get wasted on field collections. Molecular markers also have huge potential to make viable the germplasm characterization as well as a program of genetic introgression, because both of them allow breeders to seek entire genic blocks, as well as providing faster gains. However, there is a need to invest on high performance genotyping systems (*high throughput*), substituting obsoletes genotyping systems used mainly by public Brazilian sugarcane breeding programs.

Other relevant issue on the development of sugarcane cultivars refers to the behavior that the genotypes face to major diseases. There is a lack of basic studies on pathogens heritage, as well as development of diagnosis systems that may be routinely applied by breeders. Therefore, we reinforce the need for investing on the characterization and evaluation of germplasms, along with the major sugarcane diseases (brown rust, orange rust, leaf scald, ratoon stunting disease, mosaic leaf virus, sugarcane yellow leaf virus). And also secondary diseases that may end up shifting to primary diseases, due to the mechanization trend in planting and harvesting system (pineapple rot and Fusarium, among others). Molecular markers and prospection of resistance genes are valuable tools to elucidate these themes.

Regional selection strategies on expanding areas

Areas for expansion of sugarcane cultivation in Brazil are generally "cerrado" (savannah) areas (west and northwest of São Paulo, South of Minas Gerais, eastern Mato Grosso do Sul, north and south of Goiás, Tocantins, south of Maranhão and western Bahia). Although these areas are located in latitudes similar to each other, all of them show special particularities when compared to areas traditionally occupied by this crop. In such regions, many contrasts are observed, for instance, remarkable differences concerning vegetative growth, flowering, sucrose accumulation and responses to pests and diseases, as well as an extremely high water deficit. Sugarcane genetic breeding programs have adopted specific strategies for the obtainment of cultivars adapted to these new production environments, re-directing hybridization and selection processes, and implementing regional experimental stations for selecting more adapted cultivars. Cultivars called as eclectic or as having higher stability must be left out in benefit of specific-adapted regional cultivars, as sugarcane growers have access to new technologies.

In order to have an effective impact of such strategies on the development of new cultivars, some priorities have been pointed out, such as:

- The need for a characterization of natural variability, integrating other areas of knowledge, specially pedology, mineral nutrition, geo-statistics and climatology.
- Analysis of phenotype stability from a group of varietal competition essays. Such procedure is essential for the characterization and regional selection of new cultivars and environments.
- For traits related to yield, an important aspect on regional selection concerns the choice of yield-related traits in "cerrado". For example, tolerance to drought can be expressed by the rationing ability, lower loss of culm's weight and absence of flowering. These traits are considered of strategic importance under such conditions.
- For new areas, there is a need to perform a regional selection work, including the utili-

zation in the hybridization phase of germplasm more adapted to restrictive conditions. Therefore, it is necessary to develop numerous studies to investigate tolerance mechanisms present on high-performance genotypes in restrictive environments and also to identify others that may be incorporated on future materials. There is a wide genetic variability in sugarcane in relation to water deficit response. This variability is an important tool for the development of new tolerant genotypes and can be amplified with the inclusion of other species or genera on sugarcane germplasm.

- It is possible to obtain selection gains through better characterization of parents adapted to specific regions, and regional allocation of populations generated from these planned crosses until their final selection and characterization as a regional cultivar. Generally, cultivar allocation has been performed in an inefficient way, due to an incorrect utilization by growers of the characterizations generated by breeding programs.
- One area of future effective contribution will be the development of molecular markers to allow a better selection of superior genotypes for traits that show important interaction, allowing the allocation of genotypes in a specific environment.

Selection for drought tolerance

Tolerance to drought is defined as the ability to minimize losses on production in a water-deficient soil. In plants, mechanisms that lead to tolerance to drought may be divided in two main groups: Escape and tolerance mechanisms. Escape (or avoiding) mechanisms allow plants to avoid losing water on tissues during drought conditions through the maintenance of cell pressure and volume, whether it is by absorbing water using a more abundant root system, or by a reduction on non-stomata's transpiration rates such as leaf cuticle. Tolerance mechanisms enable plants to keep their metabolism even under the same low soil water potential, especially due to an osmotic adjustment and an antioxidant capacity. Drought escaping mechanisms involve complex alterations on development that require temporal and spatial regulation due to drastic changes that they may cause on plant's metabolism. Therefore, drought tolerance mechanisms are more desirable to plant genetic breeding than escape mechanisms. Although all the advances obtained through conventional breeding, the lack of genetic, molecular and physiologic information on drought tolerance mechanisms as well as their heritage, are all limiting factors for a greater success in generating better cultivars.

Thus, strategies for selecting sugarcane genotypes tolerant to drought have been proposed, such as:

- Promoting the selection of new genotypes in environmental drought-prone areas, characterized by having a serious drought period during the year (that is, to promote selection where this problem occurs).
- Intensifying experimentation (e.g. increase number of repetitions and plot size; use subdivided plots to minimize local effect), when essays are designed for selecting drought-tolerant materials, whereas environment variations under drought condition (mainly from soils), tend to impact negatively on heritability and repeatability from each cycle.
- Intensifying molecular characterization, setting associations between genotypes and phenotypes, so that the possibility of predicting phenotypic performance from genetic information can be exploited during selection. Establishing genetic mapping programs associated to conventional breeding may also lead to the identification and manipulation of genes involved in responses to drought. In addition, prospection of genes of interest to sugarcane breeding (tolerance to drought, sucrose accumulation, lignin biosynthesis etc), must be intensified.
- Exploring the genetic information existing in Sorghum (*Sorghum bicolor*), consider-

ing that it is a model plant, with a complete sequenced diploid genome, and within all the grasses, it is the closest relative to sugarcane (84% homology between genomes). Moreover, it is a drought-tolerant plant, and may be used as a link to many interest traits of genetic breeding.

Molecular markers, genetic mapping and molecular marker assisted selection

The utilization of molecular markers, especially functional markers, may enable the utilization of a fast and efficient technology that would permit a previous selection of seedlings before taking them to the field, known as marker assisted selection – MAS. MAS represents the main contribution of molecular markers on genetic breeding, considering that they promote an increase on selection efficiency as well as reducing costs in a breeding program. As a pre-requisite for MAS it is necessary the existence of an intensive genetic mapping program. However, MAS is not a reality in sugarcane yet, although there are many articles on the identification of molecular markers associated to qualitative and quantitative traits. Major bottlenecks concerning the use of MAS are:

- Speed of analysis (genotyping) used by current systems is too slow.
- There is a need to identify not only one marker, but also the individual haplotype, which will verify the presence of traits of interest in genotyped individuals. Individuals selected by having the marker could then be taken for field evaluations through assisted selection. However, this strategy must involves fast genotyping of thousands of individuals, and would be crucial the use of high-throughput sequencing technology, capable of generating huge quantity of information.
- Sugarcane mapping usually makes use of F1 populations (derived from crossings between two parents) where marker's linkage phase is not known. In comparison to other species, on sugarcane genetic mapping just a part of the data is used for analysis (genome sampling) where only single-dose markers are used and fitted in actual theoretical models.
- Ligation tests between markers are impaired by the enlargement of the distance between marks, what causes the loss of many existing ligations, which are not statistically detected.
- ESTs-based markers must be prioritized, because even that map position cannot be correctly estimated, these markers show higher probability of being linked to an interest QTL.
- To perform assisted selection it is necessary to know the linkage phases among markers and especially among QTLs. It is also needed to study the interaction between *QTL x environment* and the correlation among traits, and also how to verify if the correlation is due to ligation or pleiotropy and how to predict breeding values.
- On current sugarcane scenario, there is little development of theoretical models for the identification of QTLs, and it is such a complex issue considering the need for estimating linkage phases between markers and QTLs. Generally, models are adapted to accommodate them in more ordinary software.
- Association mapping in sugarcane seems to be a very interesting alternative, although it answers to different questions than those raised when using mapping populations.
- The development of sugarcane's genetic mappings anchored on sorghum's genetic or physic maps will allow for a direct utilization of information about genes derived from sorghum's genome complete sequencing on sugarcane breeding.
- Sequencing not only of the expressed sequences, but getting a draft of the complete sugarcane genome through high-throughput sequencing will provide a better comprehension of the complex polyploidy nature of this crop and will also help on the development of biotechnological systems capable of optimizing genetic breeding.

Therefore, it is necessary to establish multidisciplinary teams for these topics, having in mind the complexity of such themes and the existing volume of information. There is also a need for investment on genetic mapping programs as well as on the development of software more appropriately designed to analyze sugarcane data.

In conclusion, it is strategically very important for Brazil to be a world reference country not only about sugarcane production, but also on biotechnology research; and for this the country needs the support from universities and public research institutes. Although having a leading position in sugarcane genomics, this could be threatened by the great interest that foreign biotechnology companies have on bioenergy and in the establishment of many bioenergy centers on biomass research, including sugarcane such as EBI in the United States.

Genetic transformation and prospective interest on breeding genes

Significant gains on sugarcane yield were achieved through conventional genetic breeding. However, increases on sugar levels did not occur as the same proportion, indicating that the genetic base used for crossings is not broad enough for this trait. A similar scenario would make viable the development of a genetically-modified plant that overpasses the limits of gains obtained through conventional breeding.

Innovative processes, such as biotechnology, would allow much greater gains, never reached through crossings before as the barrier of sexual compatibility is broken by this kind of technology; and virtually any kind of living organism is capable of supplying interest genes for breeding.

There is a well-established and very efficient sugarcane transformation process that is based on biobalistics. Nevertheless, this system has some limitations, e.g. the insertion of high number of copies of a gene of interest. It becomes necessary to improve the transformation system, as well as implementing new technologies as the *Agrobacterium*-mediated transformation technique, which offers some advantages as a lesser number of copies and a more precise insertion of the transgene.

Add to the development of methodologies for obtaining sugarcane transgenic plants, it is important to seek promoters that show stability of expression, since gene silencing is very frequent on this plant. Basic studies and development of strategies to avoid transgene silencing are of great relevance for successfully applying biotechnology techniques in sugarcane.

The development of commercial transgenic sugarcane is impaired because each transformation event obtained must be individually deregulated. In genetically-simpler crops (soybean and maize, for instance) sexual propagation, trait (or transgene) is transferred to the interest cultivar through crossings, not being necessary a new deregulation of this cultivar. For genetically-complex species, as sugarcane, transference of interest traits through crossings is unviable, since the probability of recovering an initial genotype is nearly zero. Thus, it is necessary to come up with an especial deregulation process that reflects individual features of this important crop. A second commercial sugarcane variety with the same interest feature of another already deregulated, should be submitted to a simplified regulatory process analysis that contemplate only the genetic characterization of GMOs.

Thus, factors that interfere on genetic transformation of sugarcane were discussed and the major aspects pointed out were:

- The use of genetic engineered cultivars presents a great challenge for breeding programs, even though they still have a great opportunity for the obtainment of more efficient and sustainable agriculture.
- The need to improve sugarcane transformation techniques (regeneration, evaluation of event number etc.) as well as the promoter cloning process and the execution of an evaluation of the risks.
- Transformation through biobalistics usually shows high efficiency, however, it needs to be improved to minimize copy number insertion.
- In parallel, it becomes necessary to develop an *Agrobacterium*-mediated transformation protocol in order to increase available

options for obtaining sugarcane transgenic plants.
- Perform basic research on sugarcane gene silencing in order to get a better understanding of the process and try to establish strategies to avoid this problem.
- Invest on GMO development, making advantageous use of public-domain genes as well as using strategies to unravel new genes.
- Make efforts to enact a specific legislation for sugarcane regarding to GMOs, since it is a vegetative-propagated species and deserves special treatment to make economically viable the release of different cultivars with the same interest gene.
- To invest in studies focusing on prospection of genes of interest for genetic breeding, based on high-throughput technologies, capable of generating large quantity of data.
- To establish multi-disciplinary teams, integrated into breeding programs.

TECHNOLOGY DRIVERS

Critical requirements of the system presented on section Critical system requirements – CSR were transferred to technological conductors for each of the main technological areas (characterization and use of germplasm; strategies for regional selection in expansion areas; selection for drought tolerance; molecular markers, genetic mapping and marker-assisted selection; prospection of interest genes for breeding and genetic transformation), identified on section Major technology areas. Goals were presented for each of the technological conductors, and they were referenced to critical requirements of the system that the product or technology must have (see Tables 2 – 4).

The development of more efficient conventional breeding methods, will propitiate an increase on yield and sucrose content. Efficient technologies of inoculation and evaluation of response to important diseases, such as smut, mosaic leaf virus, leaf scald, brow rust, orange rust and sugarcane yellow leaf virus as well as exotic diseases (Fiji, Sereh etc.) are fundamental to ensure yield. In the same way, it is also needed a better comprehension of genetic heritage of these diseases in order to define selection strategies.

For the development of cultivars focused on a greater fiber content (scenario 2), studies on the characterization of cell wall components, evaluation of fiber quality and allied to the quantification of genetic variability of germplasm available for such traits, are of major importance. Such studies could identify the most suitable type of biomass for 2nd generation ethanol.

The adoption of a quick analysis system for fiber content through NIR (*Near infra-red*) technologies will allow for a correct and efficient selection of seedlings.

The development of genetically modified cultivars that contain genes promoting enzymatic hydrolysis would permit a faster and lower-cost fiber processing. Biotechnology must contribute to fiber quality (composition) which may be altered through the manipulation cell wall composition genes (celluloses, hemi-celluloses etc.).

Conventional genetic breeding may have its efficiency increased through the incorporation of molecular markers (marker assisted selection). Moreover, it is imperative to reiterate that both scenarios will become reality only if investment on R&D is given priority.

GAPS AND BARRIERS

This section identifies current and future gaps, and barriers on technological conductors of the section Technology drivers. Thus, we present herein abilities and knowledge that, both breeding and biotechnology programs must be able to develop and implement, to develop new cultivars. Thus, one can indicate strategic decisions that should be taken by the government concerning generation of new knowledge:

- There is a deficiency in raw material (germplasm) used for genetic breeding. Thus, it is necessary to incentive the introduction and characterization of germplasm, as well as promoting the evaluation of natural resources available to traits that are of

TABLE 2 Technology drivers of CSR yield (To simplify, Pol requisite and fiber content were incorporated on yield).

	Yield (TCH) Scenario 1	**Present**	**5 years**	**10 years**	**20 years (Vision)**
CSR	Biomass production	79	83	89	98
	Content sugar (Pol%)	15	15	15.5	16.5
	Content fiber	12	12	11.5	11
Technology area	Characterization and use of germplasm				
Indicator	*Use level*	Low	Medium	Medium/ high	High
Technology area	Strategies for regional selection in expansion areas				
Indicator	*Gains in terms of productivity (%)*	0	5	12	20
Technology area	Selection for drought tolerance				
Indicator	*Gains in terms of productivity (%)*	0	8	18	25
Technology area	Prospection of interest genes for breeding and genetic transformation				
Indicator	*Cultivated area with transgenic cultivars (%)*	0	3	10	40

	Productivity (TCH) Scenario 2	**Present**	**5 years**	**10 years**	**20 years (Vision)**
CSR	Biomass production	79	91.3	111.25	130.34
	Content sugar (Pol%)	15	14	13	12
	Content fiber	12	14	18	23
Technology area	Characterization and use of germplasm				
Indicator	Fiber quality evaluation	Low	Medium	Medium/ high	High
Technology area	Strategies for regional selection in expansion areas				
Indicator	*Gains in terms of productivity (%)*	0	5	10	15
Technology area	Selection for drought tolerance				
Indicator	*Gains in terms of productivity (%)*	0	8	15	40
Technology area	Prospection of interest genes for breeding and genetic transformation				
Indicator	*Cultivated area with transgenic cultivars (%)*	0	1	5	20

Obs.: actually, it is expected that the development of indicators for common areas are similar. In the case of fiber cane, the use of wild germplasm will possibly confer to the new clones a higher yield potential in drought-prone lands.

greatest interest for traditional breeding (Scenario 1) or for biomass (Scenario 2), ending up with an evaluation of responses against major diseases.

- There is a lack of interest among breeding groups to share genetic material. Also, public programs are in a disadvantageous situation concerning the availability of genetic resources. Thus, it would be interesting to establish a public use germplasm collection, as well as sharing germplasm in non-competitive phases among breeding programs.
- There is also a lack of training of human resource on the different approached areas.

TABLE 3 Technology drivers of CSR "cost".

CSR	Cost Scenario 1	Present	5 years	10 years	20 years (Vision)
Technology area	Characterization and use of germplasm				
Indicator	*Cost (reference = 1)*	1	1	0.85	0.75
Technology area	Strategies for regional selection in expansion areas				
Indicator	*Cost (reference = 1)*	1	0.95	0.85	0.75
Technology area	Selection for drought tolerance				
Indicator	*Cost (reference = 1)*	1	0.90	0.80	0.65
Technology area	Prospection of interest genes for breeding and genetic transformation				
Indicator	*Cost (reference = 1)*	1	0.8	0.50	0.10

CSR	Cost (US$/t) Scenario 2	Present	5 years	10 years	20 years (Vision)
Technology area	Characterization and use of germplasm				
Indicator	*Cost (reference = 1)*	1	1	0.85	0.75
Technology area	Strategies for regional selection in expansion areas				
Indicator	*Cost (reference = 1)*	1	0.95	0.85	0.75
Technology area	Selection for drought tolerance				
Indicator	*Cost (reference = 1)*	1	0.90	0.70	0.50
Technology area	Prospection of interest genes for breeding and genetic transformation				
Indicator	*Cost (reference = 1)*	1	0.8	0.50	0.10

- Although a large number of labs carry out research in sugarcane biotechnology, there is a lack of cooperation among groups and also a connection among basic and applied research (genetic breeding).
- Although breeding programs have incorporated molecular markers for numerous purposes, it is necessary to use more efficient genotyping systems, so that Brazil can effectively implement breeding through marker assisted selection.
- There is also a shortage of human resources and infrastructure in research labs and experimental stations in public programs.
- There is a lack of suitable software for genetic analysis in polyploids. Models currently utilized in sugarcane were developed for diploid species, and show little efficiency in sugarcane. Investment on the development of specific software for polyploids should bring major advances on the comprehension of sugarcane genetics.

FINAL CONSIDERATIONS

Brazilian sugarcane breeding programs play a key role on the establishment of a new energy matrix derived from sugarcane, considering that they are responsible for the development of cultivars, which consists in the major technological input to energy generation. This way, it is necessary to re-orientate processes involved in breeding,

TABLE 4 Technology drivers of CSR "environment".

CSR	Environmental impacts Scenario 1	Present	5 years	10 years	20 years (Vision)
Technology area	Strategies for regional selection in expansion areas				
Indicator	*Reduction of inputs (%)*	1	0.90	0.85	0.80
Technology area	Selection for drought tolerance				
Indicator	*Water use efficiency (%)*	1	0.87	0.77	0.68
Technology area	Prospection of interest genes for breeding and genetic transformation				
Indicator	*Reduction of inputs (1)*	1	1	0.90	0.60

RCS	Environmental impacts Scenario 2	Present	5 years	10 years	20 years (Vision)
Technology area	Strategies for regional selection in expansion areas				
Indicator	*Reduction of inputs (%)*	1	0.90	0.80	0.70
Technology area	Selection for drought tolerance				
Indicator	*Water use efficiency (%)*	1	0.95	0.68	0.50
Technology area	Prospection of interest genes for breeding and genetic transformation				
Indicator	*Reduction of inputs (1)*	1	1	0.90	0.60

as well as the implementation of adequate and efficient tools.

The use of new germplasm sources constitute one of the major bottlenecks on the development of biomass cultivars, emphasized by the low representativeness of species with high potential for bioenergy in germplasms collections from public programs, as well as by the precarious characterization of accesses maintained on germplasm collection from different Brazilian programs. Also, for traditional breeding, where main focuses are sugar-rich cultivars, a narrow genetic base derived from the low number of clones used for breeding, has been a limiting factor for the increase on sugar content in modern cultivars. The implementation of a parallel genetic introgression program, making use of new sources of germplasm for sugar, fiber, biomass, biotic and abiotic stresses, will definitively bring a major contribution to increases yield, ensuring a more sustainable cultivation of sugarcane in Brazil. In conventional breeding, we must seek for the development of new selection methods and strategies that explore genetic variability on genetic breeding programs.

Resistance to diseases is the chosen method to control most of sugarcane pathogens, and is considered as an elemental trait on the development of new varieties, but has been superficially broached by Brazilian programs. Thus, it is imperative to emphasize the development of methodologies more efficient to inoculate and evaluate responses against important diseases such as smut, mosaic, leaf scald, rust and yellow leaf as well as other exotic diseases (Fiji, Sereh).

Biotechnology offers important tools for breeding programs, whereas molecular markers have been usefully utilized to the determination of the genetic distance between genitors, germplasm characterization (identifying accesses of interest for breeding), besides enabling a speed up on time for developing new cultivars and allowing the selection of genes of interest for a genetic introgression progress. However, systems currently used by Brazilian breeding programs, mainly public, are obsolete and little productive requiring a lot of work and workforce. There is a necessity to incorporate more efficient genotyping systems, capable of generating large amounts of data in a shorter period of time. In addition, statistical methods for analyzing molecular data also show bottlenecks that need to be overcome, since they were developed for diploid species. Therefore, investment on software development for molecular data analyses are required together with the training of human resources.

Transgeny provides a promising strategy either to broaden genetic variability of sugarcane, or to introduce traits of interest. However, transformation techniques have some limitations that need to be overcome. Thus, investment is necessary on the development of a efficient system for sugarcane genetic transformation, in order to make transgenic breeding feasible. It is also needed to reduce technological dependence that is controlled multinational companies (e.g. through patents and royalties). For all of these reasons, we must prioritize the unraveling of new genes, as well as making good use of those from the public domain. Finally, it is necessary to introduce specific legislation for genetically modified sugarcane.

4

TRM:

AGRICULTURE COMPONENT

Paulo Sérgio Graziano Magalhães and *Oscar A. Braunbeck*

INTRODUCTION

Agricultural cultivation of sugarcane includes planting, crop treatments, the alternative mechanization for planting, harvesting and hauling, the recovery of the straw, and the agricultural management. With the perspective of the increase of cultivated area of sugarcane, a lot of alterations should happen in the agricultural sector. The expectation is that sugarcane burning will complete stops and green harvester will reach 100%, at least in the areas where mechanization is feasible, in the first stage (2015) and later in the whole area (2025). That will force the complete mechanization of sugarcane cultivation. New equipments for sugarcane harvesting is today in development and the perspective are that in 2015 they will be in use in experimental areas shifting some paradigms of sugarcane planting, harvesting, loading and hauling. It is expected that great part of the area planted with sugarcane in 2025 will uses this new mechanization concept that reduces drastically the negative impacts on the soil caused by the conventional system of cultivation.

TECHNOLOGICAL NEEDS AND CAPABILITIES

Products or technologies targeted

For better understanding of the text was divided in three parts, Planting, Harvesting and Straw Recovery. The Management of the agricultural component, as presented by Arraes *et al.* in the Chapter 15, Part 3, has been presenting enough technological production, lacking of access conditions, mainly to the mills of smaller economical capacity. The usage of advanced Information and Communication Technology (ICT) systems and formal management models in agriculture is much more harnessed to the mill organization background than to the technology availability, for this reason it is not presented here as being a technological demand.

Sugarcane planting

Sugarcane mechanization process begins with the planting. Today it is accomplished in the traditional way involving three stages. First, seedbed preparation, which often includes one or two passes by offset discs to cut up and incorporate the old crop, one pass of a subsoiler to eliminate compacted inter-row areas, another offset disking and a final open furrow implement before planting the next crop. Secondly, sugarcane harvesting in a different place for stem cutting which is the most common reproduction method. Each cutting must contain at least one bud and the cuttings are sometimes hand-planted, but billet planting is becoming common, since new equipments for sugarcane planting are turning available. The last operation consists of fertilizer distribution and furrow covering.

As mentioned in the previous chapters this process include too many operations and resulting in high cost, and its usefulness has been questioned, since its practices is not been justified through an increase in yield. To improve the sustainability of the system guaranteeing the increase in yield, reducing the production cost and the negative environmental impacts caused by the sugarcane production the planting system should be modified, and for this it will be necessary to invest in basic and technological research.

Two no competitive technological alternatives, which can contribute to reach the expected benefits, are presented.

Direct planting

Conservation agriculture (CA), which aims for zero tillage with the maintenance of a surface mulch to protect the soil surface and increase biological activity in the topsoil, is increasingly becoming recognized as an effective system of crop production that protects the soil from erosion while reducing the overall use of agrochemicals (Landers, 2005). Broadly employed in the production of cereals, no tillage as a cultivation method bringing economical and mainly environmental benefits, this cultivation technique is barely explored in the sugarcane production.

In this system the physical conditioning of the soil through intense and deep tillage to receive the bud of the sugarcane is replace by the preparation in rows, avoiding unnecessary disturbances and preserving the soil structure, always maintaining it covered with straw mulch. The biological activity, the incorporation of organic matter decomposition, the permanence of the roots of previous cycles and the reduction of the traffic is capable to maintain the soil in adequate conditions for a new crop with drastic reductions of the erosion, and production costs and increases water availability. In fact, the zero tillage system (ZT) is not simply a new technology, it represents a new philosophy, with a series of new basic values, that constitute a system of sustainable agriculture (Landers, 2005).

As described by several authors that studied the effects of ZT comparing with conventional tillage, ZT favours the formation of larger diameter soil aggregates, smaller disaggregation of the soil, larger water retention, larger rates of water infiltration, reduction in thermal soil flotation, and water economy also is improved since mulch reduces evaporation. Besides, the ZT provides reduction in the number of operations, personnel's available time and involved equipments, reducing the costs in approximately 47% in comparison with the conventional tillage and it can still contribute to increase the productivity (Sørensen and Nielsen, 2005).

The adoption of ZT in the cultivation of the sugarcane is theoretically possible, but for its implementation and complete adoption by growers it still depends on basic researches which must accomplish.

Technological bottleneck. The three main principles CA technique are: direct planting of crop seeds; permanent organic soil cover; and crop rotation. According to Landres (2005) the largest threat to the sustainability of CA is the no adoption of crop rotation for breakdown the cycles of pests, diseases, and weeds and the generation of appropriate amounts of mulch, or to increase the level of organic matter in the soil, promoting biological controls and reducing agricultural chemical use and costs of production.

Of these three factors the maintenance of the soil covering is not a technological problem, because the amount of trash generated during the process of harvesting green sugarcane is enough to guarantee the covering in appropriate levels to the practice.

The other two factors still need studies and technological development that allow the definitive implementation of CA for sugarcane. In the mechanization system for sugarcane, the traffic at each harvest is intense. The system uses heavy vehicles crossing a high percentage of the area, inducing in most of the cases to soil compaction in levels non favourable to plant root development. In this way the adoption of the ZT or any other CA system needs forcible to go through the alteration of the mechanization system, forcing the adoption of a traffic control system for the reduction of soil compaction.

The sugarcane is a semi-perennial crop, planted in rows spaced from 1.1 up to 1.5 m. The crop grows for 12-18 months before mechanical harvesting by the first time by cutting stalks at ground level. A ratoon crop regrows and is again mechanically harvested after a period of 12 months. Several harvests are taken from the initial planting, thus a crop cycle consists of a plant crop and on average five ratoon crops, cut annually. In this system the adoption of a CA has raised some concern regarding to soil-borne disease carry-over. Therefore studies of alternative systems of crop rotation and methods of natural control of pests and soil diseases should be led, relating the effect of the trash and of the new species in the new agriculture ecosystem formed by the technique of CA, in the soil pests and in the natural enemies and present entomopathogen.

Billet planting, seedlings, or pre-germinated plant

Although sugarcane produces seeds, stem cutting is the most common reproduction method. The stem is cut in billets with at least 3 buds each. The billet serves as energy reservation for the bud, guaranteed its emerging and nutrition until the development of the roots. In this system it is necessary to used between 4 to 12 $t.ha^{-1}$ of sugarcane billets[1] depending on the variety and planting method.

Technological bottleneck. The equipments used for the mechanical planting of sugarcane present low technological development. They are not capable to accomplish the necessary billets dosage control and there is lack of spacing uniformity, forcing to use larger density of buds for linear meter of furrow. In mechanical planting among 8 to 12 $t.ha^{-1}$ of billets are used, Janini (2008).

To solve the problem two alternatives can be investigate technically:

a) Improvements in the sugarcane planter, with the objective to incorporate new technology similar to the ones existent for cereals, where the seeds distribution control is accomplished accurately not only of the amount but the spacing as well, guaranteeing an uniform stand of the crop.
b) The planting system could be modified, based in two hypotheses: first that the sugarcane can grow starting from only one bud, and then it is possible to develop technology that allows to plant one bud instead of 3. The other hypothesis is that it is possible to develop the sugarcane plantation starting from cane seedlings.

New planting machines will be necessary in these systems that will also force the technological investment in this area.

Harvest

Sugarcane harvest in the current and expansion areas will be fully mechanized in the near future, just leaving the semi-automatic harvest for steepness areas and with difficult access. Sugarcane burning as a cleaning pre-harvest process should also be completely abolished.

Technological bottleneck. The harvesters available today in the market as well as the planters, present low technological index and new investments should be accomplished to improve their performance. These harvesters do not dispose, for instance, of efficient control system for base cut height control, that needs to be solved to avoid the excess of soil movement, as well as monitoring the losses, or the degree of vegetable extraneous matter that is taken within the load. Harvesters just harvest a single row at the time. The result is that each inter-row is trafficked twice by the harvester and at least twice by the tractor and the infield wagon. The equipment track widths are not standardized and it frequently mismatches crop row spacing practiced in the sugarcane. The outcome is that traffic traverses very close to the crop row, which can lead to knockdown of stalks, and traffic can also directly run over rows damaging the ratoons and resulting in yield loss.

Another challenge to be overcome by the mechanized harvest is its operational limitation in steepness areas above 12%; the support equipments, tractors and wagons, don not have that limitation, due to the possibility of track width adjustment. To reach 100% of sugarcane harvest mechanization, it is necessary to produce equipments capable to operate in steepness areas.

[1] Around 8 to 15 buds per linear meter.

The alternative of producing a cane with larger fibber percentage, the "energy cane" with up to 23% of fibber, will demand alterations in the design of the existent harvesters. The base cut system, feeding, cleaning and load transfer, today presents in the harvesters are adapted to harvest sugarcane with fibber percentage between 11 and 14%, alterations of this range will implicate in reduction of the operational capacity, increase of the total losses (visible and invisible) and reduction in the capacity of cleaning, consequently cost increase.

Straw recovery

The technology of billet harvest, now available, does not use the straw, which is burned or left over the soil depending on the crop system employed (burned or green). One of the principal challenges to make possible the use of this material is the development of a mechanical system of harvest that contemplates the recovery of the straw, at least partially, with cost and quality that make possible its energy use.

Technological bottleneck. The processes for straw recovery tested up to now have three alternatives. Alternative 1 involves the sun drying, followed by windrowing and bailing or chopped into small pieces transported to the mill and shredded. The windrowing process is responsible for the high amount of mineral extraneous matter in the recovered trash. The cost of the recovery of the trash overcomes 10 US$/t. The second alternative is denominated "integral crop harvest", because the cleaning system available in the harvester are turned off so that the billets, the straw and part of the tops are delivered by the harvester to the infield wagon, for later be separate in the mill, using a dry cleaning station. This second method, a little more economical, has its use limited by the distance from the agricultural area to the mill, because it increases the transportation cost due to the low density of the transported biomass. Another difficulty of this system is the lack of equipments that make dry cleaning an efficient process, with acceptable losses of row material. An alternative (Alternative 3), derived of the integral crop harvest is the part cleaning, which is obtained reducing the harvester cleaning efficiency. Consequently the amount of recovered straw decreases, but the load density transported to the mill increases. Table 1 presents the cost of recovery of straw as function of the system adopted.

It is observed, therefore the need for new withdrawal methods propose to assist the qualitative needs for the use of the straw as source of energy.

Figure 1 synthesizes the possible alternatives for the field management.

Critical system requirements (CSR)

Having defined the products and technologies that are the targets of roadmapping, the purpose of this section is to identify the critical qualities called critical system requirements (CSR). Here are identified the functional requirements and performance, featuring high-level dimensions to

TABLE 1 Straw recover cost (US$/t).

	Alternative 1	Alternative 2	Alternative 3
Straw at the mill*	9.61	23.23	2.74
Trash separation from cane	–	2.79	3.69
Trash processing	0.89	0.85	1.14
Total cost	**10.50**	**26.87**	**7.57**

* For alternative 1 following operations are included: windrowing, bailing, loading/unloading and transportation. For integral crop the operations are: internal transport (wagon) and transport to the mill (trucks).

Source: PROJECT BRA/96/G31, adapted from BRAUNBECK and ALBRECHT, Chapter 15, Part 3.

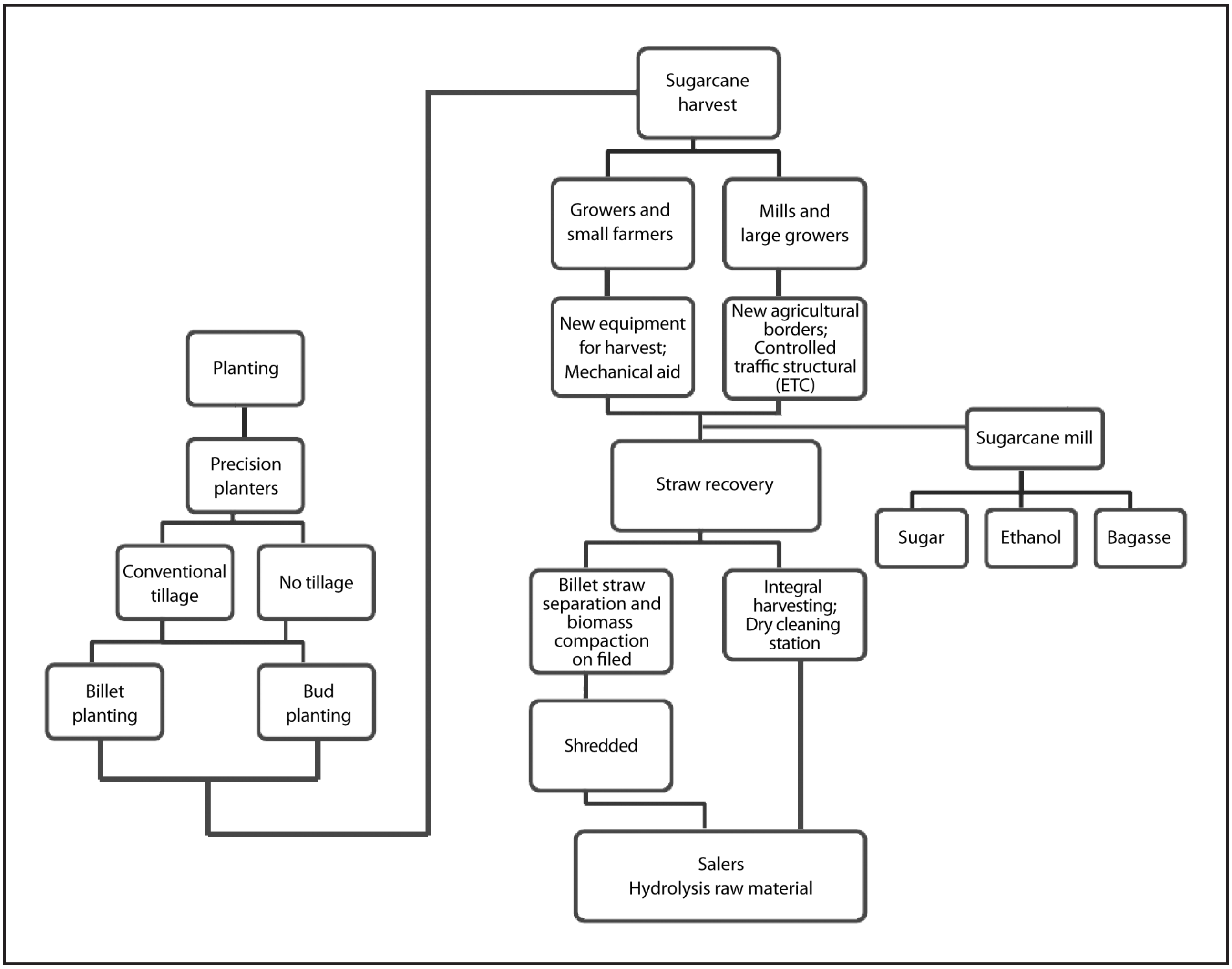

FIGURE 1 Alternative routes for sugarcane.

which the field management is related, as well as their goals over time in order to meet a set of strategic goals in terms of:

- productivity;
- cost;
- consumption of natural resources and energy balance ratio (EE/EU and GHG emissions).

In what it concerns to the agricultural sector productivity as a whole, the field management is here considered in terms of its contribution for the increase of the biomass recovery per hectare, starting in the actual of 81 t.ha^{-1} (stalks only) to reach 150 t.ha^{-1} (stalks and straw) in 20 years.

For the cost requirement, it is observed that the cost of biomass production is around US$ 22 to U$ 27[2] per ton depending on the area and it will, in the next 20 years, with the technology application, be reduced by 30%.

The environmental goals should be reached by the field management in terms of preservation of the environment, they should include the reduction of the negative impacts caused by the intensive soil preparation, reduction of the soil compaction and better use of the biomass produced for energy ends or preservation of the soil and water, and carbon recovery.

[2] The data are from a study realized by Escola Superior de Agricultura Luís de Queiroz (Esalq), and presented in (28/5/2009), during a national commission for sugar cane meeting of Brazilian Confederation of Agriculture and Cattle Breading (CNA).

A sustainable approach for agriculture demands a system that are not only environmentally friend, but also economically viable and socially responsible, Landers (2007). Important allies for such approach include the growers that adopt conservation systems and also governments and societies that support these growers. It is important to point out that in the agriculture the reduction of production cost means reduction in the final price to the consumer. Therefore the adoption of CA contributes not only for the conservation of the environment, but also with the reduction of the final price of the ethanol.

Table 2 summarizes the critical requirements of the system considered in the field management.

Major technology areas

Agronomy

The sugarcane in Brazil, as in many other countries, is harvested every 12-18 months, producing today an average 81 $t.ha^{-1}.year^{-1}$ (CONAB, 2009) and with perspective of reaching 130 $t.ha^{-1}.year^{-1}$ in 20 years. Annually approximately 20% of the total planted area is replanted, and only 30% is done using mechanical planters, in the remaining area the planting process system is semi-mechanized. Besides, traditionally 5% of the production area is reserved for "seed cane" production.

TABLE 2 Critical System Requirements for the Field Management.

CSR	Current	5 years	10 years	20 years (Vision)
Biomass Recovery of stalks ($t.ha^{-1}$)*	81	91	111	130
Biomass Recovery of straw ($t.ha^{-1}$)*	0	2	5	12
Total Biomass Recovery ($t.ha^{-1}$)	81	93	116	142
Biomass production cost (RV)**	1	0.96	0.80	0.69
Biomass production environmental impact	High	Medium	Medium	Low

* Considering the perspective of recovering at least 50% of the available straw.
** All the costs for planting, cultivation, harvesting and hauling of the biomass are included.

Planting cost of the sugarcane can be divided in two main components, the production of healthy and quality seedlings and the cost of soil preparation, furrow opening and closing, and fertilizers application. The operational planting cost depends fundamentally if this is accomplished mechanically or manually, but it is around US$ 400 to US$ 1,200 per hectare. This high cost is consequence of the great soil movement and high consumption of buds used by hectare.

Syngenta announced recently that the company is researching a new cane seedling with height of 3 or 4 centimeters, denominated "plene" with a previously treated bud to guarantee the vigor in the germination and to protect it against diseases and pests. This new technology should be commercially available in 2010. This technique promises significant progresses to the cultivation system. This new system can reduce in 15% the costs for the growers, and will result in a reduction of the request amount of seedlings for 1 (one) $t.ha^{-1}$. A specific planter will be necessary for it and it is been designed by a large tractor company.

The development of precision planters, for the conventional planting system or for the "plene" system, will make possible to reduce the amount of seedlings used per hectare, with consequent reduction of the area destined to seedlings production.

A new concept of sugarcane harvesting is emerging, without previous burning, that seeks the integral use of the plant, involving additional operations for detrashing and the compact disposition of stalk and trash for transportation. This approach has deep implications in the conventional harvest processes, associated with the production cost and mainly to the energy balance.

The straw is also one of the main components in the adoption of CA, indicating that this can just be partially recovered. Studies accomplished by the Center of Tecnologia Canavieira – CTC indicate that if at least 50% of the straw can be maintained in the field for soil protection the CA can be implanted with safety. The amount of biomass available after green harvest is on average 14 t.ha^{-1} (d.b.), with an insignificant amount being recovered today. The perspective is that the amount of straw produced by hectare should increase to 24 t.ha^{-1} in 20 years, this means that the straw production for energy use can reach up to 12 t.ha^{-1}, which means a contribution of 216 GJ per hectare. This energy potential is today superior to the available bagasse (175 GJ) and the possibility to use the bagasse for ethanol production through hydrolyses will demand the recovery of the straw to be used in the boilers.

Agricultural engineer

The adoption of CA goes obligatorily by the development of an efficient system of controlled traffic on the cultivated area. The project of Low Impact Mechanization for No-Till Farming, today being carried out in the Brazilian Bioethanol Science and Technology Laboratory (CTBE) is a fundamental piece for the adoption of this technology. It is expected that the first prototype will be in tests in 2010/2011 crop season and that in the following crop season it will be adopted experimentally by some mills, reaching around 100 thousand hectares in the year of 2015.

The principles of mechanized harvesting used today in Brazil do not assist satisfactorily the current solicitations in terms of efficient recovery of the biomass and long-term sustainability. Harvesting conducted with a single row harvester present high consumption of non renewable energy and low operational efficiency. It forces the traffic of harvesters and heavy equipments on more than 60% of the planted area, with consequent soil structural degradation and the reduction in crop yield. The restrictions that hold back the operation in great steepness areas are associated to the stability and lack of dirigibility. The cost of harvest-load-transport (HLT) today in Brazil represents 50% of the sugarcane production costs. Those items brought up the need of investment in technology.

Here again the strategy of controlled traffic (CT) presents as an innovation that can contribute in an effective way to the system sustainability. The CT leads to productivity earnings, reduction of operational and investments costs, makes efficient use of the rain waters, it reduces superficial water run-off and erosion, as well as improvement in the physical and fertility condition of the soil. The project of the a Controlled Traffic Structure (ETC), for sugarcane harvest consists of using a wide-frame structure with a large track width (10 to 12 m) as power unit. In the ETC a two row harvest device, using a base cutter with floating ability, will be attached. To clean the cane removing the leaves a new detrasher, based in friction principle, will be used. After passing through this device the cane is billeted and delivered into a wagon unit alongside the harvester. Having crop row spacing as a multiple of track width, guaranteeing that all traffic always occurs in the same position, the traffic zones will remain in place for several crop cycles. That will ensure longevity of the sugarcane plantation and enlarging the period among replanting.

As the ETC is destined for mill and growers with areas bigger than 10,000 ha, it is necessary to design a similar technology destined to small farmers and cane growers. The proposal of mechanical aid equipment for sugarcane harvest seeks exactly this. This equipment, capable to harvest several rows simultaneously, depends on operators that pick up the stalk over the platform and direct it to the cleaning system and storage. This equipment will guarantee rural employment and mainly the quality of life of these operators. Due to the balance in its dimensions and low centre of gravity, this equipment should be able to work in areas with inclination up to 40%. That together with its low acquisition and maintenance cost should assist the needs of most of the small cane growers, which will be forced to abandon the activity in other way.

The final cost of the recovered biomass is predominantly determined by four parameters associated to the involved processes that are: the investment level, the operational efficiency, the demand of energy and the final density of the raw material. Simpler systems, with smaller number of equipments, consuming less fuel and with high efficiency frequently result in smaller costs. The factor “load density” becomes more important as the distances between the production areas and the mill increases. In the case of handling of free material the bulk density can be increased reducing the size of the particles through chopping processes. However, the raise in density is limited and other compression systems have been presetting better results. For handling in natura material, with long fibbers, it is necessary to compress the material in bales and fastening to avoid relaxation of the material and corresponding density loss. Processes with larger pressures and temperatures, as the briquetting and the pelleting, get larger densities without fastening, but they increase the energy consumption significantly and reduce the operation efficiency.

To reach the goal of using the straw for energy in 20 years, it will be necessary the development of straw recovery and compression techniques, that can guarantee its transportation and use at competitive prices. Today the only viable technique to recover the straw consists of the integral harvest where the straw, tops and billets are delivered into the side wagon, for later separation at the mill at the dry cleaning station. This process requests high investments in dry cleaning station and is limited by the distance between the field and the mill, because the low density of the raw material. How to transform the energy potential of the straw in useful energy in the system is still technically not solved.

Electronics

The reduction of the amount of seedlings planted by hectare requests the development of specific equipments that execute the planting accurately, as well as it is accomplished for cereals, allowing, in the conventional system of planting, the reduction in up to 50% of the amount of seedlings necessary. It should be capable of planting 2 or 4 rows simultaneously and its position controlled be accomplished by precision agriculture system, through satellite guidance, guaranteeing the parallelism of the furrows. The depth control should be electronically accomplished in a way to assure a uniform germination.

Precision Agriculture (PA) technology certainly will have an important role in this context. Today partially being used the system of directional control trough navigation satellite (GPS-RTK) and data transmission system for fleet control through GPRS, should be improved contributing to the efficiency of the field operations. The tendency is that the cost of these equipments will be reduced and soon become a very spread technology. The application of fertilizers based the variable rate will be other great contribution to the sustainability of the system, reducing costs and the environmental damages.

Technology drivers

The conservative agriculture (CA) implementation in an efficient way also depends on the technological agronomic support. Parra *et al*. present in the Chapter 11 of the Part 3 the relationship of the technological areas that need to be developed for the efficient pest control which can benefited from the new cultivation system. According to the authors, studies should be conducted, relating the effect of the trash and of the decomposing species in the new ecosystem formed by the mechanical harvesting technique, soil pests, natural enemies and present entomopathogens; environmental impact of the chemical control for soil species; evaluation of the efficiency of the biological control on the pest. Bio-ecologic studies, monitoring methods and control alternatives should be initiate with intensity, because the control methods now used are empiric and with low efficiency. It is expected that the evolution of the pest control will go together with the rhythm of CA adoption.

The other problem is relative to the adoption of crop rotation due to nematodes and soil-borne disease. Sugarcane is a semi-perennial crop, typically grown in cycles of four–seven years, with consecutive ratooning, the maintenance of the trash in the soil creates a favourable atmosphere to the development of soils pests and diseases. The adoption of the practice of leguminous cultivation or traditional green fertilizer used during the reform period of the sugarcane plantation will not be enough to combat these pests (Dinardo-Miranda *et al*., 2008), demanding investments in technology (biotechnology) to reduce the problem to acceptable levels of pest infestation.

The sugarcane planters should be modified incorporating technology that allows them to plant accurately, guaranteeing with this a reduction of the amount of necessary buds for linear meter, contributing to the reduction of production cost by the smallest demand of seedlings and guaranteeing larger productivity, allowing the development more uniform stand.

The seedlings planting system proposed by Syngenta requests a new planter, now in development by John Deer. This technology should be available in parallel in order to f become feasible.

The MBI project carried on by CTBE pass through several engineering segments and presents some critical points in its development for being a project that breaks some paradigms of the conventional system of sugarcane cultivation. The proposal in development has been discussed with the technical and scientific community in workshops. It foresees several phases of the project that involves activities of different nature such as research and development of agricultural engineering, agronomics, mechanics, electronics and mechatronics, as well as administration and management for the field development.

The project of the Controlled Traffic Structure (ETC) involves 9 stages that are going from the project of the structure, traction systems and directional control, harvest equipment, storage system and load transferring, planting and cultivation to methodology of performance evaluation. The success of this project will contribute to two important lines in technological roadmap, planting and harvesting.

The mechanical aid for sugarcane harvest is being developed in a joint venture with UNICAMP-Agricef with the support of FAPESP and a prototype is expected for 2010. As well as the ETC this project involves specialists in structure design, mechanism, electronic control system etc. Its adoption in the field does not request alterations in the crop system employed, meaning low investment which contributes for its economical viability and adoption possibility by small and medium growers.

The implantation of precision agriculture system depends now mainly on agronomic studies related to soils and plants nutrition and on the development of data acquisition technology designed primarily for the sugarcane crop. The technology developed for cereals can be partly adapted to the sugarcane, guaranteeing in this way, the success of its application.

CA for sugarcane, as well as in cereals, abolishes conventional soil preparation, because the mulch maintenance and vehicles traffic reduction over the cultivated area guarantee reduction of the soil compaction and consequent yield increment. If the soil maintains along the years the appropriate structure for the development of ratoon without presenting compacted areas, the period for area replanting can be extend, from 5 to 6 years up to 8 or 10 years, depending on the variety. Replanting can be done directly over the remains of the previous crop, independently if it is sugarcane or other crop used for soil-borne disease reduction. In this way the adoption of CA contributes not only with the reduction of planting cost, but also to the reduction of the consumption of natural resources and energy balance.

In the next 20 years it is expected that the technological evolution of the mechanization in the sense of turning the sugarcane production more sustainable, present specific solutions for the sugarcane harvest without certain restrictions imposed by the tractors and the harvester, allowing the reduction of HLT operational cost. This objective can be reached through the reduction of the investments, production operational costs, crop losses, the intensity of the soil compaction and loosening processes, soil moisture content losses, the use of fossil fuels and its emissions, and the times lost by the equipments in the complex cycles of several interacting machines.

Each of the tables below shows the indicators to be pursued by each technology area in each CSR.

Gaps and barriers

The technological development of the sugarcane cultivation system has great potential to

TABLE 3 Technology drivers of the "productivity" CSR.

CSR	Productivity increase	Present	5 years	10 years	20 years (Vision)
Technology	**Agronomic**				
Indicator	*Availability of pest control for CA (%)*	n.a.	5	15	40
	Crop rotation systems specific for sugarcane (%)	n.a.	~	5	20
	Soil physical and chemical attributes and sugarcane yield determination (%)	n.a.	1	5	15
Technology	**Engineer**				
Indicator	*Precision plant system for sugarcane (%)*	n.a.	1	5	20
	New devices for sugarcane harvest (%)	n.a.	1	20	70
	Adoption of controlled traffic (%)	~	1	10	20
	Straw compression and transportation (%)	~	5%	20	30
Technology	**Electronic**				
Indicator	*On board electronics for precision agriculture application. (%)*	~	5	25	60
	Real time data transmission system (%)	1	10	50	80

Note: Percentages refer the technology driver's adoption for the productive sector.
• ~ Values non significant of some isolated initiatives.

TABLE 4 Technology drivers of the "cost" CSR.

CSR	Agricultural component cost	Present	5 years	10 years	20 years (Vision)
Technology	**Agronomic**				
Indicator	*Adoption of conservative agriculture (RV)*	1	0.95	0.9	0.9
Technology	**Engineer**				
Indicator	*Seedlings used per hectare (RV)*	1	0.95	0.9	0.85
	Vehicle traffic in cultivated area (RV)	1	0.95	0.85	0.6
	Raw material losses during harvest (RV)	1	0.95	0.7	0.3
	Straw recovery (RV)	1	0.95	0.85	0.6
Technology	**Electronic**				
Indicator	Reduction in the use of fertilizers (RV)	1	1	0.9	0.6
	HLT cost reduction (RV)	1	0.95	0.85	0.6

Note: RV – Reference value = 1

TABLE 5 Technology drivers of the "environment" CSR.

CSR	Environmental impact of agriculture component	Present	5 years	10 years	20 years (Vision)
Technology	**Agronomic**				
Indicator	*Soil compaction*	High	High	Average	Low
	Soil tillage	High	High	Average	Average
	Biologic control of pest and soil-borne disease	High	Average	Low	Low
Technology	**Engineer**				
Indicator	Number of seedling/bud used per hectare	High	Average	Average	Low
	Use of traffic control system	High	High	Average	Average
	Straw recovery	High	High	Average	Low
Technology	**Electronic**				
Indicator	*Use of fertilizers and herbicides*	High	Average	Low	Low
	Fuel consumption	High	High	Average	Average

contribute with the increment of ethanol productivity and reduction of the production cost in a sustainable way. However it was observed that there are few or reduced groups of researches with focus in this subject. The creation of CTBE was an important mark, but not enough to reach the wanted goals in medium and long period. CTC, although has contributed significantly with the development of the sector, as private organization, working with its associates' resources, have limited performance. It is then necessary to promote the formation of new research groups and to create conditions for searching youths' training.

There are also infrastructure and material resources deficiencies. The development of the agricultural goes obligatorily by field experiments that request big areas and years of study. The association with the privet initiative is indispensable through the productive sector (mills) as well as the manufacturers sector (machines, equipments, fertilizers etc.)

In the specific case of the precision planting system it is observed that although the need of developing more efficient planting equipments is recognized, researches results and available information show that this technology still needs a lot of investment to become available.

The adoption effective Conservative Agriculture, zero-tillage, as shown in this report, depends a lot on the development of other sectors of agronomy for its feasibility. Pests and diseases associated to the culture semi-perennial should be combated with investments in existent groups of researches to obtaining results in short period. Alternatives to be used for crop rotation should be study to contribute to the sustainability of the system.

Investments to implement precision agriculture are still very high and the results obtained by the research groups did not demonstrate the economical benefits of this technology yet. However it is observed that it has a great potential and in a short term period it should be adopted not only for its potential of production cost reduction, but also for environmental propose. For that it is necessary to develop human resources qualified to analyze and to interpret the results so that the technology potential can be explored, as it is happening with cereals.

FINAL CONSIDERATIONS

The agricultural cost of sugarcane production today represents about 60% of the total cost of the ethanol and sugar production; of this more than 60% refer to the agricultural component. It is observed that investments in R&D in the agricultural area are necessary and they can contribute to reach the goals of bioenergy production from sugarcane in terms of productivity increase, cost reduction and reduction of the environment impacts in the next 20 years.

Critical System Requirements shows the need to develop technological solutions that contribute with the improvement of the planting system, investing in precision planters, which will allow the cost reduction, through the reduction of the amount of buds per hectare, reduction of the area destined to the production of seedlings and obtaining a more uniform stand.

The technological option of zero-tillage following the example of what is done in cereals, comes as an attractive solution, but that requests development in the agronomy area, biology and engineering. The adoption of conservative agriculture goes obligatorily by the reduction of the traffic of vehicles on the agricultural area and this solution requests the break of engineering paradigms and the development of solutions for harvesting different from what it is available today in the market. Technological solutions to make possible the harvest of green cane and reduction of the traffic of vehicles should also be developed for the cane growers, with smaller cultivation areas and with smaller investment capacity. Equipments such as the mechanical aid for sugarcane harvest should be improved and make available commercially in few years.

The increase of the productivity in the biomass production for ethanol production include the straw recovery, that presents high energy potential, and that today is despised and left in the field. The recovery of at least 50% of the straw can be accomplished through two routes, the integral crop and separation at the dry cleaning station or through the separation and compression in the field for subsequent processing in the mill. Both need investments to turn them economically attractive.

The technological roadmapping of the agricultural component here presented is just an introduction to demonstrate that more deep study should be accomplished by researchers' groups and representatives of the private initiative, financed by public sector. Investment strategy on the part of the government for the development of the agricultural segment of sugarcane production for of energy use should be elaborated.

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TRM:

HYDROLYSIS COMPONENT

Maria das Graças de Almeida Felipe and *Carlos Eduardo Vaz Rossell*

INTRODUCTION

Brazil has the world largest and most successful program to replace fossil fuels by ethanol from sugarcane which has made great progress over the last 30 years. The expansion of renewable sources from alternative raw materials and production processes are environmentally friendly requirement for the growing demand for ethanol as a fuel, to reduce emissions of greenhouse gases.

The new world scenario leads to the advancement of technology for biofuels of which ethanol using agricultural biomass is a prime example. In this context, transforming the bagasse and cane straw (trash), processing by-products into raw sugar industry, is an alternative technology route that promises significant productivity gains in the fuel ethanol industry. Needless to say, the global environmental impacts of fossil fuels is one the major causes of pollution. Thus, the change in this matrix with the global adoption of biofuels is, in the sort term, the main way to reduce the environmental impact of fossil fuels.

Therefore, the expansion of this sector in Brazil is expected to occur not only by the conventional technology of using sugarcane juice (sucrose), but also by taking advantage of the sugars (C5 and C6) from lignocellulosic biomass (bagasse and straw). The main challenge is to develop a process that can deconstruct this biomass from the separation of its main fractions of cellulose, hemicellulose and lignin, to the use of the main sugar constituents of cellulose and hemicellulose fractions represented by glucose (C6) and xylose (C5) respectively. The use of straw, and sugarcane bagasse, for the production of ethanol will allow to use 2/3 of the energy potential of biomass that is currently under-used or wasted. That is, the juice, the main raw material in the current processes, represents only 1/3 of the energy potential of the plant. The lignin can be used for the generation of electricity or other compounds such as surfactants, adhesives etc. It is also important to consider within this context the production alternatives of other compounds from the pulp such as buthanol, 1-3 propanediol, bioplastics, acids like acetic, lactic and succinic and also from hemicellulose as specialty sugar xylitol.

Currently, the main problem for the production of ethanol from lignocellulosic materials is the lack of technology for efficient conversion of biomass into liquid fuels. The process requires several steps, basically pretreatment, hydrolysis (cellulose and hemicellulose), fermentation of C5 and C6 sugars and distillation.

In this context the hydrolysis step is a critical factor because it is dependent on the type of raw material and the nature of the plant material and its processing, which at the same time, directly affect the next stage of fermentation. It is well known that products from hydrolysis containt not only sugars but also compounds inhibitory of the enzymatic activities. The type and concentrations depend not only on the nature of raw material, but mainly on the type/conditions of hydrolysis, which can be physical, chemical or biological, as well as the combination of these. Although the enzymatic hydrolysis is most appropriate when compared to other procedures, such as acid hydrolysis to obtain cellulosic ethanol, this alone does not allow the depolymerization of cellulose that requires also the pretreatment of the raw material by physical methods, chemical or biological. This crucial step prior to hydrolysis decreases the crystallinity of cellulose assisting the action of cellulolytic enzymes by solubilization of hemicellulose, by facilitating the accessibility of the cellulose structure. Moreover, the pretreatment may also contribute to the formation and/or release of inhibitory compounds in enzymatic activities and furan compound derivatives (furfural and hydroxymethylfurfural) formed by partial degradation of pentoses and hexoses respectively, as well as phenolic compounds derived from degradation of lignin; and also aliphatic acids such as acetic, formic and levulinic.

At the same time the only viable way, so far, to expand the production capacity of ethanol plants, with no consequent increase in planted area, would be to increase the productivity of these plants. For this task, the urgency to develop technologies to the use bagasse and trash from hydrolysis methods, environmentally friendly, efficient and at low cost to the deconstruction of biomass, without loss of sugars and formation of enzyme inhibitors. However, research so far has been unable to come up with a technical and economic feasible process to produce ethanol from lignocellulosic materials at the laboratory level and less so a larger scale. Within this context, this roadmapping approach seeks some important aspects to be considered in regard to the hydrolysis component.

TECHNOLOGY NEEDS AND CAPABILITIES

Products or technologies targeted

The purpose of this section is to identify the products or technologies that are the focus of the specific component within the Hydrolysis Technology Roadmapping of the sugar and ethanol industry.

Hydrolysis of sugarcane bagasse and straw is shown as an alternative strategic to increase the supply of ethanol without requiring increased plantation area. However, the development of this technology, the object of study in several countries (USA, Canada, European Union), while evolving positively, it not mature to become commercially feasible. The enzymatic catalysis route, however, has so far achieved a performance capable of making this process technically and economically feasible.

We conducted a survey of the most likely route for the enzymatic hydrolysis to identify the steps that are holding back the consolidation of this technology. This technology route, the focus of this study, is one of the elements of the Technology Roadmapping's sugar and ethanol industry.

Figure 1 shows a simplified diagram of the process, considering the hydrolysis bagasse and subsequent conversion to ethanol.

It is shown in dotted lines the critical steps assumed to be those that are preventing to achieve a hydrolysis feasible process from a technical standpoint, and economic feasibility.

Steps are in order of importance:

1. Biosynthesis of cellulase enzyme complex.
2. Enzymatic hydrolysis of pretreated bagasse.
3. Pretreatment physical chemical bagasse.
4. Fermentation of pentoses to ethanol.

The identification of these steps shows that there is need for basic in-depth studies in order to diagnose the problems and possible solutions; and the necessary expertise and material resources to address these bottlenecks. This means involving basic research to address these technology barriers.

Critical system requirements (CSR)

Having defined the products or technologies that are the targets of roadmapping, the purpose of this section is to identify the critical qualities that they must have, called critical system requirements – CSR. Here are identified the functional requirements and performance, featuring high-level dimensions to which the hydrolysis is related, as well as their goals over time to meet a set of strategic goals in terms of:

- productivity;
- cost reduction;
- consumption of natural resources and energy balance ratio (EE/EU and GHG emissions).

Regarding the *productivity* of the industry as a whole, the hydrolysis component is considered

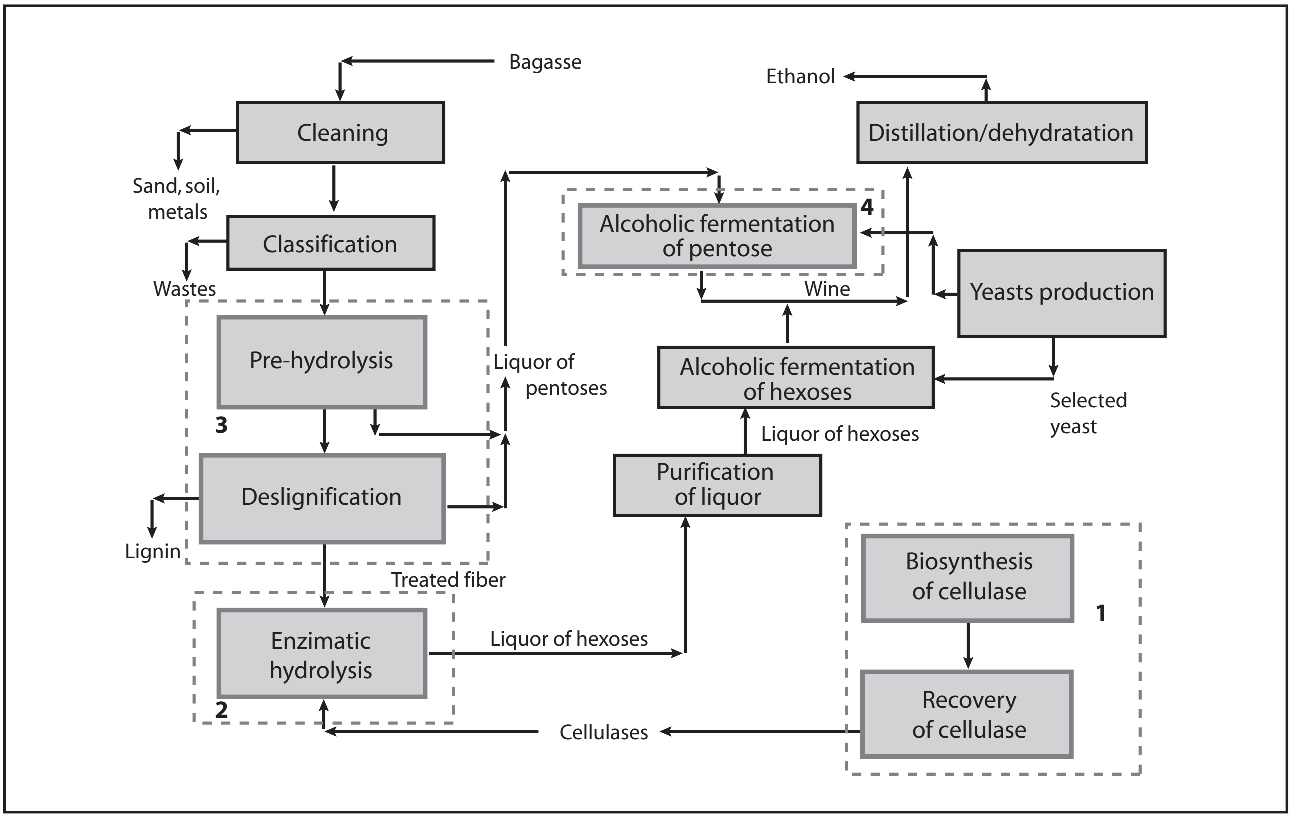


FIGURE 1 Pre-hydrolysis and enzymatic hydrolysis with prior delignification.

here in terms of its contribution to increase ethanol production, starting with a condition zero to reach 2.5 liters per ha per year in 20 years.

For the requirement of *cost*, the cost of ethanol obtained by enzymatic hydrolysis of bagasse is expected to reach the goal of US$ 0.50 per liter.

Since the environmental targets to be achieved by the hydrolysis component, in terms of a qualitative specific use of natural resources (water, bagasse and straw), and pollution, whereas in the short term (5 years), this condition will be high and will move to a low condition in 20 years.

Major technology areas

While the two previous sections have identified products and technologies focused on this work and their system requirements, the objective of this third section is to identify the key technology areas to be explored so that these attributes are achieved.

As mentioned in section Products or technologies targeted, the scope of this work comes down to four steps identified in Figure 1. Such steps are considered here with the major technology areas which demand scientific and technology developments. Afterwards each area is commented.

Biosynthesis of cellulase enzyme complex

Biosynthesis of enzymes that make up the enzyme complex responsible for the catalysis of cellulose into sugars is a major step that is preventing the consolidation of hydrolysis technology

This step is extremely strategic, considering that:

- The current cost of production of an IU (international unit of cellulase) is the major factor that adversely affects and prevents cost reduction of ethanol from bagasse for enzymatic hydrolysis.
- The enzyme activity (IU per ml of enzyme preparation) of the enzymatic complexes obtained is low, compared, for example, to the amylase activity responsible for industrial saccharification of starch.

- Research efforts that Brazil dedicated to the understanding of the biosynthesis of cellulase are not very significant compared to the research programs, public and private development, in USA, Canada and the EEC.
- There is a risk of falling into a high technology dependence through licensing procedures for enzyme production or selected strains of fungi and even producers through the sale of the enzymes by the holders of the technology.

A brief diagnosis of the problem that hampers the development of enzymatic conversion efficiency and high productivity indicates the following facts:

The enzymatic complex is composed of three main fractions: *endo*1,4β – *glucanase*, *exo*1,4β – *glucanase* and β – *glucosidades,* and their relative ratio must be balanced in order to promove an efficient saccharification.

The chemical structure of enzymes, their active centers and their role in catalysis need to be clarified these chemical structures.

The enzymes in the reaction conditions (pH 4 to 5 and temperature 45 to 55 °C) have an average life relatively low, signaling the need to develop techniques to stabilize them.

At present, there is not a complete mastery of the mechanisms of enzymes that form the enzymatic complex and the person responsible for conversion of cellulose into glucose.

We must improve our knowledge on the effects of interaction between the enzymes and lignin attached to cellulose during hydrolysis. Also, the enzymes are sequestered by the fraction of cellulose and this mechanism is not well known either.

The few groups participating in the bioethanol project, which involves several educational and research institutions have very limited amount of resources available to them. This project aims to develop technology using enzymatic hydrolysis for the conversion of sugarcane biomass into alcohol fuel from fungi selected for the production of cellulases, either submerged or semi-solid. The fermentation studies were performed on a laboratory scale, with no opportunity to develop a pilot-scale fermentation and thereby improve the process, evaluate the performance of different strains of fungi, that produce and the downstream end, develop and stabilize the enzymes, and obtain fermentation protocols that allow technical and economic evaluation of the biosynthesis of the enzyme.[1]

Enzymatic hydrolysis of pretreated bagasse

Concerning the enzymatic hydrolysis, the results still are not favorable. The reaction time was very high and do not reach the desired conversion and liqueurs sugars are low. Again, this is an undeveloped field, where reports of Bioethanol Project showed little activity of researchers. This requires laboratory facilities and pilot plants for development and optimization of enzymatic reactor's with productivity and efficient conversion rate.

There are several constraints in enzyme reactors. There is a limitation of the suspended solids in the reaction of saccharification, especially in the case of bagasse and its fractions derived from the density of this material is very low (150 to 350 kg/m^3). This limit is below 50 kg per 1,000 kg of suspension, leading to low-end liquor concentration of sugars and a high consumption of mechanical energy in the hydrolysis and thermal energy in the later stages of recovery of ethanol. The enzymatic reaction has a kinetic disadvantage. The results of tests on a pilot scale (representative) indicate reaction times of 75 to 100 hours. Part of this is due to the low activity of enzymes available (much less than that of amylase, for example) and the part that displays enzymatic inhibition by the substrate, the intermediates and the final product.

To work around this problem, we have proposed alternative reactors that combine the hydrolysis step with the step of fermentation, citing, for example, simultaneous saccharification and fermentation (enzymatic reaction by cellulase complex and fermentation with selected yeasts) and conversion directly by microorganisms that have activity cellulase and ethanol production (in

[1] Reports, Bioethanol Project – Production of ethanol by enzymatic hydrolysis of biomass from sugarcane, Contract FINEP N. 01-06-004700, Executor: State University of Campinas, Coordinator: Prof. Rogerio Cezar de Cerqueira Leite, 2006-2007.

mono-culture or co-culture). However, although these alternatives are the subject of laboratory studies, it is difficult to obtain practical results. In the case of Brazil, it is difficult to reconcile them with the process of producing ethanol from the first generation. This indicates the importance of focusing on processes of saccharification and fermentation to separate and the need to develop a reactor capable of improve the inhibitions, retain the enzymes and substrates in suspension.

Pretreatment physical chemical residues

The physical-chemical pretreatment of lignocellulosic material is a critical stage, because it depends on the efficiency of the later stages of saccharification. The cellulosic material is highly crystalline structure, hemicellulose and lignin block access of the catalysts union β 1-4 that bind together the molecules of glucose. Pretreatment involves among others:

- Reduction and uniformity of particle size in order to facilitate access of the catalytic hydrolysis of the glycosidic unions.
- Pre-hydrolysis and removal of pentoses to facilitate the subsequent stages.
- Removal of lignin to facilitate catalysis and prevent its interaction with the cellulolytic enzymes.

Although this is one of the fields in which Brazilian researchers have been active, it is appropriate to increase activities in this area, whereas the efficiency of pretreatment determines the success of the later stage of hydrolysis.

The research effort undertaken so far in Brazil has focused mainly on routes:

- steam explosion;
- explosion with steam and acid;
- organosolv delignification;
- pre-hydrolysis with dilute acids;
- delignification with alkali;
- delignification by wet oxidation.

Studies have been conducted in laboratory scale, because of deficiency of material resources. The characterization of raw materials, the current intermediate and final products showed the precarious nature of the disability analytical resources available. Again, this diagnosis leads to the necessity to introduce basic research to monitor the disintegration of the polymer cellulose-hemicellulose-lignin by the pretreatment.

Fermentation of pentoses to ethanol

Unlike the fermentation of hexoses (glucose and others) when a process is fully established, the fermentation of pentoses must be developed. Few microorganisms have the ability to ferment them into ethanol. The transformation of pentoses to ethanol is critical to achieve an efficient technology of hydrolysis at a cost of ethanol production from sugarcane. It should be remembered that the conversion of hexoses to ethanol accounts for 34% of the total potential conversion of bagasse into ethanol, and should not be neglected. At this stage, studies are still at laboratory scale, and from a commercial stage. Researchers in Sweden commented in a Latin America – European Union Biofuel Research Workshop, held in Campinas-SP, 23 to 27 April 2007, that favorable results would be obtained only in the middle and long term.

According to the literature, research in progress in this area include:

- procedures for selection and breeding of yeasts that ferment naturally pentoses in ethanol;
- development of recombinant strains of *Saccharomyces cerevisiae*;
- selection of thermophilic bacteria;
- selection of mesophilic bacteria.

Three species of yeasts were identified as high potential for fermentation of pentoses despite limited performance: *Pichia stipitis*, and *Candida shehatae* and *Pachysolen tannophilus*. The metabolism pentoses requires the presence of a minimum level of oxygen, which must be strictly controlled. These strains have a low tolerance to ethanol and aliphatic acids. Research is undergoing on the selection of more resistant mutants and protoplast fusion.

Studies to obtain genetically modified strains of *Saccharomyces cerevisiae* to metabolize pentoses were directed to the following strategies:

- Insertion of bacterial genes that carry out the isomerization of xylose to xylulose (xylose isomerase); latter fermentable by *Saccharomyces*;
- Insert in *Saccharomyces cerevisiae* of genes that allow the assimilation of xylose;
- isomerization of xylose into xylulose via the addition of an isomerase.

At present we have not achieved promising advances. For example, the use of thermophilic bacteria, studies of *Thermoanaerobacter ethanolicus* demonstrate the necessity of use pentoses – very dilluted broths. *Clostridium thermohydrosulfuricum* has been widely studied in cases of direct conversion (CDM). Among the difficulties highlighted, the authors state the following: formation of significant acetates leading to low yield strength, low tolerance to ethanol and vulnerability to contaminants. Thermophilic bacteria, genetically modified, also have been studied in order to avoid the formation of acetate in parallel to the formation of ethanol.

Generally the main problems related to the use of thermophilic bacteria are low tolerance to ethanol, a strong sensitivity to inhibitors, in parallel formation of significant amount of by-products and the need to add growth factors in the medium.

The possibility of use of mesophilic bacteria, some bacteria such as *Zymomonas mobilis* are not able to ferment the pentoses, but are very efficient in the metabolism of glucose to ethanol via the Entner Doudoroff pathway. The introduction of genes of *Escherichia coli* allowed the fermentation of xylose to ethanol.

An important feature of *Zymomonas mobilis*, as one of the microorganisms most promising for fermentation liquor of hydrolysis, is their strong tolerance to ethanol and inhibitors as well as the high productivity of fermentation. It is considered one of the recombinant microorganisms most promising for the successful fermentation of pentoses. Yet it is also necessary to solve the problem related to the instability of the genetically modified organisms. Other mesophilic bacteria capable of metabolizing pentoses in the absence of oxygen are *Escherichia coli* and *Klebsiella* which are being subjected to genetic modifications, and are investigated as alternatives to alcoholic fermentation liquor of hydrolysis. Importantly, the only experience of industrial alcoholic fermentation of sugar based wort, using a strain of *Zymomonas mobilis*, held in Germany 90 years, was not successful and the unit was turned off back to the conventional process with yeast as a fermentation agent. The information we have about that process is that the conditions in which the fermentation proceeded led to rapid contamination which inhibits fermentation.

To perform alcoholic fermentation of a liquor containing pentoses and hexoses possibilities under study requires sequential or simultaneous fermentation of pentoses and hexoses. In two simultaneous fermentation process microorganisms that ferment, respectively, glucose and xylose are grown in coculture. Most of the work in this field used two yeasts: *S. cerevisiae* and *P. stipitis* (pentoses).

The difficulties encountered were:

- the metabolism of xylose proceeds more slowly than glucose, leading to inhibition of the alcoholic microorganism that metabolizes the pentose;
- catabolic repression of glucose on xylose utilization;
- competition between *S. cerevisiae* and the yeast responsible for fermentation of xylose by oxygen present in the medium;
- possible incompatibility between the two strains.

Another possibility has been operating the fermentation in a sequential scheme, fermenting glucose first and then the xylose (or vice versa). Results were obtained with a mutant strain of *Escherichia coli* unable to metabolize glucose was employed *S. cerevisiae* to a second stage of fermentation of glucose. Again, referring to the reports of Bioethanol project and the available literature, it shows an expressive performance of Brazil in the development of microorganisms for conversion of pentoses to ethanol, compared with number of groups and publications abroad. This indicates that there is a need for skills in this area and to encourage groups to develop these activities, as well as provide material resources for carrying out studies.

TECHNOLOGY DRIVERS

At this point, the critical system requirements presented in section Critical system requirements (CSR) are transformed into technology drivers for each of the major technology areas identified in section Major technology areas. These technology drivers will be the critical variables in determining the technology alternatives to be selected later. To that end, here are presented goals for each technology driver, which are referenced to the critical system requirements that the product or technology must possess. The goals of the technology drivers specify how well certain alternative technology should play at some point in time. In other words, the targets are set for the delivery of the final system.

Each of the tables below shows the indicators to be pursued by each technology area in each CSR.

The projections made on the CSR "productivity" were established according to the mark final route of maximum use of the material. Firstly was considered optimal recovery of straw estimating removal of 50% for conversion of biomass or production of electricity. Another pillar of the stage was recasting the production system (distillation), steam generator operating at pressures of 90 bars and temperature of superheat of 590 °C, tube generator with high efficiency, electrification of the joint preparation and extraction of sugar. In this reformulation we obtained large surplus bagasse for use in the process of conversion of biomass to about 50%; and finally taking into account the projected growth in agricultural productivity roadmap put forward by breeding and farm management, also projecting in 20 years a yield of 130 t/ha/year. It was considered for the calculation basis of the impact of the introduction of the enzymatic hydrolysis pretreatment by steam explosion and ethanol production from hexose, only the first 5 years and

TABLE 1 Technolog drivers of the "productivity" CSR.

Hydrolysis productivity (L/ha.year)	**Present**	**5 years**	**10 years**	**20 years (Vision)**
2nd generation ethanol	0	1,156	1,800	2,500
1st generation ethanol	6,800	8,350	9,450	11,700
Total	**6,800**	**9,481**	**11,250**	**14,200**

TABLE 2 Technology drivers of the "cost" CSR.

		Present	**5 years**	**10 years**	**20 years (Vision)**
CSR	**Hydrolysis Cost (US$/l)**	n.a.	0.75	0.60	0.50
Technology area	**Enzymes**				
Indicator	*Cost (reference = 1)*	1	1/2	1/3	1/4
Technology area	**Reaction**				
Indicator	*Cost (reference = 1)*	1	1/2	1/3	1/4
Technology area	**Physical pretreatment**				
Indicator	*Still lacks an indicator*				
Technology area	**Fermentation of pentoses**				
Indicator	*Cost (reference = 1)*	1	3/4	1/2	1/3

TABLE 3 Technology drivers of the "environment" CSR.

		Present	5 years	10 years	20 years (Vision)
CSR	**Environmental impact of hydrolysis**	n.a.	High	Average	Low
Technology area	**Enzyms**				
Indicator	*Use of water, environment pollution, use of bagasse*	1	1/2	1/3	1/4
Technology area	**Reação**				
Indicator	*Water consumption (l of water/l of ethanol)*	75	50	40	30
	Reduction of effluents	n.a.	1/3	1/2	2/3
	Conversion yield bagasse to sugars	80%	85%	90%	95%
Technology area	**Physical pretreatment**				
Indicator	Still lacks an indicator				
Technology area	**Fermentation of pentoses**				
Indicator	*Water consumption (reference = 1)*	1	80%	60%	40%
	Reduction of effluents	0	20%	40%	60%
	Fermentation yield (theoretical reference = 123 l/t of bagasse)	30%	70%	85%	95%

from then there is the pentoses uses reaching the process optimization from 20 years.

In addition to the technology presented here, there are some prerequisites that must take into account the availability of bagasse and trash next to the productive sector, acquisition of new equipment to meet the current model of crop and equipment accurately and breeding cane to obtain high biomass production and even a less recalcitrant lignocellulosic structure. This is because alternative technology requirements for certain goals affects another component of the TRM; these goals should be explicit and serve as a prerequisite for the other components.

PRESENT SCIENTIFIC AND TECHNOLOGY CAPABILITIES

The State of São Paulo has good scientific and technology capability in the area of bioenergy, as there are a significant number of research organizations from different sectors that have appeared since the Proalcohol. These studies have received funding support from funding agencies, especially the Fapesp. Also CNPq and Finep, participates in this integration effort and in the promotion of training of personnel.

Thus, the thematic projects, involving different segments of the research including the productive sector, are promoting activities for form specialists in this area.

GAPS AND BARRIERS

This section identifies current and future gaps, barriers and drivers of the technology section-Technology drivers. To that end, here we present the skills and knowledge that the workforce of the future industry will have to develop to implement new technologies. This identification allows to indicate what kind of strategic decision on education and academic programs should be taken by the State.

The partial reports 1 and 2 of Bioethanol Project of the Ministry of Science and Technology, bringing together the recent work of the most representative acting on hydrolysis showed that:

- Permanent researchers in Brazil, working on topics selected as critical, is extremely low for a strategic study such as the hydrolysis of bagasse for ethanol. New researchers should be trained immediately to high standards; the same applies for existing researchers.
- The report also shows the physical deficiencies with regard to the infrastructure of research laboratories.
- In the specific case of the biosynthesis of enzymes, the number of groups involved is very low, considering the impact it will have in the introduction on the technology of converting bagasse to ethanol (40% increase in ethanol production for the same area cultivation). Added to this the fact is the current cost of enzymes which frustrates the commercial introduction of this technology.
- According to the results of these reports, the enzymatic hydrolysis has been addressed only through experiments at laboratory scale, and thus it is necessary to scale-up. The studies carried out do not address the complexity of issues such as enzyme kinetics, inhibitions, the stability of the enzyme, and the impact of substrate matter and reactor design. It follows then that will be necessary to organize working groups dedicated to the study of enzyme reaction.
- In the fermentation of pentoses, there are not yet some microorganism, whether natural or induced mutations to genetically modified varieties, capable of transforming the pentoses of bagasse into ethanol on a commercial scale. The preliminary economic assessments indicate for the hydrolytic processes to become economical and sustainable, the pentoses sugars must also be converted into ethanol. Few groups are engaged in this research in Brazil. In other centers (Sweden and USA) although more advanced, the results still fall far short of expectations, with no promising alternatives in the short and middle term. Thus, it is a matter that requires an urgent need to develop human resources.
- The consensus is that the efficiency of conversion of lignocellulose into sugars is dependent upon a physical-chemical primary treatment to modify the structure of complex highly crystalline cellulose-hemicellulose-lignin, in order to make the cellulose accessible to enzymes and thus allow the course of hydrolysis to be productive and with high conversion factors. Although at this stage, the reports on bioethanol project showed a significant contribution of researchers working in pretreatment, faced many ifficulties in achieving their objectives, and this lead us to the conclusion that the current level of dedication of researchers in this area is not enough to achieve positive results, and thus recommend to increase the number of researchers in this area.
- The barriers that have limited the progress of the study in pre-physical chemical treatment are due to the lack of laboratory equipment, pilot plants to develop research; and also lack of equipment for chemical and physical analysis capable of measurement and quantification of changes in chemical structure of lignocellulosic material.

FINAL CONSIDERATIONS

The world faces a great challenge to find alternatives to replace fossil fuels, a sustainable energy source for starting the use of renewable raw materials with a consequent reduction in emissions of greenhouse gases. The ethanol produced from sugarcane in Brazil is currently the best route to overcome this global challenge.

The development of technologies for the complete use of the whole sugarcane (sucrose, bagasse, straw) is the main bottleneck to increase ethanol production without incurring increasing the land area planted.

The hydrolysis of lignocellulosic biomass is still a major constraint to increase productivity gain of ethanol fuel production to take advantage of the by-products generated in the production of sugar and ethanol, such as cane bagasse and straw. The increased availability of these materials is concomitant to increase productivity of ethanol by the application of new technologies in the production process. On the one hand, the replacement of manual harvesting by mechanical harvesting will provide larger amount of sugarcane tops and leaves, and at the same time there will be larger availability of bagasse by improving the efficiency of boilers.

The critical point to reach depolymerization technology of plant biomass lies in the fact that they have not yet established the right conditions for hydrolysis characterized by an efficient and low cost process allowing the availability of sugar constituents of the raw material for fermentation.

As for the full use of sugarcane, is required higher efficiency of the basic steps of the hydrolytic process as pretreatment of biomass, to facilitate the accessibility of cellulolytic enzymes; the choice of these steps should take into account the fact that it does not contribute to the generation of compounds inhibitory of enzymatic activity as those derived from furan, phenolics and acids. This requirement is essential for the efficiency of the fermentation process.

Considering the total use of sugar constituents of biomass for the use of its cellulose and hemicellulose fractions, the hydrolyzate will contain a mixture of sugars (C5 and C6) which necessitates the discovery of novel microorganisms and of our biodiversity and/or obtain genetically engineered strains capable of fermenting C5 sugars which are represented mostly by xylose and in small amounts by arabinose. At the same time, it is necessary to search for techniques to separate these sugars after the hydrolytic process.

It is important to discover microorganisms capable of detoxification of the hydrolysates in order that the biomass subjected to a pretreatment solubilize the hemicellulose, which helps to release together the sugars, compounds inhibiting enzymatic activities, harming the subsequent stages of the production process.

The major challenge in producing ethanol from any cellulosic material, such as the use of whole sugarcane biomass, is not only in the researches for the selection of bacteria that produce effective and inexpensive hydrolytic enzymes, but also in relation to knowledge of the mechanisms involved in the action of these enzymes to the deconstruction of the matrix of plant biomass. Allied to this, there is also a need for research into genetic improvement of strains producing cellulases and other enzymes that may help in the process of hydrolysis, in addition to studies on changes in polysaccharide structure constituent of plants, to facilitate the deconstruction of lignocellulosic biomass, which is hampered by its complex structure which is heterogeneous, recalcitrant and enzimatic hydrolysis resistant.

Finally, it is safe to say that so far for the establishment of a technology for producing fuel ethanol from lignocellulosic materials, the stage of degradation (hydrolysis) of biomass to fermentable sugars is presented as a great technical and economic challenge and its success is closely dependent on enzymes be highly efficient and profitable. With this in mind, a technology could be designed for obtaining second-generation ethanol that increases the production of biofuels in a sustainable manner.

The above findings justify the need for an immediate creation of a team of researchers in basic sciences: physics, chemistry, biochemistry, and biology, to advance the development of hydrolysis technology.

6

TRM:

BIOMASS THERMOCONVERSION USING BTL (BIOMASS TO LIQUID) TECHNOLOGY

Luís Augusto Barbosa Cortez, Rodrigo Aparecido Jordan, Juan Miguel Mesa Pérez and *José Dílcio Rocha*

INTRODUCTION

Among the vegetable biomass with energetic purposes, sugarcane has a privilege position in Brazil. It is a consolidated culture with well developed logistics in terms of harvesting and transportation, giving an enormous competitive advantage in relation to other energetic cultures.

However, even with the exceptional level reached by the sugar-alcohol industry, energetic use as well as the current productive process is still low. This is because the ethanol production process used until now is based only the use of sucrose, which contains between 32% and 35% of the primary energy of sugarcane. The greatest part (between 65% and 68%) is concentrated in the lignocellulosic fraction made up by the bagasse and cane trash.

Ethanol production through the process of fermentation of sucrose is of about 86 liters per ton of sugarcane, representing approximately 26% of the primary energy of the full cane. Each ton of clean sugarcane (stem), the following dry matter is produced: 140 kg of cane trash, 140 kg of bagasse and 150 kg of sugars. According to LEAL (2007), for these quantities, the primary energy is distributed in the following manner: cane trash (2,500 MJ), bagasse (2,500 MJ) and sugars (2,400 MJ).

The thermochemical route presents itself as an option for the conversion of the sugarcane lignocellulosic material into biofuels, passing by obtaining synthesis gas, followed by catalytic synthesis, which makes achieving hydrocarbons, alcohols, hydrogen, ammonia, synthetic natural gas etc., possible. The processes of the thermochemical route are known as BTL, biomass to liquid, or biomass for the production of liquid fuels.

Gasification is a route used to transform the components of biomass into synthesis gas (CO and H_2), used in the catalytic synthesis for the production of liquid fuels. The gasification technology is currently in an advanced phase of development. However, problems with feeding biomass in pressurized reactors, cleansing the gases and the need for high-scale production to reach economic feasibility, are factors which have barred its commercial exploitation.

Biofuels synthesis shows good economic feasibility indicators only when used in large scale. Some studies show values greater than 1,700 MW in energy from biomass, others refer to 5 million tons of biomass per year as the minimum economic size (LORA, 2008). This means that bubbling or fixed bed gasifiers, typical of small thermal capacities are not viable for industrial projects of synthesis gas production for biofuels. On top of that, the O_2 production plants have relative costs that are disproportionate for small capacities.

The dragged bed gasifiers, although easily scalable, require a very fine granulation in the biomass, which is technically difficult to achieve, due to the high power consumption in pretreatment. Pretreatment by roasting improves the granulation reduction process. For this reason, biomass fast pyrolysis for the production of slurry (mixture of bio-oil and fines charcoal from the process) and its later nebulized gasification, appears like an option for the operation of this type of gasifier, as well as reducing costs related to transportation of biomass.

Fast pyrolysis is a technology which already proves to be economically viable in plants with capacity starting at 2 tons/hour of biomass. This process transforms the biomass in charcoal (20% to 30%), bio-oil (20% to 30%), pyroligneous acid (5% to 10%), and the remainder of hot gases with temperature between 400 °C and 600 °C. However, the production yield of bio-oil must be increased, since currently it is still low.

It is expected that gasification of bio-oil under pressure and in oxygen atmosphere should generate a much cleaner synthesis gas with quality for its use in the catalytic synthesis process. The use of pressurized reactors, fed with bio-oil, aims to reduce the investment costs and increase the production scale of synthesis gas. Although this may be true, there are many technology bottleneck points to be covered, in relation to feeding bio-oil, the quality of the gas, operational conditions of the reactor etc.

TECHNOLOGY NEEDS AND CAPABILITIES

Products or technologies targeted

Fast pyrolysis for the production of bio-oil for obtaining synthesis gas, within the proposed technologies, appears as an option for the use of sugarcane trash and bagasse in the production of synthetic biofuels through BTL, thus increasing the production of energy per hectare without the need to increase the planted area, by means of a more efficient use of the primary energy of sugarcane.

In this scenario, fast pyrolysis may be used as a pretreatment phase, improving the biomass characteristics for long-distance transportation, thus reducing the costs related to this phase, which currently weigh heavily on their cost.

Bio-oil may be considered a liquid biomass which presents density of 1,200 kg/m^3, much greater than the gross density of polydisperse biomass which is in the range of 80 to 240 kg/m^3.

Transporting biomass in its liquid state, that is, as a bio-oil, is more convenient than in the polydisperse solid form, due to its high energetic density, lower humidity levels and ashes. It is possible to adapt the transportation logistics developed for other liquid fuels to bio-oil.

Furthermore, the use of bio-oil in gasifiers has advantages related to the feeding system and the production of a cleaner gas, of better quality, both for burning in combustion engines and turbines (energy generation), as for the use in catalytic synthesis for synthetic fuels, simplifying the purifications phases.

Gasification with pressurized oxygen instead of atmospheric air results in a high quality synthesis gas which is compatible with fuel synthesis catalytic systems and with the direct use in conventional gas moved turbines. Since it is a liquefied biomass, bio-oil may better adjust to the oxygen pressurized gasifiers such as the drag or fluidized beds.

Analyzing the possibilities for production of fuels via BTL using sugarcane trash and bagasse, we hereby propose the route going through pyrolysis and then gasification, where the bio-oil shall be used as raw material for the production of synthesis gas. In this case, the biofuel shall be obtained in fast pyrolysis plants in fluidized bed, in small scale. These plants may even be modular, so that they are located as close as possible to the biomass. The mixture of the entire production of bio-oil shall be transported to a large-sized plant for gasification and production of synthetic biofuels, fertilizers and other products through catalytic synthesis. This is the description of a bio-refinery based synthesis gas. Its structure should be in large scale since the catalysis plants are expensive and are only justified for great production volumes. Figure 1 shows a scheme to exemplify this scenario.

Calculations made considering the production average in the mills in the State of São Paulo (2006/2007 harvest), show that approximately 20 mills are necessary to provide sugarcane trash and bagasse to supply a gasification and synthesis plant. This is, considering the minimum feasible capacity of 5 million tons of biomass per year. This calculation considered use yield of 50% of the bagasse and 50% of cane trash (dry biomass).

Another possibility for feasible synthesis of biofuels would be the integration with oil refineries. The bio-oil produced could even be sent

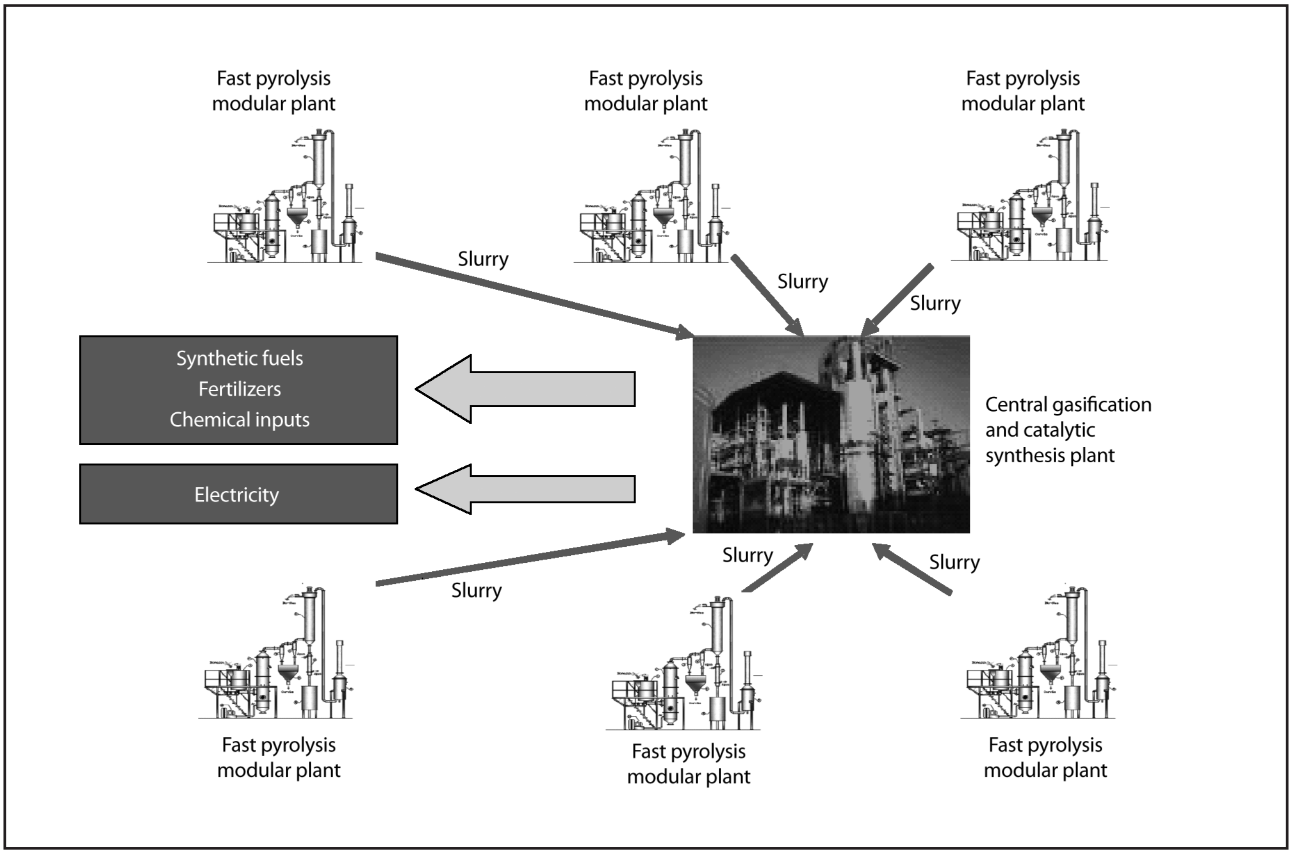


FIGURE 1 Scenario proposed for Pyrolysis/Gasification/Synthesis – BTL.

through oil ducts to the refineries, where it would be added to oil in the refining process. An example of this arrangement would be the Paulínia refineries, which could process bio-oil produced in the regions of Campinas and Piracicaba, which add up to 26 mills (UNICA, 2009; UDOP, 2009).

From the point of view of supplying raw material, it is also possible to have the integration of pyrolysis plants with hydrolysis plants, using the lignin resulting from the hydrolysis pretreatment process. The lignin is responsible for the formation of the phenolic components in bio-oil, as well as the implementation of fixed carbon in the solid fraction (LUENGO *et al.*, 2008). For the pyrolysis process, it would not be a problem to operate with lignin alone. This would even allow an increase in the processing capacity of a plant based on the conversion of lignocellulosic biomass, composed by lignin, cellulose and hemicellulose, as well as water and ashes.

At a first glance, the implementation of this scenario may seem simple, even for the fact that the thermoconversion technologies are not new technologies, having been known for many decades. However, with the advent of oil, researches with these technologies have been abandoned, meaning that some bottlenecks have not been worked out, especially referring to the application of biomass.

Figure 2 shows a simplified block diagram of the proposed route, with the critical phases shown in red, where there are bottlenecks which need to be surpassed so that the proposed scenario may reach commercial maturity.

For a characteristic of the proposed fast pyrolysis process, first there is the extraction of fines charcoal and, then, of the bio-oil. This is due to the fact that the bio-oil separation system uses a gas cleanser to extract carboxylic acids, before extracting the bio-oil. The resulting mixture of fines charcoal to the bio-oil (slurry) for gasification, allows an increase in the product supply for this process, as well as increasing the global efficiency of the proposed route.

The phases identified as critical are the technology areas to which efforts should be directed in order to solve the related problems, problems which hinder the immediate commercial application of the proposed route. Some problems still involve basic research; however most of them are of technical-economical character, related to matters such as scale increase of the technologies involved.

Critical system requirements (CSR)

The aim of the proposed route is to increase general energy yield in relation to the use of primary energy from sugarcane, where, with the production of ethanol alone by the current process, this is of around 26%. The conversion of cane trash and bagasse, whether in the form of other biofuels which are not only ethanol or in the generation of electricity, shall allow an increase in the quantity of energy produced from the same planted hectare of sugarcane.

The projections were made considering the scenarios for an increase in the production of sugarcane defined in Chapter 3 – TRM: Genetic Improvement. Tables 1 and 2 show the projections for the increase in energy produced per hectare of sugarcane due to the increase in sugarcane primary energy yield, with the use of cane trash and bagasse in the proposed route. Table 1 considers a scenario for sugarcane with higher level of sucrose (Scenario 1 of Genetic Improvement). Table 2 considers a scenario for sugarcane with higher fiber level (Scenario 2 of Genetic Improvement). In order to create a comparison parameter, these tables also show the equivalence in liters of ethanol.

For Tables 1 and 2, the following data was considered: production of 0.575 liters of ethanol/kg of sugar and use of 50% of cane trash and 50%

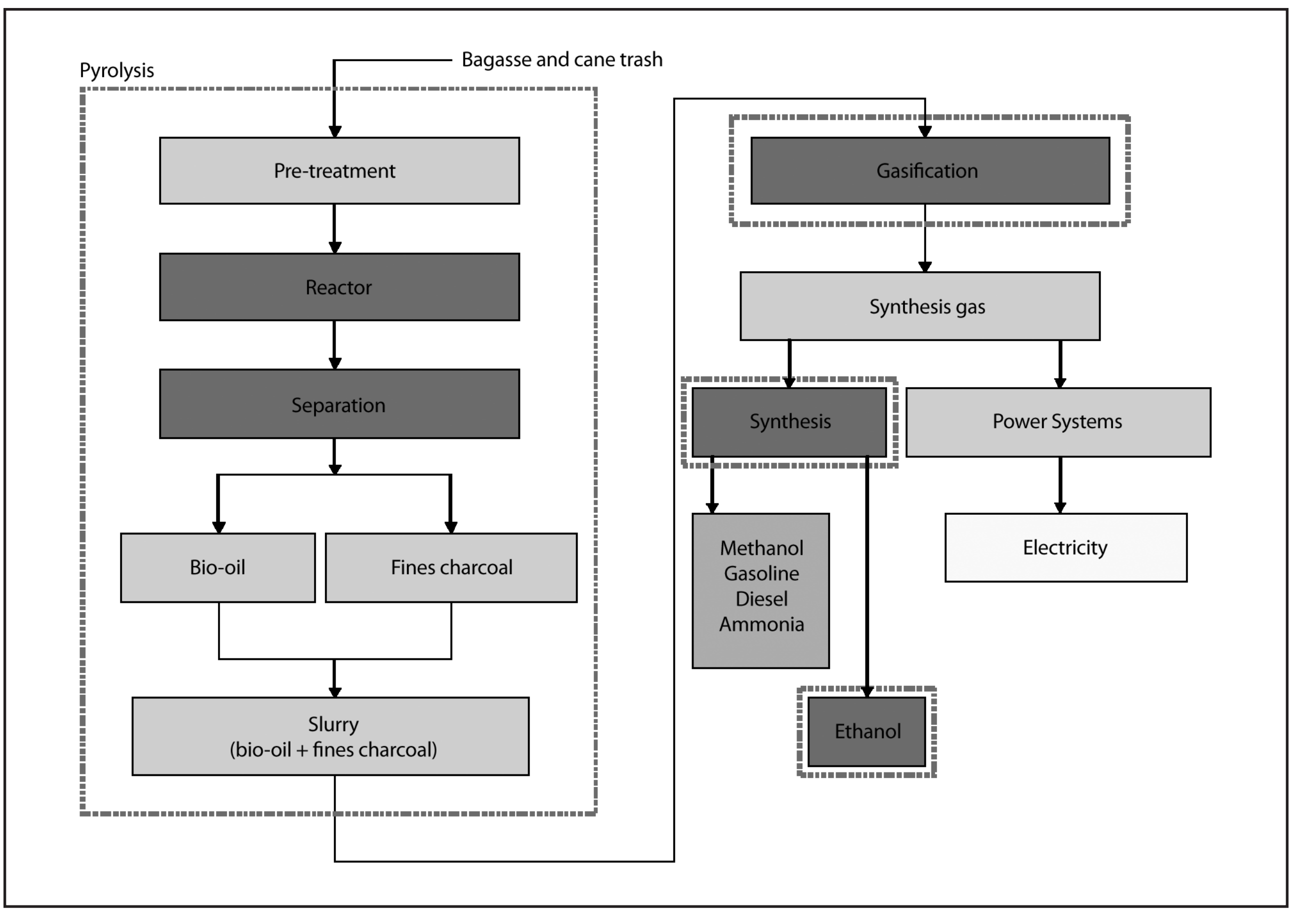


FIGURE 2 Block diagram of the thermo-chemical route for the production of synthetic biofuels and electric energy generation through pyrolysis and gasification.

TABLE 1 Projection of energy production per hectare and global efficiency of the conversion of primary energy from sugarcane, Scenario 1 of Genetic Improvement.

		Present	5 years	10 years	20 years
GJ/ha.year	1st generation Ethanol	145.4	152.7	169.2	198.3
	BTL Fuels	n.e.	39.7	62.9	89.2
	Total	145.4	192.4	232.1	287.5
Liters/ha.year	1st generation Ethanol	6,811	7,156	7,929	9,294
	BTL Fuels*	n.e.	1,859	2,947	4,182
	Total	6,811	9,015	10,876	13,476
Global efficiency (energy produced/ primary energy from sugarcane)		26%	31%	35%	40%

* Equivalence in liters of ethanol.

of bagasse in the thermoconversion processes. For ethanol an inferior calorific value was considered, of 21.34 MJ/liter (EPE, 2008). The data referring to the production of sugars, bagasse and cane trash and energetic equivalences, were the same shown in the Introduction, presented by CGEE (2004) and by LEAL (2007).

The current condition considered only the production of ethanol for the sucrose fermentation process (conventional route). This is because in Brazil, there still is not a production of synthetic biofuels by the proposed route. For the following years (forecasts), the total production is the result of the sum of ethanol production from sucrose fermentation to the production of biofuels by the thermo-chemical route composed of Pyrolysis/Gasification/Catalytic Synthesis.

The projected increase is due to, as well as the increase in sugarcane production, the implementation of the thermo-chemical route and the gradual improvements in its processes (scale, cost, efficiency etc.), foreseen for the next 20 years. This data is presented in more detail in session Technology Drivers.

TABLE 2 Projection of energy production per hectare and global efficiency of the primary energy from sugarcane, Scenario 2 of Genetic Improvement.

		Present	5 years	10 years	20 years
GJ/ha.year	1st generation ethanol	145.4	156.8	177.4	191.4
	BTL Fuels	–	47	98.6	175.2
	Total	145.4	203.8	276	366.6
Liters/ha.year	1st generation ethanol	6,811	7,347	8,313	8,967
	BTL Fuels*	–	2,203	4,623	8,211
	Total	6,811	9,550	12,936	17,178
Global efficiency (energy produced/ primary energy from sugarcane)		26%	30%	34%	38%

* Equivalence in liters of ethanol.

Since in catalytic synthesis not all gas is converted into fuel, a parcel may be used in the generation of electricity. Recycling the gas allows a greater use for the conversion into fuel, however increases the consumption of energy used in the process. So, the option to produce more fuels or electricity shall depend on the future scenario, on factors such as demand and price. The popularization of hybrid and electric vehicles, as well as the increase of mass transportation based on electric energy, are factors which may lead to a greater consumption of electric energy.

To meet the projections shown in Tables 1 and 2 in relation to the proposed thermo-chemical route, there are the critical requirements: productivity, cost and environmental impact. Table 3 shows, for the next 20 years, the forecasts for these critical requirements.

Even with two different scenarios, the productivity requirements do not change, since the parameter is energy (electric or biofuels) per ton of biomass. That is, independent of the quantity of biomass per hectare, the yield is a characteristic of the process or processes, as we are discussing a route which involves pyrolysis, gasification and synthesis.

The environmental question does not appear as a critical point for the proposed route, since the use of water in the thermo-chemical processes is minimum, and the gases generated are or may be reused for heat generation in the processes themselves.

Even if there is not yet commercial scale production, the current cost of synthetic biofuels production by the proposed route was estimated. This cost was estimated based on operation data of the fast pyrolysis pilot plant at FEAGRI-UNICAMP (PPR-200), with capacity of 200 kg/h of biomass. The current cost of gasification and synthesis was estimated based on bibliographical information, considering scale of pyrolysis plant PPR-200. This data is based on LORA (2008), SEABRA (2008) and data from the IPT (INOVAÇÃO TECNOLÓGICA, 2009).

The present cost of biomass (cane trash and bagasse) was taken for the same as the price paid for sugarcane trash used in tests at the pilot plant PPR-200, which is of R$ 60.00 per ton. For future scenarios, a price reduction was considered, to R$ 40.00 per ton in a period of 5 years and to R$ 20.00 per ton in a period of 10 to 20 years. This would be due to technical improvements in cane trash recovery, such as reduced full harvesting, as well as an increase in the excess of bagasse due to optimization of the thermal processes in the mills.

The cost estimates for gasification and synthesis, for the 5, 10 and 20 year scenarios, were also based on data from LORA (2008), SEABRA (2008) and data by the IPT, quoted in INOVAÇÃO TECNOLÓGICA (2009).

Major technology areas

Pyrolysis

The observations in relation to the technical bottlenecks in pyrolysis were made based on results from tests with the pilot plant PPR-200 at Feagri-Unicamp.

TABLE 3 Critical system requirements of the proposed thermo-chemical route for the production of synthetic biofuels.

CSR		Present	5 years	10 years	20 years
Productivity	**Liters/ton of biomass***	n.e.	172	260	341
	GJ/ton of biomass	n.e.	3.7	5.5	7.3
Cost	**US$/GJ**	51.5	31.2	16.5	13.4
	US$/liter*	1.09	0.67	0.35	0.28
Environmental Impact		Low	Low	Low	Low

Obs.: Exchange rate: R$ 2.00/US$ 1.00.

* Equivalence in liters of ethanol.

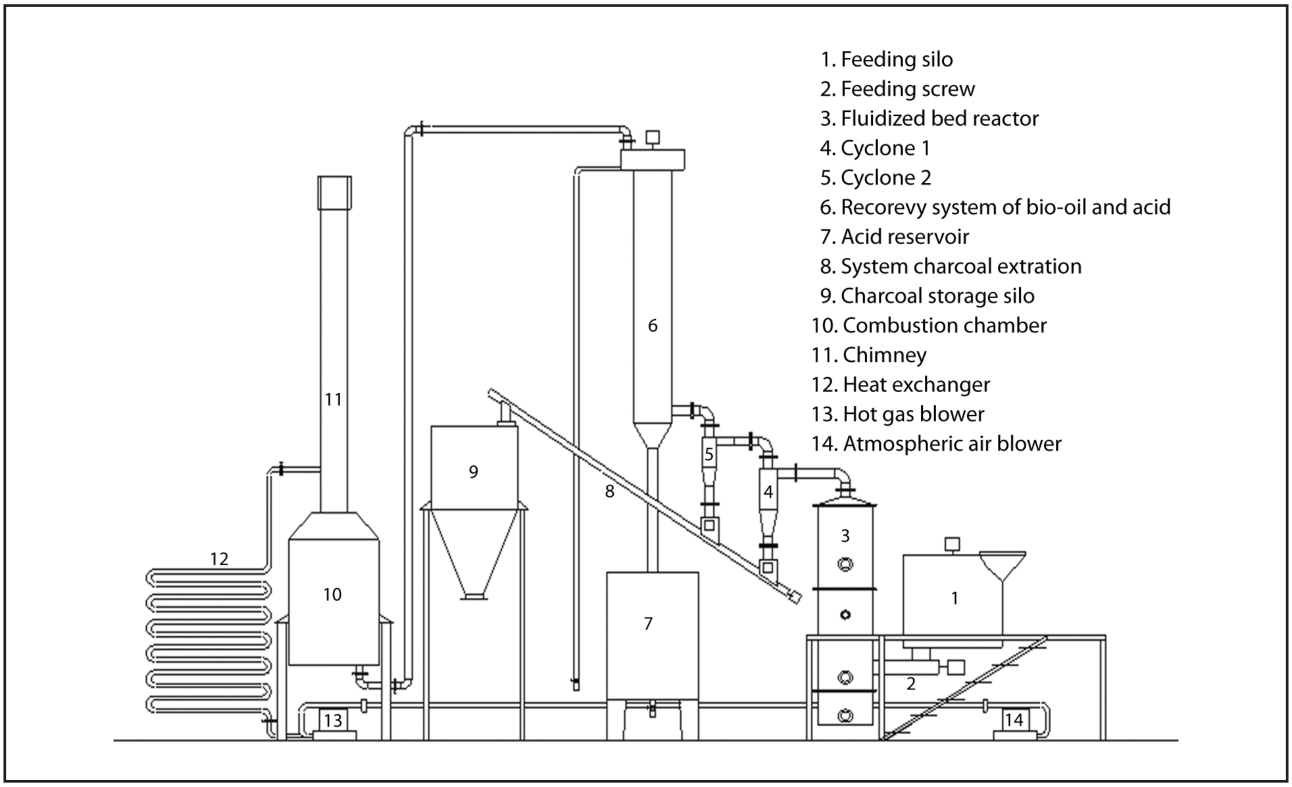


FIGURE 3 FEAGRI-UNICAMP (PPR-200) fast pyrolysis plant scheme.

Figure 3 shows a scheme with the main components of this plant. The operation of the plant happens in the following way: the biomass is fed into the silo (1), which has an infinite thread (2) which injects the biomass in the fast pyrolysis fluidized bed reactor (3). The biomass upon coming contact with the reactor bed at a temperature of about 450 °C to 500 °C is volatilized, transforming itself into a solid (fine charcoal), fumes (bio-oil and acid extract) and in gases.

The charcoal is separated in the cyclones (4 and 5) and stored in the silo (9), the acid extract and the bio-oil are separated in the recovery system (6) independently. In the reservoir (7) the acid extract is obtained and the bio-oil is removed through the superior side exit of the separation system through the rotation mechanical system. The remaining gases are burned in the combustion chamber (10). These gases could be used as fluidization agent in the bed using a heat exchanger (12) and a hot gas blower (13). However the tests held up to this point used atmospheric air from the existing blower (14).

Automation of the phases inside the pyrolysis plant

There are processes that take place in aqueous means, as is the case of the bio-technology processes: fermentation, biodigestion etc. However, for the thermal processes the biofuel should be dry or with compatible moisture content, varying between 8% to 15%, and for this energy must be used. Although in Brazil the sugarcane industry is specialized in direct burning of highly humid bagasse, other thermo-chemical conversion processes such as fast pyrolysis and gasification generally work with low moisture level biomass.

Appropriate stocking may help in the biomass initial moisture loss. Many processes normally have excessive thermal energy which may be used in drying, this is an advantage of plants located next to an existing manufacturing unit, such as mills for example, where the exhaust gases from the boiler could be used. Energetic integration of the process should be considered and practiced allowing for improved used of the raw material.

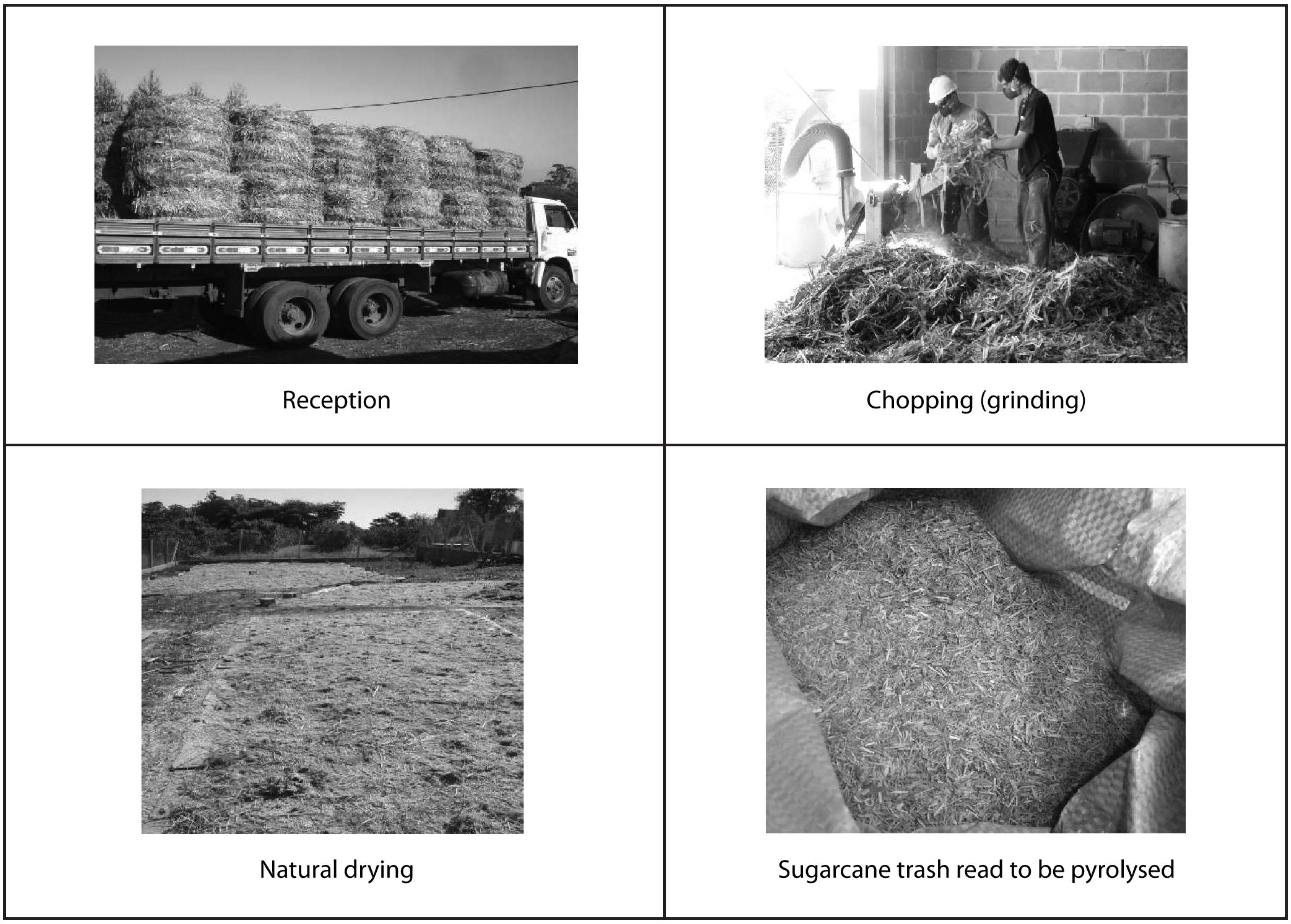


FIGURE 4 Pretreatment phases of sugarcane trash in a biomass fast pyrolysis plant pilot of FEAGRI-UNICAMP.

In the pretreatment phase, the biomass should be homogenized, involving the following operations: chopping, grinding, and screening. These unitary operations are used for the reduction and standardization of the size of particles. Some thermoconversion processes, such as fast pyrolysis, require homogeneity of the particles and control over size distribution is necessary and critical, ensuring a tight range of sizes.

Figure 4 shows the pretreatment phases of sugarcane trash when entering the fast pyrolysis plant PPR-200. Since this is an experimental plant, which does not operate continuously, these operations are all manual. However, considering an industrial scale, these operations should be automated.

Automation is an important point related to the issue of feeding the pyrolysis reactor. Maintaining the reactor operation temperature under control is very important and directly affects the yield in bio-oil. Temperatures above 500 °C in the reactor bed are not favorable to the production of bio-oil. In the same way, high air venting, used as fluidization agent of the bed in self-thermal fluidized bed reactors, as is the case of the reactor at PPR-200.

In the case of PPR-200, reactor temperature control is made through manual control of biomass feeding and venting of the fluidizing agent, which is adjusted by valves, opened and closed manually. A monitoring system gives profile data on reactor pressure and temperature.

Automation of the reactor feeding system is important, in order to have a robust plant, capable of self-adjusting to the conditions and characteristics of the biomass and the process, aiming always at a higher yield of bio-oil.

With regard to pretreatment and feeding systems in Brazil, the availability of equipment for these operations in high e.g. industrial choppers and mills, stocking silos, transporting chains and dryers of many kinds. These equipments must simply be adjusted to the needs of the pyrolysis plants, such as operation regime, capacity etc.

In automation, for operation efficiency a supervisory systems needs to be developed which is capable of receiving information from the plant, such as temperature, pressure etc. and take operation decisions, such as automatically increase or reduce biomass feeding. In the Brazilian market there is a wide variety of interfaces and programmable logic controllers (PLCs). Then there is only the matter of developing the control logic, based on the information which shall be made available.

Energy consumption in the pyrolysis process

Energy consumption in the fast pyrolysis plant is due to the need of supplying heat to the reactor and mechanical energy to move the air, biomass, cleansing water and separation of products. Figure 5 shows the energy flow balance at plant PPR-200 operating with sugarcane trash, made based on operation and yield data, considering the lower heating value of the cane trash, the bio-oil and fines charcoal, determined by analysis of these products. The energy flow value related to the gases and losses was determined by calculating the difference.

Electric energy represents the consumption of mechanical energy, which is not more than 1.6% of the energy produced in the form of bio-oil and fines charcoal. The thermal energy represents the plant's greatest consumption, of 36.5% of the energy generated in the form of fines charcoal and bio-oil. Because the reactor is self-thermal, this leads to a significant consumption of biomass, meaning that the yield of bio-oil in relation to gross biomass (mass yield) doe not surpass 22%. The gross biomass is the total which goes into the plant, not discounting moisture, ashes and percentage which goes to combustion.

Use of the gases generated in the process would allow reduction of the biomass consumption for heat generation. There would be an initial consumption to start the reactor starts and then it would be retro-fed by these gases, which would serve as source of heat and fluidization agent in the bed.

This system has been designed for PPR-200, which is even commented in Figure 3, and needs financing for tests. It is necessary to evaluate the behavior of the reactor operating with the injection of these gases, in terms of quality and use of the products.

The biomass consumed to generate heat would be made available for the production of

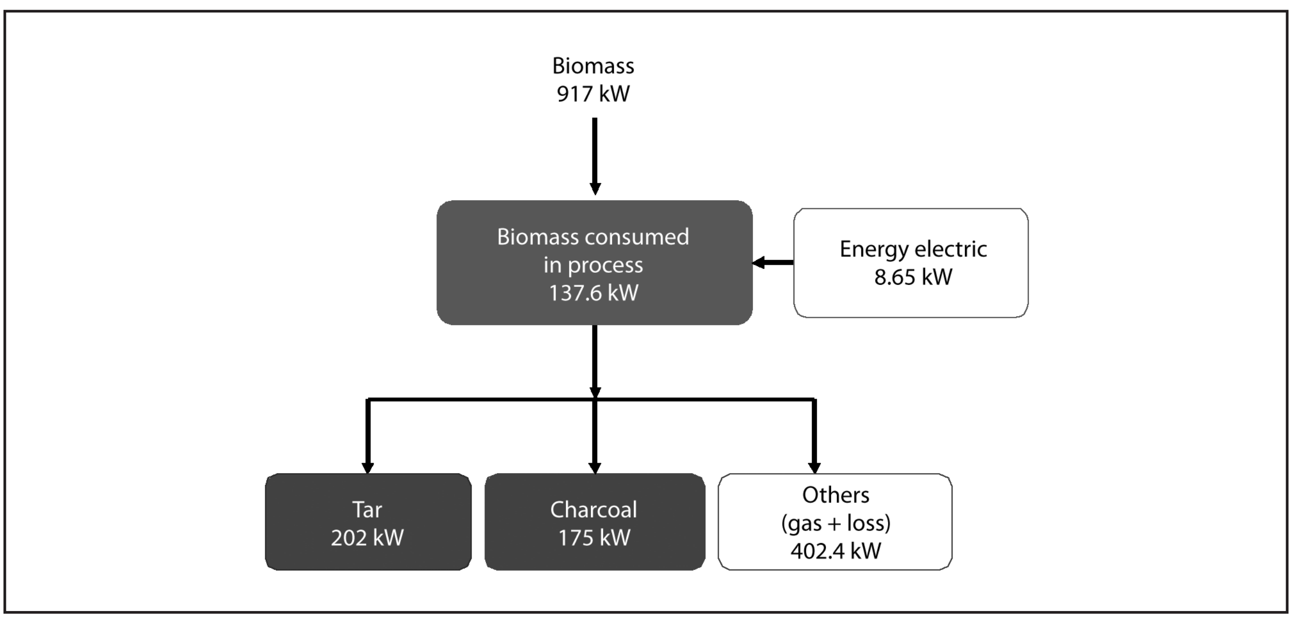


FIGURE 5 Energy flow balance at plant PPR-200.

TABLE 4 Typical yields of the products obtained from different forms of wood pyrolysis (dry base).

Process	Liquid	Charcoal	Gas
Fast pyrolysis	75%	12%	13%
Carbonization	30%	35%	35%
Gasification	5%	10%	85%

Source: OLIVAREZ GÓMEZ (2008).

fines charcoal and bio-oil. With this change, the conversion global efficiency of the plant based on the energy flow, fines charcoal and bio-oil, would go, considering current values, from 41% to 51.6%, which is still low. However there is also the question of increasing the yield of bio-oil.

Yield of bio-oil

The yield of fast pyrolysis products in laboratory scale using highly efficient bio-oil recovery equipment may reach 75% in mass (Table 4). This figure considers the total liquid mass recovered such as: water, acids, extracts and bio-oil.

In practice, as may be seen in Table 5, where the average yield of fast pyrolysis products at the pilot plant PPR-200 is shown, the bio-oil yield is not so high, in between 20% to 25% depending on the biomass composition, considering as calculation base the dry organic mass contained in the biomass fed into the reactor.

The organic mass (biomass liquid mass) is calculated subtracting the quantity of water and ashes in the biomass and discounting the percentage of biomass which suffers combustion from the oxygen contained in the fluidization air to supply heat to the process. In case of PPR-200, between 10% and 15% of biomass is used to supply heat to the process, as the reactor is self-thermal.

TABLE 5 Average yields of fast pyrolysis products at plant PPR-200, installed at FEAGRI-UNICAMP.

Product	Yield in mass base (%)
Charcoal	25-30
Bio-oil	20-25
Acid extract	10-15
Hot gases (calculated by difference)	30-35

As well as the question related to the consumption of biomass to supply heat to the pyrolysis process, there are other factors which affect the bio-oil yield, such as retention time (residence time) and the bio-oil separation system.

The total residence time at plant PPR-200, from entering the biomass particle in the reactor up to exiting the particle of bio-oil in the separator is still high, of about 8 seconds. Altering the reactor project and the separation column, it would be possible to reduce this time up to 2 seconds. This would reduce the possibility of the bio-oil particle suffering cracking, converting itself into gas.

The bio-oil separation system is another bottleneck in pyrolysis, as when it is cooled down it condenses in the form of a fog. The use of expensive however efficient equipments is not always viable when the question is biomass. For plant PPR-200 a technology of centrifuge separators was developed, which although it still operates with modest results, it is robust and cheap, and may be improved.

Scale of pyrolysis plants

In relation to scale, there are certain debates and controversies around the biomass fast pyrolysis plants. Some companies in the world use various technologies with great installed capacity, in the order of 100 to 200 tons of biomass per day. However these scales have not had much success due to the complexity of the plants and its relatively low performance.

In terms of values, as may be seen in Table 6, the cost/capacity relation is decreasing for fast pyrolysis plants. While the cost of a plant for 200kg/h is of R$ 300,000.00, the cost of a plant for 2t/h is of R$ 1.3 million, and the capacity is ten times greater.

In Brazil, studies have reached the scale of 200kg/h (PPR-200) and plants of 20 to 40 tons per day are capable of functioning satisfactorily. This

TABLE 6 Estimated costs of fast pyrolysis plants with fluidized bed reactors.

Capacity (kg/h)	Estimated cost (R$)	Est. cost/Capacity (R$/kg.h)
40	150,000.00	3,750.00
200	300,000.00	1,500.00
500	500,000.00	1,000.00
1.000	800,000.00	800.00
2.000	1,300,000.00	650.00
2.500	1,500,000.00	600.00

Source: BIOWARE (n.d.).

scale has already been projected, needing investments for its construction as a fundamental phase in scale increase.

The great technology difficulties in scale-up are related to the fact that the fluid-dynamic of the fluidized bed reactor is complex. Stable operations of the reactor (that is pressure and temperature profiles throughout the reactor in stationary regime) are only possible if the mixture between the material and the biomass is adequate. Problems of located temperature increases, sinterization, gas leakages, are common when the fluid dynamics of the bed is not dominated.

A scale-up, situation equivalent to an increase in the reactor diameter, has the inconvenience that the feeding point does not ensure a homogenous mixture of the biomass throughout the diameter perimeter of the bed. Distributing feeding points may help solve the problem, however economic and financial aspects of the implementation of these solutions must be evaluated carefully. The use of parallel reactors may be a less risky practice, however the economical aspects should be evaluated.

Stability of bio-oil

Moving from the question of process and approaching the question of products, there is the matter of high viscosity associated to the instability of bio-oil, which tends to increase with age, to the point where bio-oil resembles bitumen. This could represent a problem in transportation and application in processes, when thinking of draining through ducts. Heating the bio-oil, rather than a solution, may be a problem, if temperature is not carefully controlled, as when heated to more than 70 °C bio-oil turns to coke. On the other hand, at 60 °C it has a pretty fluid behavior.

The study of catalysts to be injected in the reactor during the fast pyrolysis process, or additives to be mixed directly into the bio-oil is an option. In this sense there have been tests using ethanol as an additive to bio-oil. The use of ethanol as well as reducing the viscosity, gave chemical stability to bio-oil, as well as improved its combustion properties. Above 40 °C, with an ethanol concentration of 15% in mass, the bio-oil is totally fluid.

The high viscosity of bio-oil *in natura* is due to the use of air as a fluidization agent, which increases the concentration of pyrolytic lignin and the degradation of the bio-oil's lighter compounds. So, substituting fluidization air for the gases generated in the process may act in the sense of reducing the viscosity of bio-oil.

The stability problem of bio-oil may be overcome by reducing the time between production and processing.

Gasification

The gasification technology is old, having been used in Germany during World War II. But, while the Germans converted mineral coal into fuel, the current challenge is to do the same with biomass.

The conversion of biomass into fuel gas allows the use of engines and turbines in applications for generating energy, whether to move cargo or generate electricity, which constitutes a technical potential for increasing conversion efficiency. From gasified biomass, known as synthesis gas, it is also possible to obtain hydrocarbons with characteristics that are similar to the commercial liquid fuels, such as gasoline and diesel.

In case of generation of electric energy, gasification allows the use of biomass in gas turbines, in whose power thermal cycle the work fluids operate at much higher average temperatures (above 1,200 °C) than in the conventional vapor

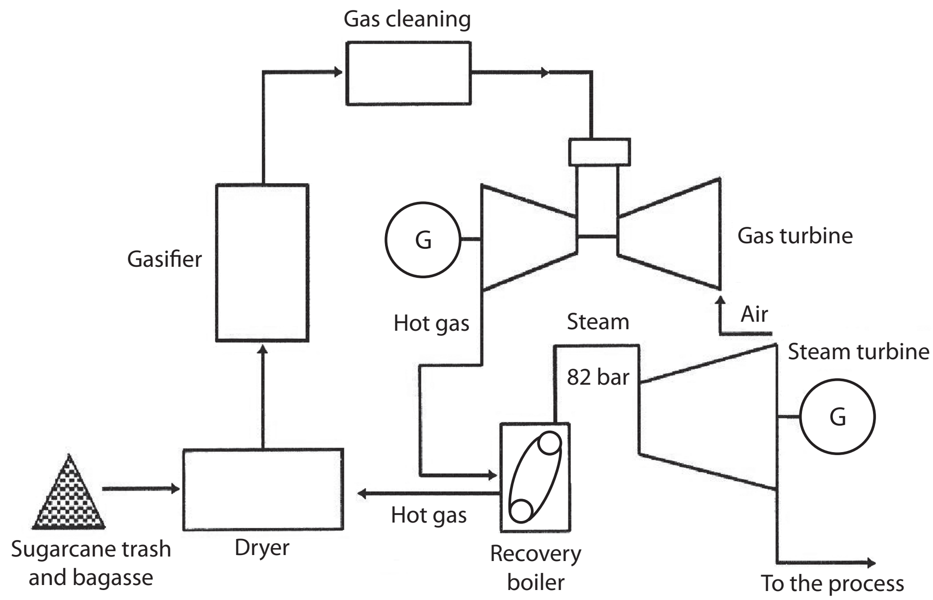


FIGURE 6 Simplified BIG-GT scheme.

cycles (below 600 °C), which reduces the thermodynamic losses and maximizes the performance.

In this sense, integration with gas turbines/vapor turbines combined cycles (biomass integrated gasification/gas turbine combined cycle BIG/GT-CC) may contribute to the increase in efficiency of conversion of biomass into electric energy. It is estimated that the BIG/GT-CC efficiency for the generation of electric energy may reach 45%, whereas in the vapor turbine cycles this efficiency is of about 15% to 35% (BNDES and CGEE, 2008). Figure 6 shows a simplified scheme of the BIG/GT-CC system, adapted from LEAL and LAMÔNICA (2003).

However, gasification of polydisperse solid biomass represents a challenge in terms of feeding reactors, as well as the question related to gas quality, as was previously commented. There are notorious cases of projects that were abandoned due to problems in feeding biomass.

Pelettization may be an alternative for the problem of feeding in pressurized gasification, as it increases the density of the biomass, improving its injection in the reactor.

On the other hand, the quality of gases is seriously compromised for its use in electric energy generation when the solid biomass is gasified integrally. Table 7 shows the requisites for the use of synthesis gas as a fuel in some applications.

Another issue is related to the capacity of the gasifiers, which should be high, for economic matters and, also, to meet the production volumes of the sugarcane mills. The fixed bed gasifiers are normally used for the conversion of small quantities of biomass, generally employed in small capacity electric energy generation projects. The ascending flow models normally produce gas with high tar levels interfering in the operation of internal combustion engines. In the descending flow models, the difficulty in handling the high level of moisture and ashes is a common problem.

Fluidized bed gasifiers on the other hand are more adequate to the conversion of a larger quantity of biomass, and systems with capacity between 10 and 20 ton/h are already operational. However, there are problems with the quality of the gases. Due to the nature of the process itself, the quantity of particle material dragged tends to be greater; a second aspect is that the higher temperature of output gases means that the alkali come out in their gaseous phase, imposing additional difficulties to cleaning.

TABLE 7 Requirements for the use of synthesis gas in combustion engines, gas turbines and fuel cells.

Impurities	Units	Internal combustion engines	Gas turbines	Fuel cells
Particle level	mg/Nm^3	<50	<30	–
Size of particles	µm	<3	<5	–
Tar level	mg/Nm^3	<100	–	<1
Alkali level	mg/Nm^3	–	<0.25	–
NH_3	mg/Nm^3	<55	–	<0.1
H_2S	mg/Nm^3	<1,150	–	<1
HCl	ppm	–	–	<1
SiO_2	mg/Nm^3	–	–	<1

Source: KALTSCHMITT and HARTMANN (2001) quoted by LORA and VENTURINI (2008).

According to SEABRA (2008), the main bottlenecks in biomass gasification are:

- low density and polydisperse biomass feeding system in pressurized reactors;
- cleansing of gases;
- long lasting and reliable operation at commercial scale of oxygen pressurized gasifiers;
- need for large scale production to make it economically viable.

Catalytic synthesis

The fuels produced from lignocellulosic raw materials are known as second generation fuel. They may be produced by the thermo-chemical route, through gasification of biomass for the production of synthesis gas, which permits the production of liquid fuels through various catalytic processes. The thermo-chemical route processes, also known as BTL processes are under development, which means there are still many challenges, especially related to the gasification phase itself.

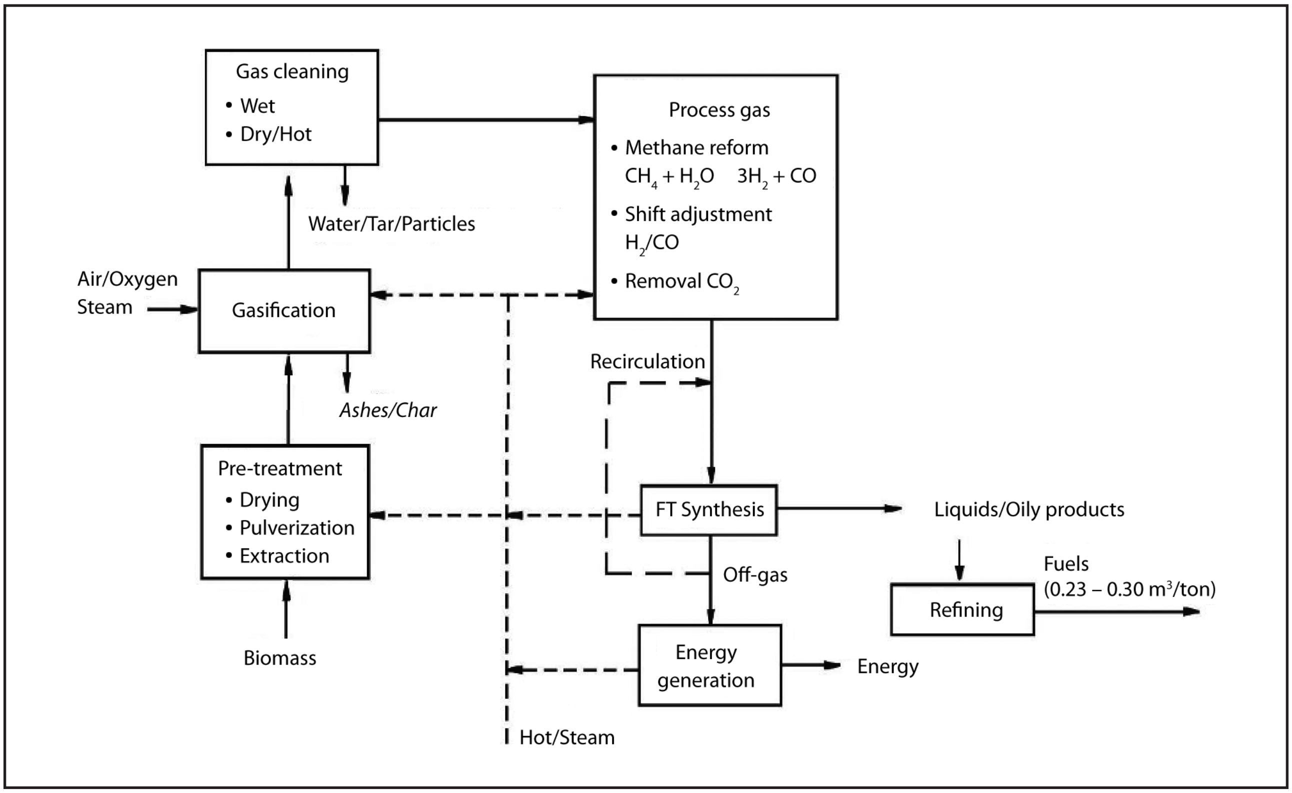
The fuel synthesis processes have a series of requirements in relation to pressure, temperature in the reactor, type of catalyst and H_2/CO relation in the synthesis gas (Table 8). The H_2/CO relation may be adjusted during gas conditioning using the shift reaction.

Another important factor is the quality of the gas, in relation to the levels of H_2S and other sulphurous compounds, particles, tar and alkali compounds. The required quality of the gas depends on which is the process which uses the synthesis gas as raw material. Table 9 shows these requirements in the case of methanol synthesis.

TABLE 8 Parameters and H_2/CO relation for different synthesis processes.

Process	Product	Pressure (bar)	Temperature (°C)	Catalyst	H_2/CO Relation
Methane	CH_4	1 – 30	300 – 400	Ni	3/1
Methanol	CH_3OH	50 – 100	250 – 280	Cu/ZnO	2/1
F-T	$– CH_2 –$	3 – 25	190 – 240	Co	2/1
F-T	$– CH_2 –$	3 – 25	250 – 300	Fe	2/1

Source: ZUBERBULHER *et al*. (2006) quoted by LORA and VENTURINI (2008).



Source: Adapted from JENKINS (2007) quoted by LORA and VENTURINI (2008).

FIGURE 7 Phases in the process to obtain fuels through the thermo-chemical route.

Figure 7 shows an arrangement to obtain fuels through the thermo-chemical route, passing by direct gasification of biomass, obtaining synthesis gas and Fischer-Tropsch synthesis.

According to SEABRA (2008), the main obstacles in catalytic synthesis of biomass are:

- cleansing gas;
- catalysts (increase reactivity and reduce costs);
- scale of synthesis plants.

TABLE 9 Synthesis gas quality parameters (methanol synthesis).

Component	Permissible concentration (mg/Nm^3)
H_2S and other sulphurous compounds	< 0.1
Particles	<0.1
Tar	<1
Alkali compounds	<0.25

Source: ZUBERBULHER *et al.* (2006), quoted by LORA and VENTURINI (2008).

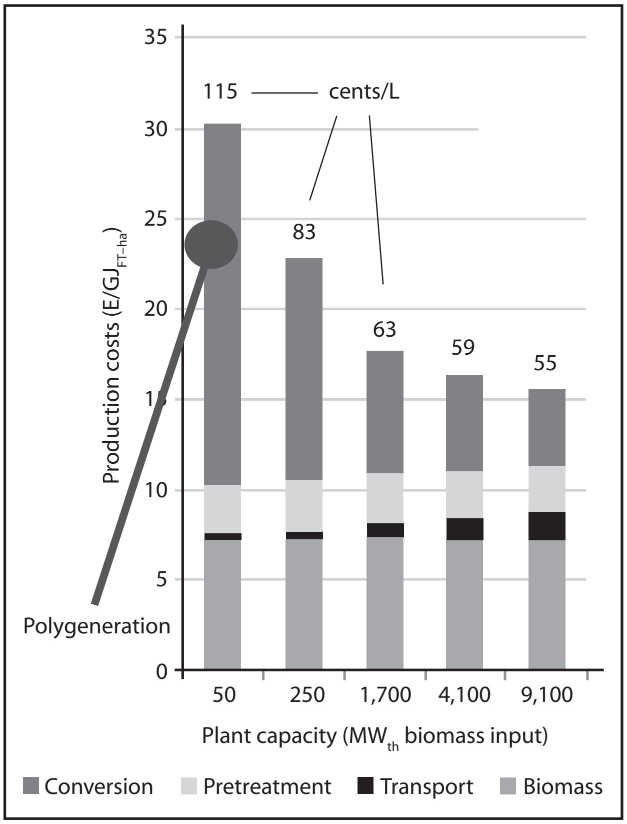
The BTL thermo-chemical route, which passes by pyrolysis production of bio-oil and gasification of the bio-oil, followed by the Fischer-Tropsch synthesis, has advantages in terms of feeding pressurized gasifiers and gas quality for use in catalytic synthesis.

Figure 8, taken from LORA (2008), shows the relation of the conversion cost with scaling of synthesis and gasification plants. The smaller the scale the greater is the cost, where there are included capital, operation and maintenance costs. It is verified that feasibility is achieved as of 1,700 MW of biomass entry.

TECHNOLOGY DRIVERS

Based on the needs of each technology area approached within the fast pyrolysis/gasification/catalytic synthesis route, technology drivers are created to meet the "Productivity" and "Cost" critical requirements.

Table 10 shows the technology drivers for each one of the technology areas in relation to the "Productivity" critical requirement.



Source: LORA (2008).

FIGURE 8 Relation between scale and cost in gasification and synthesis plants.

Automation of the pyrolysis process, reduction of biomass consumption in supplying heat to the reactor and improvement of the bio-oil recovery system will allow an increase in total product yield, from the current 55% to 71% in a period of 20 years. With this, conversion energetic efficiency of the pyrolysis process, which is now at 41%, shall increase to 70%. The current data is based in tests in a pilot plant. Bio-oil yield use as reference the organic mass available for pyrolysis (liquid mass), which ignores the humidity level and ashes, as well as the biomass consumed to supply heat to the reactor.

Table 11 shows the technology drivers for each technology area, aiming to meet the target referring to the "Cost" requirement, which foresees the reduction of the current cost, estimated in US$ 1.09 per liter of synthetic fuel, to US$ 0.28 in a period of 20 years. This reduction is the result of the increase in process efficiency, as well as reaching economies of scale for the production of synthetic biofuels.

The pyrolysis plant scale (ton of biomass/h) considers the gross mass fed into the reactor, with the moisture and ashes.

TABLE 10 Technology drivers for the increase in productivity aim of the fast pyrolysis/gasification/catalytic synthesis route for the production of synthetic biofuels.

		Present	5 years	10 years	20 years (Vision)
Productivity	**Liters/ton of biomass***	**n.e.**	**172**	**260**	**341**
	GJ/ton of biomass	**n.e.**	**3.7**	**5.5**	**7.3**
Pyrolysis					
Residence time (s)		8	4	2	2
Bio-oil yield (% in mass base)**		25	35	50	56
Fines charcoal yield (% in mass base)**		30	20	15	15
Conversion energetic efficiency (%)		41	51	63	70
Gasification and catalytic synthesis					
Conversion energetic efficiency (%)		30	40	50	60
Relation H_2/CO		1/1	2/1	3/1	3/1
Production (Liters /ton of mud)*		n.e.	373	476	572

* Equivalence in liters of ethanol (PCI = 21.34 MJ/liter).

** Product mass/organic liquid mass free of moisture and ashes.

TABLE 11 Technology drivers for the cost reduction aim of the pyrolysis/gasification/catalytic synthesis route for the production of synthetic biofuels.

		Present	5 years	10 years	20 years (Vision)
Cost	US$/liter*	1.09	0.67	0.35	0.28
	US$/GJ	51.5	31.2	16.5	13.4
Pyrolysis					
Pyrolysis plant scale (ton of biomass/h)		0.2	5	7	10
Production per plant (ton of slurry/h)		0.09	2.31	3.82	5.96
Cost (US$/ton of slurry)		150	80	50	42
Gasification and catalytic synthesis					
Gasification and synthesis plant scale (ton of slurry/h)		n.e.	44	145	358
Gasification and synthesis plants/pyrolysis plants		n.e.	1/19	1/38	1/60
Production scale (1000 liters of biofuel/h)		n.e.	16.41	72.36	179

* Equivalence in liters of ethanol (PCI = 21.34 MJ/liter).

Studies on gasification of bio-oil are currently under way in pilot units. It is thought that in 5 years it shall be possible to gasify also the charcoal mixed to the bio-oil in the form of slurry. The forecast above made for pyrolysis considers a pyrolysis module which may reach a biomass feeding scale of 10 ton/h.

Distribution of many pyrolysis modules for the production of mud shall enable reaching the economic scale for the production of synthetic fuels, which is of 5 million tons/year of biomass, approximately 600 ton/h of biomass, about 358 ton/h of mud, corresponding to 60 pyrolysis units with production capacity of 5.96 ton/h of slurry.

PRESENT SCIENTIFIC AND TECHNOLOGY CAPABILITIES

The state of São Paulo has many capable institutions. In the last 40 years, UNICAMP (FEQ, FEM, IFGW and FEAGRI mainly) has conducted studies in the field of biomass, gasification and pyrolysis, owning even a fast pyrolysis pilot plant. The IPT has done researches in the field of biomass conversion into fuel, through the route passing by gasification and catalytic synthesis.

Research directed to establishing the route being proposed may be conducted through the cooperation between universities and research centers (UNICAMP, UNIFEI, IPT and UFPA), manufacturers (Termoquip Energia Alternativa) and interested companies (Petrobrás, Oxiteno, BRASKEM etc.). The implementation of joint projects in research centers abroad is also possible.

In the field of catalysts, the NEST/UNIFEI together with the Termoquip have tested a catalytic cleansing system (Ni base) attached to a crossed-flow gasifyer. In Brazil, other universities also have high-level research groups in catalyst development. Among them, the CENPES-PETROBRAS, the Catalysis Group (DEQ/UFRN), the Studies Group in Kinetics and Catalysis (IQ/UFBA), the Group of Molecular Sieves (IQ/UNICAMP), among the others.

In the field of rapid pyrolysis, FEAGRI – UNICAMP, in cooperation with the company Bioware, is developing research related to pyrolysis of whole sugarcane and sugarcane trash. The purpose of these researches is the increase in bio-oil yield and the improvement of its physical and chemical characteristics, especially in relation to its stability. The question of scale increases in pyrolysis plants has been another point of focus.

GAPS AND BARRIERS

The cost of biomass has proved to be an important issue, needing to be worked, as it directly affects the products cost of all technologies proposed for using lignocellulosic biomass. As per studies held, considering an exchange rate of R$ 2.00/US$ 1.00, in the current scenario, an amount greater than US$ 50 per ton would not permit the use of biomass in thermoconversion technologies. The cost of the ton of gathered sugarcane trash, transported up to a distance of 20 km, may reach up to US$ 30, whereas one ton of sugarcane stem transported the same distance will not cost more than US$ 20 per ton.

The current cost of bio-oil based on the production cost calculated in tests at the pilot plant, considering the value of the sugarcane straw at US$ 30.00/ton with 15% moisture and 11% ashes, is of US$ 150 per ton (0.508 tep), considering the sales of fines charcoal produced at US$ 150 per ton. Yet the cost of one ton of ethanol (0.494 tep) is at around US$ 309. Now the price of one ton of oil (6.3 barrels) is of about US$ 441, considering US$ 70 the barrel. The cost of 1 tep of bio-oil is of US$ 295, where more than 70% of the production cost of bio-oil is due to the cost of the raw material (biomass).

A way of reducing these costs could be in the whole harvesting of sugarcane with the implementation of dry cleansing. The pyrolysis plants could be installations attached to the mills, benefitting from the whole existing structure to reduce costs in the harvesting and conditioning phases.

FINAL CONSIDERATIONS

The thermo-chemical route proposed in this roadmap is an interesting option to increase efficiency in the use of primary energy of sugarcane, with the conversion of straw and pulp into fuels.

The thermoconversion technologies such as fast pyrolysis and gasification are already known. However, there is a need to tailor these technologies to the conversion of biomass. Research directed to solving operation problems with biomass and improving efficiency is necessary. Efficiency of these technologies with the use of biomass, based in pilot tests, is still low.

The catalytic synthesis technologies are already commercial and used in the conversion of natural gas into synthetic gasoline. For the application in the biomass conversion route, there is a need to improve the quality of the gas, in what concerns the purity and H_2 and CO concentration. The question of scale seems to be one of the main barriers, in relation to production cost.

A market for the products of fast pyrolysis needs to be created, so that scale production capable of covering the minimum demand necessary for the production of synthetic fuels is rendered feasible. For this research on the application of the products generated is necessary.

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PUBLIC R&D POLICIES FOR ETHANOL PRODUCTION IN BRAZIL

André Tosi Furtado, Luís Augusto Barbosa Cortez, Maria das Graças de Almeida Felipe, Raffaella Rossetto, Paulo Sérgio Graziano Magalhães and Manoel Regis Lima Verde Leal

INTRODUCTION

The Brazilian Ethanol Program began in 1975 and one of its main aims was to alleviate dependence on foreign oil importation. At the time Brazil was importing about 80% of its domestic needs causing a heavy burden on the economy.

The country focused on producing ethanol using sugarcane as feedstock and the Brazilian Government helped to finance new cane fields/plantations and new distilleries. In less than ten years ethanol production jumped from 0.5 to about 10 billion liters/year. During the last 30 years the country has learned how to produce sugar and ethanol in a very cost-effective way and nowadays bioethanol is responsible for 60% of liquid fuels utilized in the Brazilian light vehicles fleet.

The amount of ethanol now produced in Brazil is significant in terms of the size of the domestic market (20 million vehicles) and it benefits the country in several other ways besides energy, such as:

- making Brazilian sugar more competitive;
- creating almost 1 million jobs;
- generating wealth in the rural sector;
- improving air quality in the large cities.

Nevertheless the Brazilian ethanol sector faces a new challenge in the form of the unprecedented opportunity represented by global warming resulting from GHG emissions.

Although Brazilian ethanol already presents excellent sustainability indicators, particularly regarding GHG mitigation, some aspects of its expansion have been the target of disproportional criticisms like:

- expansion of sugarcane would be somehow be related to deforestation in the Amazon;
- the production of biofuels, including Brazilian ethanol, would somehow constitute a threat to food production;
- the production of biofuels, including Brazilian ethanol, would generate a volume of emissions that would cancel its benefits.

Regarding the first point, deforestation in the Amazon has absolutely nothing to do with biofuel production in Brazil. The following arguments enable a better understanding of the issue:

- sugarcane is not produced in Northern Brazil.; the climate there is simply inadequate for sugarcane growing;
- sugarcane is a relatively small crop in Brazil (8 million hectares altogether, 4 for sugar and the other 4 for bioethanol production). The two most important national crops are soybean (22 Mha) and maize (12 Mha). The total area of Brazil is around 850 Mha hectares and the greater Amazon region accounts for nearly 450 Mha;
- creation of pasture land is probably the main factor driving the Amazon deforestation process (nearly 200 Mha).

The second factor has to do with competition with food crops. Production of food in Brazil has steadily increased over the last 30 years. Brazil is now the largest exporter of many commodities including: meat (beef, poultry and pork), sugar, coffee, soybean (2nd), and orange juice.

The third argument has to do with sustainability aspects such as water use, soil depletion and land use. Some of those aspects were simply not very important in Brazil in former times due to the small amount of ethanol produced and even today, as has been mentioned, it only occupies around 4 Mha, or 0.5% of Brazilian territory.

However, when the intention is to expand present ethanol production tenfold, (Cortez, 2002) then the land required for sugarcane production to meet such ethanol and sugar requirements may be as much as 35 Mha. The main conclusion of a study conducted by Leite (2005 and 2009) is that if ethanol production is to expand significantly in Brazil, then a great R&D effort will be necessary to decrease the demands made on all the resources involved, such as land, water, fertilizers and others.

To that end, several research initiatives have recently begun the most important of which involve EMBRAPA (Agro-energy Center), Petrobras Biofuels Division, and the Bioethanol Research Center –CTBE created by the Brazilian Ministry of Science and Technology.

Furthermore, the São Paulo Research Foundation – FAPESP has supported a study to identify R&D needs throughout the sugar-ethanol production chain. Since 2006, a series of 18 workshops has been conducted involving: Paulista Agribusiness Agency – APTA (including IAC), DEDINI, EMBRAPA Instrumentation, the Federal University of São Carlos, the Sugarcane Research Center-CTC, the University of São Paulo-USP, the Paulista State University-UNESP, and the State University of Campinas-UNICAMP.

1. THE PROMISE OF BRAZILIAN BIOETHANOL

Brazil is a developing country that has become a major producer and exporter of agricultural and agro-industrial products in recent decades and among those products is sugarcane ethanol. In the last ten years, Brazil has become the world's leading exporter of sugar, accounting for 30% of world exports of the product. This has been achieved despite all the protectionist trade barriers that were raised against this agro-industrial product, and without any question it has led to the enhancement of Brazilian sugar's competitiveness in the international market. No other country has such low costs and flexible supplies as Brazil.

The same competitiveness is repeated in the case of bioethanol produced from sugarcane. No other country can presently offer such favorable conditions in terms of cost and supply expansion possibilities as Brazil. The loss of first place in the production of bioethanol to the United States in recent years can only be understood in the light of the high tariff barriers that the US government imposes to protect its domestic markets and the high subsidies that it grants to its own agricultural producers. Brazilian ethanol produced from sugarcane is both more economical and more efficient in terms of carbon dioxide balance (GHG emissions), than the American ethanol produced from maize. This aspect is reflected in the fact that Brazil is now responsible for half of world exports of the product.

The current international context is marked by serious concern with the two major challenges:

- global warming largely caused by burning fossil fuels;
- national policies capable of reducing energy dependence on fossil fuels.

Against this background Brazil stands out very favorably, offering the world an alternative source of energy, bio-ethanol, with its great capacity for mitigating CO_2 emissions.

The production of ethanol is not the only opportunity for developing sugarcane cultivation. That crop can also help to address other important challenges such as generating electricity from a renewable source and producing chemicals from biological raw materials. Far from being endowed with antagonistic goals, those industries and their markets are actually complementary and can benefit one another.

The performance of Brazilian ethanol production is based on a technological system that initially had low production efficiency and high cost, but it was gradually improved due to a process of technological learning very much intensified by the pioneer Brazilian Ethanol Program known as the "Proalcool". The system was mainly developed in the State of São Paulo and is based on the simultaneous production of sugar and alcohol, the so-called “**Brazilian Model**”.

Technological advances have been obtained in both the agricultural and industrial phases. There is better utilization of waste from the production of sugarcane such as molasses, filter cake and vinasse. There has also been a considerable improvement in the productivity of the different varieties of cane obtained by means of traditional genetic selection techniques and improved methods of agricultural management. Although this system has achieved significant increases in productivity, it is now reaching its technological limits.

The current production capacity of Brazilian bioethanol is mainly based in the State of São Paulo, which accounts for approximately 60% of national production.

That leadership results from the following conditions:

- the best land and climate in the country for growing sugarcane;
- better transport infrastructure (roads);
- the best system of specialized research in sugarcane agriculture in the country;
- the presence of capital goods industries for the sugarcane agribusiness.

However, the expansion of sugarcane cultivation in São Paulo state will face serious territorial limitations if current optimistic projections are confirmed. The Canasat sugarcane information project (http://www.dsr.inpe.br/mapdsr/eng/index.jsp) estimates that the 2008/2009 crop of sugarcane occupies an area of approximately 4.5 million hectares, exceeding by far any other crop in the state, although livestock farming occupies an area even larger (about 10 million ha). However, São Paulo state itself is only 3% of national territory. It is therefore expected that to maintain a suitable regional balance, much of the future expansion of the area planted with sugarcane will occur outside of São Paulo state.

Accordingly, the cultivation of sugarcane should mainly expand into the regions towards the Midwest and Northeast, where much of the recent expansion of the Brazilian agricultural frontier has been taking place. The expansion into the northern region (N and NE) would only be acceptable provided it occurred outside of the Amazon Forest.

Furthermore, the technological system on which the expansion of cane production has been based up until now is beginning to reveal important internal limitations. Major changes in the technological trajectory of the cultivation of sugarcane for ethanol production are needed if Brazil is to maintain its leadership in bioethanol production while maintaining its long-term social and environmental sustainability.

Such findings reaffirm the diagnosis that the State of São Paulo is destined to lead the development of the sugar agro-industry much more in the field of technology and logistics than in the aspect of production. That leadership will be in:

- the production of equipment and technologies;
- the transportation of bioethanol produced from the Central-West, to the Tietê-Paraná waterway by a pipeline system connecting it to the Paulinia Refinery, and the ports of São Sebastião (SP) and Angra dos Reis (RJ);
- the generation of new scientific knowledge through its universities and research centers;
- the qualification and training of human resources to enable them to meet the new challenges.

Beyond the trends revealed in current perspectives, the future of ethanol will depend on the evolution of technologies on both the supply and demand side.

On the demand side, bioethanol has the great advantage of requiring very few changes in current technological systems of individual road transport vehicles. When added to gasoline in concentrations of up to 10%, practically no changes are needed in engines or fuel distribution systems. That fact, added to the innovation of the flex-fuel engines increasingly adopted in Brazil and the United States, that allow vehicles to use either ethanol, or gasoline or mixtures of the two, offers the consumer far greater freedom of choice.

However, we should not ignore the possibility that major technological breakthroughs may occur in the transport system leading to the widespread adoption of hybrid cars or electric cars. Even in that case, other opportunities will open up for sugarcane: as a renewable source of electricity, in the direct use of ethanol in hybrid engines; or possibly the use of ethanol as an energy source to produce hydrogen. In our view, rapid technological change in the pattern of demand in no way threatens the position of sugarcane as a primary source of cheap renewable energy and ethanol as a clean combustion fuel.

On the supply side, there are technological challenges. As a result of heavy investments being made by countries in advanced conversion technologies (second and third generation technology), a new horizon of possibilities has appeared. Those technologies can broaden the spectrum of biological materials that can be used in the production of ethanol to include cellulose and hemicelluloses, which are far more abundant and have lower production costs than starches and sugars.

2. THE GUIDING PRINCIPLES OF SUSTAINABILITY AND THE EXPANSION OF SUGARCANE AND ETHANOL PRODUCTION

Seizing the opportunity of producing ethanol to supply both internal and external markets requires a new level of technology that takes into consideration social, economic and environmental indicators. The new level of production must fit in with the basic principles of sustainability.

2.1 Basic conditions of sustainability

The concept of sustainability applied to a product and/or a production process implies an understanding that the production must be: economically viable (i.e., competitive with respect to other similar products without any need for subsidies); socially fair (i.e., the economic feasibility of production may not be based on the exploitation of workers, the existence of inadequate working conditions, should not induce concentration of income etc.); and environmentally adequate. The environmental dimension is the largest, because it involves various aspects related to impacts (on air, water, soil, and biodiversity) in different horizons of time (short-term impacts and long-term cumulative effects) and with different geographical coverage (local, regional or even global impacts).

In regard to the production of ethanol from sugarcane in production conditions typically found in Brazil, the economic dimensions of sustainability has not been object of discussion so far since Brazilian ethanol is the only biofuel that is economically viable without subsidies as compared to gasoline, even at current levels of oil prices (45-50 US$/barrel). Moreover, when that analysis is done for a horizon of 20-30 years and takes into account a significant expansion of production, then the economic dimension needs to be further prioritized. Thus, the medium to long-term goal will be to keep the production costs of ethanol as low as they are now even for levels of production from 4 to 5 times higher and even with the use of so-called second generation technology.

As regards the social dimension, the principles of sustainability discussed internationally delineate the conditions that are considered to be minimally adequate with respect to the principles of the International Labor Organization namely: respect for human rights, and the improvement of the living conditions of the social groups directly involved. What draw negative attention from the international community to the production of ethanol in Brazil is the harsh working conditions imposed on cane field workers. Often the disclosed irregularities are associated to slave labor and inhumane working conditions. Also in the social-economic field there is the common criticism that the ethanol production induces the concentration of income and of land tenure. The environmental dimension, as mentioned above, is now even broader. Based on the principles of sustainability intensely debated in Europe, the priority goal is to reduce net emissions of greenhouse gases (GHG) in comparison with those of the life cycle of the substituted fuel – gasoline, in the case of its substitution by ethanol. In addition to the issue of the net balance of GHG emissions, there is particular concern about the direct and indirect impacts of the changes in land use because of the associated impacts on biodiversity and the provision of food.

Ethanol production in Brazil is also criticized for the fact that the areas of sugarcane cultivation are extensive monocultures or "plantations" and therefore constitute a potential negative impact on biodiversity. The possible impacts on the quality and availability of water, fear of contamination of groundwater associated to the disposal of vinasse, and excessive use of chemicals, including some banned in developed countries are also frequently mentioned concerns. Evidence of unsustainable social and environmental productive relations associated to growing sugarcane, should be located, however, within the context of socio-productive practices that have prevailed in Brazilian agriculture since its emergence in the colonial era and are with us up until the present day, even in the more advanced segments of agribusiness. It would not be very costly, however, and would not in any way jeopardize the economic viability of producing ethanol if socially and environmentally sustainable productive practices were adopted. Such new practices will have important consequences for the future R&D agendas of the public and private sectors in Brazil, and, consequently, for the R&D agenda of the State of São Paulo.

2.2 Recommendations for public policies

All actions related to the expansion of ethanol production and the development of new technologies must be guided by the central objective that future production must be sustainable in the broadest sense.

On the economic side, there is a need to reduce transport costs. If energy and cost-efficient modes of transport were used then GHG emissions and overall costs would be lower. Assessments have shown that in a country of continental dimensions like Brazil, the present form of transporting ethanol by truck to the major domestic consumer centers and to the ports for exports represents a very costly overhead.

Better use of sugarcane products and by-products is essential to reduce production costs and in some cases, to obtain better results in avoiding GHG emissions. In the short and medium-term, the generation of a bioelectricity surplus using by-products and marketing it in the power grid is the best opportunity. Therefore, we recommend the large-scale generation of bioelectricity to better exploit the existing potential.

The so-called second-generation technologies need to be developed to enable the production of biofuels from cellulosic biomass, and the country needs to master the production processes involved. In the case of sugarcane, it would be possible to use residual biomass (bagasse and cane straw, called "trash"), and increase productivity (per tonne of cane per hectare), with the added advantage that such products are available at the factory gate.

In regard to **social aspects**, a central concern in view of the socio-demographic structure of rural areas is the generation of both skilled and unskilled jobs. There must be progressive qualification of persons to perform new functions that will arise directly from the mechanization of harvesting and tillage. However, it is essential that the process should occur in a balanced manner compensating the jobs destroyed by mechanization with the offer of new, more qualified and better-paid jobs.

If the production of cane sugar were to be done mainly in small and medium-sized rural properties by independent suppliers, there would be potentially less social tension and better distribution of income, since small farms preserve more manual work. Key issues are: how to avoid excessive verticalisation in the production of ethanol; and how to provide conditions for small and medium farmers to be competitive (e.g., having access to technology, gaining access to machines and implements).

Therefore, it is essential that there be a technological breakthrough that would enable the adoption of less capital-intensive harvesting technologies thereby preserving employment while at the same time being less aggressive to the environment.

Looking at the **environmental aspects**, it is possible to reduce the impact at this level through an agro-ecological land-use plan. That will minimize the problems associated to the misuse of land, although it is would be of an indicative nature rather than regulatory. Accordingly, it is essential to monitor the results and find ways to improve them. More specifically, such zoning would help to avoid the excessive concentration of sugar as a single activity in a given region as is already the case in certain regions of the state. Much can be done to induce the diversification of crops, providing greater diversity to the agricultural regions, without hurting the principle of economic profitability.

The "Agro-ecological Land Use Plan" should seek to minimize the direct impact of the change of land use, targeting the expansion of cultivated areas into degraded lands, occupied by extensive grazing and livestock. In that way, the expansion of ethanol production could take place without any need for deforestation.

The negative environmental impacts of the cultivation of sugarcane are not restricted to deforestation. The burning of sugarcane before harvesting involves significant emissions of pollutants into the atmosphere and the waste of an important energy resource. Policies to encourage harvesting without burning, and making use of cane straw in all Brazilian states, are essential prerequisites of the new trajectory of sustainable ethanol in Brazil. Similarly, the development of alternative tilling methods for cane needs to be encouraged, first in terms of research and development, and then to define the best techniques to be actually used.

Legal Reserves (RL) and Permanent Protection Areas (APP) are defined by Brazilian legislation. However, even in the state of São Paulo those laws are not fully complied with. What can be done for the effective enforcement of legislation, and in the shortest time possible? New economic instruments are needed here.

Little is known about the effects of the use of fertirrigation in terms of GHG emissions. More specifically, little is known about methane and nitrous oxide emissions associated to the application of fertilizer industry products as a whole. This is a topic that requires further research. Still on the subject of fertirrigation, its long-term effects and the possible contamination of groundwater are also unknown aspects. There is law in São Paulo on the disposal of vinasse, but not in the rest of Brazil. Even in São Paulo, that law is based on limited current knowledge.

The use of chemicals banned in other countries, and in some cases also banned in Brazil must be effectively curbed and the use of fertilizers and agricultural chemicals must be effectively minimized.

In short, there must be a national agenda to lead the sustainable production of ethanol. That agenda should be proactive, defining actions to anticipate the criticism and questioning stemming from all segments of both Brazilian and international society. Furthermore knowledge needs to be produced regarding all the important pending issues and not only in regard to the mitigation of the impacts so often referred-to.

3 A NEW AGRICULTURAL MODEL FOR SUGARCANE PRODUCTION

Agriculture is the key to the success of Brazilian ethanol. An important part of the productivity gains of ethanol were achieved in agriculture. The role of research, particularly in São Paulo, has been the key to that success. The advances obtained resulted in a trajectory based on traditional techniques of plant breeding and the use of state of the art management techniques in agriculture. To avoid that trajectory's becoming exhausted by diminishing returns there must be changes in the degree of agricultural innovation. Advances in the agricultural phase of production are essential to maintain the competitiveness of Brazilian ethanol since sugarcane itself accounts for 70% of the overall costs of any ethanol plant.

Listed below are some guidelines for an R&D policy designed to construct a new development model for the cultivation of sugarcane:

1) Productivity of sugarcane

1.a) Promote basic research on **photosynthesis** in order to understand the main mechanisms involved in the conversion of light into biomass. The photosynthesis reaction is the most important one in the process of biofuel production and is still very little studied in Brazil.

1.b) Encourage research in biotechnology to serve as a basis for increasing productivity by conventional breeding or **transgenics**. Obtaining transgenic plants is a necessary step. More studies should be developed to regulate transgenic plants in a manner consistent with our reality, and issues related to intellectual property rights should also be considered.

1.c) Continue research development for sequencing the **sugarcane genome**.

1.d) Promote the development of varieties of sugarcane with high biomass production with a focus on energy use as a primary function for the optimization and selection of clones and/or varieties. In that context, the clones may be selected in terms of primary energy, i.e. Mega-Joules per ton of sugarcane (MJ/tc). This concept considers the total energy of sugarcane, including fiber, sucrose and reducing sugars, i.e. the selection of so-called "**energy cane**".

1.e) Brazil must make strenuous efforts to establish a **collection of sugarcane germoplasm** for public use, representative of genetic diversity in the Saccharum complex. The largest collection of germoplasm includes many representatives of the Saccharum complex and is now under the management of the Sugarcane Technology Center (CTC) and is restricted to this institution. There are three other collections belonging to existing sugarcane improvement programs: the Inter-University Sugarcane Development Network (Ridesa), the Agronomic Institute of Campinas-IAC (represented mainly by parents for crossing purposes, with few representatives of the Saccharum complex); and the collection of CanaVialis (Monsanto). Any process attempting to replicate the USDA and/or the CTC collection will necessarily be subject to limitations. It is therefore necessary to establish policies for the use and introduction of access to the "Saccharum Complex". Priorities should be given to species with greater potential for use in breeding, and to *S. officinarum* and *S. spontaneum*. However, the *Erianthus* and *Miscanthus* genera are both adapted to unfavorable environmental conditions like cold and drought, have high biomass-producing capacity, and are therefore very interesting for bioenergy purposes.

2) Interaction of sugarcane and the environment

2.a) Investigate **molecular mechanisms** and their physiological responses and undertake the biochemical characterization of the various cultivars.

2.b) Study the **impacts of climate change** on the cultivation of sugarcane.

3) Nutrition of sugarcane and fertilizers

3.a) Encourage studies on new sources of **fertilizer**, with higher efficiency and less impact on the environment; develop microbial systems aimed at greater efficiency in the use of nutrients; and conduct genetic improvement for higher yields in marginal soils with decreased need for fertilizers.

3.b) New studies in fertilizer use for sugarcane should investigate: the question of **fertilizing the subsoil** by means of long-term studies experimenting with doses higher than those currently employed for the purpose of **improving the chemical environment** for root growth in the subsurface which can be especially interesting in regard to those regions with poor soils and very dry winters into which the cultivation of sugarcane tends to expand; the management of long-term **fertilization with N** in sugarcane raw; the contribution of biological N fixation (BNF), one of the possible reasons for the use of smaller quantities of nitrogen in sugarcane in Brazil, has an important role in nitrogen nutrition and should be further investigated, because there is still controversy about the magnitude of their contribution agronomic; assessment of environmental fertilization of sugarcane in an energy-balance perspective, especially in regard to the production of greenhouse gases.

3.c) The use of irrigation in agricultural production, mostly needed in the states of the Central-Western and North-eastern regions of Brazil but it also increases productivity in areas such as the west of São Paulo State. Studies are needed to minimize water use and costs in general, but also new equipment and technologies, need to be evaluated.

4) Control of pests and use of pesticides and fungicides (agrochemicals)

4.a) Bioecological studies involving the biological control of pests are technologies that aim at sustainability and should be encouraged. In particular, alternative intensive monitoring and control methods for the control of the **giant cane-borer**, T. licus, should be sought for immediately as the current control methods are empirical and inefficient.

4.b) Studies must be conducted identifying the **effects of trash and the new agro-ecosystem** formed by the harvesting of unburned cane. New soil pests, natural enemies and entomo-pathogens may be present.

4c) Evaluation of the efficiency of the **biological pest control** (biological and microbial control should be favored by mechanical harvesting).

4.d) Studies for **monitoring pests** (including GIS) and for adequately sampling and rationally controlling them, either through biological or chemical means.

4.e) Studies on the **environmental impacts of chemicals** and alternative controls on the agroecosystem (selectivity, occupation of niches, biological imbalances, resurgence of pests, resistance management).

4.f) Search for and identification of new agents for biological control, involving epizootiological studies of diseases, pest population dynamics, selection of strains and biological control agents.

4.g) Feasibility studies on farmer use of already synthesized pheromones for pest monitoring and control, and conducting research aimed at developing and synthesizing other pheromones in the short, medium and long terms.

5) Use of waste by-products in ethanol production from sugarcane

5.a) There is a lack of basic research and studies of a technical-economic-social-environmental nature to characterize the impacts and/or determine other forms of direct use of the stillage and by-products, such as concentrating vinasse, biodigestion, incineration etc. The recycling of nutrients is already common in sugarcane agribusiness in the form of returning solid and liquid wastes such as filter cake, ash, and especially vinasse to the fields.

5.b) The development of technology for the production of ethanol from cellulosic materials, mulch or trash left over in the process of harvesting unburned cane (stalks and leaves), which may produce vinasse with different physical-chemical properties than the present-day vinasse. That requires the performance of studies aimed at understanding the possible impacts caused on the land and environment.

6) Direct planting of sugarcane

6a) There is a need for research and development of planting machinery with a planting capacity of the same quality as manual planting.

6.b) Research and development of procedures aimed at reducing the movement of soils and soil compaction are needed, allowing for minimum tillage techniques to be applied without loss of productivity.

6.c) New technologies should address issues relating to planting machinery adapted to minimum tillage conditions and the presence of trash and with a planting quality superior to that obtained in traditional planting conditions.

7) Consolidation of green cane harvesting (without burning), recovery of trash

7.a) Analyzing the group of existing technologies, we can conclude that they do not satisfactorily meet requirements in terms of current environmental legislation, efficient recovery of biomass, sustainable use of soil and the ability to operate in areas with the greatest topographic limitations. We must invest in the development of harvesting technology to circumvent those problems and allow for the full exploitation of sugarcane. A major challenge is the development of a system of mechanized harvesting covering the recovery of trash, at least partially, with cost and quality that allow its energy potential to be exploited. It is necessary to encourage the development of specific solutions for the mechanization of sugarcane growing focused on reducing the traffic involved in the tilling process and fostering precision agriculture.

7.b) Development of sampling systems capable of operating on slopes of over 12%, associated to a machinery that can operate with two lines requiring, in principle, increased gauge and improved stability.

7.c) Semi-mechanized harvesting aids. The development of systems to facilitate the manual labor may be a trend in areas where mechanical harvesting is not the appropriate solution. That will help minimize the social problem created by totally mechanized rapid harvesting of raw cane.

7.d) Trash is one of the options for increasing the availability of biomass for co-generation plants in the factories and is also needed in the field to protect soil and improve tillage. Further studies should be conducted to determine what the minimum quantity of plant residue is that should remain in the soil to get the maximum benefit from that coverage, and how much can be released for co-generating purposes.

8) Management and monitoring of sugarcane cultivation

8.a) The development of real time (*in loco*) sensors for the inspection or monitoring of the culture to avoid additional operating costs is a major target of industry and research.

8.b) Investments must be made to enable **the standardization of the on-board electronics of agricultural machinery** and communication between equipment of different manufacturers using open protocols.

8.c) Encourage research in **robotics technology** in the search for greater precision in operations, safety of operators and the highest quality of field operations and equipment delivered to the mill.

8.d) Development of equipment to improve the **monitoring of sugarcane throughout the cycle from planting to harvest**, including the improvement of productivity of the monitoring devices by incorporating information on the quality of the cane.

4. NEW MODEL AND INDUSTRIAL END USES OF ETHANOL

The current production system based on the simultaneous production of sugar and ethanol, located near the consumer market, and supported by the road transport system must be revised in order to become sustainable. The new production system will be located in the hinterland far from the markets and specialize in the production of ethanol alone. The conditions to ensure profitability of this new support system will be a much more efficient use of by-products of sugarcane capable of producing energy and a far more economical transport system.

The following is a list the main policy guidelines for the establishment of a new design:

1) Logistics and transport of cane ethanol

1.a) Establish an integrated sugarcane agribusiness logistics system addressing the **transport of sugarcane**, bagasse (transporting surpluses to a central processing unit if necessary), trash, ethanol, sugar and the vinasse used in fertirrigation.

1.b) Develop studies to optimize the **transport of ethanol** and reduce its costs. The new type of transport could be done through the grouping of units (clusters), and implementation of intermodal transport (river, ethanol pipelines etc.).

2) Reducing the use of water and energy in the industrial process

2.a) Promote the implementation of projects that **reduce the uptake of water** per ton of cane processed. Establish a State Plan for release during the first phase of the paradigm "**Zero Water**" in the production of ethanol.

2.b) Encourage the implementation of projects that **optimize the use** of cane bagasse and cane trash to produce energy, ethanol and sugar, and the use of other products resulting from the processing of biomass.

2.c) Encourage the **production and marketing of electricity surplus**, through the promotion of specific auctions (according to the Aneel regulatory agency rules) and the design and construction of core collectors of electricity to reduce investment in the grid network in more remote areas of the state, creating rules that establish who should bear the costs of interconnection.

2.d) Promote the **generation of power from the stillage**, through its biodigestion, and employing the biodigested stillage residues in fertirrigation in the cultivation of sugarcane. Provide incentives to other forms of stillage exploitation. There is a lack of basic research and studies to characterize the technical, economic, social and environmental impacts stemming from the direct use of the stillage, such as applications of concentrated vinasse, biodigestion, incineration etc.

3) Use of by-products

3.a) Introduce the concept of utilization and valorization of by-products like **yeast**, **higher alcohols**, and others in Brazilian industrial policy.

3.b) Establish an integrated state plan to facilitate the collection of agricultural waste (trash), to be transformed into ethanol or electricity.

4) Environmental control of the application of wastewater

4.a) Establish a plan for environmental control and monitoring of the use of antibiotics in producing ethanol and in stillage applied to soil.

5) Second generation technology

5.a) Develop and deploy second generation ethanol production technology based on hydrolysis induced by chemical means (acid hydrolysis) or biological means (enzymatic hydrolysis) for the recovery of ethanol from ligneous-cellulosic cane waste. That would increase the production of ethanol and/or biofuels and other products in the state, without increasing the area of sugarcane planted.

5.b) Develop and deploy second generation thermal conversion technology known as gasification and pyrolysis in the production of chemicals, biofuels and electricity, using ligneous-cellulosic sugarcane waste. Gasification for the production of electricity creates the possibility of sugarcane increasing its participation in the generation of electricity in the country thereby reducing the environmental impacts stemming from the implantation of large hydroelectric projects Gasification for producing synthetic biofuels (Fischer-Tropsch) will open a new route, possibly the most economical being hydrolysis, to obtain biofuels from ligneous-cellulosic waste, or even from whole cane. Together with pyrolysis it offers a promising new possibility of obtaining bio-products that could replace those derived from petroleum.

6) Development of ethanol and sugar chemistry

6.a) A whole range of bio-products can be developed by using sugarcane derived biomass, sugar and/or ethanol and transforming them into other products with added value.

7) Industrial process control and monitoring

7.a) Deploy faster and more accurate methods of measurement on line to reduce losses and enhance control throughout all stages of sugarcane processing.

7.b) Create and maintain updated (through lines of credit and encouragement and special training programs) reference laboratories for the monitoring and supervision of the quality of ethanol fuel sold in the state.

7.c) Create a state "quality seal" (or actively participate in a national seal being developed by the Inmetro) for the sugar-alcohol sector, resulting in the adoption of quality standards for products and in implementing a traceability system to control all links of the production chain and marketing.

8) Synergy in the production of ethanol and biodiesel

8.a) Facilitate integrated production of ethanol and biodiesel in the state, encouraging the use of ethanol in the biodiesel production chain and the substitution of diesel fuel used to harvest and transport cane, using instead the biodiesel produced in the plants themselves.

8.b) Develop technology enabling the substitution of diesel oil by ethanol or biodiesel fuel in cane harvesting and transport.

5. TOWARDS A NEW MODEL FOR POLICY INNOVATION

Considerable investments in R&D in the areas of agricultural production and industrial processing are necessary in order to achieve the desirable scenario of a new model for sustainable agricultural and industrial production of ethanol. That model will not arise from a simple progressive and automatic adjustment of the current production system to market stimuli and incentives alone. It presumes there will be more effective leveraging of a far greater volume of resources and the coordination of initiatives to introduce considerable changes in the current path of production in the sugarcane agro-industry.

Besides the technological goals listed above, it is up to public policies in combination with the relevant stakeholders in the sector to improve the scientific density of the technological innovation system in Brazil. To that end, two other points deserve attention: the need for constant training of human resources at high level and the need to undertake basic research.

If Brazil wants to continue heading the bioethanol field, it will have to convert its current advantage in production into effective scientific and technological leadership. That could be achieved through the publication of researcher's work in important journals, and through its companies' leading the industry in terms of registering new patents making it clear to the international community how well the country manages staff qualification and technological developments in the sector.

To achieve such a quantum leap instead of the essentially incremental progress that has been the tradition up until now, the institutions and agencies involved in fostering such activities at state and national level must mobilize resources for innovation and to provide good training for staff in both the agricultural and industrial stages of production. The quantum leap will only occur if there is an articulated and coordinated policy on innovation.

Accordingly, it is very important to invigorate the public sphere of science and technology associated to ethanol by:

1. Revitalizing Research Centers of the APTA (IAC. IB, IZ, ITAL, IEA and others).
2. Promoting mechanisms of cooperation with other public and private centers (IPT, CTBE, CTC and the universities themselves) as for example in the case of Fapesp's Bioen Program in which an expressive volume of resources is directed to applied technology issues in association with the private sector (Oxiteno, Dedini and Braskem).

A policy with national dimensions is essential and must contemplate the following actions:

1. To support graduate and post-graduate programs which operate in subjects and themes related to biofuels, both in the agricultural phase and in the consumption phase. To reinforce programs such as Fapesp's Bioen, which encourage basic research related to sugarcane and bioethanol, and which promote cooperative research between University-Corporation.
2. Providing mechanisms for coordination and joint actions of state agencies (Fapesp, Department of Development, APTA, IPT and other research institutions, state) and federal government agencies (Embrapa, Inmetro, ABNT, ABDI, Finep, CNPq, BNDES) for the creation and implementation of technology programs for Ethanol (Second Generation Technologies, Flex Hybrid Cars, Power Pole etc.).
3. Creating mechanisms for the integrated use of Sector Funds, Resources and the Participation of Aneel's special ANP, and Fapesp in promoting coordinated action between the Federal Government and State; consolidating programs such as the Fapesp Bioen Program to encourage basic research related to sugarcane and bioethanol; and promoting cooperative research activities between the Universities and Private Enterprise.
4. Supporting the FAPs in structuring an agenda for research conducted in other states with the greatest potential for the expansion of sugarcane (MS, MT, GO, TO, BA, MG, PI, MA).
5. Promoting technology-based companies, suppliers of goods and services to the sugar-alcohol sector, and the creation of technology parks in bioenergy (as for example, Vale in São Jose dos Campos, and the Energy City of San Carlos) through Sebrae, BNDES, the Bank of Brazil, Finep and the Development Department of the São Paulo State Government.
6. Developing an agenda for international cooperation in research in the area of bioenergy with strategic countries endowed with the capacity for innovation or of geopolitical importance, articulated by Fapesp, CNPq, Finep and Embrapa.
7. Translating efforts to implant the certification of ethanol (Inmetro and Europe) into items on the research agendas together with technological innovation to overcome the associated technical difficulties.
8. Integrating ethanol-promoting policies into the national energy policy and putting them on the national climate change agenda making use of the CDM to accelerate technological innovation and foster demonstration projects (e.g., recovery of straw and trash and their use in CHP) in the sugar-alcohol sector.
9. Developing a policy to encourage Patent and Intellectual Property registrations in the sugar-alcohol sector in collaboration with the Inpi.
10. Consolidating a promotional and regulatory system at both state and federal levels that fosters the adoption of new technologies consistent with the new model of ethanol production.
11. Making efforts to create and establish Legal and Regulatory Frameworks for the development of the sugar-alcohol sector that reflect all internal and external requirements (e.g.

certification) in order to construct a better scenario over the coming years or decades. An example of a successful regulatory framework led by the SMA/SP was the State Law that was implemented to put an end to burning and had important impacts on the process of mechanization, reduced low grade employment (casual day-workers), and induced positive effects on other Brazilian regions, as well as improving the image of Brazilian ethanol.

12. Creating lines of low-interest credit (BNDES, Banco do Brasil) and tax abatement mechanisms for federal taxes (IPI) and state taxes (ICMS) destined to stimulate financing and acquisition of more energy-efficient and socially and environmentally sustainable equipment (high-pressure boilers, co-generation equipment, harvesters with low levels of soil compaction, biodigestors for vinasse etc.).

FINAL CONSIDERATIONS

In the short term, Brazil needs to implement a series of public policies to promote the long-term competitiveness of its bioethanol.

If the country wants to respond to criticism, particularly foreign criticism, as to how large quantities will be produced, it has to focus not only on cost reduction but also sustainability aspects such as soil use, fertilizers, water use, and others.

To a large extent the answer to those questions lies in the development of technologies that will help to decrease negative impacts by requiring less land and at the same time guaranteeing long-term sustainability.

Those technologies are not available yet. They need to be developed, mainly in Brazil, because the country hosts nearly 30% of all cultivated sugarcane areas in the world.

Nevertheless in Brazil it is a relatively small crop area when compared to the areas under maize, wheat, rice and soybean.

The implementation of more R&D efforts will be a big challenge for Brazil to face because the necessary improvements require well-established research infrastructure and human capacity. Furthermore, the gains obtained in the last 30 years after the demise of the Proalcool, were obtained in the face of only moderate difficulties as compared with the difficulties involved in the development of second generation technologies.

Brazil is reasonably well prepared for the challenge however as the country already produces more than 10,000 PhDs a year and has an important research financing organizations with agencies such as Fapesp, CNPq and Finep endowed with respectable funds.

The challenge is how to put together public and private research funds and pursue goals that can doubtless be achieved, but that must, at the same time give satisfactory answers to foreign consumers and publics, and help to satisfy domestic needs such as the one represented by the electricity demand looming in the near future.

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POSTFACE

Luís Augusto Barbosa Cortez and *Carlos Henrique de Brito Cruz*

This book is a compilation of texts written from Fapesp's Ethanol Public Policies Project – PPP workshops, or by authors invited for the relevance of their work in the sugarcane ethanol subject. This provides closure to the Ethanol PPP Project, or at least to its first phase.

However, some important themes failed to be covered. Such is the case of automotive engines and their development, ethanol fuel cells, and ethanol hybrid cars, to mention the automotive use of ethanol, currently its leading application. All the issue related to the mid and long-range term of the automotive industry and its energy, were not covered here. The outlook of ethanol as a fuel was not discussed either; its future, if it remains in the Brazilian and global energy matrix for a long time, or if it is replaced by some other higher energy density fuel e.g. buthanol.

As it is widely known, Brazil became the leader in producing ethanol from sugarcane, gradually improving its agro-industrial productivity indexes (1975-2010). This took place due to several factors, including successful long-term policies that resulted in incremental gains. However, the present situation is quite different, requiring technology leaps increasingly based on science. For instance, sugarcane agriculture must be rethought, making it a modern, waste-free agriculture, with a better understanding of photosynthesis and genomics, using rationally all natural resources. This will imply redeveloping a new agriculture, not for sugarcane alone, but a new model of land usage in Brazil, considering the proper use of space, protecting biodiversity, and ensuring the integration of food and energy production. This process has already begun with agricultural zoning; however, but planning and implementation is a long-term assignment.

For this reason it is a must that from now on, we conceive a new model for whole sugarcane exploitation, promoting an actually sustainable production system, placing the human being and its welfare in the center of all discussions. Regarding conversion technologies for wholly exploiting sugarcane, present discussions cover a whole family known as "second generation" that spans from hydrolysis and its variants to thermal conversion (pyrolysis, gasification etc.). Each of these technological variants may bring some special benefit to Brazil. It is necessary to analyze them, understand their hurdles and opportunities.

In this sense, given the complexity of the subjects covered and their evaluation, we consider it important to include in this book a first attempt to build a roadmap for each major agricultural and industrial component. We consider that the chapters for the roadmaps, in spite of having been thoroughly discussed by many specialists, cannot be deemed final; on the contrary, they are a first step in the difficult journey of building a modern biomass civilization. The final part of this book comprises a summary of the main conclusions in a chapter entitled "Public Policy Guidelines". In each area, bottlenecks were pointed out, and investments and other policies were recommended.

We hope that the text presented herein will, in some way, help young researchers in this important moment the world is going through, while considering sugarcane as a possible source for liquid fuels, bioproducts (plastics, among others), and bioelectricity. Different centers are actively involved in bioenergy in Brazil (Centro Paulista de Bioenergia, Laboratório Nacional de Ciência e Tecnologia do Bioetanol – CTBE, Embrapa Agroenergia) and abroad (National Corn to Ethanol Research Center – NCERC, DOE Bioenergy Research Centers in the USA), among others. These initiatives associated to Fapesp's Bioen Program, new Fapesp partnerships with corporations (Dedini, Oxiteno, Braskem, and Vale), in addition to federal government actions to foster research may – if well coordinated – be successful on the long run.

It is expected that, in the next few decades, the bioenergy area as a whole will undergo an important leap. It should be noted here that in many countries neither energy assurance nor biofuels production and use to mitigate GHG emissions are important issues, but they are seen as means to generate wealth from innovation.

It is very important to remember that sugarcane, though being a large culture in the São Paulo state, where it occupies 5 million ha (20-25% of the state area), is not very representative throughout Brazil, where it takes 8 million ha (1% of the total land), and less than 20 million ha worldwide. Each of other cultures such as wheat, corn, rice, and soy individually surpasses 100 million ha, therefore attracting more investments in science and technology. Thus, sugarcane is increasingly a Brazilian agenda, and Brazil should stay alert for the science and technology development in this area, as most of innovation should take place right here, since we intend to remain leaders in sugarcane ethanol.

Another point to be remembered is the rapid corporate transformation taking over the sugar-alcohol industry, with mergers and acquisitions, and the implications this will have in science, technology, and innovation. It is expected that the new groups will be growingly sensitive to innovation in the energy and green chemistry areas, increasing the industry income.

In this sense, upon closing this book, it is important to leave here a final message that innovation, as well as socio-economic development, so much longed for by Brazil and developing nations alike, will only happen with a new generation of high level human resources. People are an unrelinquishable demand for innovation, hence, at this time, if there is an area where it is worthwhile to invest heavily, it is in the development of human resources at all levels, above all investing in people who are willing to work hard, to grow, to associate their future to the future of sugarcane ethanol, and to the future of the country.

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