Ethanol in the Brazilian Energy Matrix

Sergio Valdir Bajay

Luiz Augusto Horta Nogueira

Francisco José Rocha de Sousa

Brazil has made good progress in recent years in terms of planning the production and use of energy. This planning encompasses various objectives, including: supplying demand at relatively low costs; diversifying energy sources, diminishing the risk of energy shortages and reducing the market power of some large suppliers; and controlling environmental and social impacts, maximizing positive effects.

Renewable sources of energy may be essential for Brazil to achieve the commitments included in these goals, but for this to happen the planning must be backed up by energy policies and long-term goals that have yet to be defined by the National Energy Policy Council. These goals must take into consideration environmental benefits, for example the reduction of greenhouse gas emissions, social benefits such as job creation, technological development, and energy cost reductions that can result from the use of renewable sources.

The oil price shocks of 1973 and 1979 showed the world the need to plan, not only for energy supply, but also for energy demand, for example via conservation programs. Multi-sectoral analyses since the 1970s and 1980s have sought to reduce dependency on oil and increase energy security. The stabilization of oil prices since the mid-1980s reduced the urgency of this work, but the domestic and international environmental impacts of the energy industry, for example acid rain and the greenhouse gas effect, have since 1900 rekindled the interest in renewable energy sources. Today, issues of energy security, reduced availability and the high costs of oil are once again encouraging the diversification of energy sources.

In Brazil, the transportation sector – in particular the light vehicles segment – was significantly affected by these price fluctuations. There were important changes in the relative participation of fuels, with alterations in public policies, restrictions in supply and technological innovation. The result was that gasoline consumption fell from 1979 to 1989, rose once again until 2006, and then stabilized. Anhydrous ethanol moved in tandem with gasoline, while hydrous ethanol, on the contrary, grew between 1979 and 1989; then fell until 2004; and has risen ever since. Natural gas for vehicles (CNG) was introduced during this period and grew rapidly, but its consumption is now declining. These large and always short-term fluctuations impose elevated costs, and further emphasize the need for planning.

The deregulation of the sugar-energy industry in Brazil in the 1990s forced a great improvement in efficiency, with production costs falling. During this period, it became clear that it is possible for competition to exist in some markets that were previously considered to be natural monopolies. Biofuels became part of global agendas and new technologies started to change our paradigms with respect to the generation and use of energy, now taking into account decentralization, cogeneration and new fuels.

On the other hand, the significant growth of Brazilian proven oil reserves has changed the scenario. There are plans to expand oil-refining capacity by approximately 1.36 million barrels/day by 2014 (a 67% increase over 2008), so reducing crude oil exports and adding value to domestic crude. This would generate large exportable surpluses of gasoline and diesel oil starting in 2017. If export market conditions are unfavorable, domestic production of fossil fuels could be directed to the Brazilian market, so reducing the demand for ethanol. This is another factor implying the need for a specific regulatory framework to organize the market in order to stimulate productive investments, promote fair competition, and fight economic abuses while assuring a steady flow of information.

This regulatory framework should:

a) Consolidate and improve current legislation with respect to the decision-making chain and the regulatory conditions and instruments for market supervision;
b) Clearly define the tax framework for fuels, taking into account their positive externalities and the structural differences between the fossil and renewable fuels markets;
c) Promote development of domestic ethanol marketing, including the futures market and long-term contracts; and create mechanisms to promote private stockage;
d) Encourage investments in infrastructure for ethanol transportation and storage; define regulatory frameworks for pipelines destined for ethanol and other biofuels;
e) Stimulate the establishment within the market of electricity produced from sugarcane, with adequate pricing mechanisms and support for grid connection and marketing.

Current conditions are very different from those pertaining in the 1970s, when anhydrous ethanol was structured and regulated to gain a foothold in the Brazilian market. Today Brazil produces large amounts of biofuel at hundreds of plants. The sector employs hundreds of thousands of people and generates significant social and environmental benefits. In this new scenario, it is essential to assure that biofuels enjoy a sustainable future in Brazil, a country whose energy matrix must remain based on renewable sources.

▶ 1 Introduction

With great or lesser degrees of success, governments in all countries plan the growth of their energy systems and take steps to assure a reliable supply of energy at reasonable prices, something that is crucial for economic development and the well-being of society. Energy planning can also encompass broader objectives; for example, taking into consideration the strong relationship between the supply of and demand for energy with social, economic, and environmental factors. The desirable development of energy systems should also consider its relationship to the promotion of productive activities, job creation, and its impact on local and global environmental quality, this latter being of increasing importance.

Synthesizing this broad range of demands, the two universal and most important goals for the development of energy systems can be seen as a reflection on the greater interdependence between economies and their acknowledgment of global environmental issues. These goals are:

I Reducing the cost of energy supplied, with implications for productive competiveness, and;
II Maximizing environmental sustainability, measured primarily in terms of greenhouse gas emissions.

These two factors are present in the majority of analyses on energy supply planning in Brazil. The country has a great variety of energy sources available for energy production. It is well known that, until recently, Brazilian energy has been relatively "cleaner" while being produced at internationally competitive prices. However, these natural advantages have co-existed with several problems during the last four decades: oil price shocks; frequent and substantial changes in transportation fuel policies; electrical energy shortages; and the increasing difficulty of expanding hydroelectric generation, especially due to environmental factors.

Production of fuels and electrical energy is especially relevant for the value it adds to natural goods and its connections to the socio-economic system. This is demonstrated by Brazil's recent experiences with ethanol, where the sectoral energy chain not only achieves the basic goal of supplying energy at competitive prices in a way that is environmentally sustainable, but also promotes regional development and creates jobs at a much greater intensity than do conventional energy chains, for example petroleum. However, the down side is that given the wide range of options, broader planning is required, with a requirement for greater information and understanding if we are to develop better systems for energy production and use.

It is in this context that we seek to evaluate the prospects for sugarcane in the Brazilian energy matrix, which is commonly understood as the structure of production and use of energy in the country. Given its high efficiency in the absorption of solar energy, the sugarcane bioenergy chain allows for production of transportation fuels and the generation of electrical energy. As a basic scenario, we assume the production of one billion tonnes of sugarcane in 2020, approximately twice the current production, occupying 7.3 million hectares for ethanol. This scenario assumes that 70% of the sugarcane would be used to produce 65 million m^3 of ethanol, destined 77% for the domestic market, with the generation of 74 TWh of surplus electrical energy, representing 10% of predicted national power demand in that year.

▶ 2 An assessment of fuels and technologies

In this paper, the authors analyze the supply chains of the main fuels that comprise Brazil's energy matrix, including thermoelectric generation and the use as fuels of waste products from these supply chains. The fuels examined are petroleum and its derivatives, natural gas, mineral coal, uranium, and the main liquid biofuels used in Brazil, which are ethanol and biodiesel.

2.1 Petroleum and its derivatives

Petroleum is a complex mixture of hydrocarbons that was formed during millions of years from organic material under high pressure, in sedimentary basins located on onshore or offshore. Oil is classified mainly according to its density, viscosity, and sulfur content. Most Brazilian reserves are located offshore with relatively high densities, viscosities, and sulfur contents, which tends to reduce its quality.

Petroleum is rarely consumed directly as a fuel. Usually, it is shipped to refineries where derivatives are obtained through various distillation processes and cracking of hydrocarbon chains. Refineries also reduce the amount of pollutants present in the oil, especially sulfur, through chemical processes such as hydrogenation. Some refineries also produce raw materials such as naphtha and ethylene for the petrochemical industry. Various processing residues such as petroleum coke and refinery gases are consumed as fuel in the refineries, or else sold.

Petrobras, the main owner and operator of Brazilian petroleum refineries, has invested significantly to expand its refinery capacity for processing heavy crude oil from recently discovered reserves in the offshore Campos basin, in the state of Rio de Janeiro. Recent investments have also gone toward hydrogenation units. The company is planning new refineries through 2030, some of them scheduled to produce premium gasoline for export, especially for the American market, while other refineries will increase the production of raw materials for the Brazilian petrochemical industry.

The supply chain of petroleum and its derivatives comprises the following stages: prospecting; production; transport to the refineries; refining; transport of derivates to distribution companies or large consumers; distribution; and retail sale to small and medium final consumers. Long distance transportation of petroleum and its derivatives has traditionally been done in Brazil by tanker ships and pipelines, whereas distribution is handled by tanker trucks.

In addition to its final uses as a fuel for vehicles and as a source of heat production in ovens, dryers and boilers, petroleum derivatives are also used in Brazil as fuel in steam-cycle thermoelectric plants, or in diesel units, or in cogeneration plants with the simultaneous and sequential production of mechanical/electrical power and thermal energy from the same fuel source (Bajay, 2009b).

2.2 Natural gas

Natural gas is a mixture of light hydrocarbons, predominantly methane, in gas form. Its origins and formation are similar to those of petroleum, and consequently it too is concentrated in sedimentary basins on land or offshore. When it is found mixed with petroleum, it is called associated gas.

The supply chain for natural gas in Brazil comprises the following stages: prospecting, production, transportation to the processing units, processing, transportation to the city gates or Petrobras' points of consumption, and distribution to final consumers. In some other countries natural gas is stored in caves, mines, or depleted petroleum fields. In Brazil, the only storage available is within the transportation and distribution networks themselves. Various other countries also permit supply directly from producers and importers to large final consumers without passing through the distribution network. In Brazil, this has happened only in the case of consumption within Petrobras' own production units. The heavier components of natural gas are separated in the processing units to produce naphtha or gasoline, leaving behind virtually only methane to be sold as "dry" natural gas.

Ownership of natural gas is transferred at the city gates, where it is sold by producers or importers, denominated "carriers" and responsible for transportation, to distribution companies. Activities upstream of the city gate are similar to the oil industry, if not actually integrated with these, while downstream activities after the city gate are typical of a "network industry" such as electricity distribution.

Natural gas can replace several other fuels with relative ease, provided a supply network is available. This applies in particular to petroleum derivatives used in ovens, dryers, boilers, thermoelectric or cogeneration plants, and refrigeration units and air conditioning. Consumption of natural gas exhibits high price-elasticity, especially in industry.

The main Brazilian markets for natural gas are industry, thermoelectric generation and natural gas for vehicles. The fuel's restricted availability, the still-limited coverage of transportation and distribution networks, and rising prices in recent years have restricted the use of natural gas as an energy source in Brazil. Gas is consumed in thermoelectric stations in plants powered by internal combustion engines, Brayton or combined cycle stations, and also cogeneration plants that can use any of these technologies.

2.3 Coal and its derivatives

Coal can be broadly classified as steam coal and metallurgical coal. The former is used essentially as a fuel, especially in thermoelectric plants, while the latter is used mainly as a reducing agent (coal coke) for processing primary materials such as pig iron. The stages of the steam coal supply chain coincide with the initial stages of the metallurgical coal supply chain: prospection, production, processing (which, if any, usually takes place near the mine-head) and transportation to the place of final use as fuel, or conversion into coke.

The main use of steam coal in Brazil is for thermoelectric generation in steam-cycle power plants (Bajay, 2009b) in the South of the country. Some industrial plants in southern states use coal in furnaces and in particular boilers, with the main consumers being the chemical, pulp and paper, food and beverage, ceramics, and cement sectors. The high ash content of Brazilian coal, all of which is mined in the South of the country, and the lack of adequate rail infrastructure, make it very costly to transport this fuel to other regions. There are currently some plants under design or construction in the North, Northeast and Southeast of the country that will burn imported coal.

Most of the metallurgical coal consumed in Brazil is turned into coke at plants that are integrated with the largest steel plants. Of the remainder, most is consumed in powdered form as a blast furnace fuel in the steel industry, with smaller amounts consumed in furnaces in the mining and pelletizing, nonferrous metals, cement and other industrial sectors. Pulverized coal injection in blast furnaces permits substituting part of the coke needed to produce pig iron with lower-cost coal.

Coke plants also produce coke oven gas and tar, in addition to coke itself. Coal coke is virtually all consumed as a reducing agent in blast furnaces at steel plants. It is also used as fuel in these furnaces, and to a lesser extent in ovens of other industrial sectors including non-ferrous metals, iron alloys, mining and pelletizing, and cement. Coke oven gas is used as fuel in coke plant processing units, in the boilers and furnaces of steel mills, and for generating electricity in these plants. The other byproduct of coal coke production is tar. This is used as a raw material, as fuel in steel mills and for generating electricity in these plants.

2.4 Uranium

The nuclear fuel cycle consists of the following production stages: mining and concentration of uranium; conversion of concentrate (yellowcake, U_3O_8) into uranium hexafluoride (UF_6); enrichment; production of fuel for nuclear power plants; and reprocessing spent fuel, in the case of a closed cycle. Brazil currently acts in the stages of mining, concentration, enrichment and making fuel for nuclear plants, operating via a federal government-owned company called Industrias Nucleares do Brasil S.A. (INB), under the auspices of the Ministry of Science and Technology (MCT). Imported yellowcake is added to that produced in Brazil and converted to uranium hexafluoride then enriched abroad, sent back to Brazil to be converted into the uranium dioxide (UO_2) contained in the locally-made fuel elements used in nuclear power plants. Conversion and enrichment will be performed in Brazil in the near future.

The global nuclear industry has for more than five decades developed and improved several technologies for nuclear power stations, so that today there are four generations of nuclear reactors (Mongelli, 2006). The two nuclear plants operating in Brazil, together with a third under construction, are second-generation plants (Bajay, 2009b).

2.5 Liquid biofuels

Biofuels production represents one of the paths for using solar energy via photosynthesis. In general, the production of biofuels involves an agricultural phase, when biomass is produced, and a subsequent industrial phase in which this biomass is transformed into an energy vector suitable for final use, typically in internal combustion engines. The final cost of biofuel, as well as its environmental impact, therefore depends on these two phases.

Figure 1 illustrates the principal technology paths in the industrial stage of bioenergy production. It includes known and consolidated technologies together with alternatives that are still under development. Fermentation thus includes existing established processes such as the production of ethanol from sugar and starch, and processes still being studied, for example using the biochemical conversion of cellulose. The analysis of this paper focuses on production of ethanol from sugarcane bagasse and production of electricity from agricultural and industrial sugarcane waste, together with biodiesel production from the raw materials that have proved most promising in Brazil.

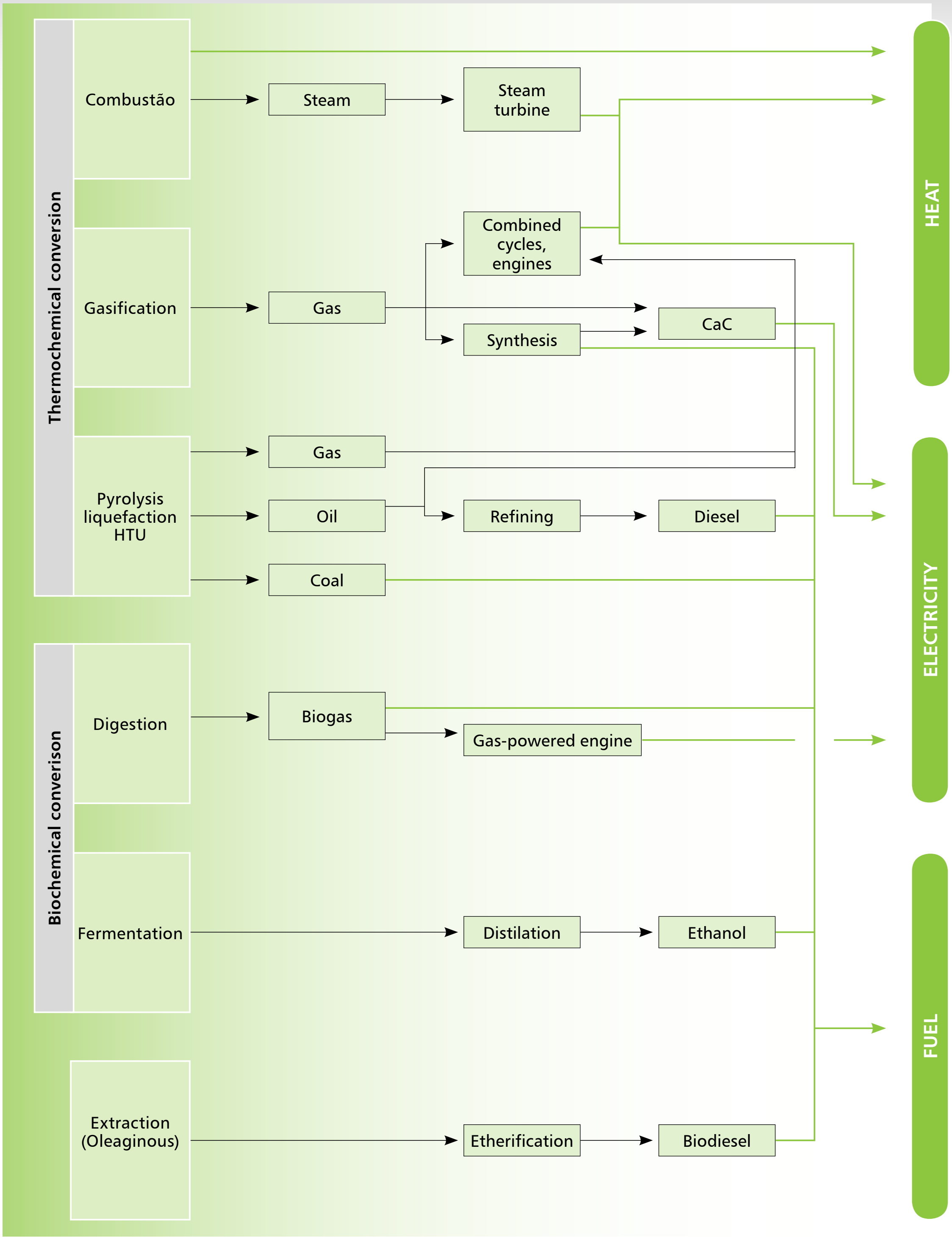
2.5.1 Ethanol

The ethanol supply chain in Brazil is almost always integrated with sugar production. It starts with sugarcane cultivation, with productivity in the Center-South region reaching about 80 tonnes per hectare in the best plantations (Nogueira, 2009). Recent decades have seen remarkable progress in the agricultural technology used in Brazilian mills.

As shown in Figure 1, the industrial stage uses a process of biochemical conversion: fermentation, followed by distillation. This produces anhydrous ethanol that is blended with gasoline for use in conventional Otto cycle engines, and hydrous ethanol to be used in engines that are specifically designed for consumption of this fuel. These may be ethanol-only engines, or flex-fuel engines that can run on a variable gasoline-ethanol mixture. The raw material can be sugarcane juice, or in the case of plants that produce both ethanol and sugar it can be molasses, or indeed mixtures of both sugarcane juice and molasses depending on the availability and economic factors. Sugarcane juice is extracted by crushing or diffusion and pre-concentrated in several stages and sterilized before being forwarded to the multi-stage fermentation phase in batches or a continuous stream, with the yeast being recycled (the Melle Boinot process). Distillation occurs in multiple phases. Anhydrous ethanol requires an additional dehydration step. The best distilleries currently achieve productivity of 85 liters of ethanol per tonne of sugarcane (Nogueira, 2009).

Brazil enjoys high productivity and lower ethanol production costs thanks to high agricultural yields, which come from the high photosynthetic efficiency of sugarcane. However, productivity and cost efficiency are also a result of using bagasse to generate electricity in cogeneration plants, often supplying not just the energy needed for the mill's own production process but also substantial surpluses that are sold to electricity distribution companies or large consumers.

Technology paths for bioenergy production Figure 1



Source: Turkemburg et al, 2000.

The sugar-ethanol sector is Brazil's largest self-producer of electricity and also the largest generator of surplus electricity for the grid. The use of high-pressure boilers and efficient steam turbines, along with a reduction in energy consumption in the mills themselves, has allowed for increasing generation of surplus electricity. The gradual mechanization of the sugarcane harvest is freeing up part of the sugarcane straw to be burned in the cogeneration power plants, so contributing to further increase of the electricity surplus.

2.5.2 Biodiesel

Oils and fats can be converted to fuel suitable for use in Diesel cycle engines via processes of transesterification. The biodiesel supply chain thus involves, as a first step, harvesting an oilseed plant, followed by extraction of the vegetable oil. An alternative is an animal processing activity, such as a slaughterhouse, with the supply of animal fat and the subsequent transesterification of fatty materials. For the transesterification process, the raw material is mixed with an alcohol in the presence of catalysts. This separates the glycerin and produces esters of fatty acids known as biodiesel. The catalyst may be alkaline, acidic or enzymatic, and the alcohol may be ethanol or methanol. Alkaline transesterification has offered the most interesting path so far, with faster reaction kinetics. The raw material is important when deciding whether to use acidic or basic catalysis. Enzyme catalysis promises advantages such as fewer byproducts, but is still in early development. Ethyl transesterification is more interesting for Brazil and could reach similar levels of quality, but the path is more complex than the methyl one.

A wide range of raw materials can be used for biodiesel production, including: vegetable oils such as annual crops like soybean and rapeseed and perennials such as palm trees; animal fats; and waste oils and fats. The productive contexts for biofuel are therefore equally varied.

A few years ago, Petrobras patented a process known as H-Bio, for producing diesel oil in refineries. It is based on processing a mixture of vegetable or animal oil with fractions of petroleum diesel. This process was implemented, but was discontinued in August 2007 due to the high cost of vegetable oils (Sousa, 2009b).

▶ 3 Supply and demand

The main determinants of energy consumption in a country are economic growth and population increase. Naturally, the level of demand is influenced by the adoption of technologies, by consumption patterns that are more or less efficient and by structural changes that may occur in the composition of economic output and in the income distribution within society. The following sections offer basic information for an analysis of the Brazilian energy matrix, presenting a brief review of the current state of the market with current and forecast supply and demand for different energy vectors, based on official and independent studies.

3.1 Petroleum and its derivatives

3.1.1 Demand

Even though diesel is banned for use in light vehicles, it figures prominently among Brazil's vehicle fuels. Fuel oil and liquefied petroleum gas are in relative decline as industrial options, while the participation of ethanol and biodiesel is expected to rise.

Diesel consumption is strongly correlated with Gross Domestic Product (GDP) and accounts for 42% of the overall petroleum derivatives market. The apparent consumption of major petroleum products is shown in Table 1.

There is a regulation banning the consumption of diesel in passenger, freight and mixed-use vehicles with capacity under 1,000 kg, counting the weight of the driver, crew, passengers and cargo[i].

Fuel oil exhibits a trend for decreasing market share, so much so that fuel oil sales fell by 50% between 2000 and 2007. It is also worth noting that industrial consumption of LPG has been dropping since the start of the new century (MME, 2008).

Demand for biodiesel was ensured significant growth in 2009 thanks to regulation CNPE No. 2 of April 27, 2009. This established a 4% minimum (by volume) of biodiesel to be blended with petroleum diesel sold to final consumers starting July 1, 2009. The trend will continue through 2010, because the government also established a minimum percentage of 5% starting January 1, 2010 (resolution CNPE No. 6 of September 16, 2009).

The Brazilian vehicle fuels matrix for 2008 is shown in Figure 2. As can be seen, diesel accounts for 52.4% of fuel consumption in the road transportation sector. In second place is Type A gasoline, on 25.4% (note that Type A gasoline is blended with ethanol to make Type C gasoline before sale the final consumer).

The share of fuels for Otto cycle engines in the vehicle fuels matrix started falling in the 1970s, up to when a significant number of heavy vehicles had used gasoline. Diesel cycle fuels overtook Otto cycle fuels in 1980, and since then the share of diesel has remained around 52%, with small fluctuations.

However, it is important to note that the demand for Otto cycle fuels (gasoline, ethanol and natural gas) has risen steadily in absolute terms, except for brief periods of more serious economic difficulties.

As can be seen in Figure 3, these three Otto cycle fuels do not exhibit homogeneous behavior in terms of their participation in the fuel matrix between 1970 and 2007. In fact, the share of pure gasoline fell from almost 99% in 1970 to reach an historic low of 48.3% in 1988. Conversely, the share of ethanol (anhydrous and hydrous) started the period at close to 1%, rising to a maximum of 51.7% in 1988, then dropping to 29% early in the new century before pulling up to 34.2% in 2007. Natural gas began near zero in 2003, reaching 9% in 2007. It is worth observing that if all the vehicles using natural gas (consumption of 2.56 million m^3 in 2007) switched to hydrous ethanol, the demand for this biofuel would be increased by 3.7 million m^3 (Sousa, 2009b)[ii].

3.1.2 Production

Brazilian petroleum production grew at 6.5% per year from 1998 to 2008. Domestic production in 2008 was 663.28 million barrels, with Petrobras accounting for 645.29 million barrels or 97.3% of the total.

This positive performance continued in 2009. Average petroleum production (including LNG) during the first quarter of 2009 was two million barrels per day, according to the ANP[iii]. On May 4th 2009, Petrobras daily production set a new record of 2.06 million barrels (Petrobras, 2009).

Table 1 Apparent consumption of petroleum derivatives in Brazil

Fuel	thousand m^3		%
	Diesel	2008	2008/2007
Diesel	41,558	44,764	7.7
Biodiesel	260	1,125	332.7
Type C gasoline	24,235	25,175	3.9
Type A gasoline	18,483	18,881	2.2
Anhydrous ethanol	5,843	6,294	7.7
Hydrous ethanol	9,367	13,290	41.9
Total ethanol	15,210	19,584	28.8
Liquefied petroleum gas (LPG)	12,005	12,259	2.1
Fuel oil	5,525	5,172	-6.4
Aviation gasoline	4,891	5,227	6.9
Aviation kerosene	55	61	10.9
Kerosene for illumination	31	24	-22.6
Total	**97,757**	**105,972**	**8.4**
CNG (thousand m^3/day)	**7,015**	**6,614**	**-5.7**

There are currently 14 oil refineries in Brazil, of which 12 are owned by Petrobras and two, Manguinhos (currently disabled) and Univen, are private. Total refining capacity at 31 December 2007 was 323.75 million m^3 per day (2.04 million BOPD) with a high utilization factor – average processing in 2007 was 1.74 million BOPD of oil, of which 77% was domestic crude (ANP, 2008). The average processing profile – see **Figure 4** – indicates a concentration of production in medium derivatives (diesel and jet fuel), but with relevant participation of gasoline (20%).

3.1.3 Imports and exports

Brazil is an overall net petroleum exporter, but with important positions as an importer of diesel oil and an exporter of fuel oil and gasoline.

Figure 2 **Vehicle fuels matrix in 2008** *% TPE (tonne of petroleum equivalent)*

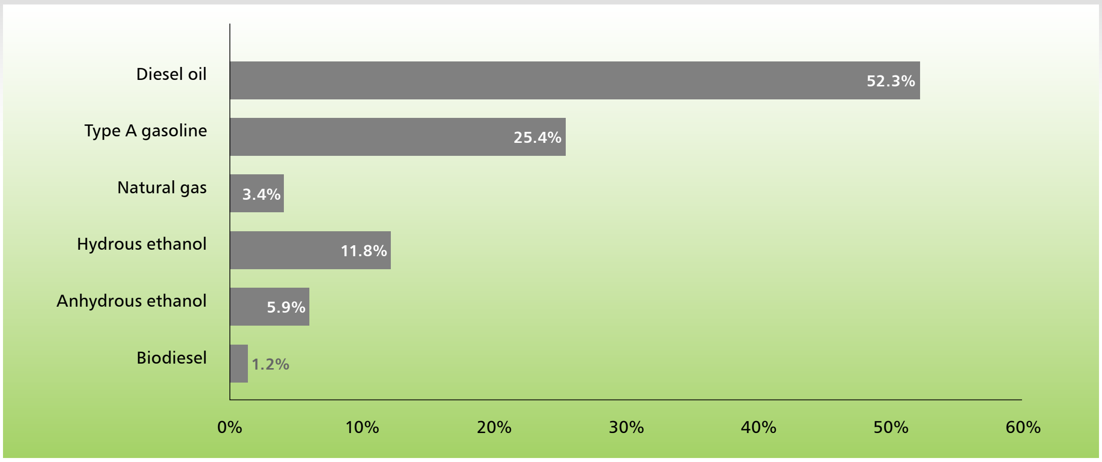
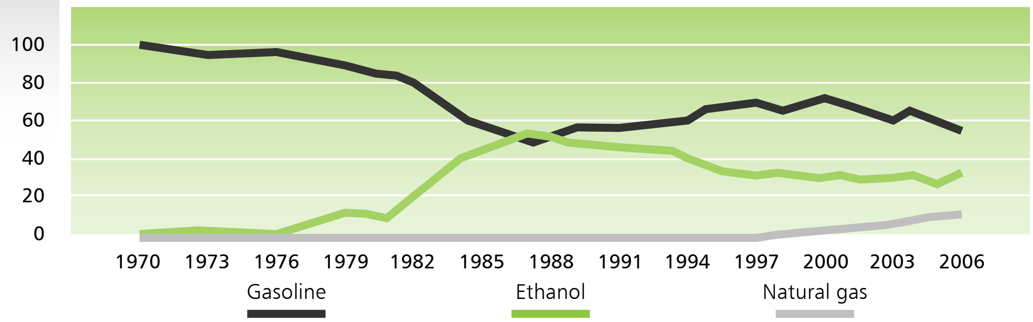


Figure 3 **Breakdown of fuel consumption for Otto Cycle engines** *Share (% TPE)*



Source: MME

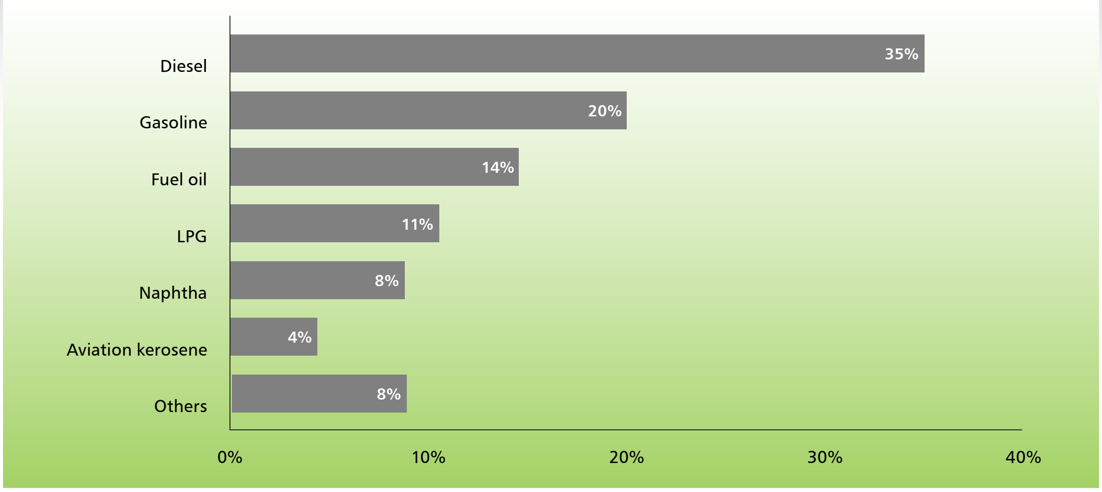
The country has been a net exporter since 2006. In 2008, it exported 432,000 BOPD at an average price of US$87/b and imported 404,000 BOPD at an average of US$111/b[iv]. Given that the average value of imported derivatives was well above the price achieved by domestic oil, the oil trade balance was negative in US$2.7 billion.

With respect to petroleum derivatives, the position of imports and exports of diesel oil and gasoline should be noted. In 2007, Brazil exported 3.70 million m^3 of gasoline (16.7% of domestic production) and imported 5.10 million m^3 of diesel oil (ANP, 2008).

Brazil exported 5.2 million m^3 of gasoline in 1988, which accounted for 41% of domestic production. In subsequent years, the volume of gasoline exported fell due to increased absorption by the domestic market, resulting from higher sales of gasoline vehicles. This situation later reversed, due to the high penetration of flex-fuel vehicles, introduced in March 2003, and the fact that most flex-fuel vehicle owners opted to use hydrous ethanol. During the first quarter of 2009, flex-fuel vehicles accounted for 87.8% of new cars and light commercial vehicles licensed (Anfavea, 2009).

Brazil will produce a large surplus of gasoline due to falling demand in the domestic market. To export gasoline as a finished product, Brazilian domestic gasoline must meet the specifications of the international market. In this context, the sulfur content of domestic gasoline and diesel is still significantly higher than the values observed in developed countries (Sousa, 2009b).

Figure 4 **Petroleum refining profile in Brazil in 2007**



Source: ANP

3.1.4 Expansion of refining capacity

As shown in Table 2, we expect an increase of 1.36 million BOPD in Petrobras' refining capacity by 2014, representing an increase of 67% compared to domestic refining capacity at December 31, 2008.

Petrobras' Business Plan 2009-2013 forecasts investments of US$34.9 billion for expansion of processing capacity to prevent Brazil from becoming a major exporter of crude oil. The plan includes expansion of 380,000 BOPD in processing capacity with construction of the Abreu e Lima refinery, located in the state of Pernambuco and expected to start operation in 2011, together with expansion of existing refineries.

On a longer planning horizon, there are plans to build two Premium Refineries that focus on producing premium petroleum products, in particular diesel fuel, and the basic petrochemical unit of the Rio de Janeiro Petrochemical Complex (Comperj). Premium Refinery I will be built in Maranhão with processing capacity of 600,000 BOPD. The first phase is planned to begin operation in 2013 and the second phase in 2015. Premium Refinery II will be built in Ceará with processing capacity of 300,000 BOPD. First phase operations are scheduled to begin in 2014, and the second phase in 2016. Comperj will process 150,000 BOPD for production of raw materials for petrochemical plus small quantities of derivatives; the first phase is scheduled to begin operations in late 2012 (Petrobras, 2009b). In addition, Petrobras has been investing in the Guamaré industrial park in Rio Grande do Norte state, building a plant to produce gasoline and improve the quality of existing derivatives (LPG, jet fuel and diesel). This will expand output to 80,000 BOPD in 2010, at which point the facility will be classified as a refinery (ESE, 2008b).

According to the company's business plan, Petrobras refining capacity in Brazil will reach 2.27 million BOPD in 2013. This will represent national self-sufficiency for diesel. Efforts will be made to bring specifications for gasoline and diesel into line with international standards, so facilitating exportation of the surplus. It is expected that by 2012, all gasoline produced in Brazil will have 50 ppm of sulfur.

Expansion of Petrobras refining capacity Table 2

Unit	Capacity (thousands of BOPD)	Start of Operation	State
Northeast Refinery	230	2011	Pernambuco
Premium Refinery I	600	2013*	Maranhão
Premium Refinery II	300	2014*	Ceará
Comperj	150	2012	Rio de Janeiro
Guamaré	80	2010	Rio Grande do Norte
Total	**1360**		

Source: Petrobras (annual report)

Given the current market structure, and the difference between oil prices in international markets and the price of principal derivatives in the Brazilian domestic market, the refining sector is very unlikely to see the entry of any new players. This perception is confirmed by the facts. We would recall that in 1998 the ANP granted permission for construction of Renor, a new refinery in the State of Ceará, but this never got off the ground. Nor is there room for small refineries: the Manguinhos refinery is out of operation and the Ipiranga refinery was acquired in March 2007 by a consortium comprising Petrobras, Braskem and Grupo Ultra (Sousa, 2009b).

3.2 Natural gas

Brazilian natural gas consumption increased from 7.73 billion m^3 to 18.15 billion m3 between 1995 and 2007 (MME, 2008), corresponding to average annual growth of 14.5%[v]. Thanks to this strong growth in consumption, the share of this fuel in the domestic energy matrix grew rapidly to reach 10.2% in 2008.

According to the Brazilian Association of Piped Gas Distribution Companies (Abegás), sales by gas distributors in 2008 were 50 million m^3 per day. The most significant consuming sectors were industry, electricity generation and vehicles, which accounted for 51.6%, 26.6% and 13.3% of sales, respectively.

Some characteristics of the market for compressed natural gas for vehicles (CNG-V) should be noted. Natural gas consumption by automobiles was 6.63 million m^3 per day in 2008, corresponding to a relatively small share of total sales by distributors (13.3%). Sales are highly concentrated in the state of Rio de Janeiro, which accounted for 43% of the national market. The fleet converted to use CNG-V in March 2009 was 1,596,511 vehicles. This fleet remained virtually stagnant in 2008 (Folha do GNV, 2009), thanks to a pronounced slowdown in the rate of vehicle conversions due to the reduced attractiveness of CNG-V prices for consumers compared to gasoline and hydrous ethanol, and the fear of a lack of natural gas for automobiles[vi]. Conversion rates remained weak in 2009: just 2,726 vehicles were converted to natural gas in March 2009. If this trend continues, the natural gas fleet will gradually shrink[vii] (Sousa, 2009a).

Given the above-mentioned problems, CNG-V demand fell by 5.4% in 2008, in TPE (MME, 2009).

3.3 Coal and its derivatives

Consumption of steam coal in thermoelectric plants fluctuated significantly in the period 1970-2007, but always with an upward trend, while industrial consumption dropped sharply from 1987 to 1998, then leveled off. Cement was the industrial sector mainly responsible for the relatively high consumption of steam coal in the eighties and nineties, but this was replaced in the current decade by cheaper petroleum coke. Leading industrial steam coal consumers in 2007 were the chemicals sector, with 191,000 tonnes, and pulp and paper on 164,000 tonnes.

Conversion of coal into metallurgical coke increased substantially from 1970 to the mid-eighties, when it virtually stabilized. Industrial consumption of metallurgical coal started in 1993, reaching 4,596,000 tonnes in 2007. Most of this 2007 consumption was by steel industry blast furnaces, which accounted for 3,395,000 tonnes. Other major consumers of metallurgical coal in 2007 were mining and pelletizing sectors with 864,000 tonnes; non-ferrous metals with 161,000 tonnes, and cement with 48,000 tonnes. Other industry sectors took 128,000 tonnes.

Almost all of the coke produced from metallurgical coal is consumed in the pig iron and steel sector. This consumption increased significantly from the mid-1970s until almost the end of the 1980s, when the long-term trend stabilized. One factor was coke's partial substitution by pulverized coal as a blast furnace fuel. The pig iron and steel sector accounted for 94.1% of the total 9,734,000 tonnes of coking coal consumed by Brazilian industry in 2007, with non-ferrous metals taking 2.2%, iron-alloys 1.5%, mining and pelletizing 1.3%, and the cement industry the remaining 0.9%.

The principal use of coke oven gas has been to produce thermal energy in steel mill processes outside of the coke plants. There has been an increase in the use of this gas to generate electricity at the steel mills (Bajay, 2009a).

Of the three uses of coal tar, the dominant one in the period 1987 – 1995 was producing thermal energy in steel mills. For the rest of the period through 2007, with the exception of 1977, it was used mainly as a raw material. Coal tar has been little used as a fuel for auto-generation of electricity in steel mills (Bajay, 2009b).

According to Brazil's 2008/2017 Ten-Year Plan for Energy Expansion (PDE 2008/2017), new coal-fired power plants totaling 6,249 MW are being evaluated for economic feasibility and environmental impact (EPE/MME, 2009b).

The Ten-Year Plan proposes building 900 MW of thermal generating capacity in the South of Brazil through 2015, with Brazilian coal the natural fuel of choice to meet this need.

The 2030 National Energy Plan (PNE 2030) contemplates building 1,100 MW of new coal-fired plants through 2015. Long-term planning for 2016 – 2030 assumes that Brazil could feasibly build up to 9,000 MW of coal-fired plants, including 5,000 MW burning domestic coal in the South region. The remaining 4,000 MW of plants would burn imported coal, and of these 2,000 MW could be located in the Southeast and 2,000 MW in the Northeast. Starting from this 9,000 MW total capacity of "candidate" coal-fired plants, the optimization model for electricity supply expansion adopted in PNE 2030[viii] selected 3,500 MW to be built between 2016 and 2030, located only the South and consuming domestic coal.

Table 3 reflects the baseline scenario used in PNE 2030. It breaks down demand projections between steam coal and metallurgical coal; the use of coal for conversion into coke or electricity; and its final consumption as an energy source. This table clearly shows the strong increase in total coal consumption between 2020 and 2030, due mainly to its increased conversion into electricity.

Table 4 also reflects the baseline scenario used in PNE 2030. It shows the projected supply of coal, disaggregated for steam coal and metallurgical coal, highlighting the current and future importance of metallurgical coal imports. It also shows a substantial increase in domestic steam coal production from 2020, based on the assumption that Brazil's average coal reserves will increase by 40% from 2015, with substantial investments to build new coal-fired power plants in the period 2020-2030.

3.4 Uranium

Uranium consumption in Brazil has been cyclical, with much higher values seen from 1997 onwards due to the startup in 2000 of Angra II, the country's second nuclear power plant (EPE/MME, 2008).

Brazil currently has two nuclear power stations, Angra I and Angra II, with installed capacities of 657 MW and 1,350 MW respectively. Both are Pressurized Water Reactors (PWR). The first has been operating since 1982 and the second since 2000. They are located next to each other on the Itaorna beach in Angra dos Reis, Rio de Janeiro state, and are operated by Eletronuclear, a subsidiary of Eletrobrás. Both companies are state owned and linked to the Ministry of Mines and Energy.

The PDE 2008/2017 contemplates the construction by Eletronuclear of one more nuclear plant in the forecast period. This is Angra III, a 1,350 MW PWR station similar to Angra II and due to come on stream in November 2014 beside the two existing plants.

In the 2030 PNE, the EPE forecasts the Angra III nuclear plant starting operation by 2015. Among the various alternatives for expanding electricity supply in the period 2016-2030, the EPE considered the possible addition of a further 6,000 MW of new nuclear capacity, located 3,000 MW in the Southeast and 3,000 MW in the Northeast. Plants were assumed to have installed capacity of 1,000 MW each, a load factor of 85% and a lifespan of 40 years.

Based on the projected demand associated with the reference scenario in the 2030 PNE, the MELP model (Portuguese acronym for Long Term Expansion Model) for optimization of electricity supply expansion indicated construction of 4,000 MW of new nuclear plants, divided equally between the Southeast and Northeast. The first of these plants should be operational in 2019, located in the Northeast between Recife and Salvador. The two new nuclear plants in the Southeast should be located between Rio de Janeiro and Espírito Santo. Under this demand scenario Brazil's total nuclear capacity would generate 15 TWh in 2010, 30.5 TWh in 2020 and 51.6 TWh in 2030 (EPE/MME, 2007).

EPE projections for the production and importation of uranium in 2010, 2020 and 2030, associated with the baseline scenario of PNE 2030, are shown in Table 5. Note that, according to these projections, the increased domestic production should eliminate imports by 2030.

3.5 Liquid biofuels

Brazil liquid biofuels markets exhibit unequal degrees of maturity. Regular use of ethanol blended with gasoline began in the first decades of the 20th century, but biodiesel should be seen as an innovative product, on the market only since 2003. Biofuels accounted for 16.5% of energy demand in the transportation sector in 2008 (EPE/MME, 2009a), and enjoy good prospects for expansion in coming years.

3.5.1 Ethanol

Vehicles with flex-fuel engines were introduced into the Brazilian market in 2003 and have accounted for the majority of light vehicle sales in recent years. Reflecting this growing importance, ethanol consumption has increased in both absolute and relative terms, displacing part of the consumption of gasoline and anhydrous ethanol. According to figures from the National Energy Balance, 13.3 million m^3 of hydrous ethanol and 6.3 million m^3 of anhydrous ethanol were consumed in 2008, with average annual variations of +14.3% and -3.2% respectively between 2003 and 2008 (EPE/MME, 2009a).

Projected demand for steam coal and metallurgical coal in Brazil Table 3

In 10^3 tonnes, for transformation and for final consumption, in the "surfing the swell" scenario (see section 3.6 below)

		2010	2020	2030
Steam coal	Transformation	8,653	10,397	20,918
	Final consumption	1,082	1,657	2,311
Metallurgical coal	Transformation	10,456	13,818	15,380
	Final consumption	6,034	9,216	11,804
Total	**Transformation**	**19,109**	**24,215**	**36,298**
	Final consumption	**7,116**	**10,874**	**14,115**

Source: EPE/MME, 2007.

Estimated Supply of Mineral Coal *In 10^3 t, in Brazil's National Energy Plan of 2030* Table 4

		2010	2020	2030
Production	Steam coal	9,735	12,055	23,228
	Metallurgical coal	210	210	210
	Total	9,945	12,265	23,438
Imports	Metallurgical coal	16,281	22,824	26,974

Source: EPE/MME, 2007

In the most recent harvest (2008/2009) Brazil produced 572 million tonnes of sugarcane, part of which went to produce a record 26.6 billion liters of ethanol. As shown in **Table 6**, the production of hydrous ethanol exceeded the production of anhydrous ethanol during recent years, a consequence of the demand trends mentioned above, with significant expansion in both total output and the volume exported.

The sugar and ethanol sector has 418 production plants, of which 155 produce ethanol, 15 produce sugar, and 248 produce both sugar and ethanol. These adequately meet domestic demand and generate growing surpluses for export. Several projects are underway to increase the installed capacity for producing ethanol from sugarcane. Estimates by the productive sector made prior to the financial crisis indicated investments of US$33 billion through 2012, divided US$23 billion in the industrial area and US$10 billion in agriculture (UNICA, 2008).

Looking ahead, Meira Filho and Macedo (2009) used demand projections from five institutions (MAPA, EPE, IE-UFRJ, UNICA and Cepea) to indicate probable demand by 2020 for 45 million m^3 of hydrous ethanol and five million m3 of anhydrous ethanol, a total volume 155% higher than in 2008 and implying average annual growth of 12.9%.

These projections are subject to a degree of uncertainty related to activity level and in particular the profile of the vehicle fleet, which will incorporate new technologies such as electric and hybrid vehicles. Nevertheless the projections seem reasonable, bearing in mind the one-decade horizon and particularly considering that the Brazilian vehicle fleet could grow from its current estimated 24 million vehicles, of which are 41% flex-fuel, to around 40 million vehicles, with 75% of them flex-fuel (EPE/MME, 2007).

Table 5 **Projected supply of U3O8, in tonnes, in Brazil's National Energy Plan (PNE) for 2030**

	2010	2020	2030
Production	151	844	1,646
Imports	304	127	0

Source: EPE/MME, 2007.

Table 6 **Ethanol production in Brazil** *In thousand m^3*

Harvest	2004-05	2005-06	2006-07	2007-08	2008-09
Anhydrous fuel ethanol	7,689	7,352	5,128	6,354	6,406
Hydrous fuel ethanol	5,118	5,973	7,696	10,964	13,821
Exported ethanol	2,631	2,526	3,928	3,518	5,228
Total ethanol for other uses	703	708	729	686	1,166
Total	**16,141**	**16,559**	**17,481**	**21,522**	**26,621**

Source: MAPA, 2009.

3.5.2 Biodiesel

The production of biodiesel has expanded rapidly, thanks to a market that is guaranteed by the requirement under Law 11.097/2005 for a blend of biodiesel – 5% from 2010 – in all petroleum diesel sold in Brazil. Estimates suggest that annual biodiesel production capacity exceeds three billion liters, against consumption of around 1.2 billion liters in 2008, produced mainly from soy oil, complemented by animal fats and by lesser amounts of various other oilseeds (Nogueira, 2009).

Given that biodiesel is intended only for blending with petroleum diesel oil, the estimate of its future demand in the Brazilian market is linked to projections of the demand for diesel and prospects for alteration in the level of the biodiesel blend.

To assess the growth of the diesel market, we used the estimate of the baseline scenario presented in the National Energy Plan. This scenario assumes Brazil will enjoy stable economic expansion with progressive trade integration among markets, a continuing process of domestic adjustment, some increase in purchasing power and expected annual average GDP growth of 4.3% in the period 2005 to 2030. In this context, the demand for diesel, whether or not it includes biodiesel, is expected to expand significantly. Main sectoral drivers are transportation and agriculture, with their participation in final national energy demand growing from 17% in 2005 to 19% in 2030, when domestic consumption is expected to reach 82.8 million m^3 (EPE/MME, 2007).

This study indicates diesel demand in 2020 of 82.8 million m^3. Based on this number, and assuming a 5% blend, demand for biodiesel in that year could be 3.08 million m3, corresponding to the current installed production capacity. Other studies could be undertaken, taking into account the segmentation of the biodiesel market in farming, electricity generation in stand-alone systems and the metropolitan market for diesel, together with the possible export sales of biodiesel, although current price structures are not attractive (Nogueira, 2009).

3.6 Electricity

Electricity consumption in Brazil in 2008 was 428.7 TWh, 4% up on 2007 when consumption was 412.1 TWh (EPE/MME, 2009a).

The average growth rate of electricity consumption in Brazil between 1980 and 2005 was 4% per year. If the 1970s are added in, when there was strong growth in both Gross Domestic Product (GDP) and electricity consumption, the average annual rate jumps to 6.2% (EPE/MME, 2007).

The National Energy Plan 2030 (PNE 2030) defines four alternative scenarios for economic growth in Brazil through 2030, combined with three scenarios for the global economy (EPE/MME, 2007). The four national settings are called "on the crest of the wave", "surfing the swell", "paddling" and "shipwreck", while the three international ones are named "one world", "archipelago" and "island" (Bajay, 2009b).

"Surfing the swell" was adopted as reference scenario in the 2030 PNE and served as the basis for projecting the expansion of supply of various energy sources in general, and specifically the generating capacity of different types of power plants. Average GDP growth under this scenario is 4.1% per year, as is average growth in electricity demand. This is slightly higher than the 4% per year growth of consumption recorded in the period 1980-2005.

The 2008-2017 Ten-Year Plan for Energy Expansion (PDE 2008-2017) adopted a baseline scenario that has economic growth of around 4% in 2009 and 5% per year from 2010 to 2017, plus population growth of 1.2% through the horizon of the study. Based on these assumptions, growth in electricity consumption would be 5.4% per year, including self-production.

Table 7 shows the contracted capacities for different types of power plants at the various auctions for new energy held until 2008, together with the prices paid.

In its reference scenario the 2008-2017 PDE forecasts vigorous expansion of installed generating capacity in Brazil, adding 55,055 MW. **Table 8** shows this expansion by type of power plant by 2017.

There is a decrease in the share of hydropower plants, from 81.9% in 2008 to 70.9% in 2017. This is offset by increases in the participation of other types of plants, especially the substantial increase in the participation of thermoelectric stations, rising from just 0.9% in 2008 to 5.7% in 2017. This swing towards a "dirtier" energy matrix in Brazil has been the target of strong criticism from various segments of society, ever since various oil-fired thermoelectric power plants won the auctions for "new energy" in recent years.

These auction results were certainly not foreseen in the 2030 PNE, published in 2007. **Table 9** shows the imagined trend under this plan for the installed capacity of various types of electricity generation stations.

▶ 4 Reserves/resources and production potential

This section provides key elements for the discussion of possibilities for developing the domestic energy matrix. It presents a synthesis of the availability of primary energy sources that should be harnessed for the production of different vectors that can be used to meet the above-mentioned needs.

4.1 Petroleum and its derivatives

On December 31, 2008, Brazil's proven oil reserves stood at 12.64 billion barrels, corresponding to a reserves/production ratio equal to 19 years[ix] (ANP, 2009). At that time, Petrobras' proven oil reserves were 94.2% of proven reserves in the country, and the company's rate of reserves replenishment in 2008 was 123% (Petrobras, 2009c).

Contracted capacity and prices paid for types of power plants and fuel at auctions for new energy Table 7

In MW and R$/MWh

	A-5 2005 16/12/05	A-3 2006 29/6/06	A-5 2006 10/10/06	FA 2007 18/6/06	A-3 2007 26/7/06	A-5 2007 16/10/07	SA 2007 19/5/08	JI 2008 19/5/08	A-3 2008 17/9/08	A-5 2008 30/9/08	Total	%
Hydroelectric	1,006	1,028	569	46		715	1.443	1.383		121	6,311	37.3%
Biomass	224	60	61	140						35	520	3.1%
Coal	546					930				276	1,752	10.4%
Natural gas	1,264	270	200								1,734	10.3%
Liquefied natural gas						351			265	703	1,319	7.8%
Process gas			200								200	1.2%
Biogas		10									10	0.1%
Diesel oil	244	102	69								415	2.5%
Fuel oil		212	5		1,304	316			811	1,990	4,638	27.4%
Total	3,284	1,682	1,104	186	1,304	2,312	1,443	1,383	1,076	3,125	16,899	
(R$/MWh)												
Average price		128.95	128.90	137.32	134.67	128.33	78.87	71.37	128.42	141.78		
Hydroelectric			120.86	134.99		129.14	78.87	71.37		98.98		
Thermal			137.44	138.85	134.67	128.37			128.42	145.23		

FA= alternative sources; SA = Santo Antonio; JI = Jirau
Source: EPE.

Expansion of Brazilian generating capacity, by type of power plant

In MW; estimates in the PDE 2008-2017; installed capacity each December

Table 8

Sources	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Hydro[a]	84,374	86,504	89,592	91,480	92,495	95,370	98,231	103,628	110,970	117,506
Nuclear	2,007	2,007	2,007	2,007	2,007	2,007	3,357	3,357	3,357	3,357
Oil[b]	1,984	3,807	5,713	7,153	7,397	10,463	10,463	10,463	10,463	10,463
Natural gas	8,237	8,237	8,453	8,948	10,527	12,204	12,204	12,204	12,204	12,204
Coal	1,415	1,415	1,765	2,465	2,815	3,175	3,175	3,175	3,175	3,175
Alternative sources[c]	1,256	2,682	5,420	5,479	5,479	5,593	5,593	5,913	6,233	6,233
Process gas and steam	469	959	959	959	959	959	959	959	959	959
Indicated thermal plant	-	-	-	-	-	-	-	900	900	900
Total	99.742	105.611	113.909	118.491	121.679	129.771	133.982	140.599	148.261	154.797

[a] Includes small hydro; [b] fuel oil and diesel; [c] biomass and wind. • *Source:* EPE/MME 2009b.

Proven domestic oil reserves could double thanks to the announced recoverable volumes in the sub-salt offshore fields. Announced sub-salt reserves range from eight to 14 billion barrels, distributed as follows: five to eight billion barrels in the Tupi field, three to four billion in Iara, and 1.5 billion barrels in Parque das Baleias. However, there are strong indications that the aforementioned reserves are even greater. This is because the sub-salt area so far granted for prospection (41,000 sq km) corresponds to just 38% of the total sub-salt area. Following this logic, the director general of the National Petroleum, Natural Gas and Biofuels Agency (ANP), during a presentation at a joint public hearing by the Mines and Energy Committee and the Economic Development, Industry and Commerce Committee of the House of Representatives held on May 13, 2009, spoke of expectations that proven reserves could hit 50 billion barrels thanks to the sub-salt fields (Sousa, 2009b).

4.2 Natural gas

On December 31, 2008, Brazil's proven reserves of natural gas stood at 364.24 billion m^3 (ANP, 2009), with 63% of the volume being natural gas associated with oil. This means that the bulk of future natural gas production will continue to depend on oil production. The share of Petrobras in this volume was 92.7% (337.62 billion m^3). The reserves/production ratio in December 2008 was 17 years, as shown in **Table 10**.

Tabela 9 **Predicted growth in the installed capacity of various types of power plants in Brazil, according to the 2030 PNE.** *In MW*

Source	Installed capacity in		Increase	
	2020	2030	2005-2030	2015-2030
Hydroelectric	116,100	156,300	87,700	57,300
Large[1]	115,100	156,300	87,700	57,300
Thermal	26,897	39,897	22,945	15,500
Natural Gas	14,035	21,035	12,300	8,000
Nuclear	4,347	7,347	5,345	4,000
Coal[2]	3,015	6,015	4,600	3,500
Others[3]	5,500	5,500	700	-
Alternatives	8,783	20,322	19,468	15,350
Small hydro	3,330	7,769	7,000	6,000
Wind	2,282	4,682	4,653	3,300
Sugarcane biomass	2,971	6,571	6,515	4,750
Urban waste	200	1,300	1,300	1,300
Imports	8,400	8,400	-	-
Total	160,180	224,919	130,113	88,150

[1] Includes binational power plants. • [2] Refers only to domestic coal; no expansion of imported coal. • [3] Expansion after 2015 is not very significant, numerically, because it refers to remaining stand-alone systems (0.2% of national consumption).
Source: EPE/MME, 2007.

This does not mean that natural gas will run out in 17 years, because new discoveries are being made. Proof of this is the fact that the rate of growth of proven natural gas reserves in the period 1997 to 2007 was 4.8% per year, even with the increase in production seen during this period.

Past performance is not the only reason for being optimistic about a significant increase in proven reserves of natural gas in the medium term. The announcement of large discoveries of recoverable hydrocarbons (around eight to 14 billion barrels of oil)[x] in the sub-salt area is another indication (Sousa, 2009a), despite the difficult logistics of producing associated natural gas in the sub-salt fields. Problems include high concentrations of CO_2, pipelines greater than 18" in water depths of 2,200 meters, and wells lying about 300 km from the coast.

4.3 Coal and its derivatives

Brazil's identified and measured coal reserves at December 31st, 2007 were 10,084 10^6 tonnes. On the same date, the inferred reserves were 22,240 10^6 tonnes, giving total reserves of 32,324 10^6 tonnes[xi], corresponding to 2,752,932 tonnes of petroleum equivalent (TPE). Of the total reserves, 27,175 10^6 tonnes (84%) were steam coal and just 5,149 10^6 tonnes were metallurgical coal. Total known reserves of peat in Brazil on the same date were 487 10^6 tonnes (EPE/MME, 2008a).

Brazil has the 10th largest coal reserves in the world (EPE/MME, 2007).

Mineral prospecting studies for coal have been at a virtual halt in Brazil for the past 20 years. Evidence of this is that the volume of total reserves has been steady at around 32 billion tonnes since 1985 (EPE/MME, 2007).

Growth of natural gas reserves — Table 10

Proven reserves (P/R) (in millions of m³)		2000	2001	2002	2003	2004	2005	2006	2007	2008
Brazil	Reserves	216,574	219,692	244,548	327,673	322,485	306,395	347,903	365,688	364,236
	P/R (years)	21	20	20	26	24	21	24	25	17
	Land	78,597	77,009	76,070	76,597	73,761	71,752	71,462	68,131	66,305
	Offshore	137,977	142,683	168,477	251,075	248,724	234,642	276,441	297,558	297,931
	Associated gas	157,237	157,550	173,969	178,411	182,195	188,914	209,022	217,764	229,209
	Non-associated gas	59,337	62,143	70,578	149,262	140,290	117,482	138,881	147,925	135,027

Note: Data for proven reserves of natural gas are updated according to the ANP Superintendency of Production Development.

Source: ANP, January 2009.

Brazilian coal reserves are located mainly in Rio Grande do Sul, where most of the mining is open-cast. There are also significant[xii] coal reserves in Santa Catarina, where most mines are underground, and some small reserves in Paraná.

4.4 Uranium

Brazil's total uranium reserves as of 1997[xiii] are 309,370 tonnes of U_3O_8, equal to 1,254,681 TPE[xiv]. Of the total, 177,500 tonnes are identified and measured reserves, while 131,870 tonnes are inferred reserves (EPE/MME, 2008a). Brazil has the sixth largest uranium reserves in the world (Mongelli, 2006).

It should be noted that 57% of these reserves are associated with costs below US$80/kgU, meaning that they are competitive by international standards, and only 25% of the country has been surveyed for uranium so far (EPE/MME, 2007).

4.5 Liquid biofuels

The potential for production of biofuels, and in particular ethanol and biodiesel, is associated with the availability of the natural resources needed for their efficient and sustainable production. In the case of Brazil and most humid tropical countries, there is a significant available area of vacant or underutilized agricultural land. Assuming the adoption of the best available technology paths, biofuel production capacity far exceeds current demand expectations.

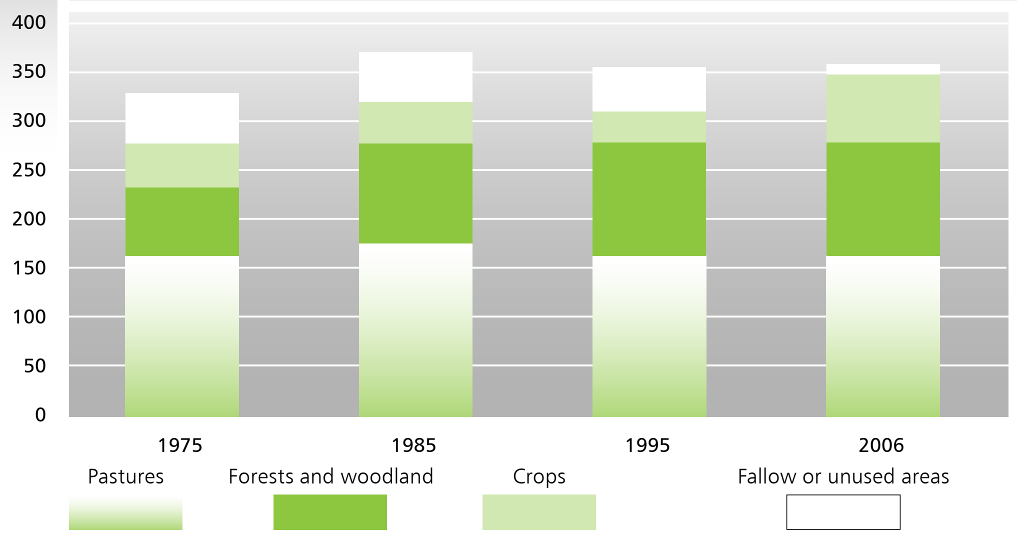
Brazil has a surface area of 851.4 million hectares, much of it covered by tropical forests. Based on the results of the 2006 Agricultural Census, the total area of rural properties was 354.8 million hectares representing 42% of national territory excluding protected areas, unsuitable areas, lakes and rivers, and the legally-defined reserves of native forests and other biomes. These rural properties are dedicated to natural and planted pastures, native and planted forests and perennial and annual crops. Brazilian arable farming grew 83.5% between 1995 and 2006 to occupy 76.7 million hectares, about 9% of national territory. As shown in **Figure 5**, this growth occurred mainly in areas that were unused, or resting, and to a lesser degree in some pastureland. This process of agricultural expansion has been occurring in a systematic way since the 1970s, so that the ratio of pastureland to crops was reduced from 4.5 in 1970 to 2.2 in 2006 (Nogueira, 2009).

The Sugarcane Agro-Ecological Zoning program was developed under the coordination of the Ministry of Agriculture, Livestock and Supply (MAPA) to demarcate Brazil's potential for expansion of biofuel production, considering in particular sugarcane ethanol (Embrapa, 2009). This zoning estimated that 64.7 million hectares (7.5% of total Brazilian territory) would be available for sugarcane production, taking into account cropland and ranching areas where sugarcane is currently not grown, but where it has potential. Soil and climate information, environmental protection areas, geomorphologic characteristics and topographic maps were also considered. The process also incorporated federal and state environmental legislation and analysis of agronomic data for sugarcane including optimal temperatures for growth, best soil types, water requirements, and others. Adding together the 7.8 million hectares currently used for sugarcane plantations or sugar and ethanol, plus the additional area to be cultivated with sugarcane by 2017, which we estimate at 6.7 million hectares, the total land to be occupied by sugarcane in that year would be about 20% of the area defined as suitable by the zoning, and equivalent to 1.7% of national territory.

Brazil's potential for sugarcane production effectively far exceeds its raw material requirements, even within the most optimistic demand scenarios and including exports. As an exercise to assess the current potential we can consider the overall values of 2007/2008 harvest, when Brazil produced approximately 22 billion liters of ethanol from 3.6 million hectares of sugarcane plantations. Based on this empirical data, adding 10% of anhydrous ethanol to all the gasoline consumed in the world (1.3 billion cubic meters) would require 136.5 billion liters of ethanol. Producing this volume under current Brazilian conditions would require 23 million hectares of sugarcane plantation, equivalent to the area currently occupied by soybeans in Brazil and about one third of the area designated by the Agro-Ecological Zoning program as apt for sugarcane.

By analyzing the Brazilian situation and employing land-use models and satellite images to study the dynamics of sugarcane expansion in different regions of the country, Nassar and colleagues (2008) convincingly show that sugarcane expansion has occurred mostly in pastures. They also indicate that plantations could continue to expand in a similar manner, without affecting the production of meat and milk, even with an estimated 5.1% growth of the cattle herd, thanks to productivity gains in the period (Nogueira, 2009).

Figure 5 **Land use in rural properties in Brazil** *In millions of hectares*



Source: IBGE (2008).

5 Technological evolution and conversion efficiencies

5.1 Petroleum and its derivatives

Development of the sub-salt petroleum fields off the Brazilian coast will require new technologies both for prospection and production.

In geophysical terms, the layer of salt acts as a mirror to reflect acoustic waves, preventing their penetration and so hindering precise studies of its thickness and the conditions beneath it.

Paraffins present in the oil represent another challenge. At 8,000 meters down, the oil temperature is 60º C or 70° C, but when it flows through sea-bed pipes in water at 4° C it suffers abrupt cooling and the paraffin solidifies. Among the possible solutions are heated pipes, enhanced insulation, and the use of chemical compounds to keep the paraffin liquid.

The sub-salt oil reserves also contain high levels of CO_2, which need to be separated in an economic way at the surface, processed, pressurized and re-injected into the oil fields to increase pressure, dissolve the oil and facilitate the flow.

5.2 Natural gas

Technological innovation in gas-fired thermoelectric plants have been obtained by incremental advances in gas turbine technology, associated with the use of new materials and new concepts for refrigeration systems of the turbine blades. These have allowed for use of higher temperatures at the turbine intakes, yielding higher efficiency.

5.3 Coal and its derivatives

AGenerally speaking, coal deposits of the South of Brazil contain low-carbon coals, known commercially as high-volatility coal with high ash content (50%) and variable sulfur content. Raw coal (ROM) in Rio Grande do Sul has approximately 1% sulfur, while in Santa Catarina it has about 4% and in Paraná, 7%. The mineral matter disseminated in the organic matter makes processing difficult, with low yields, except for coal from Paraná that offers a higher yield (Osorio et al, 2008).

The efficiency of Brazilian thermoelectric plants burning pulverized coal and operating subcritical steam cycles is relatively low, ranging from 33% to 35%. The use of supercritical and ultra-supercritical steam cycles can raise this efficiency to 44% and 50%, respectively. The use of combustion boilers with fluidized beds can achieve efficiencies between 40% and 44%, while coal gasification integrated with a combined cycle (IGCC) is already used in several demonstration plants abroad, and can raise the efficiency of a coal-fired plant to 52% (EPE/MME, 2007).

In estimating the capacity of new thermoelectric plants that could be built in Brazil consuming domestic coal, the 2008/2017 PDE assumed a mining recovery factor of 60%, a usable percentage of 50%, an average capacity factor of 55% and plant efficiency of 35% (EPE/MME, 2009).

5.4 Uranium

One kilogram of uranium in the form of UO_2 powder contained in the fuel elements requires the mining of 8 kg of U_3O_8, the conversion of 7 kg of U_3O_8 to UF_6, and the enrichment of 4.8 kg of UF_6.

Second-generation PWR power plants like Brazil's Angra II and Angra III have an average efficiency of 33% (EPE/MME, 2007).

Designs of first and second-generation reactors rely exclusively on active safety systems and inherent safety features (Mongelli, 2006).

Third and fourth-generation nuclear reactors are still under development, although some units are operating on a commercial scale.

The main features of third-generation reactors are (Mongelli, 2006):

- Standardized design for each type of reactor, in order to expedite licensing, lower capital costs and reduce construction time.
- Simplified projects that facilitate the operation of reactors and make them less vulnerable to operational failures.
- Greater availability and increased lifespan to up to 60 years.
- Minimization of the possibility of core meltdown.
- Use of advanced safety systems.
- Higher burning rates, to minimize the amount of waste.
- Use of burnable poisons to increase the lifetime of the fuel.

Several countries are devoting great efforts to the research and development of closed nuclear fuel cycles and the concept of partitioning and transmutation, which is the separation of transuranic elements and fission products in the fuel that have a longer half-live, and burning these in dedicated reactors, in a double strata fuel cycle. This double cycle consists of the conventional cycle of fast thermal reactors – the first stratum – in which the U and Pu (Th) can be recycled via aqueous reprocessing (Purex/Thorex), complemented by a transmutation cycle. In this second cycle – the second stratum – the minor actinides, long half-life fission products and Pu (Th) are partitioned by electrochemical processes to feed a dedicated burner reactor – transmutation. The first stratum of the cycle has technically mastered, but second stratum processes are still at the demonstration stage (Mongelli, 2006).

Fourth generation reactors are called 'revolutionary' within the nuclear industry, to distinguish them from third-generation reactors which are 'evolutionary'. They meet the most modern safety requirements with a combination of active, passive and inherent safety systems. These requirements dictate that any severe accident – a reactor core meltdown – must be confined within the plant, so reducing or eliminating evacuation and emergency requirements (Mongelli, 2006).

Most fourth-generation reactors utilize a closed fuel cycle with the dual objective of minimizing the production of waste and maximize use of fuel. Given that more efficient fuel recycling takes place in a fast spectrum reactor, most fourth-generation reactor projects now under development are fast reactors.

5.5 Biofuels

While the technology employed for conventional production of sugarcane ethanol has evolved significantly, with average annual increments of 3.1% in agro-industrial productivity during the past three decades, there are still interesting opportunities for further improvement. Examples of technologies that will increase the energy sustainability of this agribusiness, some of which are already being implemented, include the use of cogeneration systems with high pressure boilers; harvesting cane raw (unburned) to allow for use of the energy in the straw; and the introduction of hydrolysis processes for the cellulosic wastes of ethanol manufacture. Notable results in the agricultural stage include varietal improvement, use of biological pest control, introduction of precision-farming systems and the adoption of high-performance logistics systems.

A summary of progress to date and medium-term possibilities for performance gains in sugarcane ethanol production is presented in **Table 11**, together with values for agricultural and industrial productivity. For more details, see Nogueira (2009).

The performance levels shown for the first stage of process optimization, predicted for the period 2005 – 2010, have effectively been met. In some mills and distilleries, especially new units, the levels have been surpassed. As can be seen, even without considering the introduction of additional production paths such as cellulosic ethanol, the higher productivity due to agribusiness should, in the coming years, allow a decrease of 3.4% in planted area per unit of ethanol produced – a significant result for technological research and development in the sector. If the production of bioethanol from cellulosic waste is also considered, productivity could reach, 10,400 liters of bioethanol per hectare in the same time frame (Nogueira, 2009).

Taking into account the introduction of new technologies, with the better use of sugarcane waste, the adoption of procedures for hydrolytic conversion of cellulose and the use of optimized cogeneration systems, Macedo et al (2008) estimated that the energy balance will evolve favorably in these units. The relationship between energy produced and consumed in the process, estimated at 9.3 using 2006 data, should rise to 12.1 in 2020, whether priority is given to maximizing production of ethanol or electricity.

Production paths for biodiesel also show good prospects for improvement, considering conventional technologies. However, there are still uncertainties about the viability of some crops, especially from the viewpoint of energy balance, so more work is needed to better characterize the most desirable systems. Looking further ahead, new possibilities such as the development of processes for producing biodiesel from algae with high lipid content, or by fermentation processes employing polysaccharides as raw material, may represent promising options, but this is yet to be confirmed.

6 Competitiveness of biofuels

The price and cost of biofuels are relevant factors in determining the appropriateness and sustainability of their use. For biodiesel, the market is defined by compulsory use and prices have been set via the auctions held periodically by the ANP. Considering the auctions held during the period of mandatory blending and weighted for volumes sold, the average price of biodiesel in this period was R$2.42/liter (ANP, 2009a). Given the manner in which the price is defined, we believe it adequately covers the costs of production. However, it is significantly higher than the pre-tax price of the diesel it substitutes, confirming that this biofuel is still at the embryonic stage of development.

Impact of the introduction of new technologies on bio-ethanol production Tabela 11

Period		Productivity		
		Agricultural (t/ha)	Industrial (litre/t)	Agri-industrial (litre/ha)
1977–1978	Initial phase of the National Ethanol Program. Low efficiency in the industrial process and agricultural production.	65	70	4,550
1987–1988	Consolidation of the National Ethanol Program. Agricultural and industrial productivity increase significantly.	75	76	5,700
Current Situation	The bioethanol production process operates with the best technology available.	85	80	6,800
2005–2010	First stage of process optimization.	81	86.2	6,900
2010–2015	Second stage of process optimization.	83	87.7	7,020
2015–2020	Third stage of process optimization.	84	89.5	7,160

Source: CGEE (2007).

The scenario is quite different for ethanol, which has a more complex market with free pricing and demand divided between the compulsory blending in gasoline (anhydrous ethanol) and the use as pure fuel (hydrous ethanol). In the following paragraphs, we attempt to analyze the competitiveness of ethanol in the Brazilian context.

Initially, it should be noted that economic studies of the sugarcane ethanol market, looking at the determination of production costs and studies of price formation mechanisms, entail their own complexity. This arises from the possibility of using the raw material for different products like sugar – which has important domestic and foreign markets – plus the relevant possibility that consumers of hydrous ethanol who drive flex-fuel vehicles, increasingly common in the Brazilian vehicle fleet, can choose to use this biofuel or not, depending on the price each time the tank is filled. This means that in addition to the usual costs associated with production factors, opportunity costs are also of great importance in the ethanol market.

The following factors also contribute to making economic studies more difficult: (**I**) significant rigidity of international sugar markets, with different marketing processes and quotas established by major buyers, distorting price formation; (**II**) the artificiality of the petroleum market, where prices are not related to direct costs; and (**III**) especially for Brazilian ethanol, the virtual absence of stabilizing mechanisms to mitigate these sources of instability, for example buffer stocks or futures markets.

In the current scenario, we must also add to the above-mentioned factors the high volatility of commodity prices, especially petroleum and foreign exchange and financial indicators. This means that the figures below are indicative, but make it possible to establish some interesting references with respect to the economic viability of sugarcane ethanol, associated with its cost structure and competitiveness with crude oil.

6.1 Prices and costs of ethanol

As a result of the progressive improvement in processes, with productivity gains in both agriculture and industry, Brazilian sugarcane ethanol is recognized as the world's lowest-cost biofuel (BNDES, 2008). It is competitive with gasoline in terms of producer costs and prices and consumer prices, although it suffers losses due to distortions in the Brazilian petroleum derivatives market.

The feasibility of using ethanol instead of gasoline can be confirmed by comparing prices at the distilleries, without freight or taxes, as shown in Figure 6. The values refer to the average price of anhydrous ethanol in the state of São Paulo, as reported by the Center for Advanced Studies in Applied Economics (Cepea) of the Escola Superior de Agricultura Luiz de Queiroz, University of São Paulo, and the price of regular gasoline in the U.S. Gulf Coast spot market, as reported by the U.S. Energy Information Administration.

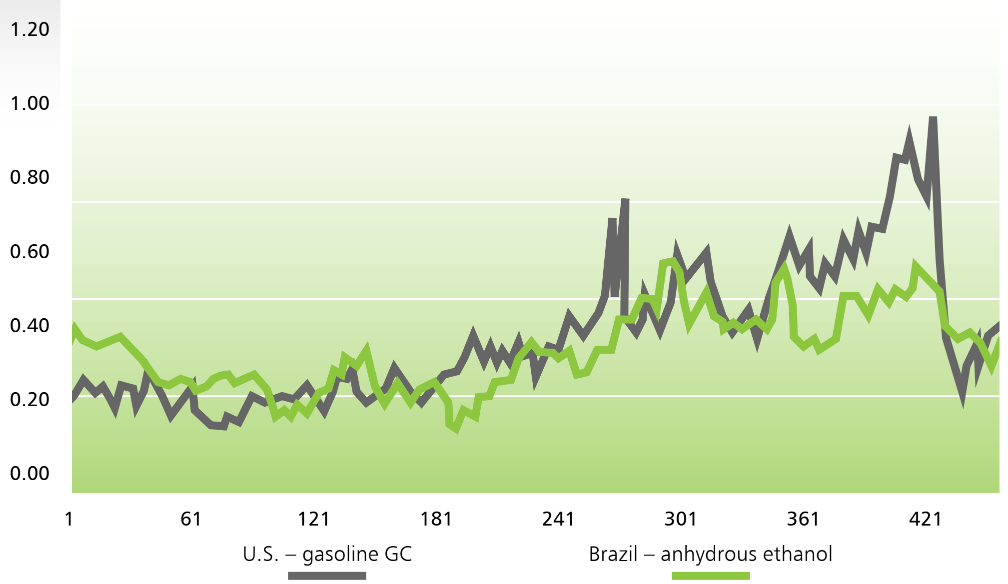
From these trends, we can conclude that, in addition to exhibiting lower volatility than gasoline, producer prices for sugarcane ethanol began to be consistently more attractive than those for gasoline in recent years, excluding taxes and any subsidy. In other words, under these conditions, without taxes, the addition of anhydrous ethanol made it possible to reduce, at least most of the time, the average market price of Type C gasoline (a blend of Type A gasoline with ethanol).

Another way to assess the evolution of the attractiveness of ethanol when compared to conventional fuels for the final consumer is comparing the average retail price of ethanol with that for regular gasoline. Observing the price series summarized in **Figure 7**, it can be seen that hydrous ethanol has regularly been competitive with gasoline, with lower cost per kilometer, due to its lower price at the producer level and in the tax structure. The values in **Figure 7** are derived from fuel price surveys provided regularly by ANP, applied on a large sample that covers the entire territory of Brazil (ANP, 2009b).

Ethanol has generally been preferred for flex-fuel vehicles, up to a limit of 70% of the gasoline price. In this context, it should be noted that during most recent years, except during short periods, it has been cheaper to use ethanol than gasoline. Of course, this price difference varies by region. It is greater in producing regions, where ethanol use is more attractive than gasoline all year round, while in distant regions, gasoline is almost always more competitive.

Figura 6 **Prices paid to producers for gasoline in the U.S. and sugarcane ethanol in Brazil**

In US$/liter, without taxes



Source: Cepea (2009) and EIA (2009).

Figura 7 also shows the regular pattern of price variation, rising at the end of the harvest and falling at its start in the middle of the first semester. This pattern was broken in the most recent period, when the price of gasoline was artificially held down by Petrobras acting under government instruction. This intervention, carried out without specific rules and with little transparency, is one of the most disturbing distortions in the Brazilian fuel market. It gives bad cost indications, wrongly directs the market, and in effect constitutes disrespect for the law: selling below production cost is dumping, while selling above market prices is equally pernicious and signals the existence of market barriers to be eliminated. This topic is addressed below, when we examine legal and regulatory issues.

After looking briefly at ethanol's competitiveness for producers and consumers, relative to gasoline, it is opportune to review production costs. The costs of Brazilian sugar and ethanol agribusiness were for a long time audited by the federal government, which set prices throughout the sugar-ethanol supply chain, including commercial distribution. It was similar to mechanisms that were in force for decades throughout the fuel and electricity supply chains, until the current regulatory framework for the energy sector was introduced.

Major liberalization of the sugar-ethanol sector started with the 1997 harvest, and was completed by 2002. This allows economic agents to freely decide their prices based on market strategies, considering availability and outlook in the sugar and fuel markets. Estimating costs is a complex task in this competitive environment, because – in addition to the great diversity of situations, with different products and technologies being used – the main cost component in ethanol is the raw material, which can be produced by the processing company itself, on leased land, or grown by independent producers. The difficulty of consistently knowing production costs is not unique to the bioethanol market; in an analogous way the detailed production costs for oil and natural gas are even less easily available.

As a reference for conditions in the Center-South at the start of the 2009 harvest, the Organization of Sugarcane Planters of the Center-South Region of Brazil (Orplana) estimated the total cost of producing ethanol at R$0.762 per liter, with raw material representing 62.1% of this. The value indicates producers operating on a very tight margin, and possibly negative in some periods. This is exacerbated if we take into account the relatively inflexibility of the sugarcane industry, which is subject to marked seasonality, working with raw material that must be harvested each year, and which requires building up large inventories for winter.

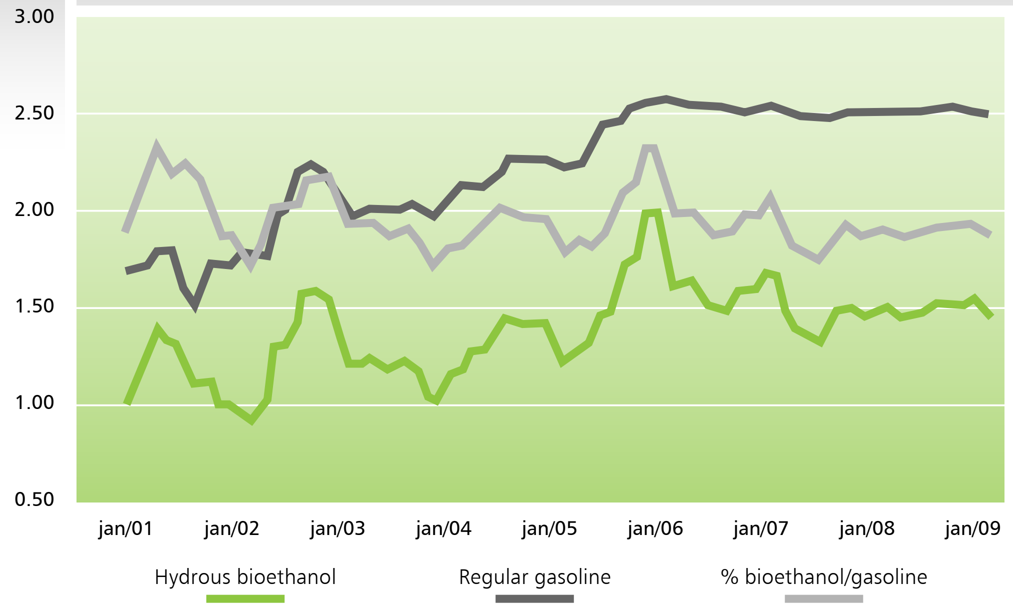
Conab, the agency responsible for monitoring the activities of Brazilian agriculture, recognizes that these factors have brought the sugar-ethanol sector to an "a major economic crisis, certainly the most persistent and long-lasting since the sector was deregulated," requiring important adjustments to make this agribusiness sector attractive again (Conab, 2009).

6.2 Tax aspects of the competitiveness of ethanol

Fuel taxes constitute one of the most important and effective instruments for implementing energy policies in several countries. Besides being important sources of revenue, these taxes allow for differentiation between seemingly similar products to help steer evolution of the matrix energy in a desired direction. In the case of ethanol this aspect is essential and should be used more widely.

In Brazil, taxes have been differentiated between various vehicle fuels according to the economic implications and typical applications of each one. Taxes have particularly favored:
a) diesel fuel, used for productive activities and cargo and passenger transportation;
b) natural gas, whose consumption was in principle desirable to stimulate and enable domestic production and the deployment of infrastructure for gas transportation and distribution; and
c) biofuels, for their social, environmental and economic benefits. However, given that both the Union and individual states tax the fuels that are available to the Brazilian consumer, the final price composition is complex and varies between states, depending on the rates and the way the Tax on Circulation of Goods and Services (ICMS) is implemented (Nogueira, 2009). As an example, Figure 8 shows taxes on vehicle fuels in Rio de Janeiro (Sindcomb, 2009).

Figure 7 **Average consumer price of regular gasoline and hydrous ethanol** *In R$/liter*

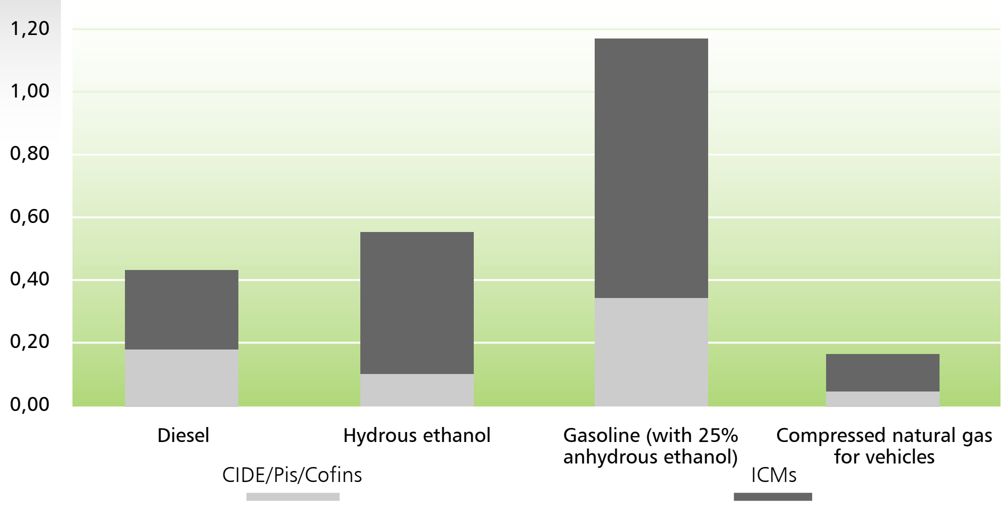


Source: ANP (2009).

The level of these taxes is critical to the final price for consumers. It is often the difference that decides which fuel will be used, particularly for vehicles that have full flexibility to use more than one fuel, as is the case with natural gas and most of the fleet with ethanol engines. The situation in Brazil differs from other countries, where there are not so many fuels and the fleet does not have the same flexibility to choose between fuels at the moment of filling the tank. It is worth noting that the additional investment required to gain flexibility is relatively low in the case of ethanol; somewhat higher for natural gas. This difference is important to the consumer at the time of purchasing the car, considering fixed and operational costs, but is of limited relevance afterwards when operational costs are decisive.

Despite their enormous importance, fuel taxes in Brazil have been implemented in a disjointed manner, rarely taking into account strategies for national development. While ethanol enjoys lower rates of CIDE and ICMS in relation to its substitutes, it has been hampered by distortions in producer prices for natural gas and gasoline. **Figure 9** shows average prices practiced in Brazilian and U.S. refineries (ANP, 2009c; EIA, 2009), with values converted using exchange rates reported by the Brazilian Central Bank (BC, 2009). It can be seen that through much of the recent past Brazilian gasoline prices have been held artificially low by freezing refinery prices and reducing federal taxes.

Figure 8 **Taxes on vehicle fuels in Rio de Janeiro** *R$ per liter, May 2009*

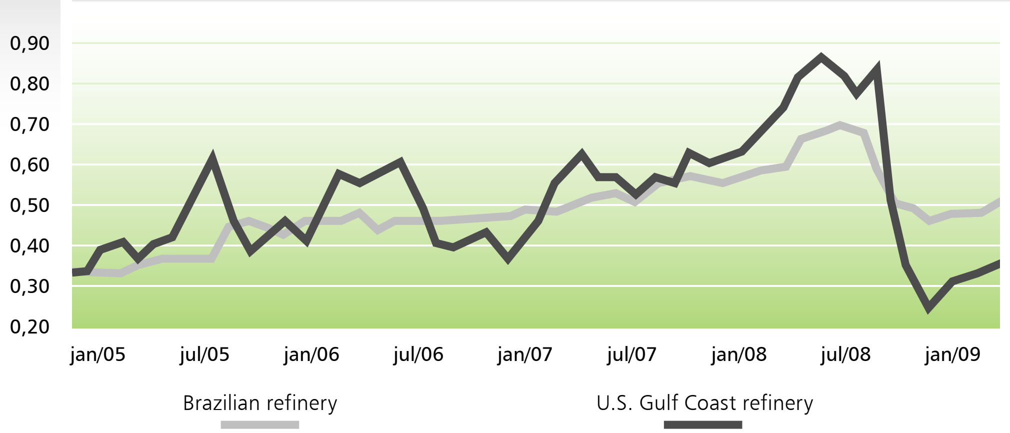


Source: Sindcomb (2009).

This procedure gives consumers incorrect signals about the value of energy sources, increases market uncertainties and leads to a significant loss of tax revenue. Considering the difference between domestic and international prices, the losses for Petrobras in the period 2005-2008 would be around US$2.8 billion. More serious for Brazilian society and the fiscal equilibrium of the federal government is the implicit tax waiver. In the period April-December 2008 the reduction of the CIDE (Contribution on Intervention in the Economy) by R$0.10 per liter (a 35.7% discount) implied a loss of R$1.2 billion to the national treasury, without society having any clear idea of the relevant benefit, objective or strategy to be achieved. **Figure 9** also shows that in some periods, domestic prices are higher than international market prices, which implies higher earnings for Petrobras, a state-owned company.

As can be seen, current tax legislation has negatively impacted the competitiveness of ethanol; legislation should be improved as an instrument of national energy policy. In this sense, it would be appropriate to consider two actions: a) a return to the regulatory nature of CIDE, providing a relevant differentiation between the final price of fuels and attenuating the price volatility of petroleum in the international market; and b) revisiting the difference between the CIDE and ICMS tax rates in order to guide energy development in the desired direction in a balanced and efficient manner. To this end, it is essential that the price structure for vehicle fuels – taking into account costs, margins, taxes, fuel mileage and eventual engine adaptation costs – leads to a strengthening of the energy matrix in a way that is compatible with the availability, impacts and benefits of each fuel.

Figura 9 **Prices for standard gasoline received by Brazilian and American producers**
US$/litro, sem tributos



Source: EIA (2009 and ANP (2009c).

6.3 Electricity generation from sugarcane bagasse

The Brazilian electricity sector sells wholesale energy using the Regulated Contracting Environment (ACR) and the Free Contracting Environment (ACL); the search for affordable tariffs is currently the main policy goal for electric energy generation (Bajay, 2009b).

In the ACR environment, power from existing generating stations – called "old energy" – and from planned generating stations – "new energy" – is contracted for the supply of "captive consumers" via lowest-price auctions. There are also auctions for stand-by energy. In the "new energy" auctions, entrepreneurs offer energy in lots with a minimum quantity of 1 MW av, stipulating their required fixed revenue (RF in Portuguese). Auction winners are those offering the lowest tariff. A cost-benefit index (ICB) for thermoelectric stations is calculated by the federal government's Energy Research Company (EPE) and is the average price expected if stations are dispatched according to the operational premise used by the EPE in the auction modeling. As noted below, the methodology used to calculate this indicator has been the object of much criticism and has not reflected the competitiveness of stations that generate electricity using sugarcane bagasse.

In the ACL, producers, retailers and large "free consumers" negotiate bilateral contracts.

Law No. 10,438 of April 26, 2002 created incentives for alternative sources of electrical energy (Proinfa in Portuguese). This was to be implemented in two phases. In the first stage, 3,300 MW would be built through 2006, counting small hydro, wind generation and thermoelectric or cogeneration plants burning biomass. In the second stage running through 2022, power generated by such plants would supply 15% of annual growth in energy use and 10% of total electricity consumption. Proinfa was revised by Law No. 10,762 of November 11, 2003 and is seen within the new institutional model for the Brazilian electricity sector as an instrument for creating opportunities to diversify national generating capacity. However, the strong emphasis that the model placed on lower tariffs ended up limiting the implementation of the second phase of the Proinfa program.

Proinfa energy contracts are the most expensive in Brazil, according to the June 2009 Tariff Newsletter published by DGSE/MME. This report said the price of electricity from Proinfa in May of 2009[xv] was R$165.92 per MWh, while the price of the cheapest energy within the energy mix in Brazil was R$71.49 per MWh. The newsletter also revealed that the most expensive energy after Proinfa was from thermal generators. The average price for biomass at energy auctions, for delivery starting in 2010, was R$153.48 per MWh, while for oil-fired thermal plants with delivery starting this year, the average standby price was R$147.20. The average price at energy auctions with natural gas as fuel, with delivery starting in 2011, estimated by the MME, was R$145.24/MWh. For coal-fired thermal plants the average auction price of energy, with delivery starting in 2012, was R$141.08/MWh.

The figures published in the DGSE/MME Tariff Newsletter for thermal power plants are averages of the cost benefit indexes of plants that won new energy auctions held since 2005. In other words, those values are tied to capacity factors simulated by the EPE before each of these auctions. In a dry hydrological period, power plants with a high degree of flexibility and high fuel costs, such as those burning fuel oil or LNG, will have to be dispatched at a capacity factor much higher than the one calculated before the corresponding auction, with unit generating costs well above the values of their respective cost-benefit ratios.

The EPE has not used the same matrix of values for Prices for Settlement of Differences (PLD) when calculating the Variable Cost of Operation (COP) and Short-term Economic Cost (CEC) parameters and the physical security of generators, which are part of the formula used for calculating the ICB (Bajay, 2009b).

Wise Systems, with help from Tractebel Energia SA[xvi], the largest private power generator in Brazil, calculated the ICB for six thermal power plants using different fuels, using internal rate of return (IRR) ranging from 10% to 16% and applying three PLD matrices in the calculations of physical security, COP and CEC. Matrices for 2007 and 2008 were based on PDEs 2006-2015 and 2007-2016, and were used to calculate the COP and CEC in the auctions for new energy in 2007 and 2008, respectively. The Marginal Cost of System Expansion (CME) matrix corresponds to the use in COP and CEC calculations of the same PLD values used in the calculation of the physical security of generators.

The first of these generators is a 50 MW cogeneration plant burning sugarcane bagasse. It would be built in the Southeast, with a null variable cost per unit (CVU) and completely inflexible operation. Two 350 MW plants would be built near Brazilian coal mines, one in Rio Grande do Sul and the other in Santa Catarina. Each has an Equivalent Forced Outage Rate (TEIF) of 7.5% and scheduled outages (IP) of 8.5%. The CVU of the Rio Grande do Sul plant is R$48.10 per MWh and the degree of inflexibility is 60%, while the CVU of the Santa Catarina plant is 50% higher at R$72.60, but the degree of inflexibility is smaller. The fourth plant is also coal-fired with installed capacity of 350 MW, but would be built in the Northeast burning imported coal. It has TEIF of 3.5%, IP of 5.5%, and CVU of R$83.81/MWh. The installed capacity of the fifth power plant is also 350 MW, also built in the Northeast but burning fuel oil. Its CVU is R$266.05/MWh with TEIF of 1% and IP of 2%. Finally, the sixth plant is a 500 MW LNG-fired station located in the Southeast, with CVU of R$172.20, TEIF of 2.2%, and IP of 6.3%. These last three plants have 100% flexible operation.

The physical guarantees calculated for the plants are: biomass, 17 MW av; Rio Grande do Sul coal, 298 MW av; Santa Catarina coal, 298 MW av; imported coal, 300 MW av; fuel oil, 174 MW av; and natural gas, 315 MW av.

The same conditions for BNDES financing were applied to the six power plants in the form of Project Financing operations.

These simulations performed by Wise Systems show just how much the ICB of thermoelectric plants varies according to the desired IRR, and most importantly the PLD matrix adopted. Among the thermoelectric and cogeneration plants simulated, the most competitive consume imported coal and sugarcane bagasse.

By working with static configurations for both demand and supply, the marginalist methodology employed by the EPE does not provide good estimates of the physical security of the power plants, in particular for thermoelectrics, either for the period of their ACR contracts or for their economic life (Bajay, 2009b). Castro, Brandão and Dantas (2009) demonstrate that this methodology has underestimated the physical guarantee of the biomass power plants and overestimated the physical guarantee of thermoelectric plants with high CVU, such as those using imported coal, LNG and fuel oil.

7 Policy, planning, and regulation

7.1 The market for vehicle fuels

Until the mid 1990s, Brazil was very dependent on imported petroleum and derivatives. By 2007 the country was consuming 32.7 million m^3 of diesel oil and 32.5 million m^3 of gasoline equivalent, counting fuels used in Otto Cycle light vehicles: gasoline, ethanol, and natural gas. In that same year Brazil exported 3.5 million m^3 of ethanol and 3.7 million m^3 of gasoline while importing 3.3 million m^3 of diesel. Dividing the Brazilian transportation sector between light vehicles, essentially for personal use, and commercial vehicles for cargo and passenger transport powered by diesel engines, has proved to be efficient and allowed for the adoption of tax differentials to favor economic activities.

The last 40 years have seen important changes in the relative participation of fuels used by light vehicles, because of supply restrictions, governmental policy changes and technological innovation. Gasoline consumption has fallen steadily since the increase in the ethanol participation in 1979, reaching its lowest point in 1988. It increased again until 2006 and has stabilized since then. The market for hydrous ethanol moved the opposite direction: consumption increased from 1979, to a peak in 1989, then decreased until 2004, when it started growing again with the introduction of flex-fuel engines and attractive prices. Data for anhydrous ethanol are less precise. To a certain extent it has tracked the gasoline market, but is also subject to the variations between 20% to 25% of the ethanol blend in gasoline, according to short-term government policies. Making this market even more complex, CNG use started in 1991 and today serves a fleet of 1.6 million vehicles, accounting for 9% of light vehicle fuel consumption in 2007.

It is important to note that the current option for ethanol in flex-fuel vehicles is a result of direct price competition: when ethanol costs 70% of gasoline, or less, then ethanol is preferred. The cost of sugarcane ethanol based on factors of production is between US$0.35 and US$0.41 per liter, which corresponds to petroleum at between US$60 and US$72 per barrel.

It could be said that, if the current scenario for the consumer prices of gasoline and hydrous ethanol remains unchanged, then the vast majority of vehicles with flex-fuel engines will continue to run mainly on ethanol. Huge private investments to expand ethanol production capacity are being made to ensure the necessary supply. Another factor that will tend to maintain and even expand ethanol participation in the fuel matrix is the prospect of significant future productivity gains for ethanol, even including an increase in the surplus electricity. However, it is possible that the demand for ethanol will be seriously affected if wrong policies are implemented, or if there is a lack of clear policies for the energy market to maintain a balanced use of biofuels, promoting the consumption of gasoline in flex-fuel engines and the use of diesel vehicles in the current Otto Cycle market.

7.2 A law for liquid biofuels

After decades of pioneer development of a renewable energy market in Brazil, where two biofuels, ethanol and biodiesel, are now widely used, it is important to evaluate the new perspectives created by the substantial increase in the country's proven oil reserves and production through 2020. There are plans to expand oil refining capacity by around 1.36 million BOPD by 2014, thus increasing the country's 2008 refining capacity by 67% to minimize exports of crude oil and add value to domestic crude. According to government plans there will thus be large exportable surpluses of gasoline and diesel starting 2017. These exports will of course depend on foreign markets, so we should consider the risk that domestic production of fossil fuel will be directed to the domestic market, in particular for light vehicles with flex-fuel engines, promoting gasoline consumption and diverting demand from hydrous ethanol.

This outlook finds the sugarcane agribusiness today weakened by successive harvests of low profitability, experiencing an alarming crisis of economic decline, as portrayed by Conab (2009). Ethanol production has become the overriding goal of the sugarcane industry during the past decade. However, with the advent of flex-fuel vehicles the domestic market for ethanol has been determined by gasoline prices, which are fixed in a very non-transparent manner and are subject to possible contingencies, while the export market remains largely blocked by high protectionist barriers. It is important that energy policies focus on the differential benefits of biofuels and re-establish strategies that allowed their development to current levels. Without this, the best scenarios presented above may never be more than just good intentions.

In this context, it is important to correct a deficiency: ethanol has been used for decades in Brazil, but there is no specific law to regulate its market, like those that exist in various countries that have sought to encourage the use of ethanol and biodiesel. In addition to general objectives such as stimulating productive investment, promoting a level playing field with defense of free competition, and ensuring the flow of information, a specific law could:

- Consolidate existing legislation, above all with respect to the decision-making chain, the conditions and instruments for monitoring the market and the authorization of agents. For example, the Interministerial Council for Sugar and Ethanol (CIMA), today responsible for defining public policies relating to ethanol, should receive enhanced status and have its coordination functions strengthened.
- Clearly define the tax structure for biofuels, taking into account externalities and establishing mechanisms to sustain competitiveness in volatile scenarios, possibly via the flexible arbitration of taxes. In this sense, the CIDE tax levied on the sale of petroleum derivatives should have its procedures for application and rate adjustment redefined.
- Establish mechanisms for regular support of research and development activities within the sugar and ethanol sector, with for example the establishment of a sector-specific fund to finance basic and applied studies.

7.3 The thermoelectricity market and the opportunities for bioelectricity

Some important observations need to be made about current conditions in the wholesale electricity market in Brazil, indicating the need for changes (Bajay, 2009b):

- There is no convergence between the policy to prioritize new medium and large hydroelectric plants and the environmental policies of the federal and state governments. In this context, it is unlikely that the growth in supply from new dams projected in the 2008-2017 Ten Year Expansion Plan (PDE) and the 2030 National Energy Plan (PNE) will materialize.
- Most new hydroelectric plants will be run-of-river, so reducing the capacity for multi-year regularization of large reservoirs that exists in the current Brazilian hydrothermal system and requiring the installation and increasing dispatch of thermoelectric plants for complementation. The projected growth in the share of thermal power plants and perhaps renewable alternatives such as wind and small hydro are underestimated in the 2008-2017 PDE and the 2030 PNE.
- Rules for calculating prices, in auctions for new energy, have favored the contracting of thermoelectric plants that have high variable unit cost, such as fuel oil, liquefied natural gas and imported coal. These, in turn, lead to higher electricity rates when they are dispatched. These rates are much higher than the average predicted in EPE simulations. They also cause a significant increase in emissions.

Changes are required in the methodology for calculating the thermoelectric ICB. According to Bajay (2009b) changes must take into account: conditions for dispatch outside the order of merit used by the National System Operator (ONS); the growing capacity factor of these plants throughout the period of their supply contracts; and improvements in the calculation of physical guarantees (FG) for biomass plants that have zero variable cost per unit (CVU) and for plants like imported coal and fuel oil with high CVU.

Also according to Bajay (2009b), the Mines and Energy Ministry (MME) needs to implement long-term policies that lead to the gradual introduction of:

I Thermoelectric plants and cogeneration units that supply the National Interconnected System (SIN) at the base of the load curve with non-renewable resources whose CVU is not very high (nuclear, domestic coal, and cogeneration with natural gas);
II Power plants using renewable sources that complement hydropower during the dry season (such as cogeneration plants burning sugarcane bagasse in the Southeast and Midwest), or that supply the base of the load curve (small hydro and cogeneration plants burning waste biomass, including sugarcane waste).
III Parameters that are standardized for technology and fuel, and reflect the costs and socio-environmental benefits of the various generation options in the calculation of the ICB. This is a better solution than establishing environmental compensation for coal or fuel oil, as determined by Instruction No. 7 of April 13, 2009 from the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA).

As for Proinfa, it would be appropriate for the market shares established for each alternative electricity source (small hydro, biomass, wind) to take into account targets associated with environmental policies, costs and available volumes, plus the capacity of local manufacture (or the interest to promote it). It is important for the program to include incentives to reduce the cost of energy produced by participating facilities, something that could be achieved by means of specific auctions, or by making Renewable Energy Certificates tradable, as foreseen for the second phase of the program (Bajay, 2009b).

Specifically, a policy and targets for promoting the generation of electricity from sugarcane waste could be implemented by restructuring Proinfa, or through a new law, establishing the legal basis of a regulatory framework for biofuels in Brazil.

▶ 8 Options for evolution of the Brazilian energy matrix

Until the 1960s, the planning for expansion of energy systems in the world was essentially sectoral, and the sectors involved were electricity, oil and gas, plus coal in some countries. Planning was on the supply side, and the challenge for projecting energy demand was to try to capture the key market trends.

The oil price shocks of 1973 and 1979 showed the need to also plan the demand side through energy conservation programs, tariffs that vary by time and season, interruptible tariffs, and so on.

Multisectoral actions focusing on both supply and demand were developed in the second half of the 1970s and the first half of the 1980s. The main motivation was to find options to reduce the dependence on petroleum derivatives and increase energy supply security using local sources, or failing that using external sources that were less volatile than petroleum.

The decline and subsequent stabilization in oil prices since the mid-1980s put a partial brake on this process. However, growing concern about the environmental impacts of the energy industry – acid rain, smog, the ozone layer and the greenhouse effect – has reawakened interest in the use of these more comprehensive approaches.

Concern over the increased use of renewables in the energy matrix of most countries was quite strong in the 1970s. It lost importance through the next two decades and then returned with force in the first decade of this century.

The 1990s showed that there can be competition in some markets that were once considered to be natural monopolies. That decade also saw several important players in the energy industry start to globalization their activities, not just geographically but also between market sectors. The rigid boundaries between the electricity, petroleum and natural gas sectors began to collapse.

Renewable energy sources are being promoted in the current decade in most countries, with many placing a special emphasis on biofuels, in particular ethanol and biodiesel.

Whatever the degree of importance that each country gives to planning its energy matrix, this matrix now normally includes the entire energy industry and includes actions on both the supply and demand sides.

Planning for the evolution of this matrix is a problem that involves multiple objectives, among which we can highlight:
I meeting energy requirements at reasonable costs;
II diversification of energy sources and supplies in order to reduce the risks of shortages and minimize the market power of some major suppliers; and
III minimize negative environmental and social impacts. As with any issue involving conflicting goals, compromise solutions must be sought. Renewable energy sources in general, and the more competitive of these in particular, play a key role in finding these solutions.

Brazil has several options for increasing its energy supply using its own sources. Few countries are endowed with such a diversity and availability of natural resources that can be used as fuel or to generate electricity. In fact, analyzing the historical data available in the National Energy Balance, we can see that Brazil diversified its energy sources from 1970 to 2007. According to projections in the 2030 National Energy Plan (PNE 2030), this diversification should continue to increase through 2030.

On the other hand, the share of renewable sources in domestic energy supply declined from 57.7% in 1970 to 45.9% in 2007 and, according to projections in the 2030 PNE, is expected to decrease further to 44.7% through 2030. Although renewable sources in 2007 provided a share of the Brazilian energy matrix that was far higher than the global average of 12.9%, Brazil is nevertheless moving in the opposite direction to most other countries that are adopting a series of policies to encourage increasing participation of renewable sources in their energy matrices.

One of the main goals of recent policies to promote renewable energy worldwide has been reducing the negative environmental impacts of producing and consuming energy, particularly by reducing emissions of gases that cause global warming. In Brazil, the opposite has happened in recent years, particularly after recent auctions for new energy where the winners have offered substantial capacity from thermoelectric stations burning fuel oil and coal, with high pollution potential.

The marginal costs of supply for major fuels and electricity in Brazil have been shown to be increasing in recent years. In addition, there are currently many uncertainties about the unit costs of production from various sources and/or technologies, such as oil and natural gas from the newly-discovered sub-salt oil fields, biodiesel, nuclear power plants, thermoelectric plants burning domestic coal, and others. These uncertainties can be sensed when reading the 2008-2017 Ten-Year Energy Plan (PDE 2008-2017) and, in particular, the 2030 PNE. To minimize the cost of energy supply, the Brazilian government should therefore encourage the expansion of energy sources that exhibit low unit costs of production such as hydroelectric plants – both large and small – and ethanol. These are sources where Brazil enjoys major competitive advantages.

Brazil has made progress in its energy planning in recent years, with the creation of the Energy Research Company (EPE). This prepares 10-year and long-term plans for the Ministry of Mines and Energy (MME). Additional progress, however, today faces a significant barrier, which is the lack of long-term energy policies. These still need to be decided by the competent agency within the federal administration, which is the National Energy Policy Council (CNPE), chaired by the Minister of Mines and Energy and with the participation of the ministers principally affected by energy policy.

The country faces two major options for the future development of its energy matrix. If current energy policies are maintained – most of which have short or medium-term horizons, and with the operating rules of the fuels and electricity markets currently in force – the tendency will be for the share of renewables in the domestic energy supply to fall even more than predicted in the 2030 PNE. Discounting very optimistic assumptions regarding the growth of some renewable sources, such as electricity generation in large hydropower plants, this plan did not take into account the new oil and natural gas reserves in the sub-salt fields.

On the other hand, if the Brazilian government wants to reverse this situation, starting to consistently and continuously promote renewable energy sources, especially the most competitive such as ethanol, it must establish policies and long-term goals that provide orientation for new planning exercises. These goals should reflect the benefits that can be offered by these sources, including environmental, social (job creation), technological development (for example second generation ethanol) and cheaper energy supply.

In the case of biofuels, specific legislation with a long-term perspective, like that of the United States, would be a next step after the recent natural gas legislation that has already been approved by Congress, and the legislation proposed for oil and gas prospecting and production in the sub-salt fields off the Brazilian coast. This could ensure the harmonious future development of production, consumption and export of biofuels, side by side with their fossil competitors.

Conditions in the fuel market are now quite different from those pertaining in 1970, when Brazil regulated the introduction of hydrous ethanol. Today, the market is diversified, with large volumes. It offers social and environmental benefits, with demand stimulated by the flexibility of fuel choice.

Given the new realities and demands, and to serve the interests of society, it is essential to ensure the sustainability of biofuels in Brazil, a country whose energy matrix should continue to incorporate a significant share of renewable sources.

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Explanatory Notes

[i] This refers to Instruction (Portaria) No. 23, of June 6, 1994, from the now-extinct National Department of Fuels (DNC in Portuguese).
[ii] Considering the following average consumption of vehicles as reported in the Folha do Gás Natural: CNG (10 km/m^3) and hydrous ethanol (7 km/liter).
[iii] Source: www.anp.gov.br, link "dados estatísticos".
[iv] Source: www.anp.gov.br/petro/dados_estatisticos.
[v] Importation of natural gas from Bolívia started in August of 1999.
[vi] Some authorities and specialists argued at the start of 2008 that using natural gas as a vehicle fuel should not be a priority, because it could be substituted by other fuels.
[vii] If we assume a vehicle scrappage rate of 3% a year, then 47,895 vehicles would be scrapped in 2009, a quantity that is far greater than the number of conversions predicted for this period based on extrapolation of the quantity seen in March of 2009.
[viii] This is the MELP model – Long Term Expansion Model (Modelo de Planejamento da Expansão da Geração de Longo Prazo) – that was developed by the Electrical Energy Research Center (Cepel) linked to Eletrobrás.
[ix] The world ratio of reserves to production was equal to 42 years on December 31, 2008 (BP, 2009).
[x] It should be noted that there is natural gas dissolved in the petroleum.
[xi] This total reserve value has been unchanged since 1986, indicating the lack of geological prospection for this mineral in recent decades.
[xii] Around 90%.
[xiii] In the case of uranium, there have also been no recent geological surveys.
[xiv] Taking into account losses in mining and processing; ignoring recycling of the residual plutonium and uranium.
[xv] Updated using the IPCA inflation index.
[xvi] Tractebel Energy calculated the physical guarantees of the projects.