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CONTEXTUALIZATION AND ASSUMPTIONS FOR THE TECHNOLOGY ROADMAPPING FOR ETHANOL

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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

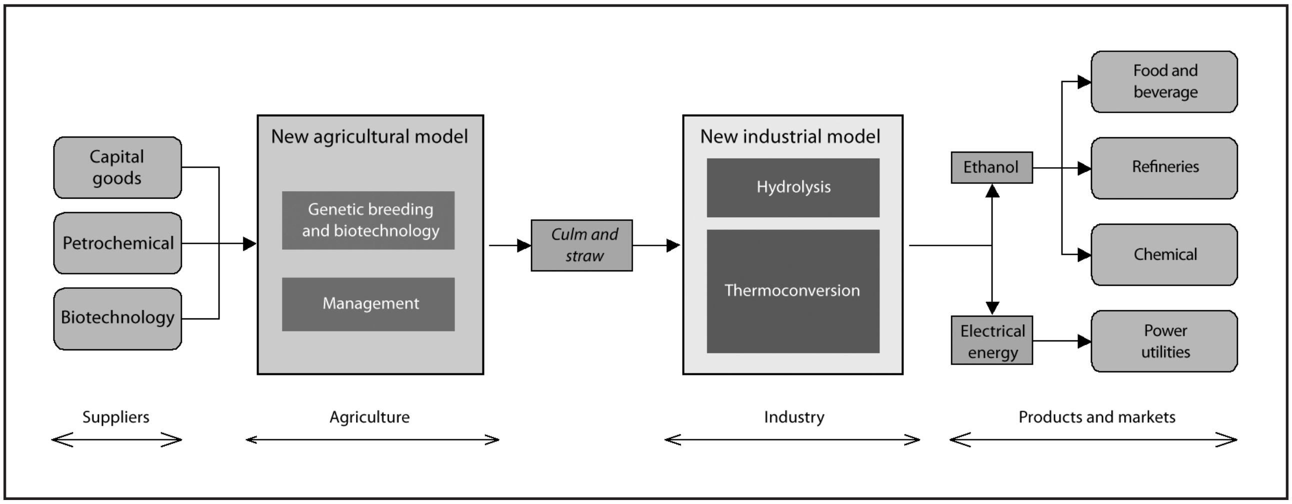


FIGURE 1 The four TRM Components.

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 2^{nd} 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

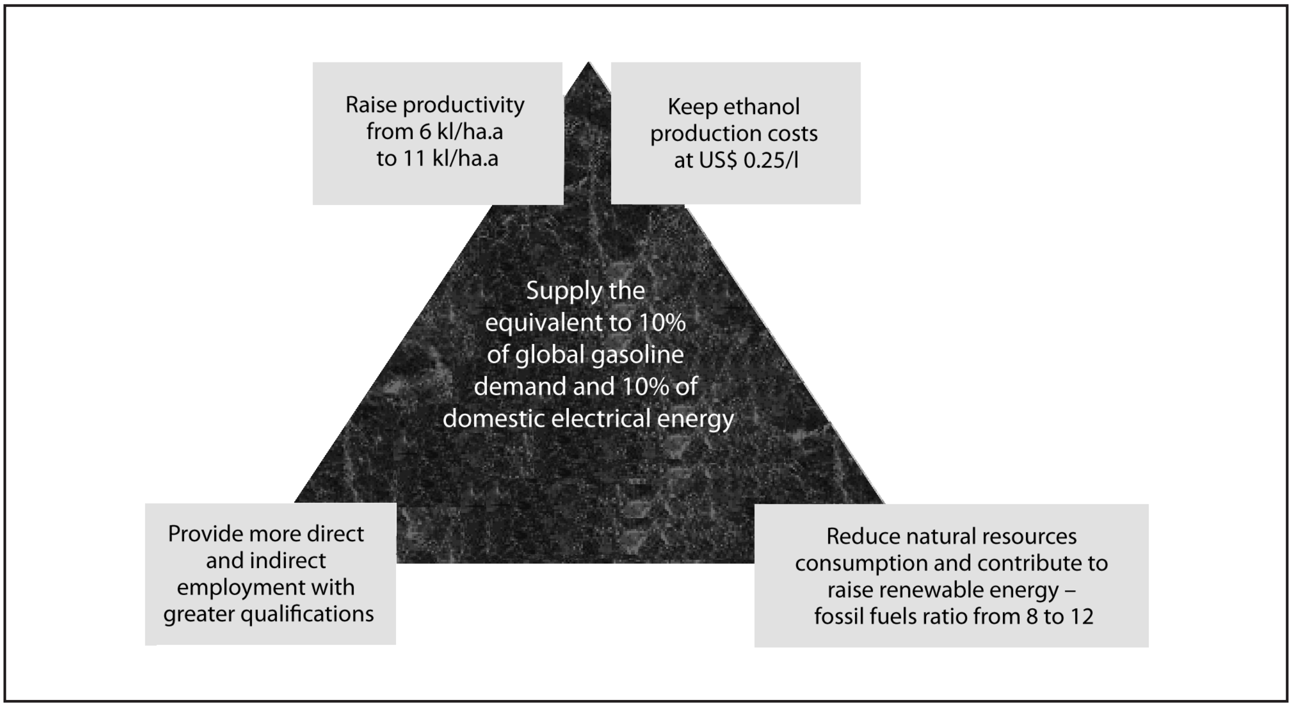


FIGURE 2 Strategic objectives for the next 20 years.

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.

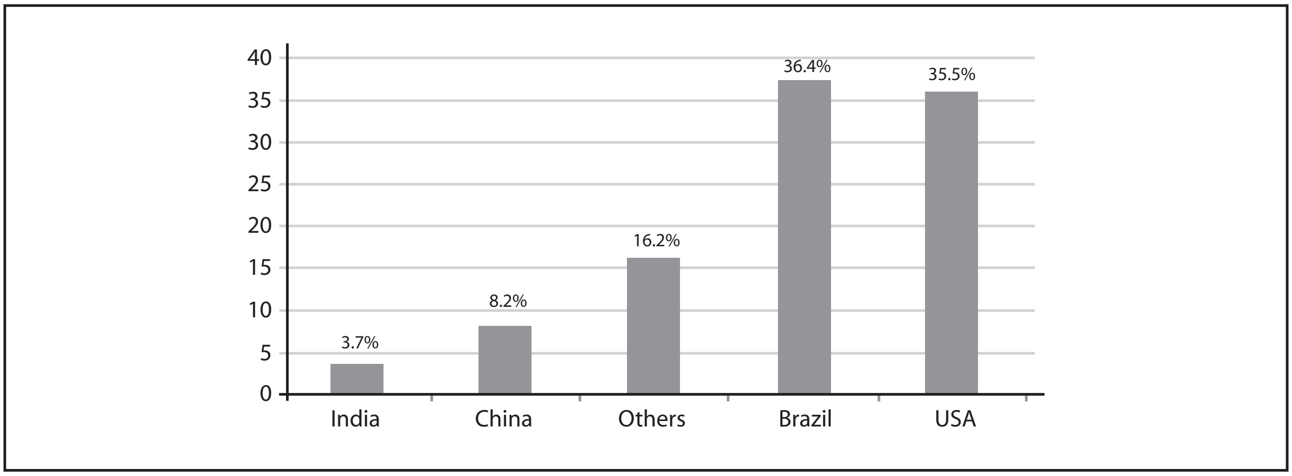
However, developed countries invested heavily in ethanol production from lignocellulosic materials, either by hydrolysis as routes for gasification followed by synthesis (Fischer-Tropsch process and others), with the expectation of achieving production costs in the medium term similar to the current 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.).

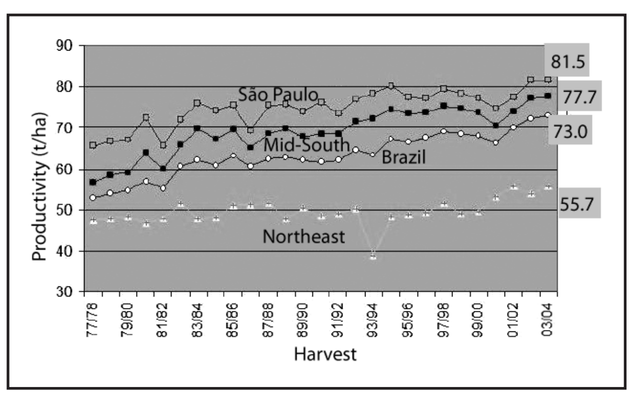
Processes

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

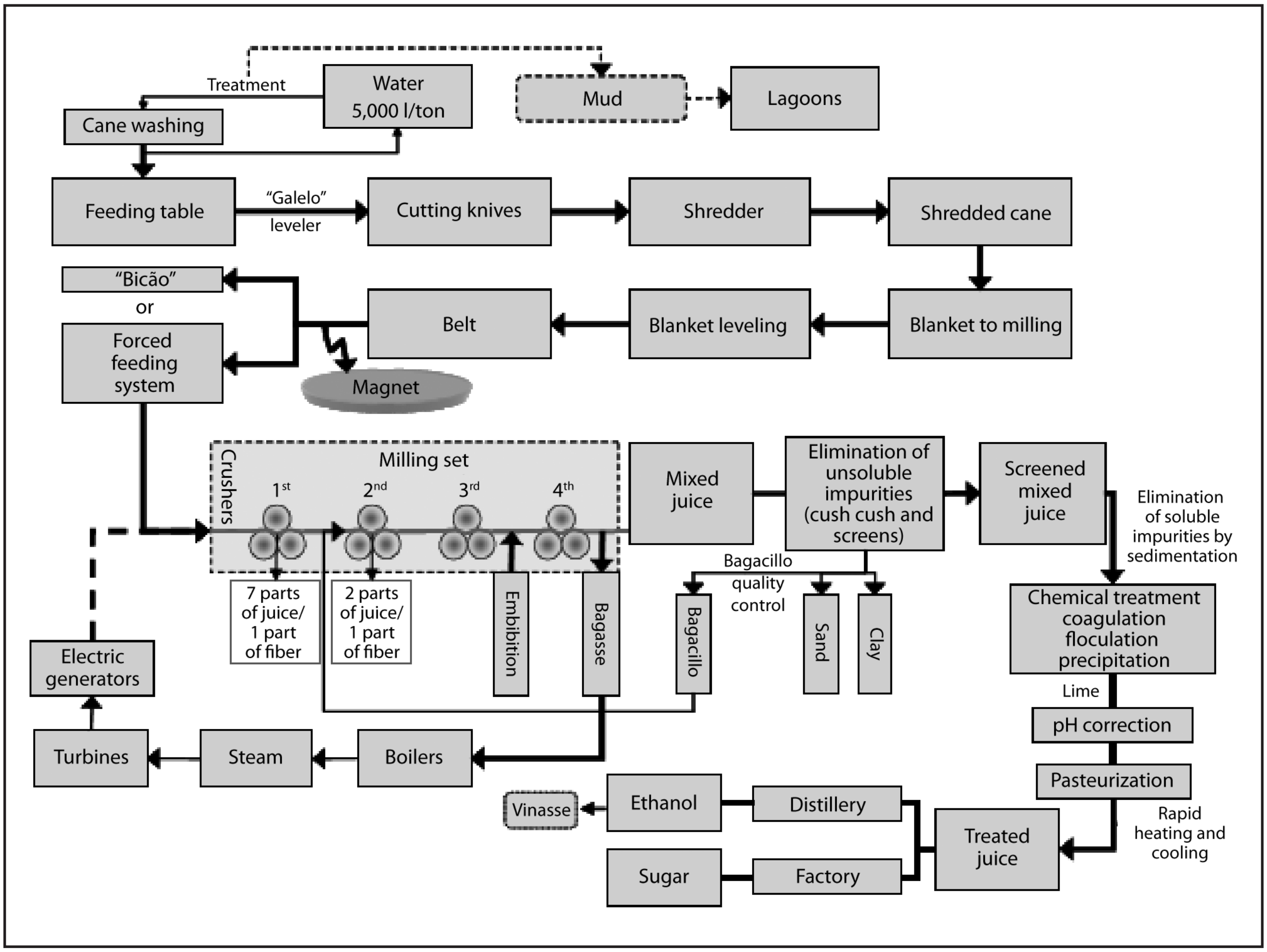
In the 2003/2004 harvest, Brazil had 320 processing plants sugarcane, and 226 installed in the Center-South and other 94 in the north-northeast. The type of production units are divided into plants, mills with distilleries and independent distilleries, the first produce only sugar, the latter producing 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.

Products	Clients	Producers	Production Model
Sugar	Food industry	Brazil and India	• 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.
Alcohol	Fuel distributors and chemical and beverage industry	Brazil and USA	
Electric Energy	Sugarcane industry, but also utilities and independent consumers		

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.

Country	Billion liters per year					
	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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