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The Brazilian sugar and alcohol sector: evolution, productive chain and innovations

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The sugar and alcohol sector is one of the fastest growing and developing areas of the Brazilian economy, although some specialists worry unduly that sugarcane cultivation will replace food-crop plantations. This article analyses how Brazil and the State of São Paulo became major players in that sector, and expounds a theory on the relevance of innovations for increasing competitiveness, productivity and the number of byproducts. The study analyses global value chains to gauge their importance and gain a better understanding of the sugar and alcohol sector. It shows that the value chain is under national control, unlike most other chains in which Brazil participates. Lastly, the article highlights the most recent innovations in the sector, which reflect a drive to improve competitiveness.

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I

Introduction

Although the production of alcohol, and particularly sugar, are not new activities in Brazil, its importance and global dissemination has increased in recent years because fuel alcohol is a renewable resource and it emits virtually no carbon into the atmosphere. The emergence of flex-fuel vehicles has boosted national, and to a lesser extent global, demand, and has also given new impetus to the sector.¹ This reflects the increasingly intense search for renewable and less polluting energy sources, to address worldwide environmental problems and promote sustainable growth. The most serious problems include the “greenhouse gas effect”, which requires high levels of investment and research and development (R&D) in this sector and elsewhere.

Against this backdrop, changes have occurred in industrial and technological policy in Brazil and many other countries, which are gradually starting to mix ethanol with gasoline and promote new environmental and labour standards for the sugar sector, with the aim of increasing exports and, if possible, improve its repercussions on the environment and workers.

The price of oil, and hence the price of gasoline, has a direct effect on domestic demand for ethanol, and further adds to the importance of the sector. Moreover, there are strategic issues regarding the energy potential of sugarcane, only one third of which is exploited owing to a lack of suitable technology for co-generation and separate collection of cane straw. Technological progress in that direction could mitigate problems of energy shortage in periods when Brazil’s water deposits run low (May-December), which is precisely the best time

of year for co-generation by burning the residues from the country’s sugar and alcohol industry (Piacente and Piacente, 2004; Vieira, 2003).

Many specialists are worried that sugarcane cultivation may crowd-out plantations that previously provided food products to the Brazilian and world populations. Others fear that cultivation of this crop will spread to the Amazon jungle, thereby aggravating deforestation, and, consequently, the environmental impact of this industry.

Given the growth of the sugar sector and the need to combine it with the socioenvironmental sustainability of the agribusiness, new technologies are needed that, among other things, guarantee higher productivity, the elimination of pre-harvest burning, adequate disposal or use of productive residues, and more efficient energy generation. Investments in R&D, whether by research centres or by public or private enterprises, are essential for maintaining the growth of this activity.

This article is divided into five sections, including the introduction. Section II briefly describes the development of the sugar and alcohol sector in the State of São Paulo, the country’s leading producer, and the problems caused by its deregulation. It also gives details of the main products of that agribusiness and its potential markets; subsequently, it identifies the comparative advantages of Brazilian ethanol compared to that produced in United States and the European Union.

Section III describes the sugar and alcohol value chain, including a brief description of global value chains theories, and it analyses their application to the sugarcane industry. This section also identifies some of the problems faced by globalization of the sector.

Section IV explains the current status of innovations in the sugar and alcohol sector, and how they could contribute to its development. It also discusses a number of factors that are considered strategic for keeping the sector internationally competitive. The fifth and last section presents a number of final thoughts on key areas for improvement or factors that need to be persevered with.

□ The authors are grateful for comments by an anonymous referee; any remaining errors are their responsibility.

¹ Several countries have announced their intention to start (or increase) adding alcohol to gasoline and diesel fuel. These include the countries of the European Community, Angola, Argentina, Australia, Benin, the Bolivarian Republic of Venezuela, Canada, China, Colombia, India, Japan, Mozambique, Nigeria, the Philippines, the Plurinational State of Bolivia, Senegal, South Africa, Thailand, the United States and Zimbabwe (Negrão and Urban, 2005; Souza, 2006; Lima, 2007).

II

The State of São Paulo and the sugar - alcohol sector

After 1929, a period of large-scale investments in sugarcane production began in the State of São Paulo, in response to the precarious situation of the coffee-growing sector, which accounted for a high percentage of the São Paulo economy at that time. In 1933, following the productive diversification phase, the Vargas government created the Sugar and Alcohol Institute (IAA), whose functions included controlling the production and milling of sugar throughout the country.

The State of São Paulo (Brazil's wealthiest and best endowed state, and its largest internal market) became Brazil's most important centre sugar-producing centre, thanks to support from the state government and from technological research centres and institutes (including the Campinas Institute of Agronomy - IAC). The priority given to the production of sugarcane in that state was confirmed by the implementation in 1975 of the National Alcohol Programme (Proálcool), as a federal government policy.

Under this programme, alcohol gained importance as a renewable energy source, which gives it a much higher profile today. Until 1975, the production of fuel alcohol was on a small scale, and it lacked a stable market with attractive prices. Through Proálcool, the federal government started to support the market, by providing with incentives for using mixtures of anhydrous alcohol in gasoline and for producing vehicles that fuelled by hydrated alcohol. This led to various changes and triggered the development of the sugar- alcohol sector. Enterprises in industries linked to the sector —Dedini and Zanini— sought new milling technologies for supplying cane to the first stage (using a rake-type metal conveyor) and for preparation of the sugarcane (using pressure rollers or shredding knives that do not require a roller) following the French and Cuban systems, which make better use of the cane than the Brazilian model. This led national research centres, both private and public, to increase investments aimed at improving the cane types (Mariotoni and Furtado, 2004).

Over a 16-year period, the discoveries made by those firms and research centres raised agricultural productivity in the sugar industry by around 56.8% in the State of São Paulo (from an average of 51 tons per hectare before Proálcool (1975) to 80 tons per hectare

in 1991). This contributed directly to lower agricultural production costs, which account for about 60% of the costs of the sector's productive chain. In addition to increasing productivity, following the implementation of Proálcool, the amount of sugarcane processed by São Paulo sugar refineries also increased. From 1975 to 1985, the amount grew by almost 300%: from 30.4 million tons to 121.7 million tons. Alcohol and sugar production in the state also increased from 362,300 cubic metres to 7.6 million cubic metres (4,767%), and from 2.9 million tons to 3.4 million tons (18%), respectively.

Despite those excellent results, in 1985, the National Alcohol Programme was rendered financially unviable by the fall in the oil price (which dropped to US\$ 12 per barrel), the ending of government subsidies following deregulation, and the rise in the international price of sugar (Michellon, Santos and Rodrigues, 2008). Three following periods can be distinguished in the implementation of Proálcool, from its creation until 1990:

- (i) Moderate growth (1975-1979), characterized by an increase in production driven by high levels of financing for the assembly and expansion of distilleries attached to existing sugar refineries, promoted also by incentives for using alcohol as a gasoline additive;
- (ii) Rapid growth (1980-1985), involving a considerable expansion in the production of hydrated alcohol for direct use in vehicles, and a consequent increase in sugarcane production in Brazil (from 91.5 million tons in 1975-1976 to 225 million tons in 1985-1986); and
- (iii) Slowdown and crisis (1986-1990), when alcohol lost the State subsidies granted until then, and the sector faltered in the wake of falling oil prices, resulting in a smaller proportion of alcohol-fuelled vehicles. It should be noted that in 1990 there was a radical change in the State's participation and mode of action in Brazil, with the short-lived Collor administration (1990-1992) being interrupted by a political trial. That government promoted a wholesale opening up of the Brazilian economy; a privatization process began that would last until the decade of 2000; and the State withdrew from a number of sectors, including sugar and alcohol, and the IAA founded by Vargas in 1933 was closed down.

1. Deregulation of the sugar and alcohol sector and its economic effects

In 1990, the sugar and alcohol sector was drastically deregulated. It was one of the sectors most affected by the changes in the country's institutional environment, which forced its participants to reorganize without State participation. Following the end of State intervention, economic agents adopted different strategies, involving new competitive structures, mergers and an intensive process of capital migration to "sugarcane frontier" regions, there by losing the relative equity guaranteed by the IAA in the distribution of production and in supply and price guarantees (Vian and Belik, 2003).

The refineries in which investment or the search for new production technologies ended, suffered what Schumpeter (1942) calls the creative destruction process. Over time, this process results in autonomous organization of the industrial economy, in which obsolete technologies, firms and sectors leave the market and are replaced by others that are more innovative. This shows—especially in the long run, when the process becomes inexorable—the importance of investing in innovation to maintain or increase corporate competitiveness in a capitalist economy (Nelson and Winter, 1974, 1977 and 1982).

The changes that occurred in all branches of the sugar and alcohol sector forced agribusiness directors to pursue, among other things, greater product and process flexibility, higher productivity resulting from better use of inputs, and continuity in improving the most productive types in terms of sucrose concentration (also, in this case, with continuous assistance from public and private research centres). Consequently, agribusiness leaders sought factors which, according to Schumpeter (1979), would guarantee the survival and sources of larger profits for firms participating in a competitive market, namely innovation and technological development. This differs from the practice that was widespread until the 1990s, when the most important changes in the sector's technological regime targeted the rationalization of production costs.

According to Dosi (1988), this search for new products and processes not only reflects training and the incentives generated internally in the firms, but also responds to external causes such as the state of the art in the different sectors, access to external science and technology resources (public research centres and universities, among others), facilities for knowledge dissemination and communication, labour skill development, market conditions and protection

(patents), among others. Possas (2003) states that interaction, training and learning among suppliers and collaborators throughout productive chain could be a major source of incremental innovations, dissemination of new technologies and the appropriation of gains arising from the innovation process. This further increases the importance of suppliers and public and private research centres, not only in the sugar and alcohol sector, but in other segments of the economy also.

Technological and productive progress considerably improved the economic profitability of agribusiness compared to the pre-deregulation period. The discovery of new byproducts (acetic, lactic, and citric acid; biodegradable plastics, papers and pharmaceutical products, among others) emerged from the differentiation and intensification of research and development activities undertaken by the Research Centre of the Sugarcane, Sugar and Alcohol Producers Cooperative of the State of São Paulo (COPERSUCAR), and public universities with links to the sector (Assumpção, 2004; Coutinho, 1995). In addition to those new byproducts obtained through diversification and investments in research and development, the sugarcane agribusiness also experienced other innovations, including the production of more finely ground sugars for use in diet foods, sugarcane bagasse for fodder and energy generation, chemical derivatives for cosmetic use, and a new byproduct, electric energy, capable of further expanding income potential in the refineries' productive process (Fronzaglia and Martins, 2006; Baccarin and Castilho, 2002; Jank, 2008). In addition to helping firms remain in the market by increasing their competitiveness, investments in research and development can also open up new business opportunities. This is possible when the firm succeeds in diversifying its production, enters new markets and becomes less vulnerable to sector crises (Penrose, 1959). According to that author, a firm diversifies when, without completely abandoning its previous lines of production, it starts to make other products, including intermediate goods that are sufficiently different from those that it previously produced, and whose production involves processes of distribution, production and other kinds that are also different. Alcohol and its derivatives, electric energy and diet sugars, among others, are examples of this concept of diversification in the sugar industry.

Some of the technological advances made by the agribusiness analysed in this study are based on more effective reuse of productive residues at several stages of production. Examples include the following: (i) vinasse, a residue obtained from alcohol and sugar production, which is used to irrigate the land where a new crop will

be planted; (ii) cane bagasse, which is widely used in the co-generation of electric energy and, to a lesser extent, in the production of fodder; and (iii) straw, which was not exploited until the 1990s, when it was first used to protect the soil after harvesting McCain (since 2006, the viability of using it in co-generation and the production of alcohol through acid or enzymatic hydrolysis has also been analysed).

According to Pavitt (1984, quoted in Dosi, 1988 p. 5), there are four basic ways to invest in R&D: “(i) formalized and economically expensive search process, whose costs are fully borne by the innovating firms; (ii) informal processes of information dissemination and technological training (for example through publications, technical associations, learning by observing, staff transfer); (iii) specific types of externalities in each firm, related to the concept of learning by doing; and (iv) adoption of innovations developed by other industries and incorporated into capital equipment and intermediate inputs.” In the sector under study, the two latter in particular are applied.

The changes, innovations and diversifications that have occurred in the sugar agribusiness between 1975 and 1995 include several examples of paradigm shift, such as the creation of harvesting machines that avoid burning, the use of vinasse as a fertilizer and the discovery of new sugarcane varieties, among others.

2. Main products of the sugar industry

(a) Ethanol

Brazil is one of the world's largest ethanol producers, with output of 17.5 million litres in 2006 (about 34% of the 51 million litres ethanol produced worldwide in that year); and it is ranked second after the United States, which produces 18.5 million litres, equivalent to 36% of global production. Nonetheless, Brazilian ethanol has competitiveness and price advantages over the United States substitute, owing to the energy difference of the raw material used and the technologies applied in the two countries. For that reason, and also because domestic demand is small, Brazil is the world's largest ethanol exporter. The main destinations for its exports are the European Union (29.3%), the United States (25%), Japan (10.3%) and Jamaica (8.3%) (FIESP, 2008; Neves and Conejero, 2007). Although Brazil has a large share of the world ethanol market, this is a still-developing market that offers many possibilities until it becomes consolidated. In 2005, Brazil exported about 2.5 billion litres of ethanol, exceeding the combined exports of all the other countries (FIESP, 2008). According to Souza

(2006), Brazil does not export more fuel alcohol only because of the current national production constraints, despite being ranked second in the world. Table 1 and Figure 1 show export data for the leading countries in the sector in 2006.

TABLE 1

World ethanol exports, 2006 (Billions of litres)

Country	Total	(% of total)
Brazil	3.40	(64.8%)
Costa Rica and Jamaica	0.30	(5.7%)
South Africa	0.20	(3.8%)
United States	0.20	(3.8%)
Saudi Arabia	0.15	(2.9%)
China	0.15	(2.9%)
European Union	0.10	(1.9%)
Other	0.75	(14.3%)
<i>General total</i>	5.25	(100.0%)

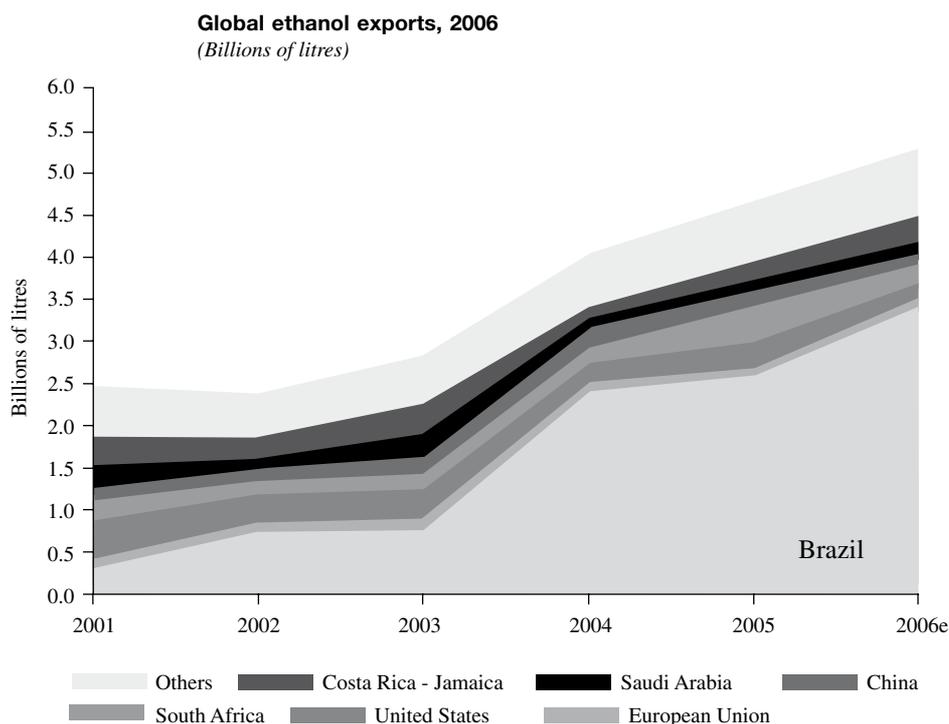
Source: Institute of Trade Studies and International Negotiations (ICONE).

The main drivers of growth in the ethanol market include expansion of the fleet of flex-fuel vehicles, which currently are confined essentially to the domestic market (accounting for 81% of new automobile sales in 2007, according to the National Association of Automobile Manufacturers (ANFAVEA); and the increase or start, depending on the country, of the policy of mixing or adding alcohol to gasoline on the international market (Toneto Jr., 2007). In addition to contributing to the expansion of domestic ethanol consumption, the emergence of flex-fuel vehicles created a new relation between ethanol and gasoline. As these products became perfect substitutes, a close correlation was established between their prices and demands.

Apart from its clear relation with gasoline, ethanol competes with sugar in production decisions, since it increases or decreases depending on the respective market trends. With the breakdown of sugar production in India, for example, the price of the commodity surged on the international market and as a result many refineries adjusted their production proportions to increase the supply of sugar.

Another important factor in the growth of demand for alcohol stems from its potential use in generating new chemical byproducts. This would be possible by turning refineries into by bio-refineries, in other words complexes of equipment, facilities and processes that convert biomass into biofuels, chemical products (ethyl alcohol, butanol, acetone, among others) and electric

FIGURE 1



Source: Institute of Trade Studies and International Negotiations (ICONE).

Note: e = Estimates (the data for Brazil and the United States were brought up to date; the figures for South Africa were projected on the basis of preliminary figures for 2006; and exports from other countries were projected on the basis of previous years' figures). In the case of the European Union, only trade outside the bloc was taken into account.

energy (co-generation) (Bastos, 2007). Unlike sugar, for which there is already a consolidated market, trade in ethanol is still subject to a number of barriers, namely: (i) protectionism; (ii) lack of confidence in the maintenance of supply and the quality and origin of the product; (iii) lack of standardization; and (iv) insufficient distribution channels to reach all of the world's markets.

The transformation of ethanol into a basic global product would largely eliminate the impact of these barriers and promote its commercialization. Standardization is fundamental for any commodity and involves dissemination and supervision of data on the raw material used, the mode of production, and respect for environmental, labour and quality laws. Although the Brazilian government and various sector and environmental entities have lobbied for the standardization of ethanol and the accompanying data (Negrão and Urban, 2005), that process depends partly on international agreements that will need to be signed with other producers and users of ethanol. As this is an ongoing process, it is not yet possible to predict the outcomes. The term "commodity" is understood as any product,

particularly agricultural or mineral, that is widely traded on the international market by importers and exporters. These products are traded on specific exchanges; in the Brazilian case, the Commodities and Futures Exchange (*Bolsa de Mercaderías e Futuros - BM&F*).

(b) Sugar

Global demand for sugar is directly related to the population's income and growth. Based on the growth of national and international income, and boosted by the expansion of the world market, domestic and international consumption of industrial sugar is expected to increase, mainly for use in the soft drinks, chocolate, food, and ice cream industries (Vieira, 2006).

The demand for sugar is also expected to grow as a result of greater participation in the global market by Asian countries, particularly China, where per capita sugar consumption is still low (7 kg per person per year, compared to 58 kg in Brazil, 18 kg in India, 34 kg in the United States and 38 kg in the European Union). Moreover, the World Trade Organization (WTO) has argued against subsidized sugar exports from European

countries, reflecting the progress of countries such as Brazil and Australia in that organization. This would guarantee the opening up of new markets for Brazilian sugar (Neves and Conejero, 2007; Toneto Jr., 2007; Vieira, 2006).

Brazil is the world's largest sugar producer (32.3 million tons, equivalent to 20% of world production); its main direct competitors are the European Union (12%), India (10%) and China (9%). Data from the United States Department of Agriculture show that, despite being world's leading producer country, Brazil posted the lowest cumulative production growth between 2004 and 2008 (16.5%), compared to India (103.18%) and China (31.79%). The low price of sugar on the world market and growing domestic demand for ethanol could explain this decline.

Although Brazil's per capita sugar consumption is high, it still exports over 60% of its production —over 20 million tons in 2008, compared to the 5.5 million tons exported by Thailand and 4 million by Australia, its main export competitors (Ministry of Agriculture and Supply, 2009). The European Union grants large subsidies with the aim of exporting part of its output, despite the high barriers it imposes on the entry Brazilian ethanol in the European common market (Mariotoni and Furtado, 2004).

(c) *Electric energy*

Self-sufficiency in electric energy production in the refineries and efforts to produce a surplus through co-generation led to the emergence of a new market and a new product in the sugar and alcohol sector. In the São Paulo refineries, for example, every ton of sugarcane produces an average of 140 kg of bagasse (dry material), 90% of which is used to produce energy in the refinery. Every ton of cane also produces 140 kg of straw, which represents an unexploited potential, because, although it is currently burnt or left in the field, it could be used to increase energy generation or, in the future, as discussed below, to increase ethanol production (through hydrolysis) (Vieira, 2006).

The growing demand for electric energy in Brazil, driven by economic development and the search for renewable and clean energy sources, has increased the share of co-generation in the Brazilian energy matrix. A relevant feature of that new energy source, which has formed part of the country's energy matrix since the late 1970s, is the fact that the power generation period coincides with the period in which hydroelectric energy (May-December) is in short supply owing to a reduction in rainfall indices and the emptying of reservoirs.

Nonetheless, co-generation still has to overcome a number of internal barriers, including: (i) the need for wind throughout the year; (ii) efficient integration with transmission lines to reduce dissipation losses; (iii) the price; and (iv) the tendering format (Piacente and Piacente, 2004; Vieira, 2006; Toneto Jr., 2007).

According to Souza (1999), the average investment per kilowatt installed in agribusiness for co-generation varies between US\$ 300 and US\$ 1,500. Rodrigues (2001, quoted in Piacente and Piacente, 2004) states that, in addition to requiring from 8 to 12 years to construct, a large-scale hydroelectric plant costs about US\$ 2,000 per kilowatt, whereas a nuclear plant takes the same time to build and the investment per kilowatt is at least US\$ 4,000. Consequently, investing to expand energy generation in the refineries is much more economically viable in the short term, and it does not depend on imported inputs or equipment, as in the case of nuclear energy.

3. **Brazil, the United States and the European Union: individual advantages in ethanol production**

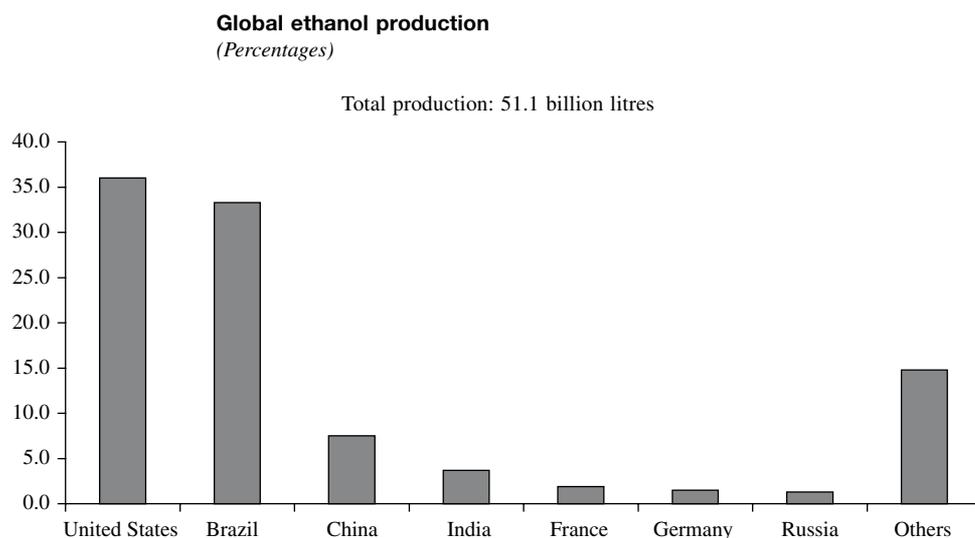
Although ethanol is also produced in other countries apart from Brazil, the United States and the European Union, only Brazil uses sugar exclusively as the raw material. Whereas in the United States ethanol is produced from maize, which has disrupted the supply of that food product on the domestic and external markets, the European Union primarily uses sugar beet, from which sugar is also produced.

Although in 2006 Brazil lost its position as the world's largest ethanol supplier to the United States (as shown in figure 2), it has major comparative advantages in terms of the raw material used, the cost of production, productivity, energy potential and the availability of land to expand production. While the cost of producing a litre of ethanol from sugarcane was about US\$ 0.20 in Brazil in 2005, a litre of ethanol produced from maize in United States cost US\$ 0.45, and a litre produced in the European Union cost US\$ 0.65 (FIESP, 2008).

According to Rodrigues (2008), if the Brazilian ethanol production cost is maintained or reduced, it would remain competitive with respect to gasoline, as long as the price of oil does not drop below US\$ 40 a barrel.²

² Roberto Rodrigues, former Agriculture Minister, Coordinator of the Getulio Vargas Foundation Agribusiness Centre, President of the FIESP Supreme Agribusiness Council, and Joint President of the Inter-American Ethanol Commission.

FIGURE 2



Source: prepared by the authors on the basis of data from the Industries Federation of the State of São Paulo (FIESP), *Agronegócio brasileiro*, São Paulo, 2008.

Brazil also has productivity advantages: in 2005, the average yield was about 7,000 litres per hectare, much higher than in United States (3,000 litres per hectare) or in the European Union (5,500 litres per hectare) (FIESP, 2008; BNDES, 2008).

In terms of the energy balance in the raw materials used to produce ethanol in those three countries, when the energy consumed in all stages of manufacture (planting, harvesting, transport, and milling, among others) is compared with the renewable energy generated, it can be seen that the yield of sugarcane is almost 8 times higher than that of maize. Sugarcane ethanol releases about 8.9 units of energy per unit of energy consumed; whereas the proportion is 1 to 1.5 in the case of maize ethanol and roughly 1 to 2 in the case of ethanol made from sugar beet (Macedo, 2007).

Sugarcane energy generation capacity is not confined to ethanol alone, which represents just one third of the energy contained in the cane. As noted above, co-generation is another important source of renewable energy that the residues from sugarcane can provide. This explains the differential energy potential between the raw materials analysed.

By not using a food raw material—as the United States does—and not using the space of food plantations because there are large arable areas available in the country, the Brazilian sugar and alcohol sector has no direct effect on rising food prices, contrary to certain specialists claim. Nor should one fear the advance of sugarcane cultivation to Amazonia, since that region's

high humidity throughout the year would reduce the productivity of the sugarcane varieties used and known in Brazil. On the contrary, although the increase in maize consumption arising from higher income levels, particularly in the Asian and Eastern European economies, is one of the main factors driving the recent crisis between supply and demand for that product, the growth of ethanol production in the United States could also be partly responsible for the food crisis, since maize is one of the world's main foods, particularly in America (IPEA, 2008).

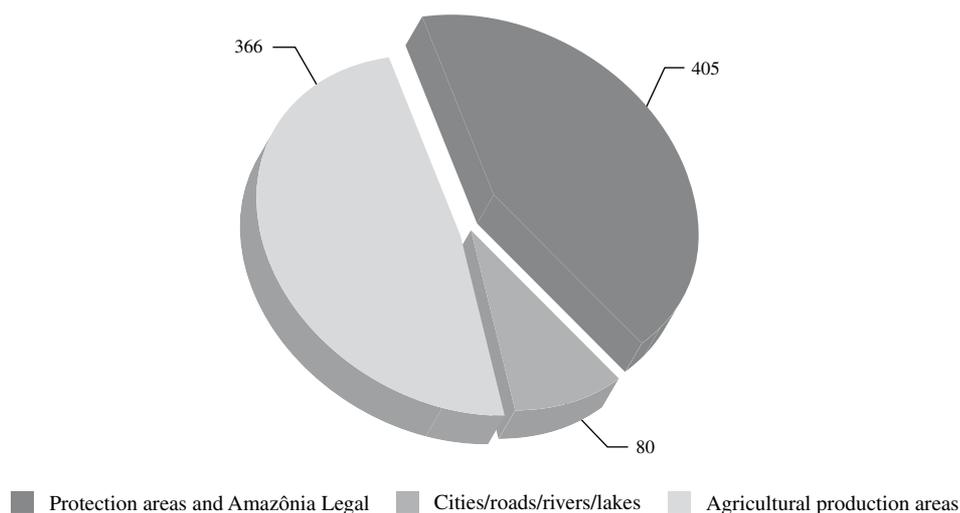
Given the size of Brazil, there is still ample space for sugarcane cultivation to expand, without encroaching on Amazonia Legal. Figure 3 shows the distribution of the 851 million ha of free land existing in Brazil.

Of the 366 million ha (43%) of arable land in Brazil, sugarcane occupies just 6.2 million ha (1.69%) whereas the pastures and fertile and virgin areas of the agricultural frontier total 300 million ha (81.97%) (Salibe, 2008).

Given that Brazilian livestock production is very extensive, but with some investment could be confined to a smaller land space in Brazil's vast fertile and virgin areas, there is major potential for the sugar and alcohol sector to continue growing without interfering with the production of other agricultural products. Moreover, thanks to investments in new technologies (cellulosic ethanol for example), the potential for higher sector productivity could allow for greater production without the need to increase the actual amount of sugarcane planted.

FIGURE 3

Division of Brazilian territory
(Millions of hectares)



Source: prepared by the authors on the basis of data from the production and Agroenergy Secretariat (SPAÉ) of the Ministry of Agriculture and Supply.

III

Sugar and alcohol sector value chain

According to Kaplinsky (2000, quoted in Stamer, Maggi and Seibel, 2001, p. 9), a value chain can be understood as “a complete set of activities needed to make a given product or service economically viable, from conception and production through to delivery to the final consumer and its disposal after use”. Thus, the whole of production and even research activities form part of the value chain.

Based on the value chain concept, Sturgeon (1997) analyses a new type of industrial organization, whose chief feature is the division of corporate activities into innovative and productive functions. The abandonment of productive functions by certain firms and sectors can partly be explained by the global value chains concept. When the chains are dominated by large buyers or large enterprises, outsourcing to firms in less developed countries is common —where production is cheaper— to make standardized products using the brand name of those buyers. If the chains are dominated by the producers, the latter will control the most important stages, including, in some cases, marketing operations (brand, publicity and distribution channels, among others).

Global value chains make it possible to analyse the linkages that exist between the various activities, even in a globalised economy. This greater integration of production and trade between firms in different countries is facilitated by the development of new communication and transport technologies (Gereffi and Korzeniewicz, 1994). Humphrey (2006) focuses on world trade in agricultural products, which includes the sugar agribusiness, and identifies three main challenges to be faced by firms and sectors that want to globalize:

- (i) Produce to satisfy world requirements, given the increasing importance of agricultural products standards; satisfy the importing countries’ food safety requirements, by providing information on cultivation, harvesting, processing and transport methods.
- (ii) Satisfy the demands of global buyers in terms of the speed and reliability of delivery, altering products on request in terms of processing and packaging, as well as product safety guarantees.
- (iii) Add value to agricultural export products, particularly in the case of developing countries whose export basket consists mainly of commodities.

Application of the global value chains scheme to an agricultural business makes it possible to analyse the causes and consequences of the organized vertical coordination, implemented in the various sectors of the business. Firstly, the role of subcontracted firms is analysed, along with the position of the producers in those chains, whether in a subordinate or commanding role. Then, the theory concerning the decisive factors in the different forms of vertical coordination is discussed. Lastly, the consequences of the value-chain dynamic is considered in developed and developing countries, and in terms of the distribution of income between firms in the various stages of the chain, and in each of those places (Humphrey, 2006).

The main types of coordination of relations between agents integrated in a value chain are as follows:

- (i) Relational links: through strategic partnerships. Participants are mutually dependent and regulated by reputation, social proximity and ethnic links, among other aspects.
- (ii) Captive links: Suppliers end up depending on large buyers. These networks often entail a high degree of supervision and control by the contracting enterprise.
- (iii) Modular links: Gains in terms of the cost of products and services are obtained without the need for investments specific to the transactions in question. In this case, the suppliers make products and provide services according to a buyer's specifications (Gereffi and Korzeniewicz, 1994; Sturgeon, 2006; Humphrey, 2006).

The analysis of the different links is based on three explanatory variables:

- The complexity of the information to be transferred between the participants in the chain, to ensure that the transaction is successful;
- The extent to which information can be relied upon, and, consequently, efficiently transferred, without specific investments; and
- The competency of suppliers with respect to the requirements imposed on them (Humphrey, 2006). The key aspects of the sugar sector value chain are the fact that it is controlled by Brazilian domestic enterprises—despite the entry of a number of large transnational enterprises in recent years—and the basically total integration of the chain inside the country. In that sense, it is almost possible to speak of a “Brazilian value chain”.

The leading players in the sector analysed in this article show little desire to develop relations with unknown suppliers of uncertain potential. Nonetheless, there is a clear relationship with cooperatives, which often undertake the sector's research and development

activities (for example, in the case of the Sugarcane, Sugar and Alcohol Producers Cooperative of the State of São Paulo – COPERSUCAR), with large firms that are already consolidated on the market, and with major research centres in universities, either state, federal or private, which also undertake R&D activities for the agriculture sector generally, as explained by Nelson and Winter (1982).

The sugarcane agribusiness chain has undergone far-reaching technological changes over the last few years, owing to its importance to the economy and Brazil's energy matrix (Ramos and Souza, 2003). The sugar and alcohol productive chain became internationalized in second half of the 1990s, with the aim of expanding sugar production capacity as a result of the influence of transnational food producers (Assumpção, 2004). Recently, a new stage of internationalization has occurred, this time to expand ethanol production capacity, given its increasing environmental and economic importance internationally.

The greatest problem in the global ethanol value chain relates to the market and economies of scale, given the low level of international demand prevailing until 2001-2002, when several countries started to show interest in mixing ethanol and gasoline, and Brazilian exports increased (see table 2). The extent

TABLE 2

Ethanol demand and supply Brazil and worldwide
(Billions of litres)

Countries	Demand by country		
	2003	2005	2010 ^a
Brazil	12.9	14.0	17.4
United States	10.6	13.3	18.9
Canada	0.4	0.8	1.5
European Union	1.5	4.9	12.9
Japan	0.8	1.9	7.2
Other	1.5	1.5	2.3
<i>Total</i>	<i>27.7</i>	<i>36.4</i>	<i>60.2</i>
	Brazil Supply		
	2003	2005	2010 ^a
	12.5	15.8	26.0
	Exports (Exports/supply %)		
	2003	2005	2010 ^a
	0.7 (5.6%)	2.6 (16.5%)	7.2 (27.7%)

Source: prepared by the authors on the basis of data from the Sugarcane Industry Union (ÚNICA) and the Ministry of Agriculture and Supply, *Anuário estatístico da agroenergia*, Brasília, 2009.

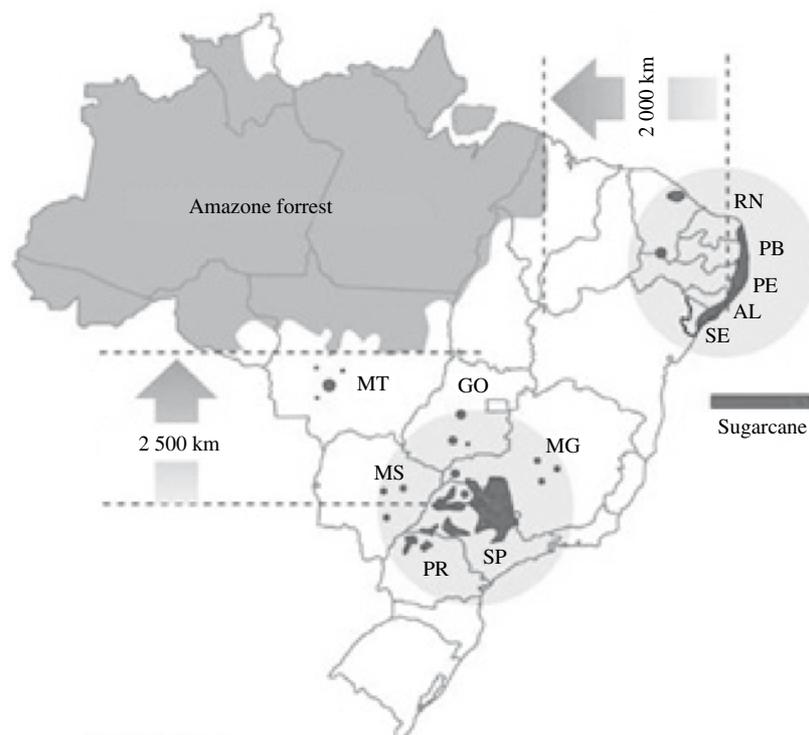
^a Estimates.

to which certain local factors affected demand and production also posed a problem for the globalization of ethanol, because prior to the enormous investments made to expand Brazilian productive capacity (as from 2002-2003, with the aim of increasing exports) production was almost exclusively directed towards

the domestic market, which still today absorbs most of the sector's sales. The sugarcane productive chain in Brazil is fully structured. The country dominates the entire productive and distribution process and has the world's best technologies for producing alcohol and sugar (see figure 4).

FIGURE 4

Production and concentration of plantations and refineries in Brazil



Source: Sugarcane Industry Union (ÚNICA).

Map legend: MT (Mato Grosso), GO (Goiás), MG (Minas Gerais), MS (Mato Grosso do Sul), PR (Paraná), SP (São Paulo). (Circle): RN (Rio Grande do Norte), PB (Paraíba), PE (Pernambuco), AL (Alagoas), SE (Sergipe).

IV

Current status of innovations in the sugar and alcohol sector

The sugar and alcohol productive chain is often divided into two types of activities: agricultural and industrial. In this article, the sugar and alcohol sector value chain is divided into four stages: (i) agricultural; (ii) link between the agricultural and industrial sectors; (iii) industrial; and (iv) commercial, as illustrated in figure 5. The analysis did not include technological research processes (research and development) and professional training, since these mostly take place outside the refineries. The main innovations in each stage of the productive chain over the last few years are shown below.

1. Agricultural activity

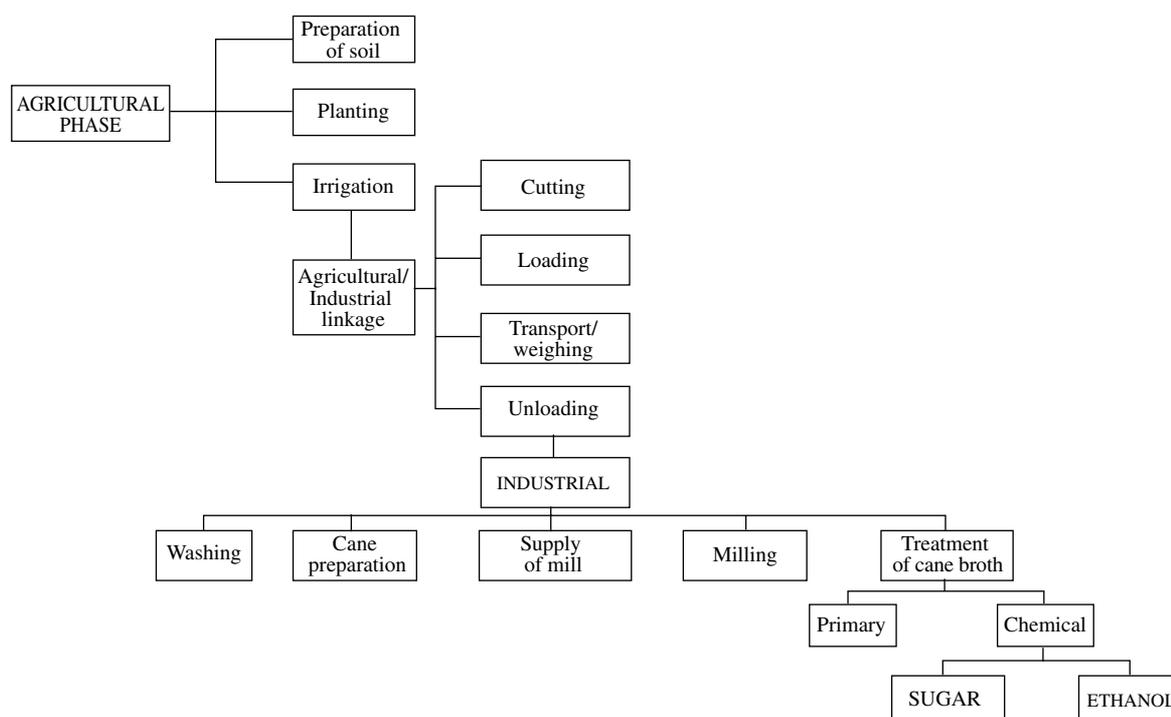
Despite its simplicity, the productive chain in the agricultural phase is directly responsible for the success

of the remainder of the productive process and accounts for about 60% of costs in the entire sugar and alcohol and chain. Sugarcane cropping has been controlled by satellite by the Brazilian Agricultural Research Enterprise (EMBRAPA), as part of a project for which a series of routines and specific procedures were created to detect, identify, classify and map crop-growing areas. Satellite-use has contributed to the development of precision sugarcane agriculture, which allows for a detailed mapping of soil conditions and rural land plots, which in turn makes it possible to analyse the viability of the plantation and mechanized harvesting methods. It also guarantees the monitoring of soil productivity, which facilitates knowledge of its nutritional needs (Abarca, 1999).

A large proportion of the nutrients needed to prepare land for planting comes from the residues of

FIGURE 5

Value chain of the sugar and alcohol sector, Agricultural and industrial phases



Source: prepared by the authors on the basis of data from the sugarcane industry union (ÚNICA).

this agribusiness, which are used to fertilize the soil and produce a 30% saving in the process. Use of this organic fertilizer and the cultivation of enhanced varieties of sugarcane have resulted in an increase of about 15% in land productivity. Filter cake, a residue formed by mixing milled bagasse and mud from the pressing, is an organic compound (85% of its composition), rich in calcium, nitrogen and potassium. It is increasingly used instead of traditional potassium-based inputs, mainly in the planting operation. Vinasse, another sector residual, is used in the fertilization and irrigation of the sugarcane crop. Obtained from the distillation and fermentation of sugarcane in the process of making alcohol, vinasse is rich in organic material and mineral nutrients such as potassium (K), calcium (Ca) and sulphur (S), with a pH ranging between 3.7 and 5.0 (Piacente and Piacente, 2004).

Sugarcane genetics is one of the areas in which the greatest progress has been made. It is now possible to choose the best type of cane to plant in a given soil, comparing pest resistance, productivity, sucrose concentration, inclination and size, among other parameters. At the start of the Proálcool programme, there were five or six commercial varieties of sugarcane in Brazil. There are currently over 500, forming a substantial and growing genetic patrimony. The increase in the number of commercial varieties, depending on genetic improvement, is also directly responsible for the growth of sugarcane productivity, which rose from 47 tons per hectare in the 1970s to 82 tons per hectare in 2005 (FAPESP, 2006).

Two highly innovative national studies are worth mentioning as an example of the sector's genetic evolution. The first, undertaken by researchers from the Luiz de Queiroz Agricultural College (ESALQ)/University of São Paulo, concerns the creation, through genetic modification, of a type of sugarcane that releases proteins that act as an insecticide when attacked by *Diatraea saccharalis*, an insect that borrows into the interior of the plant and excavates internal galleries, causing major damage to producers. If no attack of this type occurs, the plant remains "conventional" and its phenotype remains unchanged. The second study, undertaken by EMBRAPA Agrobiologia, discovered the code of the genetic sequence of *Gluconacetobacter Diazotrophicus*, one of the bacteria responsible for biological nitrogen fixation in sugarcane. This discovery will make it possible to increase the bacteria's nitrogen-generating potential, and thus reduce the need for nitrogen base fertilizers for the development of the cane plantation, with consequently lower production costs (JornalCana, 2007; FAPESP, 2006).

The greater demand for sugar and ethanol, which is driving the expansion of the sector into new areas, further adds to the importance of investment in genetic varieties of sugarcane for different soil and climate conditions. Research has been undertaken in response to that demand, and much has been learned about improving cane quality.

As the natural composition of the cane includes a high concentration of water, the key challenge is to reduce that proportion and increase the relative concentration of sugars, thereby guaranteeing higher productivity. Many varieties have been created, which differ in terms of precocity, rooting, sucrose concentration, the concentration of fibres and bagasse, and size (which facilitates or impedes mechanized harvesting), among other factors. In addition to better exploitation of sugars for ethanol and sugar production, choosing the most suitable sugarcane for each type of soil and agribusiness need ensures greater efficiency in harvesting (when the specific sizes is chosen) and in electric power generation, given its fibre concentration.

2. Linkage between the agriculture and industrial sectors

This phase, which includes the cutting of the cane, transport, unloading and storage, has caused major controversies both nationally and within the sector. Firstly, the mechanization of harvesting has intensified owing to environmental laws prohibiting burning, which are essential to be able to harvest manually. Secondly, there is a labour problem, since manual harvesting is done under subhuman conditions, for which reason it has attracted criticism both in Brazil and internationally. The pursuit of greater efficiency in mechanized harvesting aims to reduce burning and eliminate manual work in the field. This is one of the requirements to be addressed in the sugar sector, along with respect for environmental, labour and social legislation, the elimination of burning, better working conditions and, as far as possible, the maintenance of rural workers' jobs. Given those challenges, the leaders of the agribusiness also need to invest in technologies to make mechanized harvesting viable and expand it, provide incentives and professionalization and training courses to enable former farm hands to operate a computerized harvesting machine, so as to keep their current job and eliminate the need for pre-harvesting burning (Bragato and others, 2008).

Although not a very recent development, mechanized harvesting has undergone innovations to make the harvesting machines more efficient, including the following:

- (i) reduction of soil compacting and consequent root loss, by using lighter machines or those with wheels that are the same distance apart as the sugarcane plantation rows;
- (ii) the manufacture of machines capable of harvesting of land with a slope of over 12%, thereby making it possible to increase the mechanization of harvesting; and
- (iii) optimization of the process of collecting the cane along with the straw, to subsequently use the latter in industry as an energy source in co-generation or, in the near future, additional generation of alcohol (Manechini, Junior and Donzelli, 2005).

The sugarcane transport sector has also played a major role in the process of modernization and investment in agribusiness research. Studies at this stage are targeted on fuel saving, fleet rationalization, and maintenance of the flow of cane to supply the mills. Cutting, loading and transport represents 30% of cane production cost, with transport alone accounting for 12 percentage points of that figure (Iannoni and Morabito, 2002).

One of the main aims of investments and research in the transport system is to reduce idle time and shorten the truck cycle, in other words the time taken between the truck's arrival at the refinery for unloading and its return to the field, reloading in the field and return to the refinery again. In other words, the aim is to optimize operations involving those vehicles, whose idle time in the agricultural and industrial phases generates high costs for the refineries. Major investments have been made in logistics and automation of the control process for that purpose (Iannoni and Morabito, 2002).

3. Industrial activity as such

In the period 1975-1994, the industrial segment underwent technological progress that helped to expand milling capacity by 100%, and increase the efficiency of the extraction process from 93% to 97%, and of the fermentation process from 80% to 91%. In the same period, it was also possible to reduce steam consumption in distillation by 44% (Abarca, 1999). Nonetheless, those gains were achieved exclusively through incremental innovations, while maintaining the same technological paradigm. The innovations included the installation of several items of peripheral equipment, and the application of new operating procedures in the milling and extraction phases.

With the faster pace of innovations and changes in the sector, there has been greater demand for peripheral and core technologies compatible with the changes in

processes. For example, increasing the mechanization of cane harvesting, without the need for prior burning, caused problems because of the plant and mineral impurities transported to the refineries along with the sugarcane. For that reason, and with a view to developing environmentally correct technologies that help reduce costs and increase productivity, there has been growing interest in dry cleaning the sugarcane.

Dry cleaning uses a blast of air in the opposite direction to the flow of the cane on a conveyor belt. The air gathers the impurities in a chamber, making it easier to separate the straw for use in power generation. In addition, by economizing on water in washing the cane, the process guarantees an increase in the milled product (unlike washing with water, it does not reduce sucrose concentration); it also separates the straw from the cane before it passes through the mill, reduces wear in the mill, improves broth quality, and extends the useful life of the tubular flues of the boilers, among other things (*JornalCana*, 2008b). To reduce costs and improve the quality of the products and working conditions, the firm *Gases e Equipamentos Silton Ltda.* (Gasil), based in Recife, Pernambuco, has created a new technology for treating the broth in the sugar and alcohol manufacturing units. The new process purifies the sugar using ozone (O₃), instead of sulphur, thereby avoiding harmful effects on workers' health and the environment. Based on a process in which oxygen (O₂) is transformed through a high-tension electric charge, each refinery can produce its own ozone (*JornalCana*, 2008b). Another important advantage of using ozone to purify the sugar is its greater acceptance on the international market, in view of the restrictions imposed by the World Trade Organization (WTO) on products that include sulphur in their productive process (*JornalCana*, 2008d).

Fermentation, which transforms the sugars contained in the cane broth into alcohol, and is one of the main operations of the distillery, has also been improved. The Brazilian firm *Natrontec Estudos e Engenharia de Processos* has patented a continuous fermentation process, which uses flocculated yeast. This yeast is obtained by centrifuging the vinasse generated by the fermentation process itself. Continuous fermentation processes do not suffer interruptions. In other words, whereas the full cycle of discontinuous processes includes stages of loading, inoculation, fermentation, unloading and cleaning of the equipment, in continuous processes the "bio-reactor" is constantly supplied with fresh must, which ferments and is also removed constantly. The extraction current matches the feed flow to allow for continuous product flow.

It has also been discovered that increasing alcohol concentration in the fermentation process can contribute significantly to reducing the volume of vinasse (residue) in the industrial ethanol production process. Some yeasts allow fermentation with levels of 14% to 16%, which produce a 50% reduction in the volume of vinasse. Fermatec is studying a fermentation process with an alcohol concentration of 18%, which would reduce the volume of residues still further (from 7 litres with an alcohol concentration of 14%, to 5.5 litres with a concentration of 18%). Nonetheless, that process requires higher-skilled labour, without which it could be unviable (*JornalCana*, 2008c).

A new technology is currently being trialled in a demonstration unit, which promises to double alcohol production without increasing the quantity of sugarcane planted. The new technology —Dedini Hidrólisis Rápida— is being developed jointly between the São Paulo Research Foundation (FAPESP) and the Dedini group. If this specific research and development process is successful, the additional production of cellulosic ethanol will generate a new technological paradigm for the sector. The process consists of transforming cane bagasse into sugars formed by six-carbon chains (hexoses). Lignin, the fibre structure of the cane bagasse that protects cellulose, is diluted with a solvent that also makes it possible to form sugars from the process. Subsequently those sugars are fermented and distilled through the processes normally used in the refineries, resulting in higher second-generation production alcohol, based on a residue from the first generation production (bagasse) (Perozzi, 2007).

The fermentation of xylois (a pentose sugar) is one of the obstacles to producing second-generation ethanol (cellulosic ethanol). As this is more complex than cellulose and hemi-cellulose, fermentation of that sugar requires the use of a fungus, which can increase the cost and possibly make the generation of cellulosic ethanol unviable. Most sugar and alcohol producers produce their own cellular enzymes, which produce savings of up to 12-fold in fermentation costs (Bastos, 2007; *JornalCana*, 2008c).

The enzymatic hydrolysis process developed by Dedini and FAPESP should make it possible to produce two thirds of the sugarcane energy (broth and bagasse) for producing ethanol. Quadex Technology, a firm from Campinas, São Paulo, is investigating alternatives for producing ethanol from any cellulosic material (bagasse and sugarcane straw, paper, tree bark, among other materials), through the acid hydrolysis process. Conclusion of that new technology would ensure 100% exploitation

of the energy potential of sugarcane in ethanol production (*JornalCana*, 2008c; Perozzi, 2007).

4. Marketing and distribution

Lastly, there is the commercial and distribution phase of this value chain, which is also entirely dominated by the refineries, both in terms of the sale of sugar and alcohol and in terms of the sale of electricity to the distributors. A factor that has a considerable influence on the price of most products sold in Brazil is the cost of the transport used to distribute them. In the vast majority of cases, this is done by road, which apart from being expensive is also slow and of small individual capacity. To reduce both the environmental impact and product prices in the sugar and alcohol industry, the PETROBRAS authorities are considering the construction of alcohol pipelines, which would connect producer regions to consumer centres and export ports. Intensification of rail and water transport is also a potential competitor for the distribution of ethanol and sugar (FAPESP, 2008).

The increased production of electric energy through co-generation is also limited by a lack of investment in distribution networks. Many refineries end up wholly or partly discarding the surplus owing to the precarious infrastructure available for energy distribution. Investments are being made in generating capacity and the distribution network of this product to increase sales (Souza, 1999; Castro, Dantas and Leite, 2008). The expansion of energy demand in the Brazilian economy, owing to economic growth (the income-elasticity of electricity consumption is greater than one) has provided an incentive for investments in environmentally correct electricity-generating technologies.

The new technologies and processes that optimize energy can be used both in the older refineries and in the new units, since they have an up-to-date notion of the need to reduce steam consumption and thus increase the production of electric energy. Making this steam saving possible requires investment in high-pressure boilers with adequate generation capacity to exploit the energy surplus (*JornalCana*, 2008a).

A well-planned investment in co-generation produces significant results compared to investments involving small scale improvements or changes affecting part of capacity. Depending on the technological level, this potential varies from 60 kWh to 80 kWh per ton of sugarcane—a very wide range (30%) which could have decisive repercussions on the results of the agribusiness (Procknor, 2007). Table 3 sets out a number of technological options and their respective productive results.

TABLE 3

Technological options for co-generation by burning sugarcane: pressure, yield, power and costs
(Millions of reais)

Base: Boiler 300 tons/hr steam (66 bar - 480 °C)	Alternatives for the system (bar/°C)				
	66 / 480	68 / 520	92 / 520	100 / 540	120 / 540
Turbo-reducer (megawatts)	2 x 24.5	2 x 26.0	2 x 27.5	2 x 28.5	2 x 29.0
Generator (added margin value)	2 x 30.5	2 x 32.5	2 x 34.0	2 x 35.5	2 x 36.5
Fuel (pound steam/pound bagasse)	2.23	2.16	2.18	2.15	2.17
Potential generation (megawatts)	48.7	51.9	54.5	56.7	58.1
	Investment (millions of reais)				
Boiler	39	41	45	46	48
Turbogenerators	12	13	14	15	16
<i>Total</i>	<i>51</i>	<i>54</i>	<i>59</i>	<i>61</i>	<i>63</i>

Source: prepared by the authors on the basis of data from C. Procknor, *Coogeração de energia a bagaço de cana do Estado de São Paulo*, São Paulo, Legislative Assembly of the State of São Paulo, October 2007.

5. Innovative strategic agenda

Large-scale technological innovations have not only helped to maintain the sugarcane agribusiness, but have also contributed to its development, participation and international expansion through improved quality standards, respect for environmental regulations, growing price competition and the undeniable energy advantage. Nonetheless, there are a number of aspects that could promote sector growth even further:

Programmes targeting the vertical growth of sugarcane production (more production in the same planted area) and strategic alcohol storage mechanisms, to avoid price fluctuations and supply shortages. Those two programmes would help respond to criticisms regarding the possible advance of sugar cultivation into Amazonia Legal (which, as noted above, are unfounded) and into areas destined for the production of food products, thus improving the sector's international image. This has also been reported by agro-ecological study of sugarcane approved by the federal government, which proves the existence of over 64 million ha suitable for expanding sugar cropping, excluding Amazonia, the Pantanal, indigenous lands, urban zones, rivers and water sources, among others.

It is important to maintain or increase the sector's international competitiveness. Achieving this requires guaranteeing and providing incentives for the registration of national and international patents on Brazilian technologies for alcohol production, thereby ensuring the appropriation of any future royalties.

Expansion of ethanol use could also be accelerated. Investments in research and development could provide incentives for using that fuel in heavy transport vehicles, instead of diesel. That would not only help reduce pollution in large cities, but would also lower the price of the fuel used, since refinery managers could use it in their own harvesting machines and trucks. In fact, Brazilian manufacturers have been producing flex-drive motorcycles since early 2009.

Disseminating Brazil's image as a leading world supplier in agro-energy and environmental solutions (fuel alcohol, biodiesel, carbon credits, clean technologies, among others) would benefit the country and promote its products and services. This effort would ensure that sugarcane ethanol is not confused with ethanol from other agricultural sources that compete with food (such as maize or sugar beet) and would possibly result in lower entry barriers to certain international markets.

Refinery managements could diversify their activities and invest jointly in distribution channels to ensure a larger and more rapid flow of their final product to the domestic and external markets. Joint ventures could be undertaken with independent management, to definitively enter the ethanol distribution market, by purchasing existing distributors or setting up new ones, which could also act in the renewable fuel supply sector. The COSAN group, which recently took over Esso's fuel distribution facility in Brazil, is perhaps an example of this trend (Scaramuzzo, 2008).

V

Final thoughts

Before deregulation, the sugar and alcohol sector did not need or have incentives for larger investments in innovations to help improve its competitive and productive performance. At that time, sector leaders were mainly concerned to lower costs through improvements arising from the learning-by-doing process.

Following the creation of Proálcool in 1975, large-scale production of ethanol supported by government incentives to expand its consumption increased the importance of the sector in the domestic economy. This triggered a process that would consolidate alcohol as a renewable energy source in Brazil. The sugar and alcohol sector was boosted by the production of alcohol-fuelled vehicles, the introduction of imported technologies to increase milling and the emergence of public and private research centres.

The changes that occurred in the Brazilian economy in the late 1990s put an end to the control of sugarcane, sugar and alcohol production quotas and sale prices; and

refinery owners were forced to seek new strategies to keep their products competitive. To meet that new requirement, research centres, both public (universities, EMBRAPA) and private (COPERSUCAR), invested increasingly in research and development activities related to the sector.

This paper has analysed the importance of those investments in research and development for the agribusiness, and has identified several barriers that have impeded the globalization of sugarcane and ethanol cultivation, including a lack of knowledge of the composition of ethanol and international quality and sustainability requirements. Sector leaders thus need to continue investing in research and development and in seeking strategies to increase returns, by lowering costs, increasing productivity or discovering new markets—particularly abroad—that guarantee higher incomes, investments and more stringent requirements for sector development.

(Original: Portuguese)

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