Chapter 6

Sugarcane bioethanol in Brazil

Sugarcane bioethanol has been used as a fuel in Brazil for almost 100 years. Its evolution traces an interesting history, from the progressive construction of institutional infrastructure and the evolution of agroindustrial technology (which in themselves shows an exemplary trajectory of gains in productivity) to the steadily increasing importance of environmental aspects, such as the need to reducing water consumption and recycling it. In the paragraphs that follow, the Brazilian experience will be discussed in depth. The analysis starts with an overview of the historical use of bioethanol as fuel, stressing the crucial role played by a legal and institutional infrastructure created along the process, which has paved the way for this alternative energy source to become a vital component of the Brazilian energy matrix. The second section presents the current situation of bioethanol production in Brazil, especially regarding the issues of production facilities and perspectives for development of production. The last section explores the evolution of bioethanol technology innovations, focusing on the research and development of methods, equipment and processes that have enabled the sugarcane agroindustry to consolidate itself as a sustainable energy source.

6.1 Evolution of bioethanol fuel in Brazil

In 1903, the *I Congresso Nacional sobre Aplicações Industriais do Álcool* (First National Congress on Industrial Applications of Alcohol) recommended the development of infrastructure to produce automotive bioethanol in Brazil [Goldemberg et al. (1993)]. The *Estação Experimental de Combustíveis e Minérios* (Fuel and Mining Experimental Station) — which later became known as the *Instituto Nacional de Tecnologia* (INT) (National Technology Institute) — was created in 1920 and many successful tests on bioethanol driven vehicles (called «motor alcohol» at the time) were conducted there at that time. The stated objective was to substitute petroleum-derived gasoline, a product that had always been scarce and whose price tended to increase over time [Castro and Schwartzman (1981)]. Several pioneers at that time promoted the use of bioethanol to power vehicles: Heraldo de Souza Mattos, who took part in car races using pure hydrated bioethanol as fuel, in 1923; Fernando Sabino de Oliveira, author of a book entitled *O álcool-motor e os motores a explosão* (Bioethanol and the internal combustion engines), published in 1937; and Lauro de Barros Siciliano, author of dozens of studies on the use of bioethanol in engines, who conducted bench and road tests, in an attempt to spark the interest of government and entrepreneurs [Vargas (1994)].

Ford vehicle adapted by INT in 1925 for demonstrations of the use of bioethanol as fuel.

Based on these experiences, in 1931 the Brazilian government implemented a compulsory blend of at least 5% anhydrous bioethanol in gasoline (Decree 19.717, signed by President Getúlio Vargas), aiming to reduce the impacts of total dependence on petroleum-derived fuels and take advantage of excess production in the sugar industry. Initially, the mandate applied only to imported gasoline, but later it was also requested for domestically produced gasoline. The responsibility of establishing prices, production quotas per mill and fuel blends was assigned to the *Instituto do Açúcar e do Álcool* (IAA) (Sugar and Alcohol Institute). Therefore, the use of bioethanol as automotive fuel (already known to the automotive industry for over century) has been a regular practice in Brazil since 1931, practically contemporaneously with the introduction of the automobile as a means of transportation in the country.

The amount of bioethanol in Brazilian gasoline varied over successive decades, reaching an average of 7.5% in 1975, when the effects of the first petroleum crisis imposed the need to expand the use of this biofuel in cars. Due to high international petroleum prices, import expenditures expanded from US$ 600 million in 1973, to US$ 2.5 billion in 1974, triggering a US$ 4.7 billion trade balance deficit. These results came to weigh heavily on Brazilian foreign debt and inflation over the course of the following years. In today's energy market context, with different countries considering bioethanol as an energy option, it is worth looking at the main historical influences that have enabled the consolidation of bioethanol fuel production in Brazil.

In the mid-1970s, aiming to address the post-oil-crisis energy situation, a proposal was developed to reduce to dependence on imported oil. The proposal involved visionary entrepreneurs like Lamartine Navarro Jr. and Cícero Junqueira Franco and combined the preferences of the Sugar and Alcohol Institute for the exclusive production of bioethanol in independent distilleries, as well as the interests of Copersucar (the main sugar producers cooperative), which intended to take advantage of unused capacity of sugar mills. After discussions between the private sector and the government, a document with recommendations was submitted to the *Conselho Nacional de Petróleo* (National Petroleum Council) in March 1974 [Bertelli (2007)].

Another relevant factor that encouraged a positive government stance for increasing the use of bioethanol was a visit by the then President Ernesto Geisel, in June 1975, to the *Centro Tecnológico da Aeronáutica* (Aeronautical Technology Center). During that visit he was shown successful results from research carried out by Professor Urbano Ernesto Stumpf on bioethanol use in engines, utilizing gasoline with high levels of anhydrous bioethanol, and also from testing the use of pure hydrated bioethanol in specially adapted engines. It was clear that Brazil could provide itself with a good solution to the oil dependency problem: On the supply side, it could increase the production of bioethanol using the idle capacity of sugar mills; on the consumption side, it could increase the amount of ethanol in gasoline, and eventually use pure bioethanol as a fuel.

Based on these premises, and after new studies and debates, in November 14, 1975 the Federal Government instituted the *Programa Nacional do Álcool* (National Alcohol Program – Proálcool), through Decree 76.593 signed by President Geisel. The decree established special lines of credit, formalized the creation of the National Alcohol Commission (CNA) responsible for managing the program, and determined a price parity between bioethanol and standard crystal sugar. The objective was to stimulate the production of this biofuel, which had been, until then, an undervalued by-product. In this context, production goals were set of 3 billion litres of ethanol for 1980, and 10.7 billion litres for 1985. Several incentives to expand the production and use of bioethanol fuel were implemented, initially by increasing the addition of anhydrous bioethanol to gasoline. The oversight of Severo Gomes, Minister of Industry and Trade, and the support of José Walter Bautista Vidal, Secretary of Industrial Technology, were decisive in the early years of Proálcool implementation, when the initial program took shape. Later on, during the most important expansion phase, which started in 1979 under Minister João Camilo Pena, the commitment to bioethanol fuel became evident and the foundations for its consolidation were put in place. Serving as a message from this pioneering generation, the book *Energia da biomassa – Alavanca de uma nova política industrial* (Biomass Energy: In praise of a New Industrial Policy) points to the need to transcend conventional energy systems in order to become a «photosynthesis civilization» [Guimarães et al. (1986)].

With a decidedly favourable legal climate, the production of bioethanol expanded significantly. Between 1975 and 1979, bioethanol production (anhydrous and hydrated) grew from 580 thousand m^3 to 3.676 million m^3, surpassing the goal established for that year by 15%. In 1979, with the oil crisis worsening and prices reaching new heights, the Proálcool program gained new force, stimulating the use of hydrated bioethanol in engines adapted or specially made to work with it. At that time, Brazil's dependence on imported oil was around 85%, accounting for 32% of all Brazilian imports. This had serious impacts on the national economy and justified the ambitious goal of producing 10.7 billion litres of bioethanol in 1985. To this end, via Decree 83.700 of 1979, the federal government increased its support for alcohol production with the creation of the *Conselho Nacional do Álcool* (National Alcohol Council – CNAL), which oversaw Proálcool and the National Executive Commission for Alcohol (Cenal), responsible for implementing the program [CGEE (2007a)]. Under this scenario, bioethanol production reached 7.7 billion litres in 1985, exceeding the intended goal by 8%.

The combination of incentives adopted by Proálcool (which had shown itself to be capable of effectively influencing economic agents) at the time included: a) establishing higher minimum levels of anhydrous ethanol in gasoline (progressively increased to 25%); b) guarantying lower consumer prices for hydrated ethanol relative to gasoline (at the time, fuel prices throughout the entire production chain were determined by the federal government); c) guarantying competitive prices to the bioethanol producer, even in the face of more attractive international prices for sugar than for bioethanol (competition subsidy); d) creating credit lines with favourable conditions for mills to increase their production capacity; e) reducing taxes on new cars and on annual registration fees for hydrated bioethanol vehicles; f) making the sale of hydrated bioethanol at gas stations compulsory; and g) maintaining strategic reserves to ensure supply out of season.

Around 1985 the situation began to change because of falling crude oil prices and strengthening of sugar prices. These events made ethanol production unattractive and created difficulties to the bioethanol industry that led to the end of the expansion phase of Proálcool. In addition, in 1986 the Federal Government reviewed incentive policies to bioethanol thereby reducing the average sugarcane agroindustry returns and stimulating even more the use of the available raw sugarcane to produce sugar for export. An important consequence of the reduced attention given by the government to bioethanol and of the absence of specific policies to support its production was that in 1989 consumers began facing sporadic supply shortages of this biofuel. The mechanisms to create safety reserves failed and emergency measures became necessary, such as reducing the level of bioethanol in gasoline, importing bioethanol and using gasoline-methanol mixes as a substitute for bioethanol.

A tough consequence of the bioethanol supply crisis — by the way, a national product whose advertising campaign suggested «use what you need because there will be no shortage» — was the loss of confidence by Brazilian consumers, which then led to the inevitable fall in sales of pure-bioethanol-powered cars. Thus, having accounted for 85% of new car sales in 1985, sales of bioethanol-powered vehicles accounted for only 11.4% in 1990 [Scandiffio (2005)]. It was not until the middle of 2003, with the launch of flexible fuel vehicles, that consumption of hydrated bioethanol started to grow again significantly.

Paradoxically, even during the period of apparent lack of direction regarding the future of bioethanol, independent studies concluded that it was necessary to maintain the program in operation. The studies proposed realigning the rate of bioethanol growth to the new conditions, but ensuring continuity of the program, not only for its environmental and social benefits, but also for the gains in productivity underway, which made bioethanol competitive compared with crude oil at US$ 30 a barrel [Scandiffio (2005)].

By the beginning of the 1990s, after decades of strict state control, the basic structure of the Brazilian sugarcane industry was characterized by the following elements: agricultural and industrial production under the control of the sugarmills; heterogeneous production, especially in sugarcane; underutilization of by-products; and competitiveness driven largely by low salaries and mass production. Technical differences among firms in the North Northeast and Midsouth were significant and, even within a given region there existed sharp differences in productivity and scale of production [CGEE (2007a)].

During the early 1990s the Brazilian Government implemented a series of administrative changes, as part of a significant review of its role in the economy. Within that context, a process of liberalization and institutional reshaping of the sugar alcohol sector was unleashed. The Sugar and Alcohol Institute was closed and the administration of bioethanol related matters were transferred to the *Conselho Interministerial do Açúcar e do Álcool* (Interministerial Sugar and Alcohol Council Cima), which was headed by the Ministry of Industry and Trade until 1999, when management was assumed by the Ministry of agriculture. A move towards a free-market pricing in the sugar-alcohol sector started in 1991, with the progressive removal of subsidies and a reduction of the government's role in fixing bioethanol prices, a process that was completed only in 1999. The result of those changes was the creation of a new set of rules to organize the relationships between sugarcane producers, bioethanol producers, and fuel distributors. The only feature of the original framework of legal and tax measures — which provided the foundation for the consolidation of bioethanol fuel in Brazil — currently in place is the differential tax on hydrated bioethanol and bioethanol vehicles, in an attempt to maintain approximate parity for the consumer vis-à-vis the choice between hydrated bioethanol and gasoline.

In this context, anhydrous bioethanol and hydrated bioethanol are traded freely between producers and distributors. Within the sphere of agroindustry, the price of sugarcane is also free, but for the most part it is determined according to a contractual voluntary model jointly coordinated by the sugarcane planters and bioethanol and sugar producers. According to the model, the sugar content of sugarcane that arrives for processing, as well as sugar and bioethanol produced by the mills, are all converted using a common basis for comparison, ie, *Açúcares Totais Recuperáveis* (ATR - Total Recoverable Sugars). Under this concept, sugarcane is paid according to its effective contribution to production, which is measured in terms of the ATR content of the raw material delivered to the agroindustry. Prices are determined by the economic results from the production of sugar and bioethanol, taking into account sales both in internal and foreign markets. In the State of São Paulo and surrounding regions the model is run by the *Conselho dos Produtores de Cana, Açúcar e Álcool do Estado de São Paulo* (São Paulo State Council of Sugarcane, Sugar and Alcohol Producers), founded in 1997 and constituted by representatives from all the private sectors involved in bioethanol production [Scandiffio (2005)].

The process of reassigning the roles and functions of economic agents was neither smooth nor consensual. Rather, there were significant discrepancies between the conservative players and those more progressive. The first group intended to maintain the interventionist apparatus and keep their guaranties in terms of market share and profits. The second group was for a freer market, in which investment potential and profits earned were based on advantages obtained in production and not on government granted conditions. The latter group eventually prevailed. The existence of a favourable institutional framework was essential to consolidate the changes implemented.

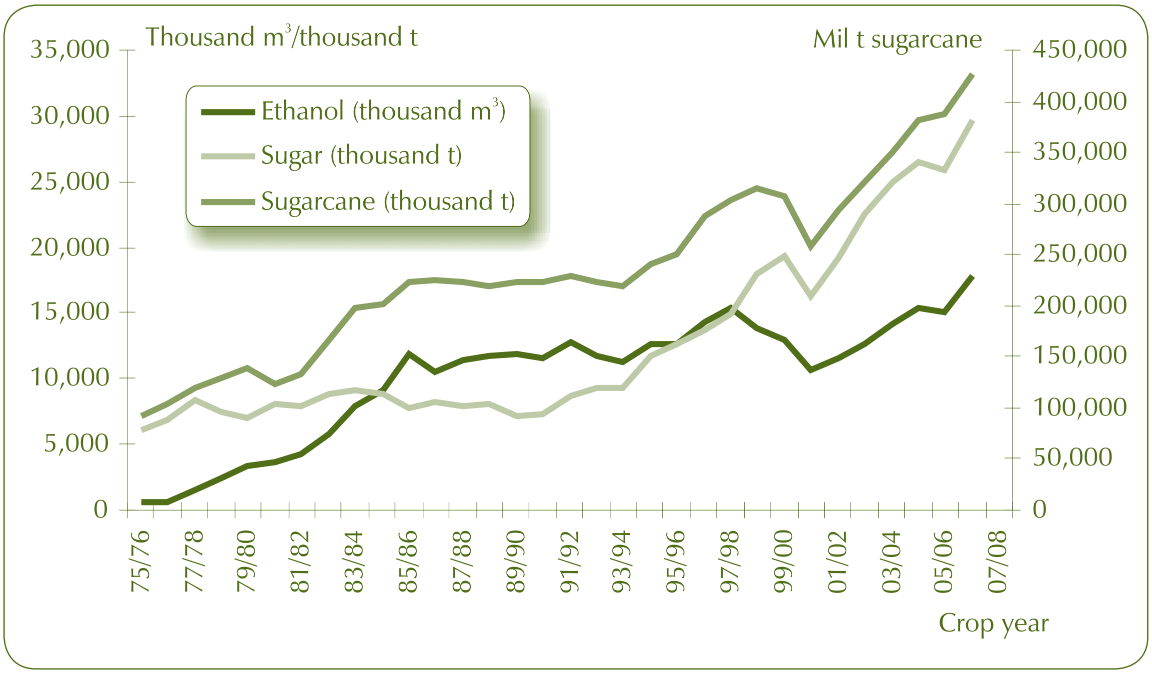
The institutional restructuring in the sphere of the bioethanol industry continued in 1997 with the creation of two important institutions, through Law 9.478: The *Conselho Nacional de Política Energética (CNPE* - National Energy Policy Council); and the *Agência Nacional do Petróleo (ANP* - National Petroleum Agency), later renamed the *Agência Nacional do Petróleo, Gás Natural e Biocombustíveis* (National Agency for Petroleum, Natural Gas and Biofuels), in accordance with Law 11.097, of 2005. The CNPE main responsibility is establishing directives for specific programs for biofuels use. On the other hand, ANP oversees the regulation, contracting, and inspection of biofuel-related economic activities, and implements national biofuel policy, with emphasis on assuring supply throughout the country and protecting consumer interests with respect to product price, quality and supply. More specifically, ANP's responsibilities include: inspecting and applying administrative and pecuniary sanctions pursuant to laws or contracts; enforcing good conservation practices, the rational use of biofuels, and environmental preservation; organizing and maintaining the archive of information and data relative to the regulated activities of the biofuels industry; and specifying quality standards for biofuels. The last attribution is of major importance, and it relies on adequate technical support as well as the establishment of communication channels between biofuel producers, engine manufacturers and environmental agencies. As seen in Chapter 2, specifications for anhydrous bioethanol and hydrated bioethanol for fuel purposes are defined by an ANP resolution.

The process of institutional review within the bioethanol sector concluded in 2000 with the creation of the *Conselho Interministerial do Açúcar e do Álcool* (CIMA – Interministerial Sugar and Alcohol Council) through Law 3.546. The purpose of this agency is to deliberate on policies related to the activities of the sugar-alcohol sector, taking into account aspects such as the following: a) an adequate share of sugarcane products in the national energy matrix; b) economic mechanisms necessary for the sector self-sufficiency; and c) scientific and technological development of the sector. CIMA is integrated by the Ministry of Agriculture, which heads it, as well as the Ministries of Finance, Development, Industry, Foreign Trade, and Mines and Energy. One of CIMA's more important responsibilities is to specify and periodically revise the bioethanol content of gasoline, within the 20% to 25% range. In recent years this level has been pegged at 25%; however, it can be reduced (and effectively it has been) contingent upon market availability conditions.

In 2003 flex-fuel cars appeared in the market and had a very good acceptance by consumers, because the owners have the option of using gasoline (with 25% anhydrous bioethanol), hydrated bioethanol, or both, depending on price, autonomy, performance or availability conditions. As a result, the consumption of hydrated bioethanol in the domestic market made a comeback, opening new perspectives for the expansion of the sugarcane industry in Brazil, as well as possibilities for meeting the demands of the international anhydrous bioethanol market for its use in gasoline blends. Ever since then, the Brazilian sugarcane industry has been expanding at high rates, consolidating itself economically and achieving positive indicators for environmental sustainability, as will be seen later in this chapter.

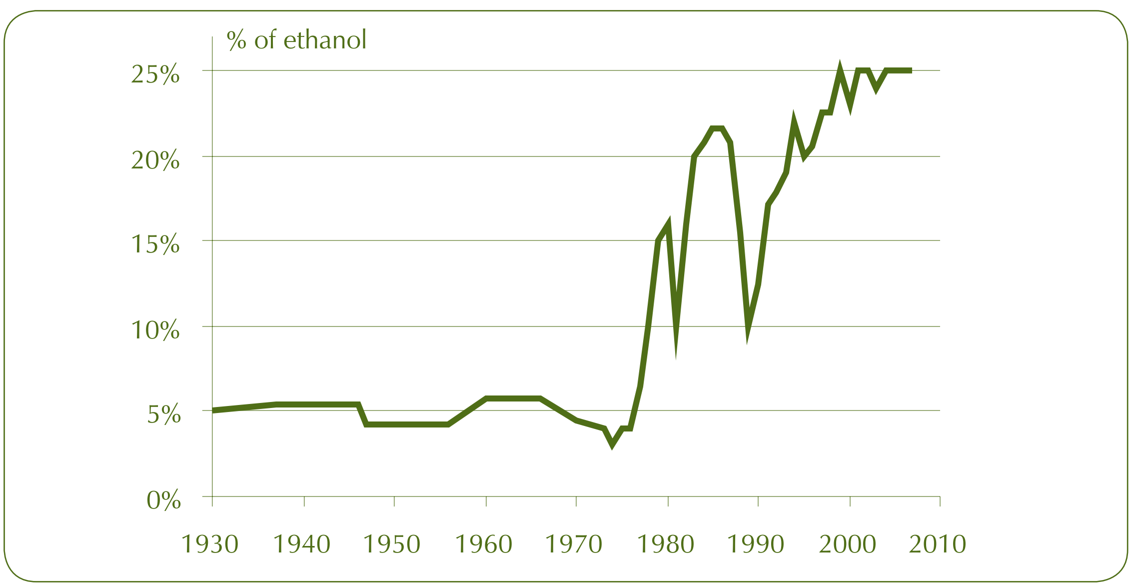
Graphs 16, 17 and 18 summarize the process described above regarding the expansion of bioethanol production in recent decades. In Graph 16, one can see how the production of sugarcane and bioethanol (anhydrous and hydrated), accompanied by the increase in sugar production, adequately attended the expansion in demand for this biofuel [Unica (2008)]. Graph 17, in turn, shows the evolution of anhydrous bioethanol levels in gasoline, from the very beginning of bioethanol use in Brazil [MME (2007) and Mapa (2008)]. Graph 18 depicts the growth in production of hydrated bioethanol vehicles. By the end of the first phase of Proálcool, in 1985, the bioethanol fleet numbered 2.5 million vehicles, accounting for 90% of sales of new cars; this share was only regained in 2003 with the launch of flexible vehicles [Anfavea (2008)]. Currently, this biofuel can be used by 5.5 million Brazilian vehicles (including cars with hydrated bioethanol and flex-fuel engines), an amount equivalent to a little over 20% of the fleet on the road (25.6 million vehicles).

Graph 16 **– Evolution of the production of sugarcane, ethanol and sugar in Brazil**



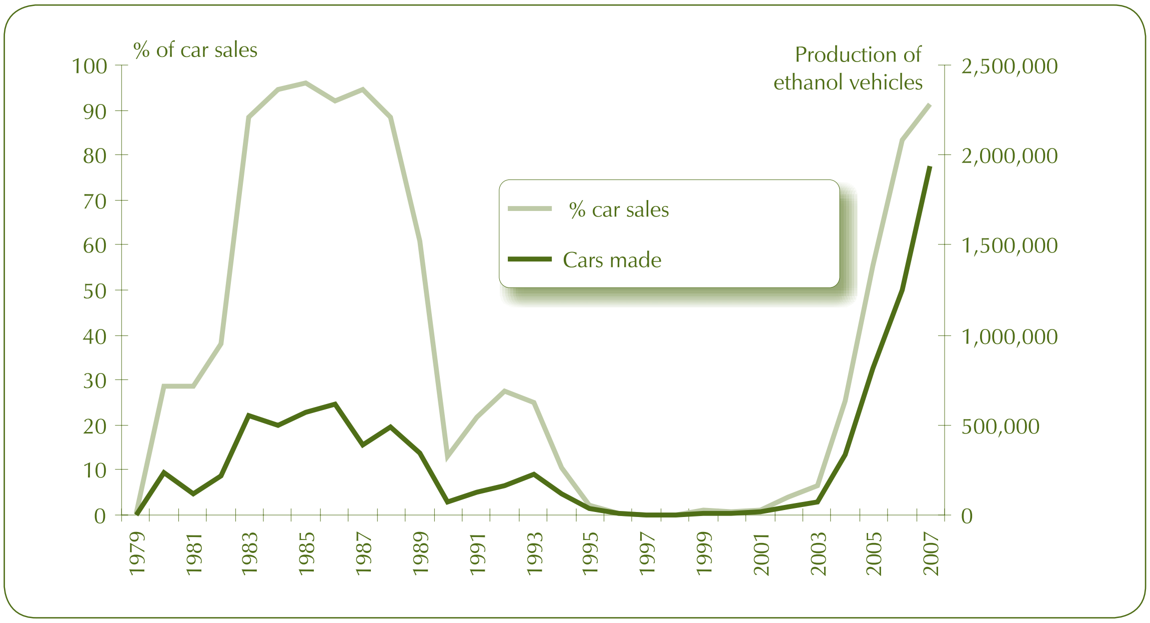
Source: Unica (2008).

Graph 17 **– Average levels of anhydrous ethanol in Brazilian gasoline**



Source: MME (2008).

***Graph 18* – Evolution of production of hydrated ethanol vehicles and share in new vehicle sales**



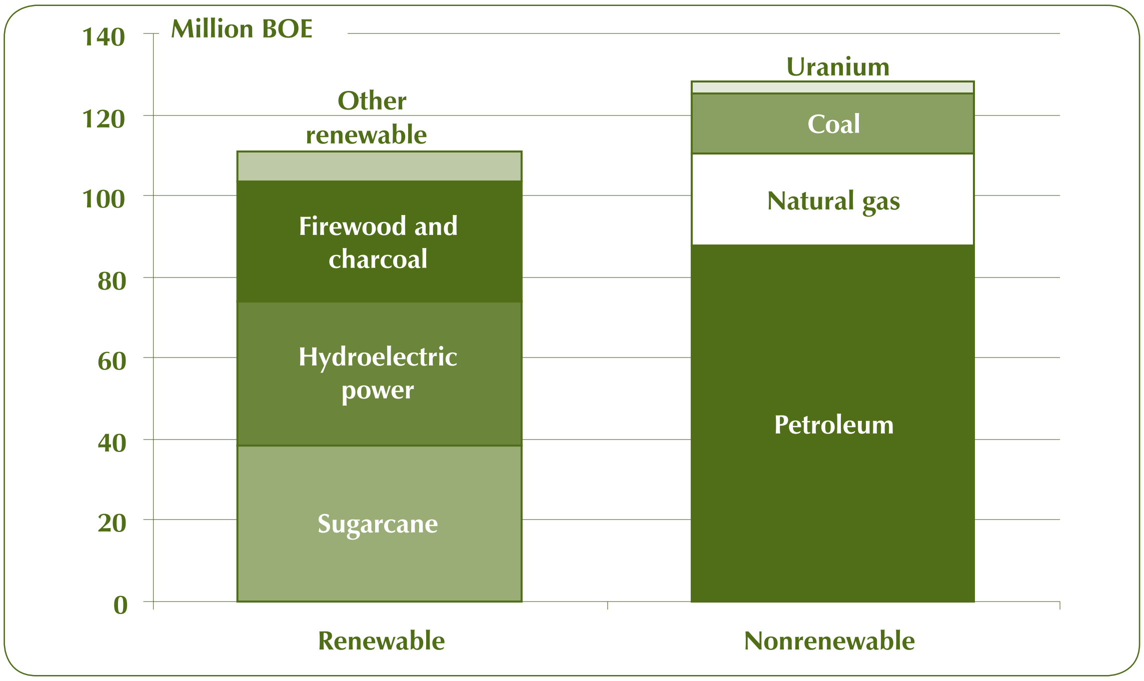
Source: Anfavea (2008).

Graphs 16, 17 and 18 show clearly that the demand for this biofuel remained quite constant during the 1990s, despite sagging sales of hydrated bioethanol vehicles, thanks to its use in gasoline blends. This allowed to keep production units in operation at relatively stable levels until the beginning of the present decade, when a new cycle of growth got underway. Thus, since the 1970s, bioethanol has been regularly used in significant volumes in Brazil and was not significantly affected by the fall in sales of hydrated bioethanol cars. The only exception to this trend was in the last years of the past decade, when sugarcane harvests were impacted by adverse weather conditions. Short-term perspectives indicate that the internal demand for hydrated bioethanol will growth significantly, with current forecasts for 9 million vehicles capable of using this fuel by 2010, which will be equivalent to 32% of the fleet forecasted for that year [Pires (2007)].

From an economic point of view, the estimated cost of the implementation of Proálcool, between 1975 and 1989, is of approximately US$ 7.1 billion, of which US$ 4 billion were financed by the Brazilian government and the rest by private investments [Dias Leite (2007)]. Valuing the volume of bioethanol fuel consumed between 1976 and 2005 at gasoline prices in the world market (adjusted for inflation) yields an estimate of US$ 195.5 billion in foreign-exchange savings, US$ 69.1 billion in avoided imports and US$ 126.4 billion in avoided foreign debt interest [BNDES (2006)].

The importance of the sugarcane bioenergy chain in Brazil is well illustrated by the fact that in 2007 it accounted for 16% of the national energy matrix, slightly above the contribution of hydroelectric power (responsible for 90% of Brazil's electric power), and 36.4% of the national energy supply derived from renewable sources (see Graph 19). In short, energy derived from sugarcane is a significant pillar of the Brazilian energy supply.

Graph 19 **– Primary energy sources utilized in Brazil in 2007**



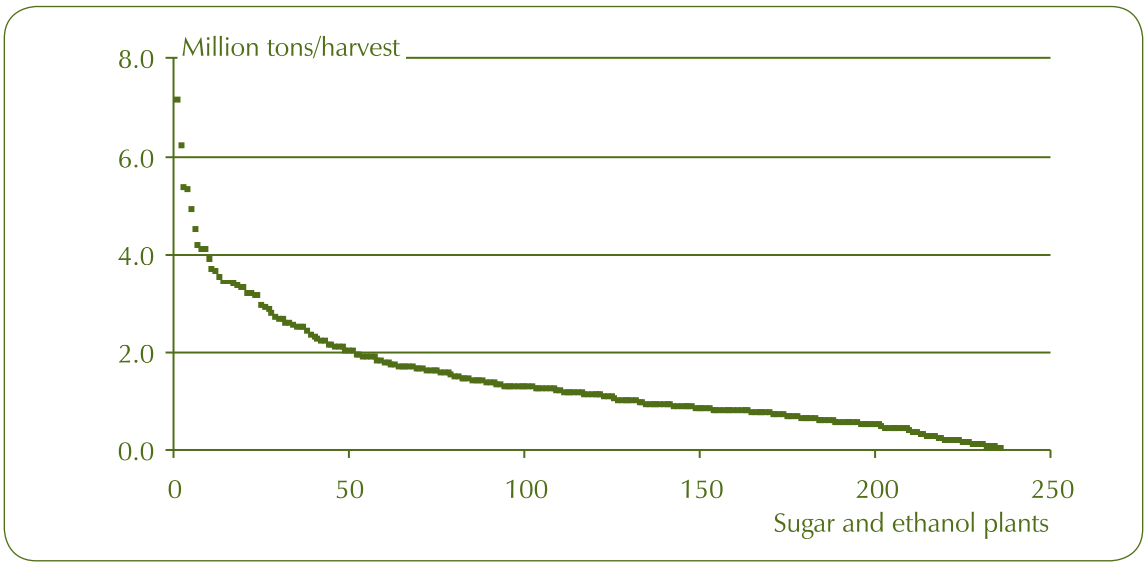
Source: MME (2008).

6.2. Sugarcane agroindustry in Brazil

Sugarcane has been cultivated in Brazil since 1532, when it was introduced by Martim Afonso, the first Portuguese colonizer, who intended to build sugar mills such as those already existing at the time on the Azores Islands. The species adapted well to Brazilian soil and during the entire colonial period was extensively and successfully cultivated along the Brazilian coast. Dozens of mills were built there, especially in the Bahian Recôncavo and Pernambuco, providing a foundation for the sugar economy in Brazil, which lasted almost two centuries. With the expulsion of the Dutch from the Northeast and the expansion of the sugar agroindustry in the Antilles region, around the middle of the 17th century, production in Brazil decreased in relative terms, though it remained an important activity in the Brazilian economy. The creation of the Sugar and Alcohol Institute, in 1933, when the use of automotive bioethanol was already a blossoming reality, provided new life into the industry. Also, from that time onwards, the sugar industry began to expand in the Southeast, first in association with the decline of coffee plantations, and later driven by the growth of the domestic market [Szmrecsányi (1979)].

Currently, sugar cane is grown in almost all states in Brazil and occupies close to 9% of the cultivated land, being the third most important crop in terms of land occupied, after soybeans and corn. In 2006, the cultivated area was of the order of 5.4 million hectares and total production was 425 million tons [Carvalho (2007)]. The biggest producing area is the Mid-South-Southeast, accounting for more than 85% of production; the largest national producer is the State of São Paulo, which contributes close to 60% of the production. The production system involves more than 330 mills, each capable of processing between 600 thousand and 7 million tons of sugarcane per year; an average mill processes close to 1.4 million tons per year. Graph 20 shows the distribution of annual milling capacity (2006/2007 harvest). As can be seen, the 10 biggest mills are responsible for 15% of the raw material processed, whereas the 182 smallest units process half of all sugarcane. Economically speaking, these numbers demonstrate the low concentration within this agroindustry, as typically seen in bioenergy systems.

***Graph 20* – Distribution of the annual processing capacity of sugar and ethanol plants in Brazil**

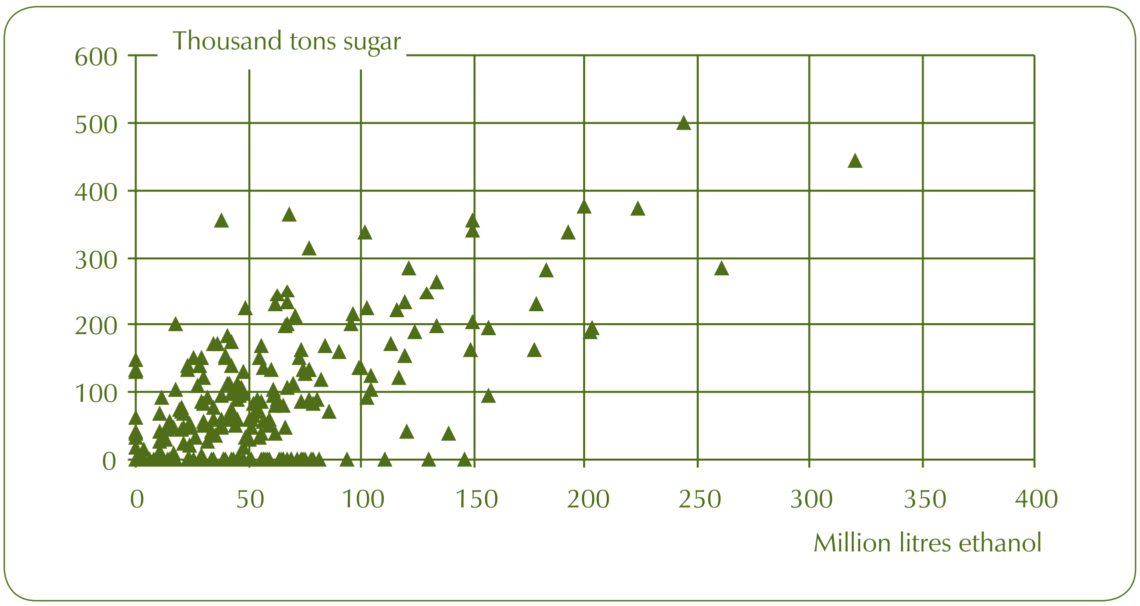


Source: Based on Idea (2007).

Brazilian plants, on average, receive 80% of sugarcane from land owned, rented, or belonging to shareholders and agricultural businesses linked to the plants. The remaining 20% is supplied by close to 60 thousand independent producers, the majority working with less than two agricultural *módulos (*an agricultural *módulo* corresponds to the smallest parcel of farmland that can sustain a family and varies by region). A large proportion of sugarcane producers can be described as small farmers, who produce sugarcane along with other farm products, not only for economic purposes but also for self-consumption, and generally rely on technical support from the mills [CGEE/NAE (2005)].

Brazilian plants can be classified in three categories: Sugar mills that only produce sugar; sugar mills with distilleries, which produce sugar and bioethanol; and independent distilleries that only produce bioethanol. The largest group is the one that combines sugar mills and distilleries (close to 60% of the total), followed by a considerable quantity of independent distilleries (close to 35%) and then by units that only process sugar (see Graph 21). Nationally, during the 2006/2007 harvest an average of 55% of available sugar content from processed sugarcane was used to produce bioethanol [Unica (2008)].

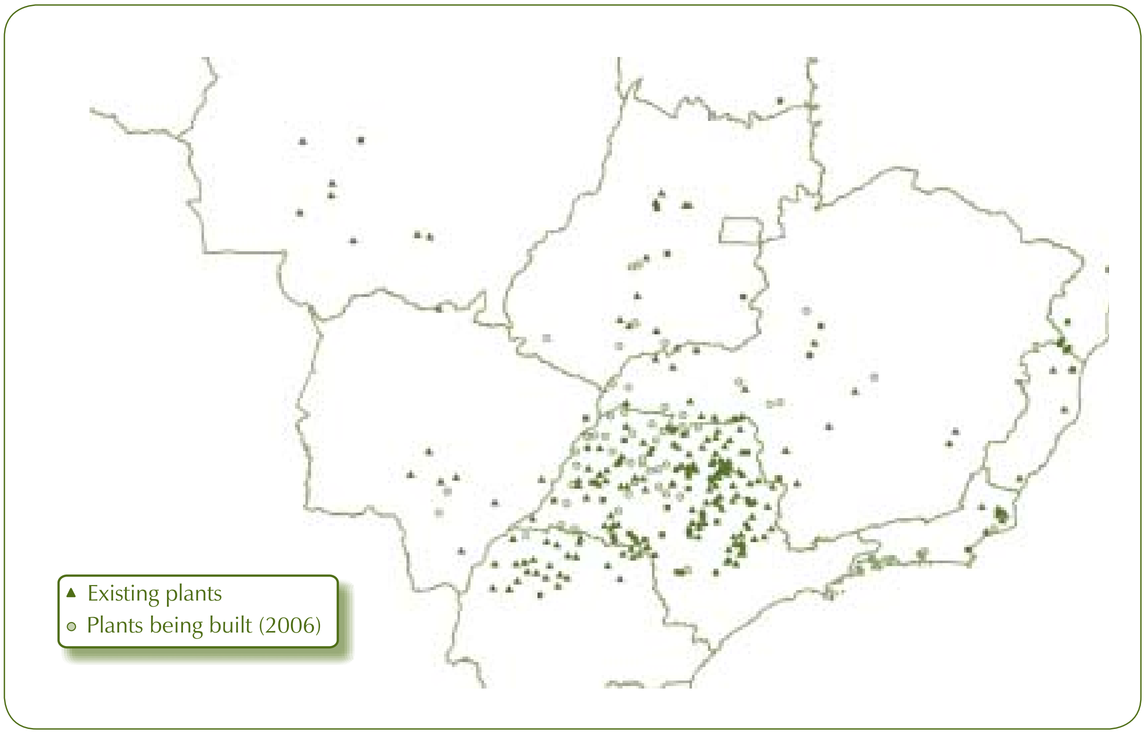
***Graph 21* – Production profiles of sugar and ethanol plants in Brazil during the 2006/2007 harvest**



Source: Based on Idea (2007)].

Geographically, sugar and bioethanol plants are located close to sugarcane producing regions, mostly in the State of São Paulo, as Graph 9 shows. In that state there is a confluence of excellent soil and climate conditions, adequate transportation infrastructure, proximity to consumer markets and an active science and technology base that has been fundamental to expand production with increased productivity. In recent years, with the relative reduction of the area available in São Paulo and rising land prices, new production units have been occupying areas previously used for pasture and, to lesser extent, for annual crops in the Triângulo Mineiro, south of Goiás and southeast of Mato Grosso do Sul. These areas are adjacent to the traditional sugarcane-producing areas of central southern Brazil (as showed in Graph 24), which make it possible to develop production systems similar to those that exist in São Paulo.

Figure 24 **– Locations of new sugar and alcohol plants in Brazil**



Source: CGEE (2006).

According to harvest figures for 2006/2007, the sugarcane agroindustry (which includes sugarcane, sugar and bioethanol production) generated close to R$ 41 billion in direct and indirect sales. The 420 million tons of raw sugarcane processed produced 30 million tons of sugar and 17.5 billion litres of bioethanol. Out of that, 19 million tons of sugar (US$ 7 billion) and 3 billion litres of ethanol (US $ 1.5 billion) were exported, representing 2.65% of the Gross National Product (GNP). In addition, R$ 12 billion in taxes and fees were collected and annual investments of R$5 billion in new agroindustrial units were made. These strong results were accomplished by a range of productive units characterized by wide variations with respect to production scale, size, geographic location, production structures and financial and business profiles. There are, therefore, differences in costs of production and levels of efficiency, particularly as a result of the significant evolution of the sugar-alcohol sector during recent decades, not just in terms of capacity and production profiles, but also in the loosening of regulations.

Brazilian sugar and bioethanol plants currently in operation can be classified into three groups, taking into consideration their financial situation, productivity indicators, and the introduction of new technologies (based on IEL/Sebrae, 2006):

Stagnated companies: Plants in critical or pre-critical conditions because accumulated debt and outdated technology with little possibility of acting independently in a highly competitive sector. Only with new resources and specific lines of credit can the outlook be changed; old technologies must be updated to enable increased agroindustrial productivity.

Profitable companies: Plants that were able to successfully adapt to sector deregulation and the lack of definition on energy policy in Brazil during the 1990s. They have expanded production capacity and invested in new technologies, resulting in reduced costs and increase productivity. Either individually or in groups, some of these companies have diversified their activities to handle international logistics and sales of their products.

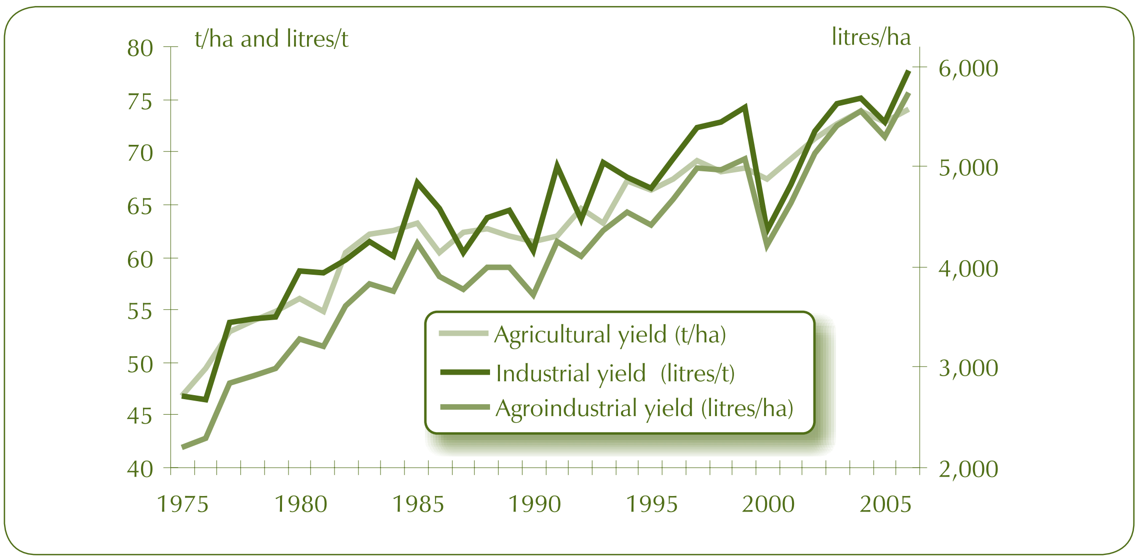
Innovative companies: Profitable companies that, by themselves or in partnerships with multinationals, stand out from the previous group. They have diversified their technological base for producing sugarcane-based products and opened up new perspectives for adding value to sugarcane.

Associated with the expansion of sugar-alcohol production, there has been significant diversification in the composition and origin of the capital invested in this agroindustry. Originally almost exclusively based on family businesses, they were often founded and run by Italian immigrants and their descendents in the Center South Region, or by regional families in the case of Northeast plants. Currently, in addition to family business, capital investments are being made by a range of companies (Cosan, Costa Pinto, Guarani, Nova America, São Martinho) as well as by strategic national (Votorantim, Vale, Camargo Correa, Odebrecht) and foreign investors. The latter group includes investors from a variety of nations, such as France (Tereos, Sucden, Louis Dreyfus), Germany (Sudzucker), United States (Bunge, Comanche Clean Energy, Cargill, Global Foods), Spain (Abengoa), Guatemala (Ingenio Pantaleón), India (Bharat Petroleum, Hindustran Petroleum, India Oil), England (ED&F Man, British Petroleum), Malaysia (Kouk) and Japan (Mitsui, Marubeni).

Another innovation has been the increasing presence of both national and foreign financial investors such as Goldman Sachs, Merryll Lynch, Adeco (George Soros), Tarpon, UBS Pactual and Cerona, individually or in consortium with sugarcane operators. In the latter case it is worth mentioning the investment groups formed specifically to implement platforms for the production and sale of sugarcane bioethanol, such as Infinity Bio-Energy, Brenco (Brazil Renewable Energy Company) and Clean Energy Brazil. Typically, the business model based on foreign capital includes Brazilian partners, with an important participation of foreign companies in dozens of mergers and acquisitions that have taken place in recent years. Although this diversification is very important, and reflects the confidence of foreign investors and the introduction of new management and governance concepts, foreign capital still represents a small portion of total investments in the sector; it is estimated that those investments accounted for 12% of processing capacity in 2007 [Nastari (2007)].

It is important to understand that the expansion of bioethanol and sugar production in recent decades has occurred not only because the increase in cultivated area, but also because the significant productivity gains in agricultural and agroindustrial activities. During the last 32 years productivity grew at an average cumulative annual rate of 1.4% in agriculture and 1.6% in agroindustry, resulting in a cumulative average annual growth rate of 3.1% in the per-hectare yield of bioethanol. Graph 22 shows this growth over the course the last three decades, in average values, for all Brazilian production units. In this graph, the data for the area planted and sugarcane production are from the *Ministério da Agricultura, Pecuária e Abastecimento* (Ministry of Agriculture, Livestock and Supply) [Mapa (2007)]; bioethanol production data was obtained from *União da Indústria de Cana-de-Açúcar* statistics. [Unica (2008)]. Thanks to these gains in productivity, the area currently dedicated to the cultivation of sugarcane for bioethanol production, close to 3.5 million hectares, is only 38% of the area that would have been required to obtain such production with the yields of 1975, when Proálcool began. This noteworthy gain in productivity — 2.6 times the volume of bioethanol for a given area — was obtained through the continuous incorporation of new technologies, as will be described in the next section.

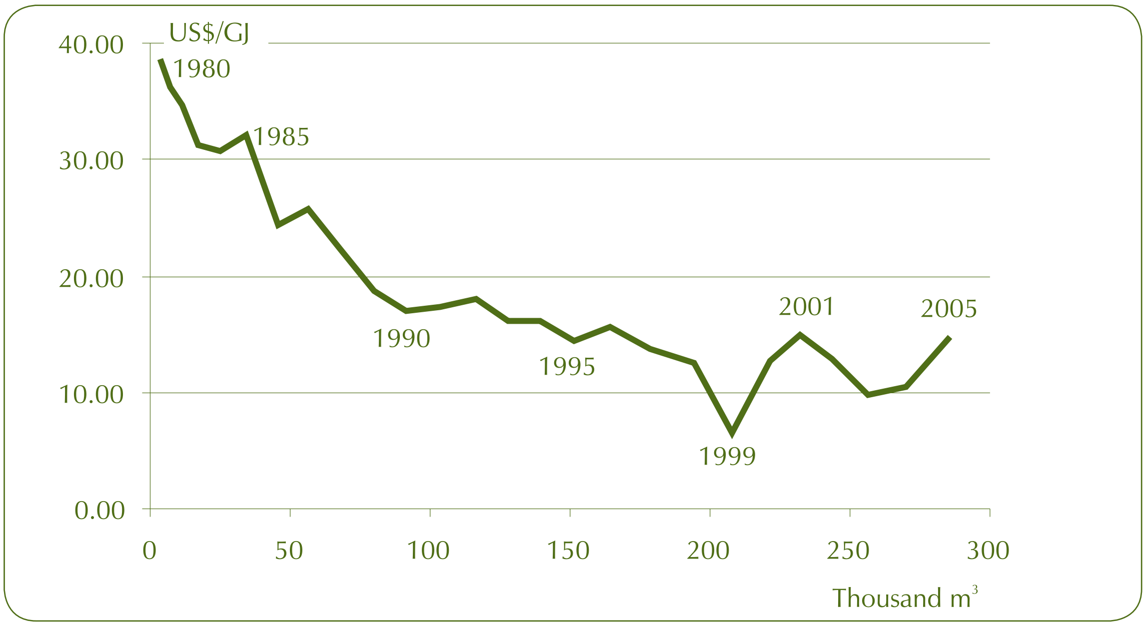
Graph 22 **– Evolution of agricultural, industrial and agroindustrial productivity in sugar and ethanol plants in Brazil**



Source: Based on Mapa (2007) and Unica (2008).

A direct consequence of the gain in productivity was the progressive reduction in costs, which is reflected in the values received by producers (See Graph 23). Sometimes referred to as the *learning curve*, this phenomenon clearly reflects a process of learning and consolidation, similar to what has been experienced by other new energy technologies such as wind power [Goldemberg et al (2004)]. The graph shows how experience and skill have translated into a progressive fall in prices (2002 US dollars), which decreased at a cumulative annual rate of 1.9% during the last 25 years. Something to note in the graph is the asymptotic tendency of prices, which have remained practically constant for the last 10 years. The stabilization of prices is usually a signal of maturity in the sphere of conventional technologies; therefore, it would reveal technological maturity in the bioethanol industry.

***Graph 23* – Evolution of prices paid to ethanol producers in Brazil**



Source: Adapted from Goldemberg et al. (2005).

According to the same logic of growth with gains in productivity and efficiency, the evolution of the sugar-alcohol sector has witnessed the formation of consortia and clusters as ways to rationalize costs, particularly with respect to the adoption of new technologies. Furthermore, the sector has enlarged the scale of production in plants and ensured the strategic occupation of contiguous agricultural areas [CGEE (2005)]. The growth in processing capacity — more than 7 million tons of sugarcane per year in the largest new units — has allowed to hold sugarcane transportation costs at competitive levels through the use of more efficient practices and greater cultivation of areas close to the plants. It is interesting to see that these larger agroindustrial units correspond, in energy terms, to an oil refinery with a 35 thousand barrel a day processing capacity, ie, they operate on a scale well below that seen in the petroleum industry.

The appendixes provide historical data on bioethanol (anhydrous and hydrated) and sugarcane production and cultivated area for the main producer states, as well as information on prices paid to bioethanol producers.

6.3 Technological research and development

During the expansion of bioethanol production by Brazilian plants, as described in the previous section, the incorporation of innovative processes and technological development played an essential role, resulting in increased production efficiency and progressive lowering of environmental impacts. On the other hand, new possibilities for sugarcane-based bioenergy production, such as employing lignocellulosic by-products to produce bioethanol and electricity, are highly dependent on processes still under development.

The existence of public institutions, Federal, and State, as well as private businesses providing know-how to the sugarcane bioethanol production chain (especially agricultural aspects), was and it will always be of critical importance with respect to genetic improvement, agricultural mechanization, management, biological pest control, recycling of wastes and better-performing agricultural-conservation practices [CGEE (2005)]. These institutions are mostly located in the State of São Paulo, where the majority of sugarcane in Brazil is grown and processed. This State is also home to the most productive Brazilian university complex, one responsible for close to half of all scientific studies produced annually in the country. Within this realm, an interesting synergy has come about based on the need for technological support and the availability of human resources well trained to provide it. The two most important promoters of this process of innovation have been the Government of the State of São Paulo and the private sector, working in partnership.

São Paulo State-funded institutions active in agroindustrial production technology and sugarcane bioethanol use include the following entities: *Instituto Agronômico de Campinas* (IAC – Agronomic Institute of Campinas), *Instituto de Pesquisas Tecnológicas* (IPT – Institute of Tecnological Research), *Instituto de Tecnologia de Alimentos* (ITAL – Food Technology Institute), *Companhia de Tecnologia de Saneamento Ambiental* (Cetesb – Environmental Waste Management Technology Company), and *Instituto Biológico* (Biological Institute). The list is completed by three State universities: Universidade de São Paulo (USP – Sao Pablo State University), home of the *Escola de Agronomia Luiz de Queiroz* (ESALQ – School of Agronomy Luis de Queiroz), traditionally active in sugarcane technology; *Universidade Estadual de Campinas* (Unicamp – Campinas State University) and *Universidade Estadual Paulista Júlio de Mesquita Filho* (Unesp – Paulista State University Julio de Mesquita Filho), which has several courses and research groups focusing on sugarcane bioenergy.

The oldest of these institutions is the *Instituto Agronômico de Campinas*, with experimental research stations throughout the State. The Institute began working with sugarcane as early as 1892. Since 1994, and in association with private enterprises (with which it shares an annual budget of R$ 2 million), the IAC has run ProCana an active program for the genetic improvement of sugarcane varieties that periodically launches new varieties and introduces new sugarcane management methods [Landell (2003)]. Procana has successfully introduced innovative and efficient practices in the management of its activities; so much so that the economic impact of its activities has been estimated at 13 times the amount of investments [Hasegawa and Furtado (2006)].

The *Centro de Tecnologia Canavieira* (CTC – Sugarcane Technology Center) stands out in the private sector. It was originally created in 1970 as the *Centro de Tecnologia Copersuca* (Copersuca Center of Technology), associated to Copersuca, a cooperative of sugar and bioethanol producers. In 2005 it was separated from that cooperative and reorganized as a nonprofit corporation. CTC currently has the membership of 161 plants, which account for 60% of the sugarcane produced in Brazil. It has an annual budget of R$ 45 million and a body of 107 researchers [Furtado et al. (2008)]. Although it is currently more visible because of agricultural research — with more than 60 sugarcane varieties launched and cultivated on 43% of the national area used for sugarcane cultivation — CTC acts throughout the entire sugarcane production chain, working in areas such as rural administration, variety improvement, phytosanitation, cultivation and harvest systems, extraction and fermentation systems, and energy systems for sugar and bioethanol plants. CTC has been the main innovation center for São Paulo plants and an important technical supporter of agricultural and industrial issues. In the sphere of sugarcane biotechnology, CTC has been conducting research since 1990. A pioneer in Brazil in the creation of sugarcane transgenic varieties, in 1997 it lead the constitution of the *Consórcio Internacional de Biotecnologia de Cana-de-açúcar* (ICSB – International Consortium of Sugarcane Biotechnology), a body that today brings together 17 institutions from 12 sugarcane producing countries. Recently, in Pernambuco and Alagoas, CTC installed research units dedicated to the development of varieties specific for those regions [CTC (2008)]. To sum up, CTC has surely been a leader in the introduction of innovations in the sugar-alcohol agroindustry and responsible for the notable gains in bioethanol production efficiency witnessed in recent decades.

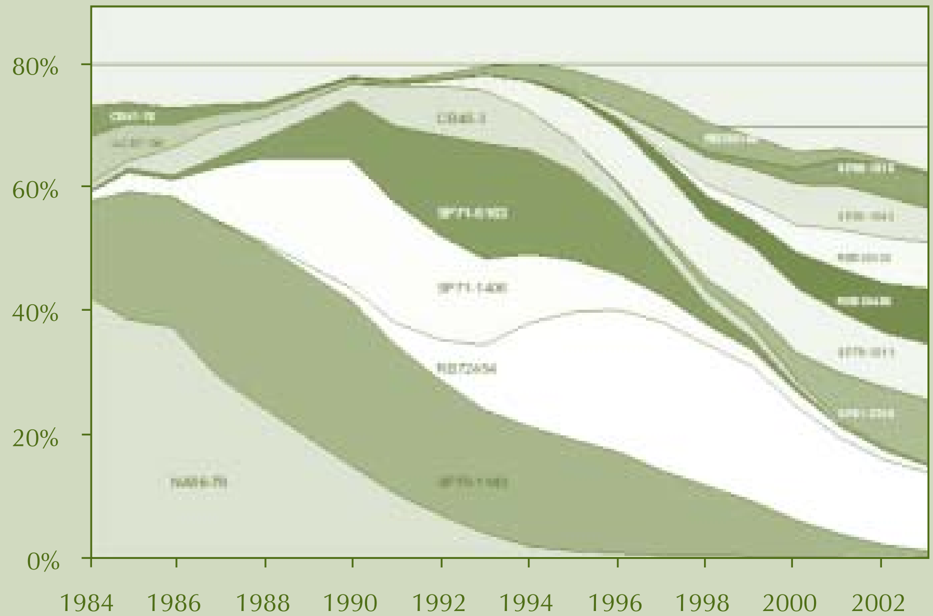
Among State institutions, the *Fundação de Amparo à Pesquisa do Estado de São Paulo* (Fapesp - Research Support Foundation of the State of São Paulo) has performed a very important role in supporting research and development activities within the sugarcane agroindustry, with significant resources invested in more than one hundred research studies in basic and applied areas, involving the academic community and private companies [Fapesp (2007)]. Examples of recent Fapesp initiatives with private companies (who provide half of the resources available for scientific community research) are the agreements signed with *Dedini Indústrias de Base* and *Braskem*. The first includes R$ 100 million for research projects on technologies for the elaboration of bioethanol. The second provides R$ 50 million for synthesis-process research using renewable raw materials derived from sugars, bioethanol and other biofuel chain products, with an emphasis on «green polymers». Fapesp also finances the *Programa Diretrizes de Políticas Públicas para a Agroindústria Canavieira do Estado de São Paulo* (Public Policy Guidelines Program for São Paulo State Agroindustry), which defines subsidies to support government initiatives in this field [Agência Fapesp (2008)].

Linked to the Federal Government and located in a traditional sugarcane producing region, *Universidade Federal de São Carlos* (UFSCar, São Carlos Federal University) also has performed an important role in the technological development of the bioethanol agroindustry, especially with regards to agriculture. In 1990, the *Centro de Ciências Agrárias* (Agricultural Science Center) of this university incorporated the *Programa Nacional de Melhoramento da Cana-de-Açúcar* (Planalsucar - National Program for the Improvement of Sugarcane), linked to the old *Instituto do Açúcar e do Álcool*. The program had as many as 30 experimental research stations around the country, making significant contributions to improve sugarcane yields in Northeastern states, especially in Alagoas [Furtado et al. (2008)]. Based on the human resources and infrastructure of Planalsucar, and to provide continuity to research on the improvement of sugarcane genetics, in 1991 was created the *Rede Interuniversitária para o Desenvolvimento do Setor Sucroalcooleiro* (Ridesa - Inter-University Network for the Development of the Sugar-Alcohol Sector), currently involving close to 140 researchers at nine federal universities (São Carlos, Paraná, Viçosa, Rural do Rio de Janeiro, Sergipe, Alagoas, Rural de Pernambuco, Rural de Goiás and Rural de Mato Grosso) located nearby the old Planalsucar experimental research stations. The program already has successfully launched 65 cultivars (canas RB) that account for 57% of the area cultivated with sugarcane in Brazil [Ridesa (2008). In addition to support granted by the Ministry of Science and Technology, which gave R$ 1.8 million in 2006, Ridasa has partnerships with 130 private companies that provide resources and benefit from the results of its research activities [Inovação Unicamp (2007)].

Genetic improvements and availability of cultivars

The phytosanitary health of sugarcane plantations relies on the periodic renewal and diversification of varieties in order to maintain high productivity and resistance to diseases and pests, which can be very harmful under monoculture conditions, as well as to control maturation characteristics (early or late), promote adaptation to mechanical harvesting and enhance resistance to certain weather condition, among others. In this regard, it is exemplary how agricultural technology has made possible to broaden the sugarcane germplasm base and the diversification of varieties utilized by this agroindustry in Brazil, by means of four sugarcane improvement programs, two of which are private. It is noteworthy that under Law 9.456/1997 — the Cultivar Law — businesses and research groups can charge producers for the use of sugarcane cultivated from the developed varieties. Each year, close to six new varieties are released to the market and the total number of varieties is currently close to 500. Among them, the most popular variety occupies 12.6% of the planted area, as can be seen in Graph 25.

Figure 25 – **Percent occupation of the main sugarcane varieties in Brazil from 1984 to 2003**



Source: Burnquist and Landell (2005).

In a sugarcane genetic improvement program, the starting point is the germplasm bank, where thousands of genotypes are stored, including cultivars used domestically, other species related to the Saccharum genus, and cultivars imported from the world's different sugarcane regions. After being obtained through crossbreedings pre-established by the researchers, the seeds are sent to laboratories at experimental stations, where the seedlings are raised and transplanted to the field to undergo successive selection phases over the course of three or four years. From the millions of original seedlings, just a few hundred clones are selected to go through long-term cultivation tests. Normally, the launching of new varieties takes close to 13 years of experimental clone testing, watching for reactions to pests and diseases and yield differences under different cultivation environments [Ridesa (2008)].

Based on the sequencing of sugarcane's 50 thousand genes carried out between 1988 and 2001 by the Fapesp-sponsored Projeto Genoma Cana-de-Açúcar (Sugarcane Genome Project), several Brazilian groups have been working on advanced biotechnological methods to identify quickly those clones with greatest resistance to disease, shortest maturation, highest sucrose content, highest total biomass, etc. In addition to the technical challenges, however, these studies depend on lengthy approval processes from the Ministry of Science and Technology's *Comissão Técnica Nacional de Biossegurança* (National Technical Commission for Biosecurity) [Burnquist and Landell (2005)].

Among federal institutions located in São Paulo, mention should also be made of three units of the *Empresa Brasileira de Pesquisa Agropecuária* (Embrapa - Brazilian Agricultural Research Corporation), which in some way are connected to the sugarcane agroindustry: Embrapa Environmental Research, in Jaguariúna, focusing on themes associated with the rehabilitation of damaged areas, sustainable use of water and biological control of pests and diseases; Embrapa Satellite Monitoring and Embrapa Agricultural IT, both located in Campinas, working with remote sensing, and geo-processing and computing. With the creation of Embrapa Agroenergy in Brasilia, in 2006, the institution is bound to be more involved in issues related to the use of sugarcane in the production of bioethanol and bioelectricity.

Last but not least, in the private sector it is noteworthy to mention CanaVialis and Allelyx, two companies working on research and development in this field. Both are located in Campinas and are supported by Votorantim Ventures, an investment fund. According to these firms they invest R$ 70 million annually in research, with special focus on improving transgenic varieties, in which genes from different varieties are inserted into the sugarcane genome to obtain more productive varieties resistant to disease and drought. CanaVialis has three experimental stations, certified by the *Comissão Técnica Nacional de Biossegurança* (CTNBio - National Technical Commission for Biosecurity), for developing its activities and servicing agreements signed with 34 plants. Together, the two companies have a team of more than 150 researchers and are dedicated to other applications of sugarcane agroindustrial biotechnology, such as molecular markers, advanced variety management systems, and assessments of genetic vulnerability [Furtado et al. (2008) and CanaVialis (2008)].

This broad technological base has strongly impacted the development of processes, equipment and systems, growing autonomously and sustaining lines of study and research based on the tangible and immediate realities of the neighbouring agroindustry. It is, therefore, difficult to say which has been the primary factor that triggered this dynamics of innovation. In essence, a parallel and simultaneous process of value generation and reinvestment has occurred: more applied knowledge, better technologies, greater efficiency, larger profits, improved perspectives and increased entrepreneurial and institutional motivation. Table 26 confirms this vision; it synthesizes the results obtained and the prospects for new advances in agricultural (annual yield per hectare for sugarcane) and agroindustrial (bioethanol yield per ton of sugarcane) productivity. Table 27 highlights which processes have the best perspectives for improving industrial agroproductivity.

As shown in Tables 26 and 27, in the coming years the expected increase in agroindustrial productivity (without considering the introduction of other production routes such as cellulosic bioethanol) should enable a reduction in the planted area of 3.4% per unit of bioethanol produced. Such significant improvement is a direct result of agroindustrial technological research and development. If cellulosic residual-based bioethanol is also included, productivity could reach 10,400 litres of bioethanol per hectare [CGEE (2005)], corresponding to a 33% reduction in the planted area per unit of bioethanol produced.

Table 26 – Impact of the introduction of new technologies on bioethanol production

Period		Productivity		
		Agricultural. yield (t/ha)	Industrial yield (litres/t)	Agroindustrial yield (litres/ha)
1977–1978	Initial phase of National Alcohol Program Low efficiency in agroindustrial processes and agricultural yields	65	70	4,550
1987–1988	Consolidation of National Alcohol Program Agricultural and industrial yields increase significantly	75	76	5,700
Current situation	Bioethanol production processes operating with the best technology available	85	80	6,800
2005–2010	First stage of optimization of processes	81	86.2	6,900
2010–2015	Second stage of optimization of processes	83	87.7	7,020
2015–2020	Third stage of optimization of processes	84	8.5	7,160

Source: CGEE (2006).

Table 27 **– Expectations for efficiency gains in bioethanol production processes (%)**

Scenario (as in Table 26)	Losses during sugarcane washing	Extraction efficiency	Losses treating sugarcane juice	Fermentation yield	Losses during dist. and stillage
Current situation	0.50	96.0	0.75	90.3	0.50
First optimization stage	0.40	96.5	0.75	91.0	0.50
Second optimization stage	0.30	97.0	0.50	91.5	0.25
Third optimization stage	0.25	98.0	0.35	92.0	0.20

Source: CGEE (2006).

In the industrial and administrative areas the results of improving processes can be replicated without difficulty; however, that is not the case in sugarcane production where differences in soil and climate variables that are region-specific have a decisive influence in production. The need to reduce costs then calls for decentralized development of improvement programs, increased cooperation between companies and expanded sharing of information between institutions. A detailed study on the evolution of the sugarcane industry in Paraná between 1990 and 2005 demonstrates that *leaning by interaction* has been the predominant learning paradigm in this industry [Rissardi Jr. and Shikida (2007)]. The study stresses the importance of direct interaction between institutes and technology suppliers and user companies for innovations to spread throughout sugar and bioethanol plants and highlights the importance of the existence of regional or decentralized technology centers for the process to unfold.

Collaboration among research centers is also important at the international level. In particular, reinforcing links that already exist between organizations in countries with potential for the efficient production of bioethanol is an important condition to strengthen the basis for an adequate development of their bioenergy agroindustries. In Latin America the following institutions have important capacities for the promotion of diversity and productivity in sugarcane agriculture: *Centro Guatemalteco de Investigación y Capacitación de la Caña de Azúcar* (Cengicaña – Guatemalan Sugarcane Research and Training Center); *Centro de Investigación de la Caña de Azúcar de Colombia* (Cenicaña – Sugarcane Research Center of Colombia); *Dirección de Investigación y Extensión de la Caña de Azúcar* (Dieca – Sugarcane Research and Extension Directorate), in Costa Rica; and the West Indies Central Sugar Cane Breeding Station, in Barbados. The last station has a famous germplasm bank that serves the entire Caribbean.

The establishment of priorities is essential to rationalize bioethanol research and development activities. In Brazil the following issues have been identified as the most relevant for the Center-South region [Macedo and Horta Nogueira (2007) and (2007b)]:

a. Processes for recovery and use of excess plant fibre and bagasse;

b. development of transgenic varieties of sugarcane;

c. selection of cultivars (conventional improvement for new cultivation areas and adoption of the concept of energy sugarcane to maximize the global results that are possible by processing both sugar and fibre for energy production);

d. Development of equipment and processes for juice extraction and bioethanol treatment, fermentation and separation;

e. precision farming systems, in which interventions in cultivation are aided by geoprocessing techniques and global positioning systems (GPS);

f. biological pest and disease control;

g. sugarcane cultivation practices compatible with mechanical harvesting;

h. new sucrochemical and alcochemical products and processes;

i. bioethanol end uses (improvements in biofuel engine technologies and bioethanol-operated fuel cells).

The Brazilian experience in financing research and development activities for the ethanol agroindustry — especially that of the State of São Paulo — stresses that besides providing adequate resources it is necessary to take the following initiatives: structure a plan of action with clear objectives and competencies, establishing coordinated management of activities and including mechanisms for monitoring and communicating results; strengthen training programs, especially at postgraduate level; encourage programs for semi-commercial pilot and demonstration units for new technologies; and, finally, take advantage of existing structures to consolidate currently active centers (eventually, incorporating new laboratories and equipment), as well as promoting and articulating available skills.

The constitution of a CT-ethanol has been suggested as one possible way to provide sustainable financing of research and development in the area of agroindustrial energy, especially basic and applied research on the entire biofuel production chain. Such instrument would allow to replicate the good results obtained with the so-called *Fundos Setoriais* (Sector Funds), in which a portion of the resources in a given energy sector (petroleum, electric power) is used for the generation and aggregation of knowledge in the same sector. It is estimated that an excise tax of 0.5% on net income from bioethanol sales will allow to raise R$ 185 million that could be used to enhance technological dynamism in the sector [Cortez (2007)].

During the course of writing this book, the Minister of Science and Technology announced the Creation of the Center for Bioethanol Science and Technology. The center will function within the *Pólo Tecnológico de Campinas* (Campinas Technology Center) and will be dedicated to a wide spectrum of technologies of interest for the efficient conversion of biomass into energy. Currently in its structuring stage, the center will include laboratories for basic research and a pilot plant and it is expected that it will have a strong focus on basic studies of the photosynthesis phenomenon, biomass production systems and advanced processes for biofuel production, such as hydrolysis.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