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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

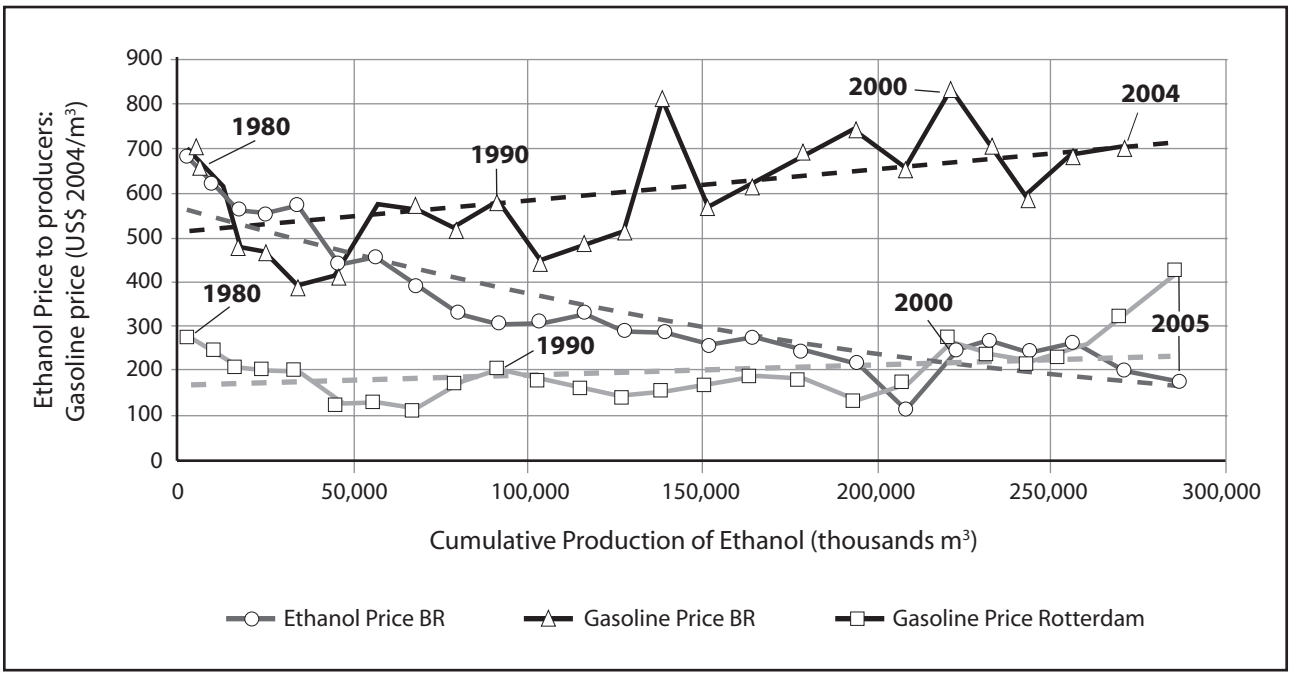


FIGURE 1 Learning Curve – Brazilian Ethanol.

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.

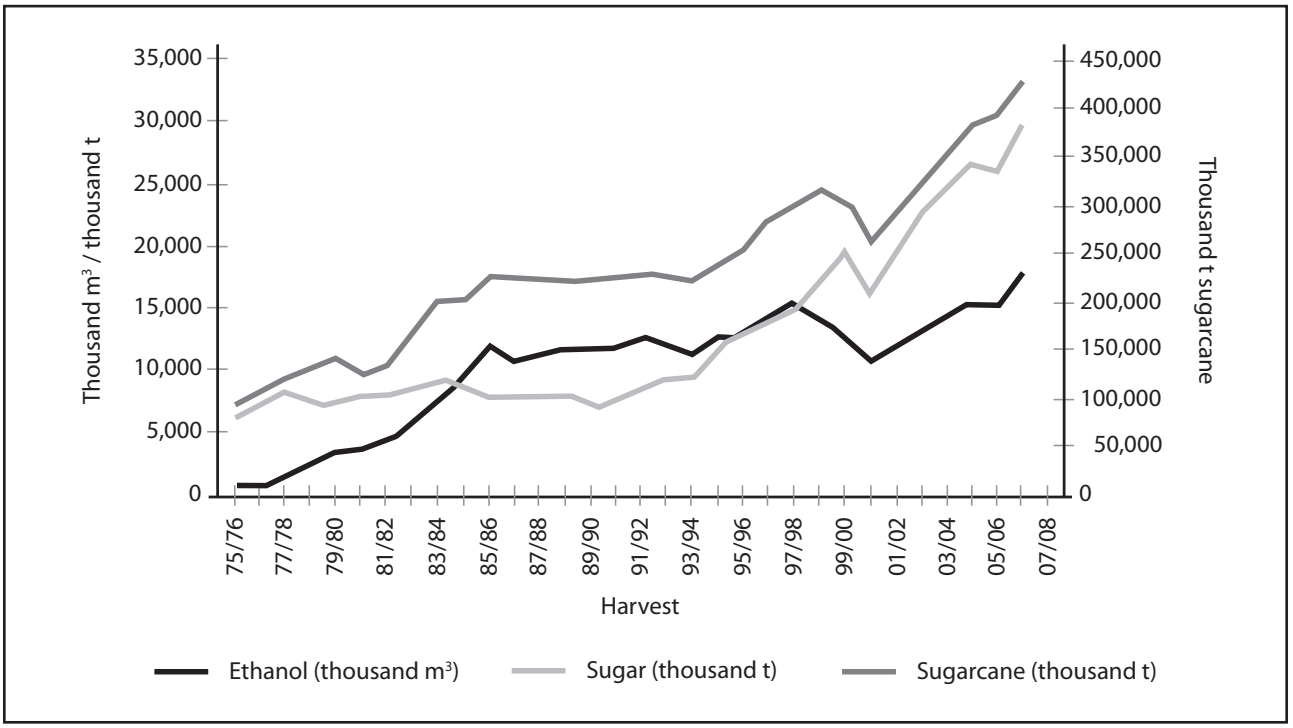
PERSPECTIVES OF ETHANOL PRODUCTION EXPANSION

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.

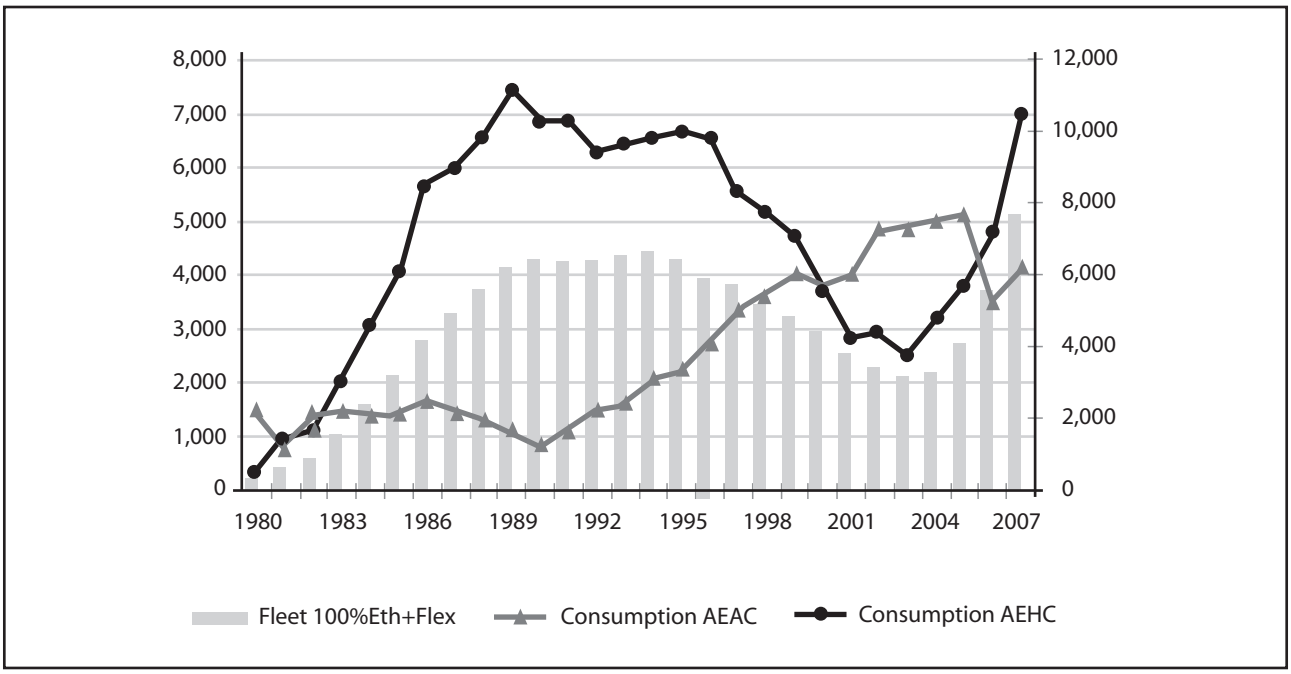
This model is known as "Brazilian model," and in this sense the expansion of ethanol production would be dependent on sugar production expansion. What happens is that today c. 50% of sucrose goes to ethanol and 50% to sugar. This percentage tends to increase driven by the rapid raise of flex-fuel vehicles (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.

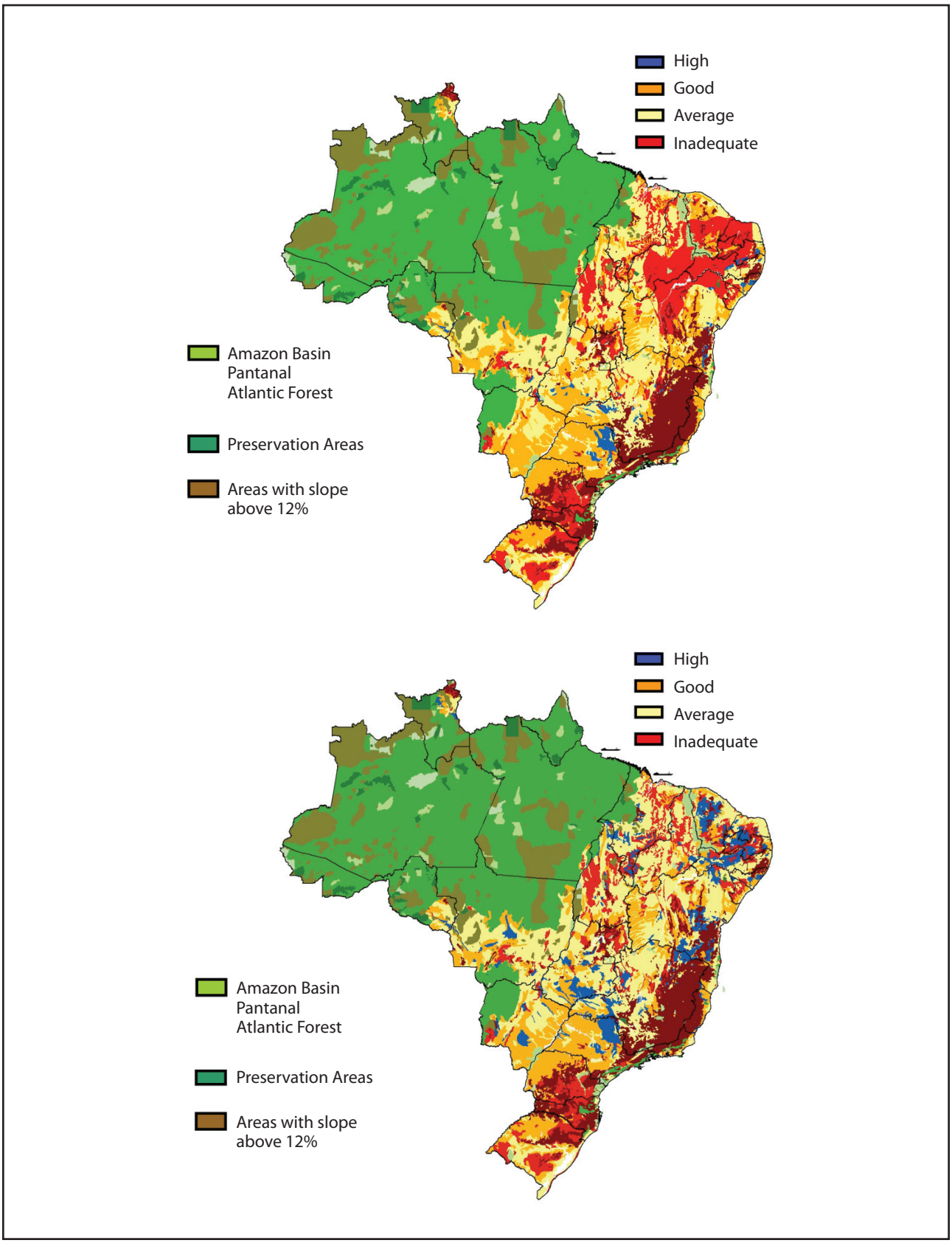
Environmentally, there are benefits from using ethanol fuel rather than gasoline. Among the benefits, perhaps the most important, is the reduction of greenhouse gas emission significantly, mainly the carbon dioxide (CO_2). It is also important to emphasize that the NIPE research group is also carrying 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

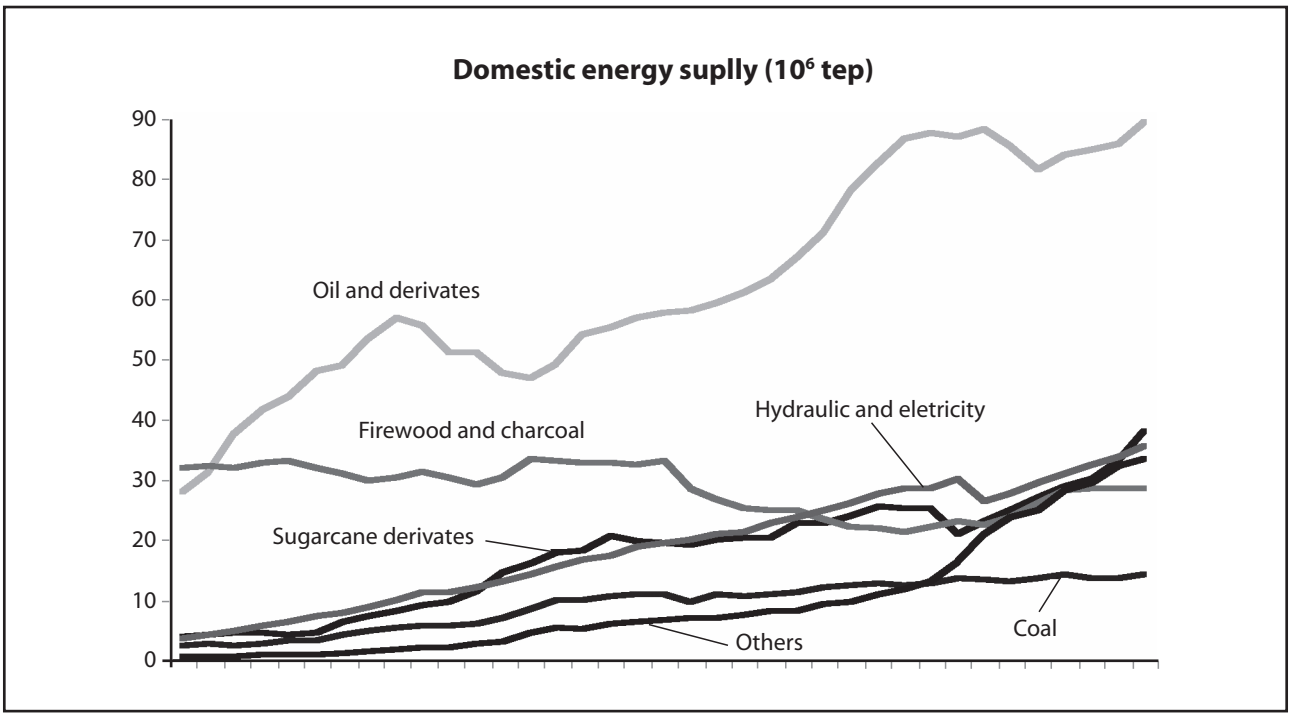
These consist of the following. The Federal Government, through the Ministry of Agriculture, Livestock and Supply – MAPA (2005), Ministry of Science and Technology – MCT, Ministry of Mines and Energy – MME, and Ministry of Development, Industry and Foreign Trade – MIDIC, who have produced the Guidelines 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.



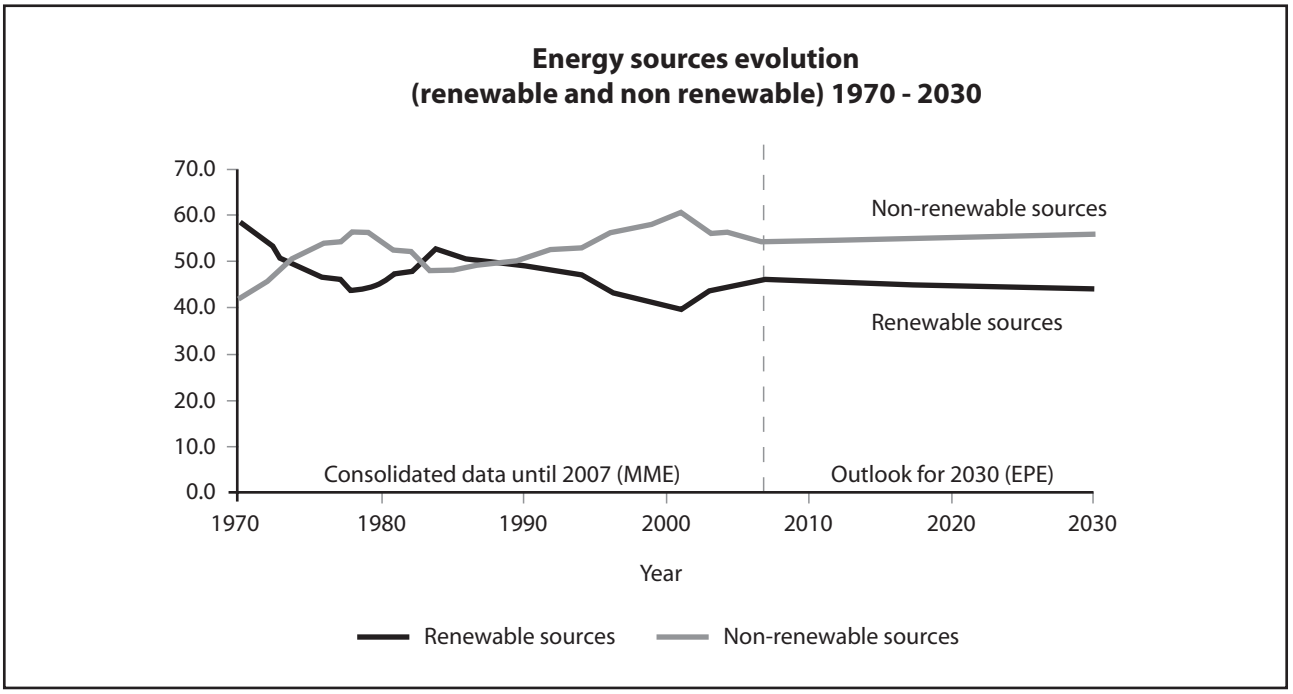
Source: LEITE, R. C. C *et al.*, 2005.
Areas excluded from the study: *green: Amazon and Pantanal, dark green: preservation áreas, brown: slope >12%.*
Areas included in the study: *blue: high productivity, orange: good, yellow: world average, red: inadequate.*

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*.

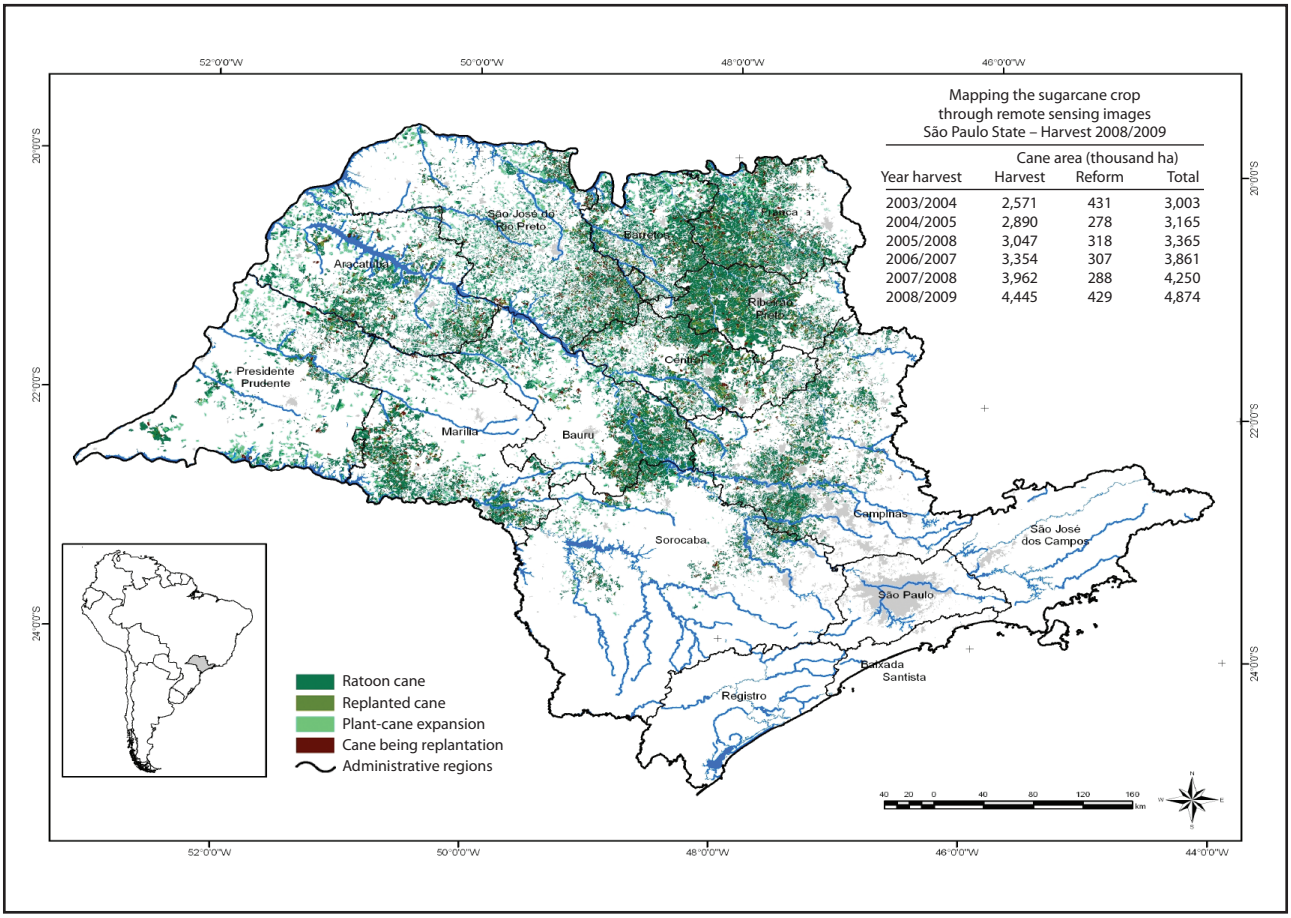
According to the *Brazilian National Energy Balance from MME* (2008), Brazil produced 45.9% of renewable energy in 2007, of which 14.9% is hydro, 15.8% was from sugarcane, 12% from wood and charcoal, and others, 3.2%, from other renewable sources. The Brazilian industry, woodfuels provide 7.4% and sugarcane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

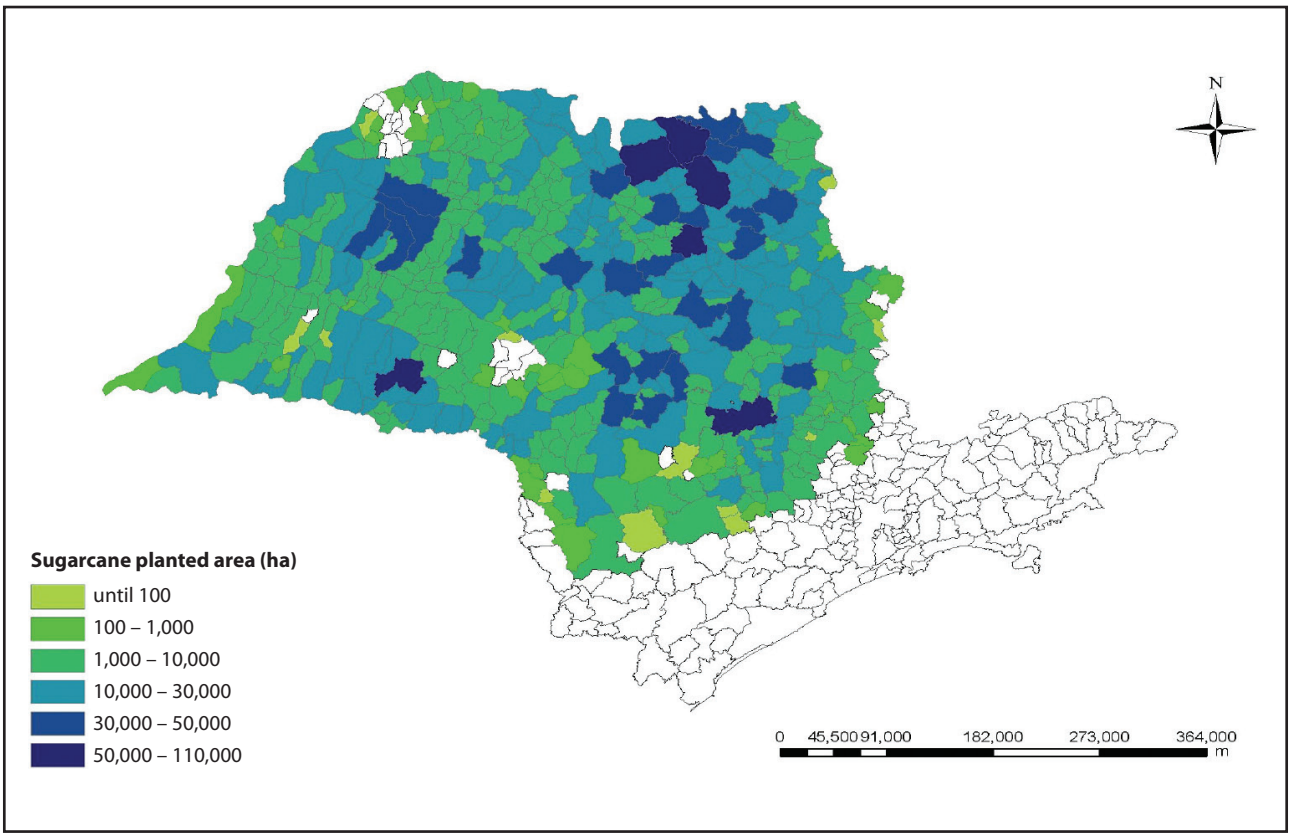
The State of São Paulo is also a leader in many other agricultural products and has the country largest agribusiness. For example, the Sate is responsible for 1/3 agro industrial GDP of Brazil representing 22% from ICMS collected. It has more than 190 thousand km^2 of agricultural land in addition to 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.

ACKNOWLEDGMENTS

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