Ethanol and Bioelectricity

Sugarcane in the Future of the Energy Matrix

Coordination and organization: Eduardo L. Leão de Sousa and Isaias de Carvalho Macedo

Biomass was man's principal source of energy from the dawn of civilization until the middle of the 19th century. As of 1850, around 85% of all energy used by man came from firewood, coal and other products of vegetable origin. Even today, despite the enormous increase in our consumption of energy from other sources, in particular petroleum, biomass still represents around 10% of world energy consumption.

Unfortunately, much of this energy is used with primitive technologies in the less developed regions of Africa, Asia and Latin America, basically for domestic purposes such as cooking and heating. The consequences of such activity include deforestation and soil erosion, which aggravate poverty in these regions. This situation has given biomass a bad name as an energy source, making it something that is frequently associated with underdevelopment and misery.

The basic fact is, however, that biomass is essentially a form of solar energy. As such it is renewable, unlike the fossil fuels that are the main causes of the environmental problems we face today.

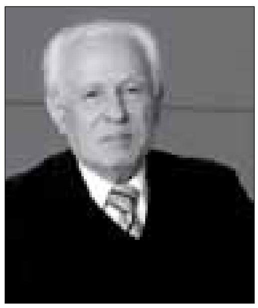
The solution is to "modernize" the use of biomass, and no other technology has so far enjoyed such success as Brazilian production of ethanol from sugarcane. Ethanol is an excellent substitute for gasoline and the pioneer work undertaken in this country since the start of the 20th century – and in particular since 1975 – offers compelling proof of the excellence of this technological option.

Ethanol today substitutes a little over half of all the gasoline that would otherwise be consumed in Brazil if the sugarcane-based fuel were not widely used.

Sugarcane bagasse is also becoming an important primary energy source for generating renewable electricity, and by 2020 could reach a production level comparable with the output of the Itaipu hydropower dam.

This book brings you nine new studies that examine all aspects of the efforts Brazil is making to modernize the use of biomass, from the sugar-energy sector supply chain to the role of bagasse in power generation, taking in the use of flex-fuel motors and the environmental and social aspects of the question. This collection provides an excellent and comprehensive panorama of the country's success, and of the prospects for further achievements to further consolidate an energy matrix that today reflects the real progress Brazil has already achieved.

José Goldemberg



Ph.D. in Physics and member of the Brazilian Academy of Science, José Goldemberg was rector of São Paulo University (1986-91), Minister of Education (1991-92), president of the Brazilian Society for the Progress of Science, special presidential advisor for science, technology and the environment, and Environment Secretary of São Paulo State. He is the author of hundreds of books and articles on physics, energy and the environment, and in 2008 received the Blue Planet Prize awarded by the Asahi Glass Foundation.

Ethanol and Bioelectricity

Sugarcane in the Future of the Energy Matrix

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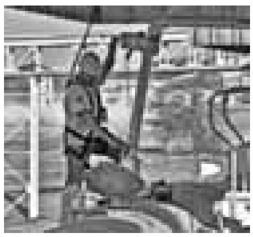

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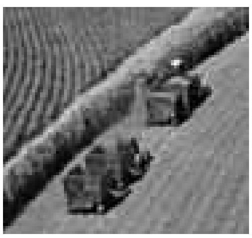

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The role that Brazil should play

This book is essential reading for all those blessed with a strategic outlook and who are interested in the formulation of structured, long-term policies that lead to a clear and definitive energy matrix for Brazil.

While this book offers scholars a guide to the future, it also shows how government action for the sector has been erratic in the past. One cannot even say that there was a strategy for the energy matrix; rather that things happened more or less at the whim of the dreams and projects of successive governments. How much time was lost because of this, and how many opportunities were missed? One day history will tell.

Now there is no time to lose. The country has reached a degree of maturity and a level of international exposure such that – no matter how good Brazilian leaders may be at seizing opportunities – it can no longer just drift along, taking advantages of favorable moments as they arise.

Brazil must have a consistent energy program if it is to advance in the global arena, and there is a relevant role for agri-energy, including biofuels, bioelectricity, ethanol-chemistry, and everything else that is agriculture-based.

The book presents comprehensive texts prepared by leading specialists in each area to addresses key questions, in particular with regard to the environment, society, and economics – the three pillars of sustainability. Each subject is examined thoroughly and precisely.

In this small space available to me, I would therefore like to introduce one additional issue: the question of politics, in a global sense.

The arguments are simple. Food and fiber agriculture can be conducted anywhere in the world. Any country can produce food, even if with heavy subsidies. But this is not true for agri-energy, because it depends on three major factors: the availability of land, with all that it contains, including water and mineral nutrients; plants that are adequate for the soil and climatic conditions; and sunlight.

Now, the sun is available in the region between the tropics of Cancer and Capricorn, where the world's least-developed countries are located in Asia, Latin America and Sub-Saharan Africa.

This means that these countries will be responsible for producing agri-energy and promoting change in the global energy matrix, with all the above-mentioned requirements regarding sustainability. What's more, agri-energy will generate wealth, income and food production in these countries. This means that agri-energy production will not only allow tropical countries to supply the world with energy – a factor that is absolutely essential for any society to advance – but will also generate the things they need for their own development.

These conditions will make possible the most extraordinary revolution in the 21st century – a change in global geopolitics – by decreasing the existing enormous distances between rich and poor, by helping to eliminate hunger in the world, and above all by reducing global warming.

Brazil can and should lead this process, occupying an important place in global history. To this end, Brazil must take care of its own domestic strategy with respect to an energy matrix that the whole world admires and respects. Only in this way will we be able to spread to other regions of the planet the processes that we have already mastered.

Roberto Rodrigues

Roberto Rodrigues is an agronomist and farmer, professor of rural economics at Unesp/Jaboticabal, coordinator of the Agribusiness Center at FGV and president of the FIESP Board of Agribusiness. He was president of the Organization of Brazilian Cooperatives, of the Brazilian Rural Society, of the Brazilian Agribusiness Association and the World Cooperative Alliance. Rodrigues was São Paulo State Secretary of Agriculture (1993/94) and Minister of Agriculture, Livestock and Supply (2003/2006).

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The Sugar-Energy Map of Brazil

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Social Externalities of Fuels

Márcia Azanha Ferraz Dias de Moraes
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Joaquim José Martins Guilhoto
Luiz Gustavo Antonio de Souza
Fabíola Cristina Ribeiro de Oliveira

Contribution of Ethanol to Climate Change

Luiz Gylvan Meira Filho
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Ethanol and Health

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International Biofuels Policies

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Ethanol Market and Competition

Elizabeth Farina
Claudia Viegas
Paula Pereda
Carolina Garcia

Ethanol in the Brazilian Energy Matrix

Sergio Valdir Bajay
Luiz Augusto Horta Nogueira
Francisco José Rocha de Sousa

NOTE: In this English edition, unless otherwise specified, the term "mill" is used generically to refer to a sugar mill, an ethanol distillery or a combined mill/distillery.

Ethanol and Bioelectricity

Sugarcane in the Future of the Energy Matrix

A Fuels Matrix for Brazil

Marcos Sawaya Jank

The Brazilian energy matrix, notable for its high degree of renewable sources, has undergone a series of changes that placed it amongst the cleanest in the world. In this decade, the participation of oil and its derivatives in the energy matrix decreased by about eight percentage points: from 45.5% in 2000 to 37.9% in 2009. At the end of this period, around 18% of the energy consumed in the country came from sugarcane derivatives, so overtaking hydroelectricity to rank second in the energy matrix.

However, it is important to note that if we look at the longer period, this progress was achieved in spite of public policies, rather than because of them. Over the past three decades, the absence of a long term fuel policy created great instability in the production and consumption of alternative energy. The oil crises were not enough to stimulate governmental policies focusing on the sustainability of renewable fuels. On the contrary, the policies adopted led to cycles of fuel substitution that had negative effects for all parties involved, including the consumer. This was especially true after the first oil crisis.

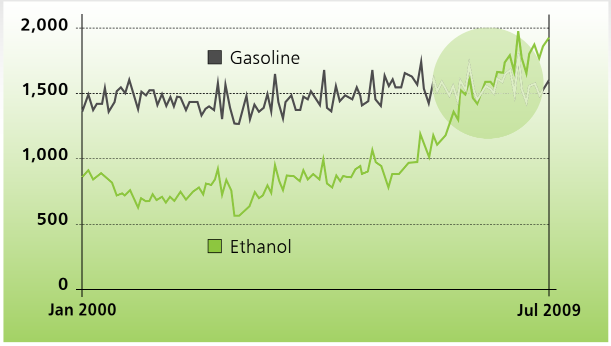
Since the 1970s, short-term fuel policies exhibited at least five distinct phases. This sent imprecise signals to the market, so impairing the flow of investments.

Phase 1: The "dieselization" of the matrix in the 1970s. The first process of substitution was diesel for gasoline, via policies of artificial pricing. This led to an increase in the diesel vehicle fleet and to imports of this fuel.
Phase 2: Expansion of the "Proálcool" national ethanol program in the 1980s. Launched in mid-1970s, Proálcool initially increased the use of anhydrous ethanol blended into gasoline. This blend had been used since 1938 with the aim of absorbing excess ethanol production and substituting tetraethyl lead (TEL), which is highly polluting, as a gasoline additive. The second oil shock came in 1979, with prices reaching a new historic high. This made it feasible to bring to market vehicles powered by hydrous ethanol, so launching a new phase in Proálcool. The success of this phase was so great that in 1985, 95% of light vehicles produced in Brazil were made to run on hydrous ethanol.
Phase 3: There was a new "gasolinization" of the matrix in the 1990s. The fall in international oil prices meant that ethanol began losing competitiveness compared to gasoline, despite good results achieved in increasing productivity in the sugar and ethanol industry. The government reduced incentives and it was impossible to remunerate the high volume of production needed to supply the fleet, culminating in a crisis of ethanol shortage in 1989/1990. Gasoline quickly recovered the ground it had lost.
Phase 4: The late 1990s brought incentives for Vehicular Natural Gas (VNG). This period saw the start of substantial conversion of vehicles to gas, substituting hydrous ethanol and gasoline. This incentive, which had as its main stimulus a temporary surplus of natural gas, led to the migration of significant portion of the automobile fleet in state capitals to use of this fuel, whose supply is now becoming increasingly scarce and expensive.
Phase 5: The flex-fuel revolution. A new phase for hydrous ethanol started in 2003 with the introduction of bi-fuel vehicles. With the new technology, the consumer can choose his fuel every time he fills up, and not when

he buys the vehicle. Between 2003 and the beginning of 2010, over 10 million flex vehicles were sold. Today, they account for over 90% of vehicles sold in Brazil.

The growth of the flex-fuel fleet and maintaining the ethanol price competitive in relation to gasoline have led to hydrous ethanol sales increasing five-fold in five years. Monthly ethanol sales (including hydrous and anhydrous) have exceed those of pure gasoline since April 2008 - an unprecedented milestone and one that is admired worldwide. Thanks to this achievement, we can now say that gasoline has become Brazil's "alternative fuel".

Monthly domestic consumption of ethanol and gasoline
(in million of liters/month)

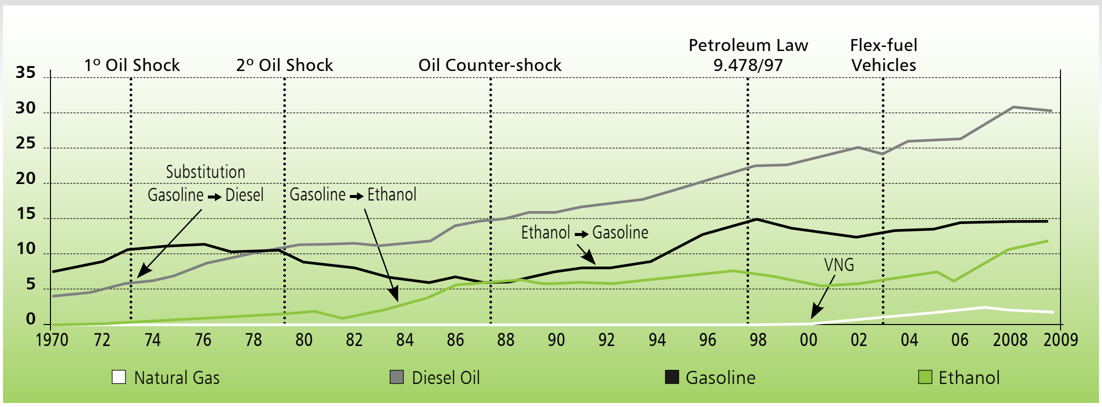


Note: Gasoline data refers to Type A gasoline; ethanol data includes the consumption of anhydrous and hydrous ethanol. ***Source:*** ANP. *Preparation:* UNICA.

Today, the market is betting on ethanol. In addition to the significant expansion of traditional mills, over 100 new units began to operate between 2005 and 2009, representing total investments of US$20 billion.

Despite this strong inflow in investments, uncertainties remain regarding the participation of ethanol in the future fuel matrix. This is understandable in the light of policy changes over the past 40 years, and current indicators do not all point in the same direction. On the one hand, the stimulus for natural gas consumption continues, despite the recent scarcity. On the other hand, gasoline pricing remains artificial, with cross subsidies between petroleum derivatives. In addition to causing problems for the industrial sector, this also distorts the market where hydrous ethanol competes directly with gasoline. At the same time, from time to

The dance of the fuels *(in million TPE*)*



* Tonnes of petroleum equivalent
Source: MME.

time there is debate about introducing diesel-powered automobiles, despite the clear evidence of the negative economic and environmental consequences of such a measure. Finally, we cannot ignore the prospects for development of the offshore sub-salt petroleum fields, which within some years will require significant investments to extract and refine oil, substantially increasing the production of oil and derivatives.

Summing up – what we have seen in the past decades, and still see today, is a cyclical situation in the fuel market. This provokes consumer insecurity and investor uncertainty. This makes long term planning essential to guide public policies that are compatible with a market economy, creating a stable environment for investments and giving consumers lasting guarantees. Such guideline must include the adoption of fiscal mechanisms that can incorporate into the price system the positive externalities of renewable fuels, which an independent market does not capture.

It is both vital and urgent to define a consistent and durable energy matrix, based on criteria of sustainability for fuel production and use. The global economic scenario offers Brazil a unique opportunity to become a world leader in fuel policies, be they for biofuels or fossil fuel, through the establishment of goals and future supply and demand scenarios for each component of the fuel matrix.

To this end, the fuels matrix should meet the expectations of the various players: biofuels producers, oil producers and refiners, fuel distributors, the auto industry, consumers, the government and society as a whole.

Biofuels have gained pride of place within Brazil's institutional framework, and this has brought several real benefits. These can be classified as social – creation of jobs and wealth in rural areas, plus better income distribution; environmental – mitigating the negative consequences of climate change; and economic – income and tax generation.

All these items are characteristics of sustainability and clean development, with social justice. This will constitute an important contribution of Brazil, and the Brazilian society, for worldwide sustainable growth.

*

This publication brings together new and illustrative information that will certainly help define an energy matrix that is aligned with the interests of society. Studies presented herein identify and quantify the benefits to society of using ethanol and bioelectricity.

The first such contribution, in **Chapter 1**, offers a detailed quantitative description and mapping of the sector, something that has never been done before with such technical rigor. The picture that emerges from this exhaustive survey shows that Brazil's sugar and ethanol industry generates annual income exceeding US$28 billion, including taxes of approximately US$7 billion.

The next study, in **Chapter 2**, reveals how the sector spreads wealth into rural communities. In São Paulo, for example, sugarcane activities are present in more than 60% of the 645 municipalities in the state, so indicating that the stimulus for economic development and job creation is spread very widely. The same study offers an illustrative simulation of ethanol's potential to create jobs: if 15% of the gasoline currently consumed in Brazil were to be substituted by fuel ethanol, this would create 117,000 jobs, generating additional income of almost R$250 million per year.

It is well known that greater ethanol use brings environment benefits, and **Chapter 3** seeks to quantify this gain. Technical measurements indicate that sugarcane ethanol can reduce greenhouse gas emissions by more than 90% when compared to gasoline. This advantage can be expressed in another way: every liter of ethanol represents US$0.20 that will not need to be spent on measures to mitigate the emission of polluting gases, so reducing the investments that the country would otherwise make in the development of other technologies to play its part in the global effort to control global warming.

However, the most important issues cannot simply be expressed in terms of dollars. The study on the public health impacts of the progressive replacement of petroleum derivatives by ethanol, the theme of **Chapter 4**, reveals a surprising projection: if the public bus fleet in the São Paulo metropolitan region switched from diesel to ethanol, there would be an annual reduction of 1,200 hospitalizations, saving 250 lives. That is half the number of deaths caused by tuberculosis in the metropolitan region in 2007. Based on the numbers presented in the study, the estimated savings in public health, hospitalizations and deaths resulting from substituting ethanol for gasoline would be one U.S. cent per liter of ethanol used, while substituting ethanol for diesel would save three U.S. cents per liter of ethanol used.

Also, when considering energy in a broader sense, sugarcane is not just ethanol. It is also bioelectricity, the electricity obtained from biomass – sugarcane bagasse and straw. This offers an ideal complement to hydropower generation, because the sugarcane harvest season is concentrated during the dry season in the South-Central region. This is another aspect, dealt with in **Chapter 5**, which cannot de ignored by those responsible for planning the Brazilian energy matrix.

Chapters 6 and **7** offer a series of proposals, including policies to encourage technological improvement of flex-fuel vehicles and to expand ethanol markets.

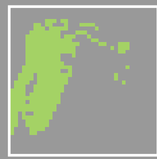
Chapter 8 describes and analyzes ethanol production in Brazil and suggested policies that could improve the commercial and marketing structures in the sector.

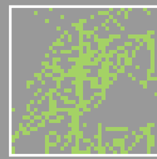
The set of studies concludes, in **Chapter 9**, with an analysis of Brazil's main sources of energy. The text presents important considerations about mechanisms to ensure that renewable and clean sources enjoy a growing participation in the country's energy matrix.

In bringing together these studies, UNICA is confident that it is contributing to the national debate that seeks to define this matrix.

01

Ethanol and Bioelectricity Sugarcane in the Future of the Energy Matrix





The Sugar-Energy Map of Brazil

Marcos Fava Neves

Vinicius Gustavo Trombin

Matheus Consoli

Sugarcane dates from Brazil's earliest colonization. Despite its historical significance, however, the sector has never been comprehensively described in its entirety. Now, for the first time, this mapping of the sugar and energy sector offers a detailed description of the complete supply chain.

This work was made possible only by using the methodology called Strategic Planning and Management of Agri-industrial Systems (Gestão Estratégica de Sistemas Agroindustriais, better known as Gesis, or ChainPlan in English), developed by Marcos Fava Neves, coordinator of Markestrat (the Center for Research and Projects in Marketing and Strategy, USP).

Application of this methodology indicated that, in 2008, the sector generated wealth totaling US$28.15 billion, equivalent to almost 2% of Brazilian Gross Domestic Product. When taking into account total sales of the various links comprising the sugarcane agri-industrial production system, the value reaches US$86.8 billion.

The industry provides 1.28 million jobs in the formal economy, according to 2008 data from the Ministry of Labor and Employment's Annual Report of Social Information (Rais). The total monthly wage bill is estimated at US$738 million.

The tendency is for sectorial GDP to continue to grow. Ethanol and sugar are still the most significant in terms of revenues, accounting respectively for US$12.5 billion and $9.8 billion, but new products adding to sector revenue will grow in importance. Bioelectricity already generates annual revenues of nearly US$400 million and is expected to grow exponentially in coming years, while yeasts already represent annual revenues exceeding US$60 million. Products such as bioplastics entered large scale production in 2010. Sugarcane diesel, biobutanol and cellulosic ethanol represent important new technological frontiers and offer real promise for the years ahead. As for carbon credits, they will also gain in importance, in proportion to the growing concern about low carbon economies.

1. Introduction

The sugarcane industry has for a long time been one of the pillars of the Brazilian economy. For over two centuries following the introduction of the first cane cuttings into the country in 1532, sugar was Brazil's main product.

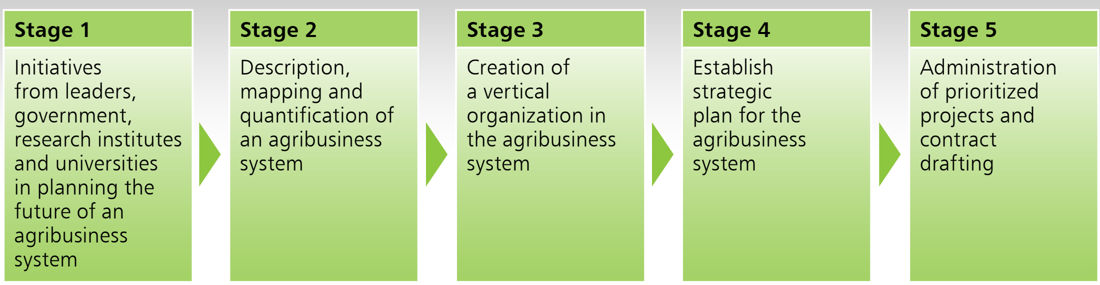
Around 40 years ago, the sector started to undergo a transformation. In addition to sugar, mills started to focus on ethanol production. More recently, attention has turned to bioelectricity, ethanol-based chemicals and carbon credit trading. All this embodies the possibility of employing advanced technologies that enhance productivity and reduce costs. It adds up to a new business paradigm, where competitiveness is the watchword.

However, advances in the sugar-energy sector have not been limited just to technology. Brazil's new production plants are also involved in social and environmental questions. The sugar-energy sector, one Brazil's largest employers, now has a working agenda that includes improving the quality of life of its workers, the rational use of land and water, mitigating the effects of mechanized harvesting and the preservation of ecosystems. While significant progress has been made, much remains to be done if the sector is to grow even more.

Internationally, it is essential to convince critics that the increase in Brazilian sugarcane production is not occurring in forested areas, and that production takes places under sustainable conditions, while persuading them with respect to the regularity of ethanol supply. Domestically, it is necessary to show Brazilian society that choosing to use ethanol as a vehicle fuel brings a number of other benefits, besides the economic saving.

One way of doing, indeed the goal of this report, this is to evaluate the economic and social impact of sector. This study compiles and analyzes data collected over a four-month period by a team of 10 researchers, seeking to measure the total financial weight, jobs and GDP of the sugar-energy sector.

Figure 1 **Proposed method for strategic planning and management of agri-industrial systems**



Source: Neves (2008).

2. Objectives

The goal of this study is to map out, delineate and quantify the agri-industrial sugarcane sector in Brazil. The main product of the study is an estimate of how much the companies that operate at the different levels of the supply chain billed in the sugar-energy sector in 2008, together with an estimate of sector GDP. In addition to total billings, another focus of research is to quantify jobs and taxes generated in the sector. This research is part of an effort by UNICA to increase available knowledge of the sugar-energy sector and provide public opinion with information about the benefits of producing and using clean, renewable and sustainable energy of agricultural origin.

3. Methodology

To achieve the objective of this study, the methodology known as Gesis (Strategic Planning and Management of Agri-industrial Systems) was used. This methodology, developed by Professor Marcos Fava Neves in 2004, has been applied to similar studies in Brazil, Argentina, Uruguay, and South Africa. The oranges (2004), wheat (2005) and milk (2007) supply chains were assessed, delineated and quantified under Neves' coordination. The Gesis methodology has been presented and published in several international business conferences and, as such, is familiar to researchers around the world. In 2007, it was used in Uruguay and Argentina for the wheat and milk supply chains, respectively.

Methodology for description, mapping, delineation and quantification Table 1a

Phases of Stage 2	Procedures
Phase 1 Description of the agri-industrial supply chain under study	Design of the agri-industrial system using boxes, reflecting the flow of products, ranging from inputs through to the final consumer (system design).
Phase 2 Presentation of the description to executives and other experts to adjust the structure	With this first version of the description, in-depth interviews are conducted with executives of companies operating in the sector and other specialists (researchers, sector leaders, others) to adjust the proposed design.
Phase 3 Research of sales data in associations, institutions and publications	Some private associations make available their members' sales information, sometimes even on the internet. A careful bibliographic review is also conducted for recent dissertations and theses, in addition to articles in academic magazines and papers, or other general publications.
Phase 4 Interviews with experts and company executives	This is the central point of the methodology. Interviews are conducted with managers, with the intention of finding the total amount sold by companies in the sector under study. Interviews are also conducted with procurement directors, seeking to estimate the market from the opposite side of supply chain links.
Phase 5 Quantification	At this point, all data obtained in the above steps is processed and inserted in the description below the name of the company. The data is then sent to participating companies to examine the values. Companies are asked to send back the data with comments and contributions.
Phase 6 Validation workshop	In the final phase, a workshop is organized for presentation of the results and discussion of the numbers.

Source: Neves (2008).

As presented in **Figure 1**, the description, mapping, delineation and quantification of an agribusiness system is one of the steps that make up the Gesis Methodology. Given the scope of the current project for the sugar and ethanol industry, only this stage of the method will be performed at this time. However, it should be noted that, because it is the initial step of the method, it lays the groundwork for the other steps to be undertaken in the future, thereby extending the focus of the study to include the development of collective goals and strategies.

Stage 2 of the Gesis Methodology, which constitutes the focus of the current study, consists in implementing the six phases described in **Table 1a** above.

4. Results

The GDP of the sugar-energy sector was US$28.2 billion, equivalent to almost 2% of domestic GDP or almost the entire wealth generated in one year by a country like Uruguay (US$32 billion). Sector GDP was estimated by calculating the aggregate sales of final goods by the sugarcane agri-industrial system, and applying the 2008 average exchange rate of US$1.00 = R$1.84. **Table 1b** presents the billings of the sector's main products in the domestic and foreign markets.

Figure 2 represents the sugarcane agri-industrial system. The values below each link indicate the gross billing for this segment with the sugar-energy sector in 2008. The sugar-energy sector's gross revenue in that year was US$86.8 billion. This value represents the sum of estimated sales of the various links in the agri-industrial chain and the financial operations of facilitating agents. The gross revenue of the sector is not comparable to the domestic GDP, because of double counting. Following **Figure 2**, the gross revenue of each link in the supply chain is presented in detail.

Table 1b **Estimates of the sugar-energy sector GDP based on final products** *in US$ millions*

Product	Domestic Market (DM)	External Market (EM)	Total (DM + EM)
	With taxes	Tax-exempt	With taxes
Hydrous ethanol	11,114.50[a]	23.78	11,138.28
Anhydrous ethanol	2,972.89[b]	2,366.33	5,339.22
Non-fuel ethanol	438.78[c]	n/a	438.78
Sugar	5,297.14[d]	5,482.96	10,780.10
Bioelectricity	389.63[e]	n/a	389.63
Yeast and additive	21.41	42.20	63.61
Carbon credit	n/a	3.48	3.48
Total	20,234.35	7,918.75	28,153.10

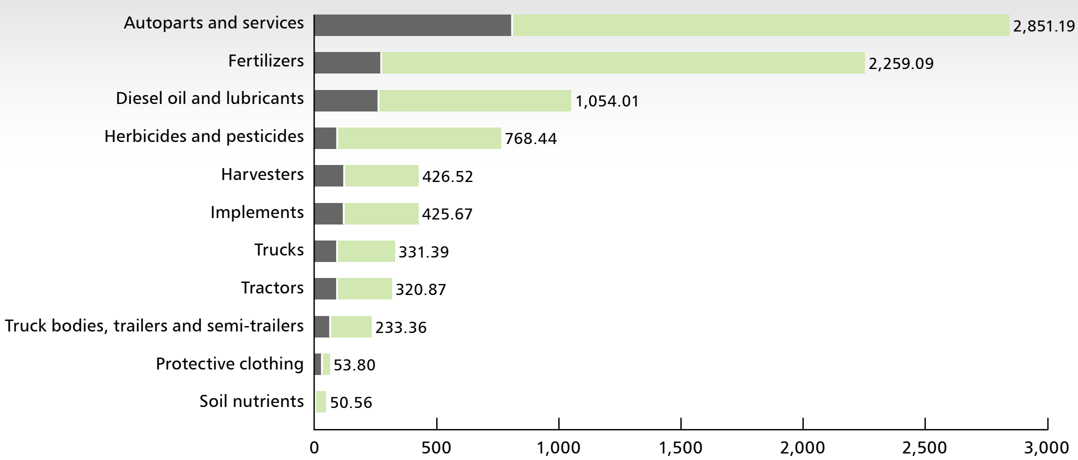
[a] Sales by filling stations, counting both the formal and informal markets. • [b] Sales by distilleries to fuel distributors, counting both the formal and informal markets. • [c] Sales by distilleries to beverage and cosmetics sectors. • [d] Sum of sugar sales by mills to industry and retail sales. • [e] Sales at energy auctions.
Source: Nevis, Trombin and Consoli, with data generated by Markestrat (2009).

The agricultural inputs industry *Prior to the plantation*

The agricultural inputs industry billed US$9.3 million in sales to the sugar-energy sector in 2008 (including revenues of US$477.5 million from herbicides and pesticides sold by agricultural cooperatives and dealers). **Graph 1** summarizes all revenues of this link, which are detailed in the following text.

Sugarcane accounted for 14% of agricultural fertilizers sales in Brazil in 2008, totaling US$2.3 million (3.14 million tonnes). This is an input essential for sugarcane plantations, and the increase in sugarcane planted area in the past few years has caused an increase fertilizer demand despite the unfavorable terms of trade. While in 2007, 19.8 tonnes of sugarcane were needed to purchase one tonne of fertilizer, in 2008 the vol-

Billings of agricultural inputs *Prior to the plantation – US$ millions* **Graph 1**



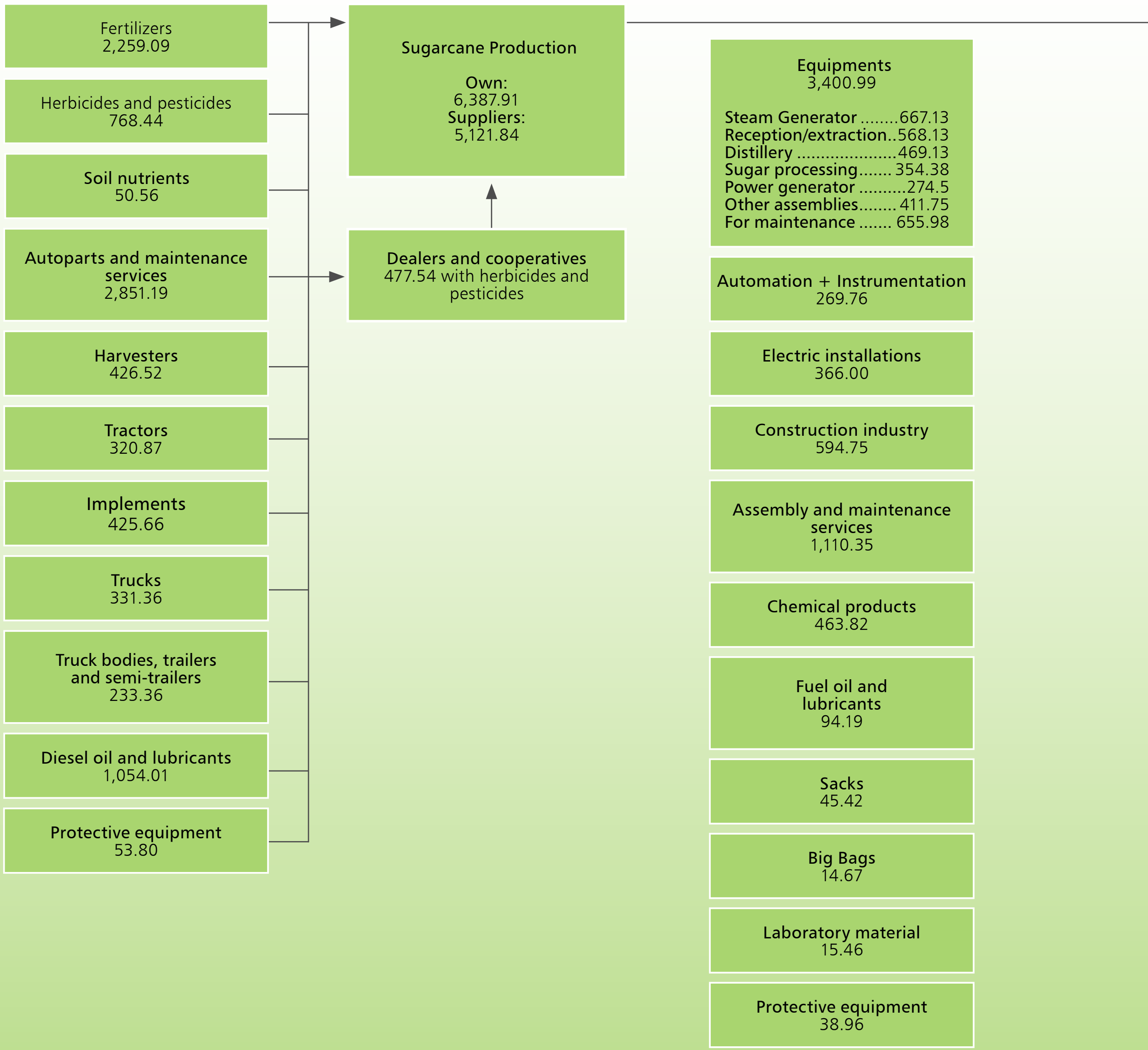
Agricultural inputs	Gross value	Sales tax[1]	Net value
Autoparts and services	2,851.19	810.00	**2,041.19**
Fertilizers	2,259.09	271.09	**1,988.00**
Diesel oil and lubricants	1,054.01	258.44	**798.57**
Herbicides and pesticides	768.44	92.21	**676.23**
Harvesters	426.52	121.17	**305.35**
Implements	425.67	120.93	**304.74**
Trucks	331.39	94.14	**237.25**
Tractors	320.87	91.16	**229.71**
Truck bodies, trailers and semi-trailers	233.36	66.30	**167.06**
Protective clothing	53.80	15.28	**38.52**
Soil nutrients	50.56	6.07	**44.49**

[1] IPI, PIS and COFINS
Source: Neves, Trombin and Consoli, with data generated by Markestrat (2009).

Figure 2

SUGAR-ENERGY SUPPLY CHAIN

Prior to the plantation	In the plantation
9,252.42	11,509.75

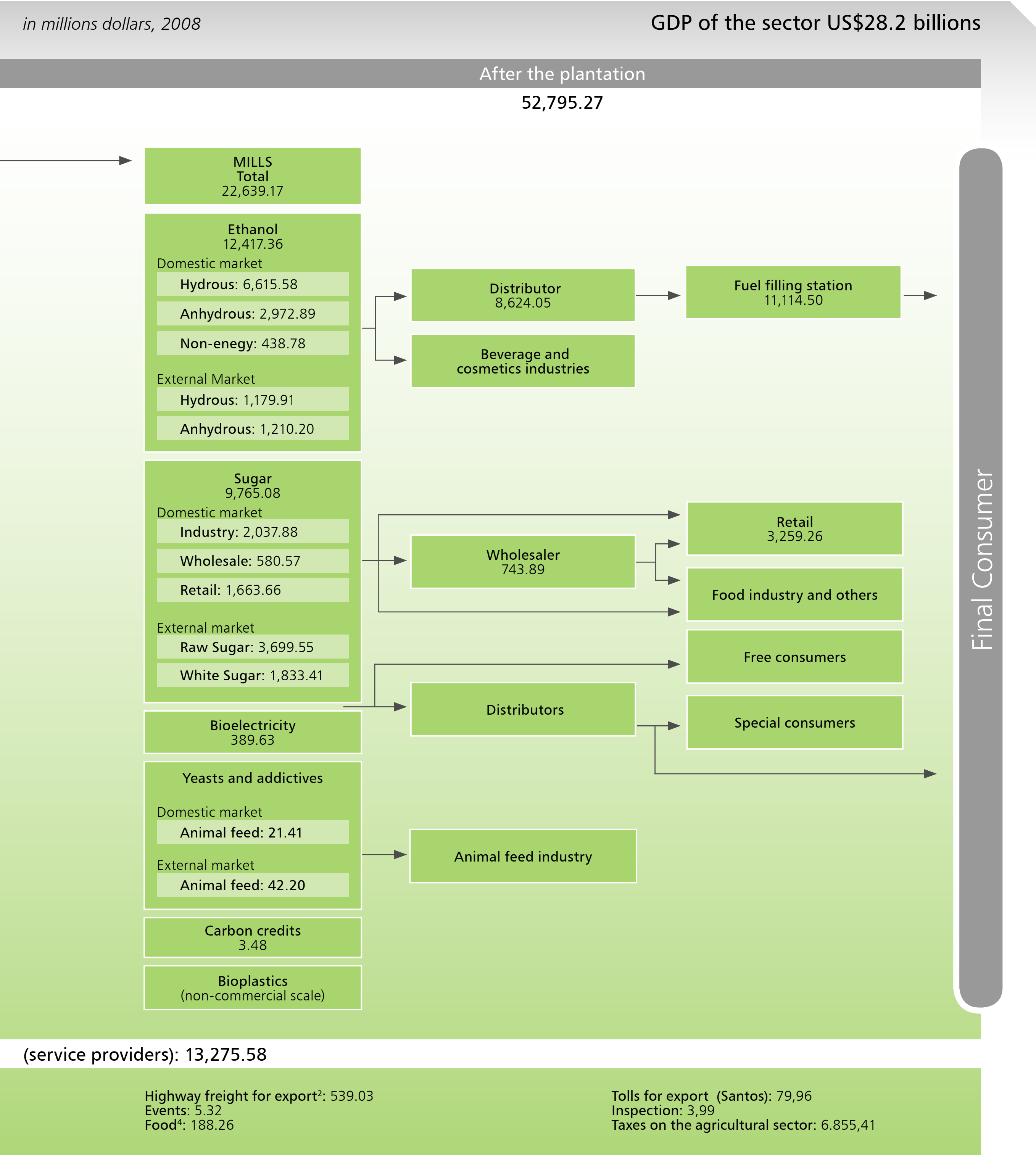


Facilitating agents

BNDES: 3,530.79
Port costs (Santos): 213.52
Payroll: 738.33

Outsourced CCT[1]: 916.32
R&D: 79.15
Health insurance[3]: Health[4]: 125.51

[1] CCT = Cutting, Loading and Transportation, in the Center South.
[2] Volumes exported through Santos and Paranagua Ports. • [3] e [4] Just for São Paulo State.



Source: Prepared by Neves, Trombin, Consoli, 2009.

ume soared to 36.3 tonnes. This happened because of increased fertilizer prices and lower levels of Total Recoverable Sugars (TRS). Sale of soil nutrients for sugarcane plantations were estimated at US$50.6 million in 2008, with consumption of 2,999,000 tonnes.

In 2008, the Brazilian agricultural pesticides and herbicides sector billed US$768.4 million for sales to sugarcane planters. Cooperatives were responsible for 61% of sales of pesticides and herbicides for sugarcane, with agricultural dealerships responsible for 2%. Together these billed more than US$477.5 million. Sales made directly to mills accounted for 37%. Of the total disbursed by sugarcane farmers for pesticides and herbicides, 73.5% was spent on herbicides, 22.8% on insecticides and 3.7% on fungicides.

Approximately 3,970 tractors were sold to the sugar-energy industry in 2008, for a total of US$320.9 million. Sales to the sugar-energy sector represented 9% of total tractor sales in Brazil, and the sector bought 47% of tractors rated at over 200 hp. Revenue from sale of implements was approximately US$425.7 million. This segment includes plows, tipper trailers, disk harrows, sprays, cultivators, self-propelled sprays and irrigation equipment, among others. The autoparts sector and maintenance services for machinery and equipments billed about US$2.9 billion in 2008. These amounts include parts and labor for about 144,000 machines in operation in the sector, which consume roughly US$20,000 in maintenance costs per unit per annum.

The sugar-energy sector acquired 22% of all harvesters sold in 2008, representing US$426.5 million in revenues. The sector purchased 981 units, representing 52% growth over 2007. The fleet of cane harvesters nearly doubled in size in the year, mainly due to the requirement to end pre-harvest straw burning. In 2007 there were approximately 1,280 sugarcane harvesters in Brazilian plantations.

Sales of heavy trucks – those with gross weight of 40 tonnes or more – were also driven by the growth of the sugar-energy sector. In addition to transporting ethanol, these trucks carry 80% of sugarcane after harvesting. It is estimated that in 2008, the sector purchased 1,962 heavy trucks, equivalent to 5% of total truck sales in this category in Brazil. This generated billings in the order of US$331.4 million.

Sales of truck bodies, trailers and semi-trailers in 2008 were estimated at US$233.4 million. In addition to the 488 truck bodies sold, 4,856 sugarcane trailers and semi-trailers were registered. This represented about 9% of total heavy truck body and trailer sales in Brazil, and was an increase of 11% over 2007.

Mechanized operations in sugarcane agricultural production and transportation from the field to the mill consumed almost one billion liters of diesel oil and lubricants in 2008, at a cost of US$1.0 million. Following the publication of Regulatory Norm No. 31 in 2005, mills increased their investments in the employee health and safety. This was reflected in 2008 sales of agricultural personal protective equipment (PPE), which totaled US$53.8 million.

Sugarcane production *In the plantation*

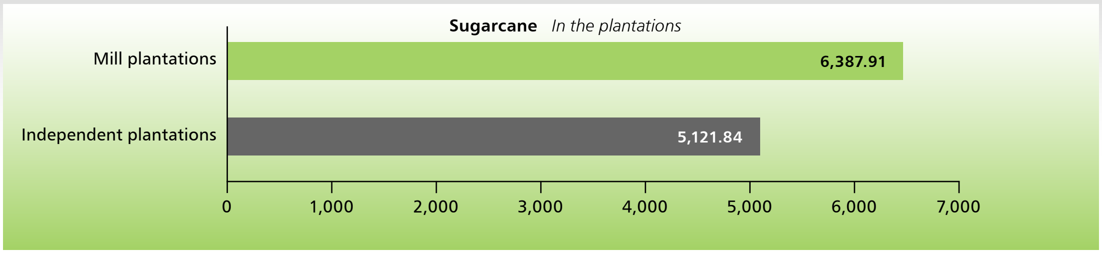
The 2008/09 sugarcane harvest reached a record production of 568.9 million tonnes with a planted area of approximately 8.5 million hectares (including areas in production, in formation, producing seedlings, and ripe sugarcane). The State of São Paulo was responsible for 68.6% of sugarcane crushing in the Center-South region of the country. In this region, the State of Minas Gerais saw the greatest increase in production during the last five years, with 1.8% growth, followed by the State of Goiás with 1.6% growth. The 568.9 million tonnes of crushed sugarcane in the 2008/09 harvest generated US$11.5 billion in revenues for the sugar-energy sector. The yield of raw material was 143.25 kg of Total Recoverable Sugars (TRS) per tonne of cane, down 2% compared with the previous harvest. The average TRS value in the 2008/09 harvest was US$0.14 . The average value per tonne of sugarcane in the 2008/09 harvest was US$20.23 (R$39.85). In the 2008/09 harvest, as shown in Graph 2, independent sugarcane suppliers accounted for approximately 44.5% of the industry's total supply (US$5.1 billion), with 55.5% coming from sugar and ethanol producers' own plantations (US$6.4 billion).

Equipment, services and industrial inputs *After the plantation*

The industrial inputs sector billed US$6.4 billion for sales to the sugar-energy industry in 2008. This value is presented in detail below.

In order to quantify the billings of industrial equipment suppliers and companies that provide assembly services, we considered the investments of the 29 industrial units that came on stream in 2008. Given that these investments would have started in 2006, they do not represent these companies' revenues in just that year. Rather, they offer an estimate of the cost of building these new units that began producing in 2008. Of the 29 industrial units, the following assumption was adopted: four were sugar mills that produce both sugar and ethanol and 25 were distilleries, for the production just of ethanol. Of the former, three had crushing capacity of 1.5 million tonnes of sugarcane, and one a capacity of three million tonnes. Of the distilleries, 15 had crushing capacity of 1.5 million tonnes and 10 had a capacity of three million tonnes.

Sugarcane revenues *US$ millions* **Graph 2**



Source: Neves, Trombin and Consoli, with data generated by Markestrat (2009).

The average investment for setting up an industrial plant was estimated at US$85 per tonne of sugarcane for milling capacity, and US$75 per tonne of sugarcane for distilleries. **Table 2** shows the proportional breakdown of required investment, and **Table 3** details the investment in equipment.

In addition to investments related to construction of new units, the study also considered sales of equipment and services for the maintenance of industrial units, which takes place between harvests. Under this heading, the study used an estimated maintenance cost in South-Central Brazil of US$1.68/tonne of crushed sugarcane. Of this 62.50% was spent on equipment and 37.50% on services. In the North-Northeast region this cost was US$2.08, with 86.70% spent on equipment and 13.30% on services. The study also included projects for automation and instrumentation sold to the sugar-energy sector in 2008 – there were about 41 such projects, in addition to those that were sold to the 29 new units already mentioned.

Table 2 **Distribution of investment by type of spending**

Item	% of total investment
Equipment	60
Electromechanical assembly	7
Civil construction	13
Electrical installation	8
Instrumentation and automation	2
Engineering services, thermal insulation and painting	10
Total	100

Source: Prepared by Markestrat from data provided by Procknor Engineering.

Table 3 **Distribution of investment by type of equipment**

Type of equipment	% of investment in equipment	
	Mill	Distillery
Steam generators	25	20
Reception/extraction system	20	25
Distillery	15	30
Sugar processing	15	0
Turbines/electricity generators	10	10
Others	15	15
Total	100	100

Source: Prepared by Markestrat from data provided by Procknor Engineering.

Based on these assumptions, the aggregate billing of industrial equipment suppliers was estimated at approximately US$3.4 billion. Automation and instrumentation sales were US$269.7 million, while assembly and maintenance service providers received approximately US$1.1 billion. The civil construction industry billed approximately US$594.8 million, and the electrical installations sector billed a further US$366.0 million for new industrial units.

The sugar-energy sector purchased chemical and specialty products worth US$463.8 million used in the production of ethanol and sugar, including quicklime and slaked lime, chemical commodities, polymers, processing aids for sugar and ethanol production, yeast, water treatment products and ion exchange resins, among others.

Fuel and lubricating oil consumed in industrial operations totaled 70 million liters, generating US$94.2 million in purchases. The sector purchased laboratory materials worth US$15.5 million, while US$45.4 million was spent on 50 kg sacks and US$14.7 million on 1,200 kg big bags. Industrial protective clothing purchases came to US$38.9 million.

Graph 3 summarizes the billing of this stage of the supply chain.

Billing *Mills*

Mills billed a total of US$22.6 billion on all marketed products, divided as follows: ethanol US$12.4 billion (55%); sugar US$9.8 billion (43%); bioelectricity US$389.6 million (1.7%); and yeasts, additives and carbon credit US$67.1 million (0.3%). The products and their distribution channels are presented below.

Ethanol *Mills*

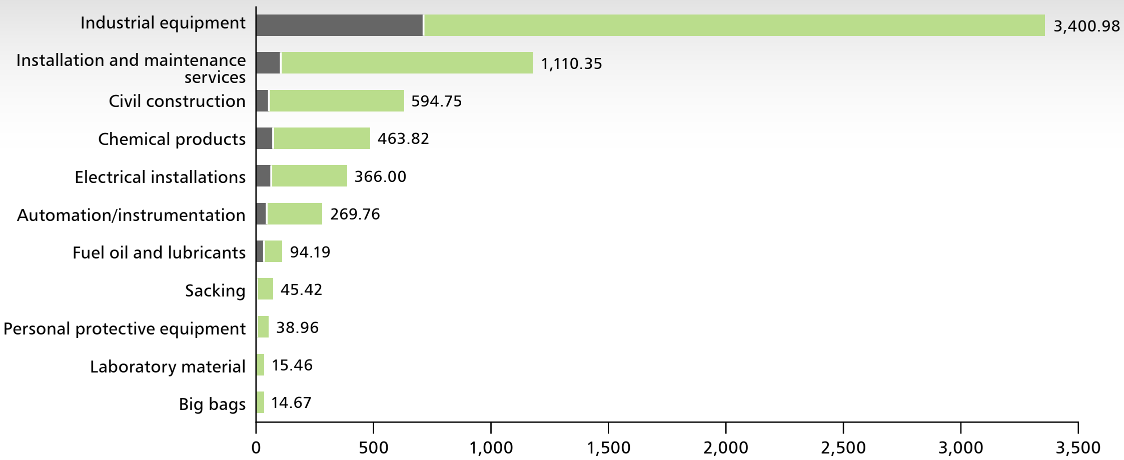
Mills earned US$12.4 billion in ethanol sales in 2008, counting domestic and export markets. Exports were worth US$2.4 billion (US$1.2 billion each for hydrous and anhydrous ethanol). However, anhydrous ethanol exports were atypical in 2008. One of the reasons for this growth was the higher demand from the United States, due to a reduction in the corn harvest caused by floods in the country's main producing region, in addition to the significant increase in the price of oil, which exceeded US$100 per barrel for part of the year.

Brazilian ethanol exports totaled 5.12 billion liters. The main buyers were the United States (34%), Netherlands (26%), Jamaica (8%) and El Salvador (7%). Despite the small volume of exports compared to total production, this shows the great potential for growth – since 2001 the volume exported has grown 14-fold, and export revenues 24-fold). The most significant increase came in 2004, when exports rose 220% by volume to approximately 2.4 billion liters. This includes ethanol destined for the chemical and beverage industries.

The domestic market in 2008 consumed 14.1 billion liters of hydrous ethanol, counting the formal and informal markets, generating US$6.6 billion in revenues for mills. Sales volumes of this product have grown considerably in recent years, with an increase of 87% over 2006. The main reason for this expansion was the introduction of flex-fuel vehicles, which in 2008 accounted for 90% of light commercial vehicle production in Brazil.

Mills sold 6.5 billion liters of anhydrous ethanol worth US$3 billion in the domestic market in 2008, counting the formal and informal markets. The main use of this product in Brazil is for blending with gasoline, currently at a proportion of 25%. Given the increase in consumption of ethanol compared to gasoline, because of the increase in flex-fuel vehicles, the consumption of anhydrous ethanol has declined in recent years.

Graph 3 **Billings of industrial inputs segments** *After the plantation – US$ millions*



Agricultural inputs	Gross value	Sales tax[1]	Net value
Industrial equipment	3,400.98	680.20	**2,720.78**
Installation and maintenance services	1,110.35	102.71	**1,007.64**
Civil construction	594.75	55.01	**539.74**
Chemical products	463.82	69.57	**394.25**
Electrical installations	366.00	64.05	**301.95**
Automation/instrumentation	269.76	47.20	**222.55**
Fuel oil and lubricants	94.19	23.09	**71.09**
Sacking	45.42	9.08	**36.34**
Personal protective equipment	38.96	7.79	**31.17**
Laboratory material	15.46	4.39	**11.07**
Big bags	14.67	2.93	**11.74**

[1] IPI, ICMS, PIS and COFINS
Source: Neves, Trombin and Consoli, with data generated by Markestrat (2009).

Sugarcane ethanol is also used in Brazil for non-energy purposes, mainly in the production of beverages, cosmetics, pharmaceuticals and chemicals. According to data from the National Energy Balance, this consumption was 720 million liters in 2008, representing revenues of US$438.8 million for the mills.

Ethanol *Distributors and service stations*

Distributors billed US$8.6 billion; filling stations US$11.1 billion.

Sugar *Mills*

Mills earned US$9.8 billion from sugar sales in 2008, including domestic and export markets. Exports produced revenues of US$5.5 billion (67% from raw sugar; 33% from white sugar). Of the 19.5 million tonnes shipped, 83% was produced in the Center-South of Brazil and 17% in the North-Northeastern region. About 50% of exports went to five countries, with the remainder distributed among more than 100 other countries. Between 2000 and 2008, on average, 25% of sugar exported by Brazil went to Russia, the leading international market, followed by Nigeria, Egypt and Saudi Arabia. Exports take the majority of sugar produced in Brazil, and Brazilian production has grown much faster than domestic consumption, which has maintained steady growth averaging 3% a year over the past six years.

Mills billed US$4.3 billion for sugar sales in the domestic market. Of this, sales to the food industry were worth around US$2.0 billion (US$1.6 billion retail and US$580.6 million wholesale). Part of the sugar volume going to industrial consumers is sold indirectly via specialized wholesalers to small factories. These wholesalers also repack sugar into smaller packages for retail sale. This specific case was not considered in our mapping, given the difficulty of estimating the volume of sales and prices for this type of wholesaler – no source of relevant secondary data was found.

The main industrial consumers of sugar are producers of soft drinks (20%), candies and chocolates (10%), chemicals (10%) and dairy products (7%), with other industries comprising 53%. The main type of sugar sold is granulated (61%), followed by refined granulated (36%), and other types (4%).

In terms of volume, the Center-South region sold 10.5 million tonnes and the North-Northeast 1.02 million tonnes. Center-South production was sold 60% to industry, 28% direct to retail and 12% via wholesale. North-Northeast production broke down as follows: 53% retail; 25% industry; 22% wholesale. Total sugar sales to industry were 6.6 million tonnes (direct sales for retail were 3.5 million tonnes, and for wholesale, 1.5 million tonnes).

Sugar *Wholesale and Retail*

Wholesalers billed US$743.9 million with sugar in 2008; retailers US$3,259.3 million.

Bioelectricity *Mills*

Bioelectricity generated from sugarcane bagasse is becoming an increasingly important byproduct for mills. In 2008, approximately 30 mills negotiated 544 MW average for annual sale over a 15-year period, providing annual billings of US$389.6 million.

Yeast *Mills*

About 10% of yeasts used in ethanol production (for fermentation of sugarcane juice) is subsequently recovered and destined for mixing into livestock feed. Exports of sugarcane ethanol yeasts in 2008 totaled 32,000 tonnes, worth US$16.8 million. That was an atypical year, however, because another 15,000 tonnes could have been exported but for a problem of contamination, now resolved. Revenues in the domestic market were US$11.1 million from the sale of 24,000 tonnes of dry yeast. The price per tonne in the domestic market was higher because of logistical costs and taxes.

Mills also sell additives based on sugarcane yeast (such as the cell wall). Exports of this byproduct in 2008 totaled 13,400 tonnes, generating revenues of US$25.4 million. A further 5,000 tonnes of additives were sold in the domestic market, generating US$10.3 million in revenues. This means that revenues from yeast and their additives in 2008 totaled US$63.6 million, of which US$21.4 million in the domestic market and US$42.2 million in the foreign market.

Carbon Credit *Mills*

Brazil ranks third in the world amongst seller countries, in terms of traded volume, but had only 3% of the global market in 2008. China and India were in first place with 84% and 4%, respectively. However, Brazil had a share of nearly 8% in primary Certified Emission Reductions (CERs) between 2002 and 2008. The worldwide traded amount in 2008 was 389 million tonnes of CO2 valued at US$6,52 billion, 14% down on 2007.

Brazil participates in the carbon credits market via the Clean Development Mechanism (CDM), because it is the only Kyoto Protocol mechanism that allows voluntary participation of developing countries. The 68 Brazilian projects registered by the United Nations Framework Convention on Climate Change (UNFCCC) in the carbon credit market generated an estimated reduction of 3.45 million tonnes of CO2 in 2008, with revenues of about US$25.4 million – the average price in the voluntary market was US$7.3 in 2008. Of the 68 projects, 24 were from the sugar-energy sector, generating an estimated reduction of 473,900 tonnes of CO_2 (US$3.5 million).

Bioplastics *Mills*

Bioplastics represent an innovative way of using sugarcane bagasse. If investments are made as planned, then in a short time bioplastics will represent a significant revenue source for mills. It is called "bio" because it comes from natural sources, and is biodegradable. Studies indicate that in up to 180 days all traces are eliminated from the environment. Thanks to these characteristics, bioplastics are prized in the organic market. The estimated annual worldwide demand for this new product already stands at 600,000 tonnes, at a price estimated to be 15% to 30% higher than the conventional product. According to the European Bioplastics Institute, almost 331,000 tonnes of bioplastics is produced, representing less than 1% of synthetic plastics produced annually. Brazilian bioplastics production is still at too small a scale for the product to be commercially marketed.

PHB Industrial, a company controlled by Pedra Agroindustrial and Grupo Balbo, has within its industrial complex one of Brazil's first pilot projects, a laboratory-scale operation capable of producing about 60 tonnes/year of bioplastics that is currently exported to Japan, the United States and Europe at an average price of US$5/kilo for pure resin. Very little of this material has been sold. Most of the material exported has gone to international companies for application development. PHB Industrial is designing a commercial plant to start operating in two to three years, an investment that will allow the company to sell bioplastics on a commercial scale to both the domestic and export markets. Press reports indicate that the unit will produce 10,000 tonnes/year and begin operating in 2010.

Braskem, a company from Rio Grande do Sul state, currently has production capacity of approximately 12 tonnes/year in its pilot plant, and has announced investments to begin producing 200,000 tonnes/year by 2011. Dow Chemical announced it was creating the first ethanol chemical complex with production projected at 350,000 tonnes/year as of 2011. And Coopersucar, working in partnership with the Solvay group of Belgium, is set to produce 120,000 tonnes in 2010 according to the Brazilian Industrial Development Agency. If investments planned through 2010 do in fact materialize, the ethanol chemical industry will require 650 million liters of ethanol.

Facilitating agents

BNDES – The bank made available US$3,530.79 million for companies in the sugar-energy sector, so stimulating the development and maintenance of the sector.

Outsourced – The sector has been going through a process of consolidation. New business groups have come into the sugarcane business, bringing professionalized management that focuses on operational efficiency and better financial allocation of capital. This has created a demand for outsourced services, so favoring the entry of companies specialized in services for operating logistics for the sugarcane sector. In 2008, the Center for Science and Technology (CCT) was responsible for US$916.3 million of outsourced services.

Road freight for export of sugar and ethanol – Road freight for sugar and ethanol exports was worth US$539.03 million. Road freight for sugar export in the Center-South of Brazil accounted for US$383.6 million, and of that amount, freight for ethanol exports came to US$155.42 million. Freight for sugar exports on Brazilian railroads cost approximately US$34.16/tonne; ethanol US$34.76/m^3. The ports of Santos and Paranaguá were the sector's main export routes in 2008.

Highway tolls for sugar and ethanol exports (Port of Santos) – Total spending on highway tolls for ethanol and sugar export freight in São Paulo state came to US$79.9 million in 2008.

Port costs (Santos) – The Port of Santos had estimated 2008 revenues of US$213.5 million relating to clearance, loading and supervision of sugar and ethanol shipments. It is worth noting that almost 70% (by volume) of Brazil's total ethanol and sugar exports passed through Santos.

Research & Development (R&D) – In 2008, US$79.2 million was allocated to sugar and ethanol industry research by bodies such as FINEP, FAPESP, Canavialis and Allelyx, CTC and IAC. It was used internally or distributed to public and private organizations including USP, UNICAMP, UNESP, EMBRAPA, Ridesa, and others.

Events – Five important sugar-energy industry events were identified in 2008. Together these cost US$5.3 million.

Specialized magazines – The major magazines covering the sector (Cana Journal, IDEA News, Energia Mundo, Cana Mix, Canavieros and Stab) billed US$3.99 million with a total of 61,000 copies in circulation.

Health plans and meals – According to the Union of Workers in Sugar, Food and Allied Sectors, workers in the State of São Paulo receive health plans and meals paid for completely or in part by the mills. The average monthly cost paid by mills for health plans is US$33.00 per person. It can thus be inferred that the health plan industry earned about US$125.5 million in 2008 from the sugar-energy sector. It is worth mentioning the great importance of these health plans for the communities where mills are located, because they reduce the burden on public hospitals. With respect to meal plans, mills in São Paulo disbursed an estimated US$188.3 million in 2008 – an average monthly cost of US$49.00 per person.

Wages / Jobs

According to the Annual Report of Social Information (RAIS) prepared by the Ministry of Labor and Employment, 1,283,258 formal jobs were registered in the sector 2008. The breakdown was 481,662 jobs in sugarcane plantations, 561,292 in raw sugar factories, 13,791 in sugarcane crushing and refining, and 226,513 in ethanol production).

The sugarcane industry has seen a growing incidence of formal employment. According to data from the IBGE, formal employment in the sector reached 80.9% in Brazil in 2007 (66.5% in the North-Northeast region; 90.3% in the Center-South; 95.1% in São Paulo). In all, there are 1.43 million jobs in the sector. Considering that every direct job creates two indirect ones, the figure increases to 4.29 million people employed in jobs related to sugarcane. São Paulo employs 40% of the total, the highest participation of any state, with 54% in sugarcane cultivation.

Illiterate and poorly-educated workers (with at most 5th grade complete) represented over 55% of the total labor force employed in sugarcane cultivation in 2008, but in the Center-South of Brazil this group did not exceed 5%. The proportion of illiterate and poorly-educated workers in sugar and ethanol manufacture is slightly lower than in cultivation. However, increased mechanization is creating a growing demand for more qualified professionals. A mechanical harvester replaces the work of 100 people with low qualification. On the other hand, it requires 10 employees trained in automation and mechanization. Agencies including SENAR, SENAI, and CTC are helping to train this new type of labor that the industry demands, but there is still room for other organizations to work to improve labor qualification in the sector.

Another issue examined was the wage level of workers in the sector, concentrated mainly between one and three times the minimum monthly salary. Moreover, even with the seasonal characteristic of the sector much reduced in recent years by the application of new technologies in sugarcane cultivation and harvesting, the total of formal jobs was 2.9% higher than the previous year (up from 572,194 in 2007 to 588,826 in 2008).

The Center-South region presents an average monthly income of R$1,062.55 per worker, while in the North-Northeast region the average is R$666.20. The national average is R$942.02. Total wages in the Center-South region are R$786.3 million, with R$422.6 million in the North-Northeast and a national total of R$1.21 billion.

Taxes

Total taxes were calculated by adding up the taxes generated at each stage of the agro-industrial system (SAG), from the sale of agricultural and industrial inputs through to the sale of final products. To eliminate double counting and arrive at a net figure for taxes in the SAG, the taxes on agricultural and industrial inputs generated in the first stage of the supply chain, which can be deducted from their own tax liability by processing companies in the next stage, were subtracted.

This calculation resulted in an estimate that taxes paid by the SAG in 2008 totaled US$9,868.2 million, but US$3,012.8 million of this amount was generated through the sale of agricultural and industrial inputs. Net aggregate taxes paid by the SAG were thus estimated at US$6,855.4 million.

Taxes were calculated using a weighted average rate, estimated from the rate that applies to the merchandise in the main producing states, taking into account tax incentives and the volumes produced. Only taxes on billings were considered in this calculation – IPI, ICMS, PIS and COFINS. In the case of the ICMS, we used the interstate rate for Center-South states rather than the weighted average. In the case of PIS and COFINS, we used the standard rates of 1.65% and 7.60%, except for ethanol which is taxed at a fixed value in R$ per liter. Also, in the case of IPI we gave priority to the rates applying to the most relevant products at each stage of the chain. For estimating aggregate taxes in the agri-industrial system, we assumed that all companies opted to be taxed on actual rather than estimated profits.

5. Final remarks

This study set out to provide a complete picture of the sugar and ethanol agro-industrial system. After five months of research it became evident that the complete supply chain is generating some impressive numbers, with total annual economic impact exceeding US$80 billion. This study – probably the most recent and complete picture of this supply chain in Brazil – can be a basis for public and private decision-making.

The sugar and ethanol supply chain has already shown its potential to supply products in a sustainable manner, helping Brazil develop one of the world's cleanest energy matrixes. It is estimated, that by 2015, 80% of the fuel used in Brazil will be ethanol. Bioelectricity has the potential to supply approximately 15% of total national demand for electricity by the end of the decade. The country is on course to dominate global sugar exports, with almost 50% of the world market in 2009 and the expectation of passing 60% in five years. Finally, it should be emphasized that new byproducts like cellulosic or second-generation ethanol, sugarcane-based diesel and biobutanol represent important new technologies that are already operating in pilot projects or on a demonstration scale. These will be important revenue sources in the coming years.

This study also shows that the sugar and ethanol supply chain, which is of fundamental importance to the Brazilian economy, has enormous capacity to spread development into the country's inland rural regions.

Details of methodology and quantification calculations

Annex 1

Stage of the supply chain	Quantification criteria	Sources
	PRIOR TO THE PLANTATION	
Fertilizers	Volume and revenues of the segment, adjusted by the percentage destined for sugarcane production. Secondary data.	ABIQUIM ANDA
Herbicides and pesticides	Volume and revenues of the segment, considering the market share of sugarcane. Secondary data.	SINDAG
Soil nutrients	Estimates based on national consumption (just lime; chalk was not considered): Utilization basis – area (ha) restoration and expansion (A) Dosage: 2 doses of 1.5 tonnes of lime/ha (B) Average FOB price of lime in the leading states (C) Estimated billing = A x B x C	MAPA (A) FNP (B) ABRACAL (C)
Autoparts (includes maintenance)	Estimates based on the amount of equipment per mill and spending with parts and maintenance. Number of mills (A) Average quantity of equipment per mill (B) Average value with equipment maintenance (parts & service) (C) Estimated billing = A x B x C	MAPA (A) RPA Consultoria (B, C)
Tractors	Average price of tractors by power (A) Number of tractors sold to the sugar-energy sector - by power (B) i = power ranges for tractors Estimate = Σ Ai x Bi	Interviews with companies in the segment - Valtra and Case IH dealers (A, B)
Harvesters	Average price of harvesters (A) Quantity of harvesters sold (B) Estimate = A x B	Interviews with companies in the segment - Santal and Case IH dealers (A, B)
Implements	Estimated amount of implements sold annually: Implements = 150% of the number of units of motorized equipment (A). Number of units of motorized equipment = 17.07 units per 1,000 ha (B). Implement lifespan = 10 years (C). Sugarcane area in thousand ha (D). Average price of implements (E) Estimated billing on irrigation equipment (all systems) for sugar-energy sector (F) Estimated billing = [(A x B x D / C) x E] + F	RPA Consultoria/IDEA (A, B, C) MAPA (D) Average of companies in the segment (Sermag, Civemasa, Tracan, DMB, Santal) (E) ABIMAQ (F)
Trucks	Estimate of new vehicles, based on the fleet and fleet renewal rate. Heavy trucks for carrying cane = 2.27/1,000ha harvested (A) Fleet renewal rate = 8.11 years (B) Cane production area, in 1,000ha (C). Average price for heavy trucks (D) Estimated billing = (A x C / B) x D	Idea (A, B) MAPA (B) Interview with dealers in segment - average values (D)
Truck bodies and trailers	Estimate based on number of units sold and average price. Number of units sold (A) Average price (B) i = product type (body, semi-trailer, 2 axle trailer, 4 axle trailer). Estimated billing = Σ Ai x Bi	ANFIR (A) Interviews with companies in the segment - average values (B)

Annex 1 **Details of methodology and quantification calculations**

Stage of the supply chain	Quantification criteria	Sources
Diesel oil and lubricants	Diesel consumption by activity in cane production (A) Sugarcane area (ha) (B) Average price of diesel (C) i = activities (cane planting, ratoon, harvesting, transporting cane to the mill, transporting inputs) Estimate for diesel = (Σ Ai x Bi) x C Average lubricant consumption liters / ha (D) Average lubricant cost (E) Estimate for lubricants = D x B x E	Agroanalysis (A) MAPA (B) Markestrat survey and Pecege (C, E) Idea (D)
Resellers and cooperatives (just for herbicides and pesticides)	Estimated % of herbicides/pesticides sold indirectly via resellers and cooperatives (A) Estimated margin of distribution channels (B) Revenue for cane herbicides/pesticides segment (C) Estimated billing = A x B x C	Interviews with herbicides/pesticides industries and cooperatives (A, B) SINDAG (C)
Agricultural protective clothing	Average spending/tc (A) Sugarcane production in tonnes (B) Estimated billing = A x B	Research with mills (A) CONAB (B)
	In the plantation	
Sugarcane production	Sugarcane production in tonnes (A) Estimated % of privately-owned cane and suppliers (B) Average total recoverable sugars (kg/tc) (C) TRS value R$/ kg (D) Estimated billing = A x B x C x D	CONAB (A) MAPA (B) CONSECANA (C, D)
	After the plantation (industrial inputs)	
Industrial equipment	New mills and installed sugarcane crushing capacity (A) Estimated value of industrial investments per tonne of installed sugarcane crushing capacity, including equipment, instrumentation/automation, and electric installations in new projects (B) Costs of maintaining the mill between harvests, per tonne of crushed cane in the Center-South and Northeast (C) Estimate (in %) of cost of maintenance spent on equipment in the Center-South and Northeast (D) Volume of sugarcane crushed in the Center-South and Northeast (E) Estimate of automation and instrumentation projects sold in 2008 for mills sold in previous years (F) Average price of each automation project (G) Estimated billing = (A x B) + (C x D x E) + (F x G)	Interviews with capital goods industry (A) Procknor Engenharia (B) Research with mills and Pecege data (C) Pecege (D) MAPA (I) Interviews with automation and instrumentation company (F, G)
Installation and maintenance services	New mills and installed sugarcane crushing capacity (A) Estimated value of industrial assembly service per tonne of installed sugarcane crushing capacity (B) Estimate (in %) of maintenance cost that is spent on services in the Center-South and Northeast (D) Sugarcane volume in the Center-South and Northeast (E) Estimated billing (A x B) + (C x D x E)	Interviews with capital goods industry (A) Procknor Engenharia (B) Research with mills and Pevege data (C) Pecege (D) MAPA (E)
Chemicals	Average expenditure per tonne of sugarcane (A) Sugarcane production in tonnes (B) Estimated billing = A x B	Research with mills (A) CONAB (B)
Fuel oil and lubricants	Average consumption per tonne of sugarcane (A) Sugarcane production in tonnes (B) Average price (C) Estimated billing = A x B x C	Research with mills and Pecege data (A, C) CONAB (B)

Details of methodology and quantification calculations

Annex 1

Stage of the supply chain	Quantification criteria	Sources
Sacking	Number of 50 kg sacks sold (A) Average price (B) Estimated billing = A x B	AFIPOL (A) Interviews with mills and manufacturers of sacks (B)
Big bags	Number of 1,200 kg bags sold (A) Average price (B) Estimated billing = A x B	AFIPOL (A) Interviews with mills and manufacturers of bags (B)
Laboratory material	Average expenditure per tonne of sugarcane (A) Sugarcane production in tonnes (B) Estimated billing = A x B	Research with mills (A) CONAB (B)
Industrial protective clothing	Average expenditure per tonne of sugarcane (A) Sugarcane production in tonnes (B) Estimated billing = A x B	Research with mills (A) CONAB (B)
After the plantation (mill revenues)		
Ethanol	Volume of anhydrous ethanol sold domestically (A) Average price of anhydrous ethanol (B) Volume of hydrous ethanol sold domestically (C) Average price of hydrous ethanol (D) Volume of ethanol for non-energy uses (E) Average price of non-energy (F) Volume of anhydrous ethanol sold via the informal market (G) Volume of hydrous ethanol sold via the informal market (H) Revenue of ethanol exports (I) Estimated billing = (A x B) + (C x D) + (E x B) + (E x F) + (G x B) + (H x D) + I	ANP from 1999 to 2007, EPE in 2008 (A) CEPEA-ESALQ and MAPA (B) MAPA (C) CEPEA-ESALQ and MAPA (D) EPE (E) Weighted average price using the proportions of anhydrous and hydrated volumes for non-energy recorded in 2007 (F) Estimates from ANP, Sindicom and Fecombustiveis (G, H) MDIC-SECEX, plus the proportions between anhydrous and hydrated ethanol, from UNICA (I)
Sugar	Sugar production in tonnes (A) Sugar exports in tonnes (B) Sugar exports – revenues (C) Volume of sugar sold by mills to industry, apportioned Center-South = 60%; Northeast = 25% (D) Volume of sugar sold by mills to wholesale, apportioned Center-South = 12%, Northeast = 22% (E) Volume of sugar sold by mills to retail, apportioned Center-South = 28%, Northeast = 53% (F) Average price that mills sold to industry (G) Average price that mills sold to wholesale (H) Average price that mills sold to retail (I) Estimated billing = C + (D x G) + (E x H) + (F x I) weighting values and volumes for Center-South and Northeast regions	UNICA, 2008/09 Harvest (A) MDIC-SECEX (B, C) A – B weighted by the % obtained in interviews with mills and Copersucar (D, E, F) CEPEA-ESALQ, MAPA (G) Interviews with wholesalers (H) CEPEA-ESALQ, MAPA, price of 50kg + R$15/sack (I)
Electrical energy	MW sold (A) Average price of MWh in auctions (B) MW conversion in MWh (C) Estimated billing = A x B x C	EPE and Valor Econômico (A) COGEN (B, C)
Yeasts and additives	Yeast revenues in domestic market (A) Yeast revenues in external market (B) Additive revenues in domestic market (C) Additive revenues in external market (D) Conversion of R$ into US$ (E) Estimated billing = (A+C)/E)+B+D	ICC (A, B, C and D)
Carbon credits	Quantity of tonnes of CO_2 equivalent (A) Average price (B) Estimated billing = A x B	United Nations Framework Convention and ABDI (A) World Bank (B)

Annex 1 **Details of methodology and quantification calculations**

Stage of the supply chain	Quantification criteria	Sources
	After the plantation (billings in the distribution channels)	
Ethanol distributors	Volume of hydrous ethanol sold in domestic market (A) Weighted average price (B) Estimated billing = A x B	ANP (A, B)
Ethanol filling stations	Volume of hydrous ethanol sold in domestic market (A) Average price (B) Estimated billing = A x B	ANP (A, B)
Sugar – wholesale	Volume sold (A) Average price (B) Estimated billing = A x B	Interviews with mills (A) Interviews with wholesalers
Sugar – retail	Volume sold – wholesale and retail (A) Average price (B) Estimated billing = A x B	Interviews with mills (A) DIEESE (B)
	Facilitators	
Outsourced CCT (cutting, loading and transportation)	Sugarcane production in tonnes (A) % of outsourced mechanized harvest (B) % of outsourced loading (C) Percentage of outsourced haulage (D) Price of harvest service (E) Price of loading service (F) Price of transportation service (G) Calculation of billing: A x B = W; A x C= Y; A x D=Z; W x E = V; C x F= L; Z x G= H Therefore: V + L + H	CONAB (A) Interviews with mills, Pecege (B, C, D) Logtrac, mills and IDEA (E, F, and G)
Freight	Value of shipping R$ per tonne/Km (A) Volume exported (tonne) (B) Distance traveled (C) Estimated billing = A x B x C	Sifreca (A) MDIC/Secex (B) Markestrat research with freight companies (C)
Highway tolls	Ethanol logistics data R$/m (A) Volume of exported ethanol (B) Ethanol toll cost: A x B = Y Average amount spent on tolls, seven-axle trucks (C) Truck capacity (D) Exported volume (E) Calculation: E / D = Number of trips (Z) Estimated toll cost for sugar: Z x C = W Estimated toll cost: Y + W	Copersucar and Sifreca (A) MDIC / Secex (B) Mills (C)
Port costs	**Sugar:** Amount spent on loading: US$/tonne (A) Amount spent on shipping supervision: US$/tonne (B) Clearance cost: US$/shipment (C) Shipment value (Y) C / Y = (D) Volume exported via Santos (E) Estimated cost for sugar = (A + B + D) x E **Ethanol:** Amount spent on loading: US$/$M^3$ (S) Amount spent on shipping supervision: US$/M3 (G) Clearance cost: US$/order (H) Shipment value (Z) H / Z = (W) Volume exported via Santos: (F) Estimated cost for ethanol = (S + G + W) x F	Copersucar (A, B and C) MIDC / Secex (E and F) IETHA (S, G, H)

Details of methodology and quantification calculations Annex 1

Stage of the supply chain	Quantification criteria	Sources
Health plans	Monthly number of workers in mills (A) Average health plan cost (B) Estimated billing = A x B	MTE (A) Unimed, São Francisco Clínicas and Sermed (B)
Meals	Monthly number of workers in mills (A) Average spent on meals per month (B) Number of months/year (C) Estimated billing: A x B x C	MTE (A) Interviews with mills (B)
BNDES (financing)	Consolidated financing data for the sugar-energy sector in 2008	BNDES
Events	Costs for developing and organizing events in the sugar and ethanol industry: Fenasucro and Agrocana (A) Ethanol Summit (B) Fersucro Simpo and (C) Simtec (D) Canasul (E) Agrishow (F) Estimated billing = A + B + C + D + E + F	Fenasucro and Agrocana (A) Ethanol Summit (B) Fersucro and Simpo (C) Simtec (D) Canasul (E) Agrishow (F)
Magazines	Interviews with publishers and quantification of revenue. Jornal da Cana (A) IDEA News (B) Energia Mundo (C) Canavieiras (D) Canamix (E) Estimated billing = A + B + C + D + E	Jornal da Cana (A) IDEA News (B) Energia Mundo (C) Canavieiras (D) Canamix (E)
Wage bill	Number of workers in the sugar-energy agriculture sector (A) Number of workers in the sugar-energy sector - industry (B) Average wage in the agricultural sector (C) Average wage in the industrial sector (D) Estimated cost: (A x C) + (B x D)	MTE (A, B, C and D)
Taxes	Gross revenue (A) IPI Value (B) ICMS (C) PIS (D) Cofins (E) Agricultural inputs (F) Industrial equipment and installation (G) Sales tax Σ (A x B) + (A x C) + (A x D) + (A x E) = (I) Estimated total tax: T – F – G	Reis Advogados Associados (C, D and E) Ministry of Finance / Receita Federal (B)

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Explanatory note

[i] In this case only, we used the average exchange rate for the US dollar between April 2008 and March 2009, equivalent to the 2008/09 harvest season. The value used was US$1.00 = R$1.97.

02

Social Externalities of Fuels

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This study profiles workers in the ethanol production cycle, looking at their levels of education and income. It also evaluates the extent to which ethanol production impacts employment and wages throughout the countryside.

We know that sugarcane plantation employees are in general not very well educated. According to 2007 data, they have an average of 4.2 years of schooling. In the ethanol production sector the average is higher: 7.7 years, and wages are commensurate with years of study. On average, an employee in the ethanol industry earns 25.3% more than an employee in the sugarcane industry.

These figures indicate the need for a public and private effort to increase the educational level of workers in the ethanol production cycle. However, they also show that the sector is responsible for bringing a significant number of people into the labor market – people who would otherwise have difficulty finding employment in other sectors of the economy.

The most effective way to evaluate the wages of sugarcane plantation workers is to compare them to workers involved in the production of other agricultural commodities. In this sense, wages for sugarcane workers only rank below wages for soybean production, which is highly mechanized and therefore demands a more qualified workforce. All other agricultural activities pay less than sugarcane.

In addition to the income level, sugarcane is socially important for its contribution to income distribution, because the sector is spread around Brazil. This is another factor that should be measured. No less than 1,042 municipalities produce sugarcane and/or ethanol; six times as many as the 176 municipalities where petroleum is produced and/or its derivatives are processed.

There is also a huge difference in the number of employees. According to 2007 data from the Brazilian Ministry of Labor's Annual Report of Social Information (RAIS), the sugarcane and ethanol production sector employs 465,236 workers (excluding those involved in sugar production). This is more than six times greater than the number of people involved in the petroleum production sector.

This study also offers a projection that shows how increased demand for ethanol (by substituting 15% of gasoline) would potentially generate 117,701 new jobs paying R$236 million a year.

1. Introduction

A country's energy matrix is defined by the relationship between the economic profile and the availability of energy resources. However, it is also important to analyze environmental and social aspects.

The search for clean and renewable energy sources is a response to the emission of greenhouse gases caused by the use of fossil fuels, which have a negative impact on the environment. One of the most important sources of renewable energy is ethanol. Positive environmental externalities of the production and use of ethanol justify the adoption of public policy incentives. One fact that deserves special attention is that ethanol pollutes less than gasoline in terms of carbon emissions – this implies an important contribution to the reduction of the greenhouse effect.

Considering the theoretical aspects involved, Moraes (2000) says that the positive externalities of ethanol production and consumption represent market flaws that justify government action via social regulation. He argues that prices established in a free market environment, without accounting for these externalities, could be insufficient to generate adequate returns on investment, so leading to a sub-optimal level of production.

However, in addition to the environmental aspects, other benefits of ethanol production and use should be analyzed. Among these are: "the direct and indirect jobs created; the possibility of counting on a fuel supply that is an alternative to oil derivatives; (and) the positive contribution to the balance of trade due to the avoidance of petroleum and derivative imports," according to the study by Serodio et al. (1998, p.11).

As for the social aspects, it is important to highlight job creation in the sugar and ethanol sector, not only in the industrial sector (production of sugar and ethanol), but also in the agricultural sector. Using data from the National Household Sample Study (PNAD), Oliveira (2009) points out that there were 527,401 people employed in sugarcane production in 2007, corresponding to 19.9% of all jobs created in the Brazilian agricultural sector that year. Hoffman and Oliveira (2008) found approximately 608,300 employees in sugarcane production in 2006. Moraes (2008), using data from the Brazilian Ministry of Labor's Annual Report of Social Information (RAIS), found that 1,283,258 formally employed workers were registered in 2008 in the sugarcane, sugar and ethanol sectors, respectively 37.5%, 44.8%, and 17.7% of the total.

Furthermore, because ethanol production is spread widely throughout several states and regions of Brazil, it creates important impacts on regional development. Unlike fossil fuels, which are produced in only a few states, sugar and ethanol production is present in a large number of Brazilian states and promotes development in rural towns.

In addition to production, it is important to examine the multiplier effects of the various activities and their supply chain in the economy. The direct and indirect multiplier effects extend throughout the economy, creating jobs and income.

This study aims to analyze socio-economic indicators for the sugarcane, ethanol, oil drilling and oil derivatives sectors with respect to job and income creation, as well as regional development. Various indicators are developed to analysis the social benefits of the different kinds of fuels. Taken together, these can guide a comparison between sugarcane ethanol and fossil fuel production in the following aspects:

i Job creation: presenting the evolution of indicators for the labor market, such as the number of workers, educational level, and age;
ii Location of production: identifying the main producing regions and corresponding municipal districts in order to compare the capacity for creating jobs, income and regional development;
iii Estimating the importance of sugarcane and ethanol production in the producing regions, by calculating the location quotient;
iv Measuring and comparing the impact of increased demand for hydrous ethanol, substituting demand for Type C gasoline, on the level of jobs and total income in the Brazilian economy.

2. Methodology

2.1 Information about the databases

Data from the Brazilian Ministry of Labor's Annual Report of Social Information (RAIS) and the National Household Sample Study (PNAD) conducted by the Brazilian Institute of Geography and Statistics (IBGE) were used to analyze the evolution of wages, qualification and number of people employed in sugarcane plantations, ethanol production, and the extraction and production of fossil fuel.

According to the National Classification of Economic Activities (CNAE) codes, the sectors analyzed in this study are designated as "sugarcane", "ethanol", "petroleum extraction" and "petroleum derivatives". The maximum subdivision of activities in the databases does not permit separating out specific information for ethanol made from sugarcane, nor for petroleum that is destined solely for the production of gasoline, nor even for the specific production of gasoline. The data for ethanol also contains information about the production of ethanol from cereals, wood and other vegetable sources, of ethylic ethanol from manioc and ethanol destined for domestic use. Data for petroleum production includes natural gas and bituminous minerals, among others, while data for production of oil derivatives includes several products such as butane, naphtha gas, paraffin and kerosene, and also includes support activities for petroleum and natural gas production[i].

The RAIS database[ii] is a census of the formal labor market based on information provided by companies, while information in the PNAD database[iii] is obtained through questionnaires administered to a sample number of households. Although these surveys are not comparable due to the diverging methods of data collection used, each one offers its own analytical advantages: the PNAD captures the informal job market, while the RAIS detects the level of geographic dissociation of the information, because it allows for analysis by municipality. Therefore, in order to analyze the social benefits linked to the use of different types of fuels, either during the production of raw materials, or during industrial processes, we use both data from PNAD (state level) and RAIS (municipal level).

The state and regional analysis based on the PNAD, especially regarding agricultural activities, demonstrates certain characteristics that should be taken into consideration when interpreting the results, for example:

i The IBGE (2006) considers to be a resident a person who may be temporarily absent from his/her place of dwelling on the date of the interview, for a period not greater than 12 months, by virtue of the nature of his work or in order to be closer to his workplace. This means that the member of a family living in any state in the Northeast region who is temporarily working in another state, in agricultural activities that use this type of migratory labor, will be counted in the Northeast state.
ii Data for the North region includes the agricultural economically active population (EAP) from Tocantins state, but only urban residents in the states of Rondônia, Acre, Amazonas, Roraima, Pará and Amapá (the former North region).

The data for the number of jobs offered by the Input-Output Matrix (IOM) differs from other bases, such as the PNAD and the RAIS, given that the data in the IOM is grouped by sector. This creates the need to estimate the jobs in the missing sectors. The great advantage of this database for the current analysis is that it shows the impact of a demand shock on a specific sector; not only on the number of jobs and level of income in the sector, but also on the other sectors linked to it. This linkage occurs both in sectors connected to the supply chain and in sectors where the demand comes from agents of the supply chain. This gives us an important analytical tool for analyzing the impacts on jobs and income in the Brazilian economy.

2.2 Earnings equation

We used information from the PNAD for 2002 through 2007 to analyze the evolution of wages, worker qualification and the number of people employed in the sugarcane, ethanol, petroleum production and petroleum derivatives production sectors. To allow for a comparison between income in different years, these will all be expressed in Reais of March 2009, adjusted using the National Consumer Price Index (INCP)[iv].

The formula for earnings, with the expansion factor associated with each individual in the sample, is adjusted by the method of weighted least squares.

In this analysis, we adopt as the dependent variable (Y) the natural logarithm of the principal income of those employed. Under these conditions, the general regression model used is:

$$Y_j = \alpha + \Sigma \beta_i X_{ij} + u_j$$

where α and β_i are parameters and u_j is a heteroscedastic random error representing the effect of all the variables that were not considered in the model, obeying the usual statistic properties. The model will be estimated using data from PNAD 2007.

The following explanatory variables are considered:

a A binary variable for gender (S), that assumes the value of 1 for females and 0 for males.
b The person's age (I) measured in decades.
c The squared variable age chart (I2), considering the fact that income does not vary linearly with age. If the parameters for age and age squared are indicated by $\theta 1$ and $\theta 2$, respectively, we should have $\theta_1 > 0$ and $\theta_2 < 0$ and the expected value for Y (and of income) will be greatest when the individual's age corresponds to – $\theta_1/(2\ \theta_2)$
d The educational level (E) of the individual, considering the relation between schooling and wages as a polygon function, to capture the increase in rate of return of education above a certain level. Hence, in models were the existence of a threshold effect is considered, in addition to the E, variable, the variable $E=Z_j(E_j-\delta)$ is included, in which δ is the vertex abscissa, in other words, it is the education level in which the return rate becomes greater, and Z_j is a binary variable such that

$$Z_j=0 \text{ para } E_j \leq \delta \quad \text{e} \quad Z_j=1 \text{ para } E_j > \delta$$

e The logarithm for the number of hours worked per week. The coefficient of this variable will be the elasticity of income in relation to the weekly work time.
f A variable will be used to distinguish formally registered employees (the base) and undocumented employees.
g Two binaries to distinguish the person's color (C): white (the base), black or mulatto, and yellow.
h One binary to distinguish the role of the individual in the family (F): reference person versus a base category that includes all the remaining conditions (spouse, child, other relative, unofficial member, pensioner, domestic employee, relative of domestic employee).
i Five binaries to distinguish the regions (R): North, Northeast (base), South, Southeast not including São Paulo, Midwest and the state of São Paulo.
j One binary variable to distinguish household situation (D): urban (base) and rural.
k Binaries will be introduced to distinguish the different sectors of activity (SA): sugarcane (base), ethanol production, oil production and petroleum derivatives production.

2.3 Formula for the location quotient (QL)

To analyze the relative importance of the sugar-ethanol and petrochemical sectors in the various producing regions, we propose using the location quotient (QL). This identifies the existence of specialization/agglomeration in the productive activity of the state or region. To this end we use 2000 and 2008 employment data from the RAIS referring to the number of jobs created and the number of establishments. The data on jobs created is used to calculate the location quotients (QL). Information in the RAIS can be viewed by municipality, which permits an analysis of how the various activities are spread throughout the economy.

The formula proposed by the IEDI (2002) to calculate the location quotient is:

$$QL_{ij} = \frac{E_{ij} / E_{j}\bullet}{E\bullet_{j} / E\bullet\bullet}$$

where: the location quotient of sector i in region j

E_{ij} = jobs in sector i in region j

$E_{j}\bullet = \sum_{j} E_{ij}$ = jobs in sector i in all regions

$E\bullet_{j} = \sum_{i} E_{ij}$ = jobs in all sectors in region j

$E\bullet\bullet = \sum_{i}\sum_{j} E_{ij}$ = jobs in all sectors in all regions

Using the RAIS database it is possible to verify the level of specialization of the sectors disaggregated to the five-digit level in the municipalities analyzed. According to IEDI (2002), a QL ≥ 1 is interpreted as specialization in the activity in the region in question. In this section, the Brazilian state to which the municipality belongs is considered as a region.

The following steps are taken to calculate the QL. First, we identify the states with the greatest levels of employment in the production of sugarcane, ethanol, petroleum and petroleum derivatives. For these states, we identify the municipalities in which the relevant activities were present in 2008, and then calculate the QL of each municipality to verify the existence of activity specialization. Next, the QLs are distributed into bands to identify the existence of specialization.

The location quotient has a lower limit equal to zero when there is no activity in the analyzed region. When the activity is present but there is no specialization the QL value lies between zero and one; if there is any specialization the number is greater than one. However, when a QL is greater than one, then the larger the absolute number, the greater the degree of specialization. This study therefore adopted directly comparable value ranges, so that the included municipalities have similar specialization levels. Values between one and five were considered as low specialization; greater than five and less than 10, moderate specialization; with greater than 10 indicating high levels of specialization. For the 15 municipalities in each state that generate most jobs in the sectors under study we show indicators for the number of employees, QL and the average age of the workers.

2.4 Impact on the Brazilian economy: analysis of the input-output matrix

The inter-relation between the sectors producing ethanol and Type C gasoline and the rest of the Brazilian economy generates impacts on the labor market. The input-output matrix analysis of the Brazilian economy can indicate these impacts through the multiplier effects of the activities.

This study required a greater level of detail of Brazilian economic sectors, highlighting ethanol and gasoline. Ethanol is one of the sectors used by the IBGE ("Ethanol" sector), but gasoline is included in the "Oil and coke refining" sector. Given the heterogeneity of the products in this sector (in addition to gasoline, they include mineral coal, non-metallic minerals, liquefied petroleum gas, fuel oil, diesel oil and other products), it was necessary to single out gasoline for analysis.

Also, in order to more precisely identify the impacts on the economy, Brazil was divided into the State of São Paulo and the remaining regions . The State of São Paulo was analyzed separately because it accounts for approximately half of the country's production of ethanol and is therefore the place where the greatest impacts resulting from the substitution of fuel use are to be expected. An inter-regional grid for 2004 constructed by Guilhoto (2009) was used to analyze the data.

The initial simulation was conducted for the "Ethanol" sector, based on a scenario where gasoline is substituted by hydrous ethanol. The increase in demand was calculated equivalent to increases of 5%, 10% and 15% in the volume of hydrous ethanol consumed in each Brazilian state. Using the ratio that establishes the efficiency (in km driven) between the consumption of hydrous ethanol and Type C gasoline equal to 0.70 (UNICA, 2009), we identified the equivalent volume of gasoline saved (not consumed) due to the increase in ethanol volume during the first impact. In other words, multiplying the ethanol volume in each state by the ethanol consumption coefficient in each state.

When the impact is analyzed in terms of value rather than volume, the volume of both products was multiplied by their respective prices[vii]. Because the values being used are from 2004, when these fuel prices were subject to different taxes in each Brazilian state, the prices used were the ones for each product in each state, for 2004[viii].

An alternative simulation was carried out to show the impact on jobs and income of substituting gasoline for ethanol – in other words, the impact of an increase in demand for Type C gasoline in detriment to hydrous ethanol. This simulation looked at substituting 1% of ethanol with Type C gasoline, which would be the highest substitution possible, given the demand for ethanol in the states.

Using the inter-regional input-output matrix described above, we calculated the multipliers that evaluate the impact of a variation in final demand on the economic variables of interest: the number of jobs created and the value of income. To obtain these results, one must initially calculate the multipliers for the production that is direct, indirect, or induced by family consumption. The multipliers for direct and indirect production determine how much the sectors being analyzed as well as the sectors indirectly affected by it will have to produce in order to satisfy an additional unit of final demand. This multiplier considers family consumption to be exogenous. On the other hand the multiplier that recognizes the effect induced by family consumption, also known as income effect, takes into consideration the increase of consumption in the economy, due to the growth in family incomes caused by the direct and indirect effect mentioned earlier. Methodologically, this impact is identified by making household consumption endogenous to the input-output matrix.

Using the described multipliers and the employment and income coefficients in the economic sectors, one can calculate the direct, indirect, and induced (income effect) impacts on employment and income levels in the country resulting from the increase in hydrous ethanol demand in place of Type C gasoline. If the net result is positive for the economy, then the substitution of ethanol for gasoline generates more jobs and a greater increase in total income than would occur without it.

The next section describes the results, grouped according to the database and methodologies used: analysis of the evolution of socio-economic indicators and of the estimated earnings equation, using the PNAD; calculation of the location quotients and an analysis of how widespread jobs are distributed, using the RAIS; and finally, estimates of jobs and income created considering the three scenarios analyzed for growth in ethanol demand substituting Type C gasoline.

3. Results

3.1 Evolution of formal and informal employment: PNAD data

Table 1 shows the growth in the number of people employed in the sugar-ethanol and petrochemical sectors from 2002 to 2007, according to PNAD data. It is noticeable that between the first and last years there was significant expansion of employment in the ethanol industry (79.4%), followed by the petroleum derivatives industry (61.7%). Despite lower growth, the absolute level of employment in sugarcane plantations remains very relevant: in 2007 this activity was responsible for almost 530,000 jobs.

It should be noted, however, that to identify the effect of ethanol production on employment in the agricultural sector it is necessary to consider what portion of sugarcane production is used to make sugar and what portion goes to make fuel ethanol. Using information from the Brazilian Sugarcane Industry Associa-

Table 1 Employees in the sugar, ethanol, and petrochemical sectors

YEAR	Sugar-ethanol sector			Petrochemical sector	
	SUGARCANE PLANTATIONS	PLANTATIONS → ETHANOL	ETHANOL	OIL PRODUCTION	DERIVATIVES PRODUCTION
2002	454,741	218,730	65,514	36,199	42,132
2003	452,695	224,537	67,804	48,616	37,005
2004	492,766	240,963	86,668	57,712	32,400
2005	519,715	261,936	79,995	44,977	33,483
2006	532,263	262,938	71,083	71,111	35,729
2007	527,401	287,434	11,.513	58,535	60,548
Change 2002/07	16.0%	31.4%	79.4%	61.7%	43.7%

Source: Prepared by the authors from IBGE data (2002 – 2007).

tion (UNICA) on the sugar/ethanol production mix, column 2 of **Table 1** shows the estimated agricultural labor indirectly employed in ethanol production. It is thus estimated that in 2007 almost 290,000 agricultural sector jobs can be attributed to the production of ethanol. At the other end of the supply chain, in 2007 there were an additional 120,000 jobs created in the industrial sector, making a total of approximately 405,000 jobs. In the same year, the total number of employees in the petrochemical sector, including petroleum and derivatives production, was 120,000 people.

Table 2 shows the average age and educational level of employees in the sectors being studied. Between 2002 and 2007, there was an increase in the average age of employees working for businesses where the main activity is sugarcane, compared with a decrease in the average age of employees in the other sectors analyzed.

Generally speaking, the average age of sugarcane agricultural employees is lower than in the industrial sectors. However, Oliveira (2009) shows that between 1992 and 2007 there was an increase in the average age of employees in the Brazilian farming sector as a whole, and specifically in sugarcane agricultural production. There are some indications that this increase of average worker age in the primary sector is related to the decrease in child labor[ix].

With respect to the educational profile, there is ample literature showing that farming is one of the few sectors of the economy that still employs workers with low educational levels, even employing illiterate people. Therefore, despite a 52% increase in the average years of schooling of sugarcane plantation workers between 2002 and 2007, the general level of education remains low. In 2007, sugarcane workers had an average of 4.2 years of schooling, while the average for ethanol production workers was 7.7 years. Petroleum production workings had an average of 11.7 years of schooling, and petroleum derivatives production workers an average of 11.3 years.

Comparison of educational levels *Average age and years of schooling* **Table 2**

Year	Sugarcane		Ethanol		Oil production		Derivatives production	
	Average Age	Average years of schooling	Average Age	Average years of schooling	Average Age	Average years of schooling	Average Age	Average years of schooling
2002	33.0	2.8	37.4	7.3	38.1	11.3	39.2	11.7
2003	33.5	2.8	35.6	7.3	40.0	12.2	39.6	11.4
2004	35.0	3.2	33.0	7.9	37.3	11.2	40.2	10.6
2005	33.4	3.5	34.6	8.3	37.8	11.4	36.0	12.5
2006	34.5	3.7	36.0	8.6	38.5	12.1	38.3	12.1
2007	33.9	4.2	35.8	7.7	37.7	11.7	36.5	11.3
Change 2002/07	2.9%	52.0%	-4.2%	5.1%	-1.0%	3.3%	-6.8%	-3.1%

Source: Prepared by the authors from IBGE data (2002 – 2007).

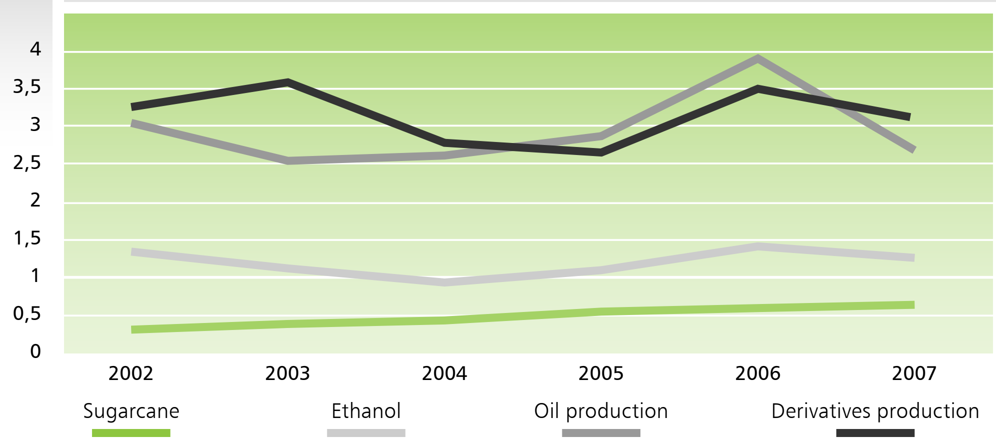
With respect to wages in the activities being analyzed, we can see in **Figure 1** that between 2002 and 2007 there was a decrease in the average income of workers in the ethanol industry (-2.3%), petroleum production (-5.2%) and derivatives production (-10.3%), while the average income of sugarcane plantation workers showed increasing and ongoing gains, up 48.0% during this period.

Oliveira (2009) states that readjustments to the minimum wage impacted the earnings of farm workers. In the period 2001-2007 there was a strong correlation between the minimum wage and the average salary of employees in both cattle breeding and arable farming. The author believes the national minimum wage underpinned the behavior of bottom-rung wages in the agricultural sector.

Despite the positive variation, the average income of a sugarcane plantation employee is much lower than in the ethanol industry. However, the employee in the ethanol sector receives less than the employee in the petroleum production sector.

It is well known that wages in Brazilian agricultural tend to be substantially lower than in the secondary (manufacturing) and tertiary (services) sectors. Also, it is important to note that the petroleum and derivatives industries have wage levels that are amongst the highest in the Brazilian economy. Miranda (2001) observed that employees working in activities related to petroleum and derivatives production in the state of Rio de Janeiro had wage levels significantly above employees in other industrial sectors. Furthermore, when petroleum employees receive specialized training to work off-shore with specific equipment, their wage levels increase by at least 30% relative to others in the sector. Depending on the market and given the risks and conditions involved, the salary difference can reach 80%.

Graph 1 **Comparison of monthly income** *In R$, March 2009*



Source: Prepared by the authors from IBGE data (2002 – 2007)..

Table 3

Earnings equation

For workers in sugarcane plantations, the ethanol industry, and petroleum and derivatives production

Variable	2007			
	Coefficient		Difference (in %)	
Constant	3.7481			
Female	-0.3101		-26.66	
Age				
Age/10	0.1849			
$(Age/10)^2$	-0.0154			(2)
Level of education				
Level of education <=10 years	0.0217		2.19	
Level of education > 10 years	0.1726		21.44	(1)
Log (hours worked per week)	0.4755			
Color (base: white)				
Black or brown	-0.0496		-4.84	
Yellow	0.5972		81.70	(2)
Condition of the person in the family (base: head of family)	0.1131		11.97	
Rural dwelling (base: urban dwelling)	-0.0771		-7.42	
Region (base: Northeast)				
North[3]	0.2437		27.60	(2)
Southeast (excluding SP)	0.2010		22.26	
São Paulo	0.3932		48.17	
South	0.2043		22.66	
Center-West	0.1798		19.69	
Productive sector (base: sugarcane)				
Ethanol industry	0.2255		25.30	
Petroleum derivatives industry	0.5471		72.83	
Petroleum production industry	0.7429		110.19	
Informal workers (base: registered/formal workers)	-0.4941		-38.99	
R^2	71.17			
F Test [4]	168.53			
N	1,317			

Source: Prepared by the authors from IBGE data (2007).
[1] This is the percentage growth of earnings associated with one year of additional education, beyond 10 years, obtained as per this sample calculation: 100[exp(0.0217+0.1726) -1]% = 21.44%. • [2] The coefficients are not statistically different from zero at a 5% significance level. • [3] Excluding rural areas of RO, AC, AM, RR, PA and AP states. • [4] The value of **F** is statistically significant at a 1% level.

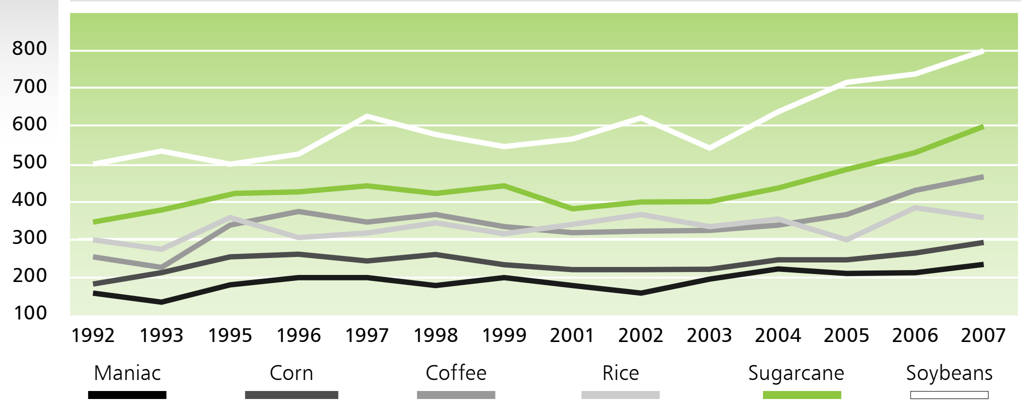
The statistical technique of multiple regression makes it possible to determine if the differences in the process of establishing the salary levels can be explained by a set of personal characteristics (gender, age, educational level, color, being or not the head of the family, living in a rural or urban situation) and job characteristics (region, hours worked per week, and main area of activity).

An equation was estimated in which the dependant variable is the logarithm of the job income of each individual and the personal and job characteristics are explanatory variables. **Table 3** shows the regression equation coefficients adjusted with 2007 PNAD data for people employed in the four sectors being analyzed[xi]. In the case of the binary variables, the figure shows the percentage difference[xii] between the expected income of a given category and the expected income of the base category, after discounting the effects of the remaining explanatory variables included in the regression. In addition, it shows the values of F and the coefficient of determination (R2). It should be noted that almost every coefficient is statistically different from zero at the 5% significance level[xiii].

According to the data in Graph 1, a person employed in petroleum production made, on average, five times as much as a sugarcane plantation employee in 2007. The wages of employees in the petroleum derivatives and ethanol industries were, respectively, 4.5 and 2.1 times the average income of sugarcane plantation workers.

However, using an estimated income equation model shows that once the effects of all the other explanatory variables have been discounted; the ethanol industrial-sector worker tends to earn 25.3% more than the plantation worker linked to ethanol production. The petroleum production and derivatives workers tend to receive incomes respectively 72.8% and 110.2% higher than sugarcane field workers.

Graph 2 **Average monthly earnings in the agriculture sector; selected crops**
(in R$ of August 2008)



Source: Prepared by the authors from data in Oliveira (2007).

Income equation for agricultural workers Table 4

Variable	Agriculture 2007		
	Coefficient	% Diff.	
Constant	2.8703	-	
Female	-0.1141	-10.78	
Age			
Age/10	0.2143	-	
$(Age/10)^2$	-0.0242	-	
Level of education			
Level of education <=9 years	0.0187	1.89	
Level of education > 9 years	0.0704	9.31	(1)
Log (hours worked per week)	0.7245	-	
Color (base: white)			
Black or brown	-0.0250	-2.47	(2)
Yellow	0.1400	15.03	(2)
Head of the family	0.0850	8.87	
Rural dwelling	-0.0044	-0.44	(2)
Region (base: Northeast)			
North[3]	0.1876	20.63	
Southeast (excluding SP)	0.3350	39.80	
São Paulo	0.4314	53.94	
South	0.4011	49.34	
Center-West	0.4067	50.19	
Agricultural sector (Base: sugarcane)			
Coffee	-0.1047	-9.94	
Manioc	-0.2639	-23.20	
Corn	-0.3688	-30.84	
Soybean	0.0023	0.23	(2)
Rice	-0.3577	-30.07	
Other agricultural activities[4]	-0.1332	-12.47	
Registered/formal workers	-0.3795	-31.58	
Temporary workers	-0.0923	-8.82	
Non-specialized workers	-0.1504	-13.97	
R^2	57.54		
F Test [4]	266.53		
N	4.745		

Source: Oliveira (2009, p. 150), based on PNAD microdata for 2007.
Note: The dependant variable is the logarithm of the income of the principal occupation.
(1) This is the percentage growth of income associated with one additional year of education, after an initial nine years, calculated as follows: 100[exp (0.0187+0.0704) – 1]% = 9.31%. • (2) The coefficients are not statistically different from zero at a significance level of 5%. • (3) Excluding rural areas of RO, AC, AM, RR, PA and AP states. • (4) Other farm activities. • (5) The values of F are statistically significant at a 1% level.

Table 5 **Importance of sugarcane and ethanol for Brazilian states**

States	Job				Establishment			
	Sugarcane*		Ethanol		Sugarcane		Ethanol	
	2000	2008	2000	2008	2000	2008	2000	2008
Rondônia	-	122	-	244	-	5	-	5
Acre	-	0	-	125	-	1	-	1
Amazonas	-	544	-	0	2	2	-	0
Roraima	-	0	-	142	1	0	-	1
Pará	-	1	968	1,537	-	2	4	5
Amapá	-	0	-	0	-	2	-	0
Tocantins	641	22	41	18	5	8	3	4
Maranhão	1,494	4,459	1,791	3,404	7	16	2	4
Piauí	5	306	2,931	2,632	3	10	2	4
Ceará	64	681	12	162	18	34	2	5
Rio Grande do Norte	3,637	1,144	373	6,137	43	34	2	6
Paraíba	7,558	11,199	4,811	10,505	153	194	14	9
Pernambuco	9,147	10,851	2,433	7,507	679	636	20	14
Alagoas	8,421	3,243	6,890	4,499	401	494	10	9
Sergipe	1,368	4,921	2,569	1,874	29	60	2	4
Bahia	350	4,606	2,911	438	26	70	6	8
Minas Gerais	5,775	15,320	6,258	14,420	155	584	29	63
Espírito Santo	3,064	6,896	844	3,354	28	90	7	5
Rio de Janeiro	1,507	1,965	720	1,463	187	245	3	16
São Paulo	85,516	136,345	15,512	65,983	5,794	16,172	210	185
Paraná	18,345	19,429	7,497	27,338	138	356	29	41
Santa Catarina	-	9	1	2	-	6	3	4
Rio Grande do Sul	109	6	15	20	6	6	5	17
Mato Grosso do Sul	7,324	20,114	3,307	14,281	38	113	11	57
Mato Grosso	8,640	8,284	4,900	8,834	71	260	18	27
Goiás	8,233	17,840	3,354	51,555	122	355	22	87
Federal District	161	27	-	39	2	7	3	3
Total	171,359	268,334	68,138	226,513	7,908	19,762	407	584

Source: Prepared by the authors from RAIS data for 2000 and 2008.
* To estimate the number of sugarcane plantation workers that can be attributed to ethanol production in each state we used the proportional production mix (UNICA, 2002/03 and 2007/08)

We can thus see that workers in the sugarcane plantation and ethanol industrial sectors earn less than the employees working for the petroleum and derivatives production sectors. However, the sugarcane and ethanol sectors employ a much larger number of workers.

Wages in the sugarcane sector are lower than those in industrial activities, but higher than wages in other agricultural activities. When analyzing the trend of wages for sugarcane, soybeans, coffee, corn, manioc and rice farm workers between 1992 and 2007, Oliveira (2009) observed a tendency for growth of average farm worker incomes in all of the crops, with sugarcane workers' wages higher than all others except soybeans, as shown in **Graph 2**.

Adjusting an equation for all Brazilian agricultural fieldworkers , based on PNAD 2007 data, Oliveira (2009) also notes the relatively favorable position of the wages paid to sugarcane fieldworkers. After taking into account the effects of other variables in the model, the income differential for other farm workers in comparison to sugarcane fieldworkers is: -9.9% for coffee, -23.2% for manioc, -30.1% for corn, -0.2% for soy, -30.1% for rice and -12.5% in other agricultural activities, as shown in **Table 4**.

As previously noted, the maximum level of geographical disaggregation possible with PNAD data is at the state level. This precludes any analysis of social and economic indicators by municipality. For this reason RAIS data was used to analyze how production spreads through the municipalities, as well as for calculation of the location quotient.

3.2 Characteristics of the formal market: RAIS data

The number of jobs and business establishments in each state for the analyzed sectors (sugarcane, ethanol, petroleum and petroleum derivatives) is shown based on RAIS data.

Table 5 shows the data for the first two sectors. According to RAIS data, the sugarcane sector employed 481,662 formally-contracted workers in 2008. Considering that part of the sugarcane crop is destined for sugar production and part for ethanol, the total number of workers was allocated in proportion to the product mix of sugar and ethanol in the 2007/08 harvest. In this way it is estimated that in 2008 there were 268,334 fieldworkers producing sugarcane specifically for ethanol production. Of this total, 50.8% were in São Paulo, which is the main producing state. Other states with a significant number of sugarcane workers are: Pernambuco (4.0%), Mato Grosso do Sul (7.5%), Minas Gerais (5.7%), Paraná (7.2%), Goiás (6.6%), Paraiba (4.2%), Mato Grosso (3.1%), and Alagoas (1.2%). Workers in this category are to be found in 24 Brazilian states (including the federal district), the exceptions being Acre, Roraima and Amapá.

We can see from **Table 5** that between 2000 and 2008 the number of formal jobs in the sugarcane sector grew by 56.59%, while the number of business establishments employing such workers grew by 149.9% (from 7,908 in 2000 to 19,762 in 2008).

The ethanol production sector is also heavily reliant on labor. In 2008, the sector employed 226,513 people and was present in 25 states (including the federal district), the exceptions being Amazonas and Amapá. The states creating most jobs in the sector in 2008 were São Paulo (29.13%), Goiás (22.76%), Paraná (12.07%), Minas Gerais (6.37%), Mato Grosso do Sul (6.3%) and Paraíba (4.64%).

Counting both activities, sugarcane destined for both sugar and ethanol production, the data shows that 494,847 formal jobs were created in 2008, spread amongst 1,086 municipalities. Of these 248 municipalities were involved in ethanol production and 1,024 in sugarcane. There were 186 municipalities with both activities.

The number of ethanol production establishments increased between 2000 and 2008 by 43.49%, going from 407 to 584. In 2000, 51.6% of these establishments were in São Paulo, a proportion that had fallen to 31.68% by 2008, demonstrating some decentralization of the sector.

Table 6 shows the number of workers and businesses involved in petroleum and derivatives production, in 2000 and 2008.

It can be seen that petroleum production employed 69,100 people in 2008, up by 227.57% compared to 2000, when the sector offered 21,095 formal jobs. The jobs in the petroleum production are spread among 22 states (including the federal district), led by Rio de Janeiro (61.97%), Bahia (12.07%), Rio Grande do Norte (7.9%) and Sergipe (5.07%). These four states concentrated 87.01% of the sector jobs in 2008.

Petroleum production was split between 411 business establishments in 2000, increasing by 111.68% to 870 in 2008.

In comparison, the production of petroleum derivatives created 21,186 jobs in 2008, distributed among 24 states (including the federal district). Leading states were São Paulo (30.89%), Rio de Janeiro (18.94%), Bahia (10.4%), Rio Grande do Sul (8.91%), Paraná (7.97%) and Minas Gerais (7.76%). Together these six states created 84.87% of all jobs in the sector in 2008. There were 84 business establishments in 2000, growing by 365.48% to 391 in 2008.

Taken together, these two activities – petroleum production and petroleum derivatives production – created 90,286 formally-contracted jobs in 2008.

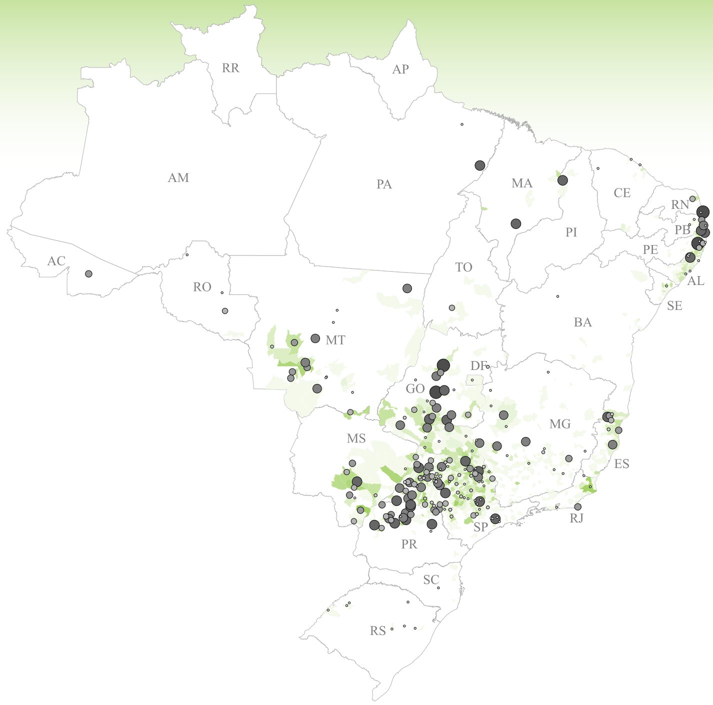
Comparing total formal employment in the sugarcane and ethanol sectors (494,847 jobs) to the petroleum and derivatives production sectors (90,286 jobs), we can see that in 2008 sugarcane and ethanol production created 5.5 times the number of jobs.

Distribution of jobs and business establishments in petroleum and derivatives production Tabea 6

State	Employment				Business establishments			
	Petroleum production		Derivatives production		Petroleum production		Derivatives production	
	2000	2008	2000	2008	2000	2008	2000	2008
Rondônia	-	-	-	-	-	4	-	-
Acre	-	-	-	-	-	2	-	-
Amazonas	499	1,192	-	597	13	12	2	2
Roraima	-	-	-	1	-	-	-	1
Pará	29	73	-	301	7	11	-	9
Amapá	-	39	-	-	-	2	-	1
Tocantins	-	-	-	4	1	3	-	4
Maranhão	215	26	-	165	10	5	-	10
Piauí	-	10	-	54	-	6	-	2
Ceará	283	523	186	801	7	15	3	11
Rio Grande do Norte	1,636	5,458	811	131	18	92	3	5
Paraíba	7	34	-	118	1	7	-	3
Pernambuco	138	301	2	162	5	18	2	14
Alagoas	44	707	-	5	5	9	-	1
Sergipe	762	3,502	304	85	13	35	3	3
Bahia	1,591	8,339	5,524	2,203	39	83	6	22
Minas Gerais	650	189	55	1,643	21	35	5	77
Espírito Santo	774	2,823	57	120	13	52	5	4
Rio de Janeiro	12,911	42,820	592	4,012	159	328	11	33
São Paulo	429	2,153	904	6,544	31	84	24	73
Paraná	342	434	104	1,689	15	10	6	33
Santa Catarina	600	276	8	372	17	15	2	21
Rio Grande do Sul	39	47	511	1,887	7	16	7	33
Mato Grosso do Sul	4	16	-	42	4	7	2	7
Mato Grosso	8	-	-	19	3	1	-	8
Goiás	134	51	2	139	14	15	2	11
Federal District	-	87	-	92	8	3	1	3
Total	21,095	69,100	9,060	21,186	411	870	84	391

Source: Prepared by the authors from RAIS data for 2000 and 2008..

Figure 3 **Distribution of formal employment in the production of sugarcane and ethanol**

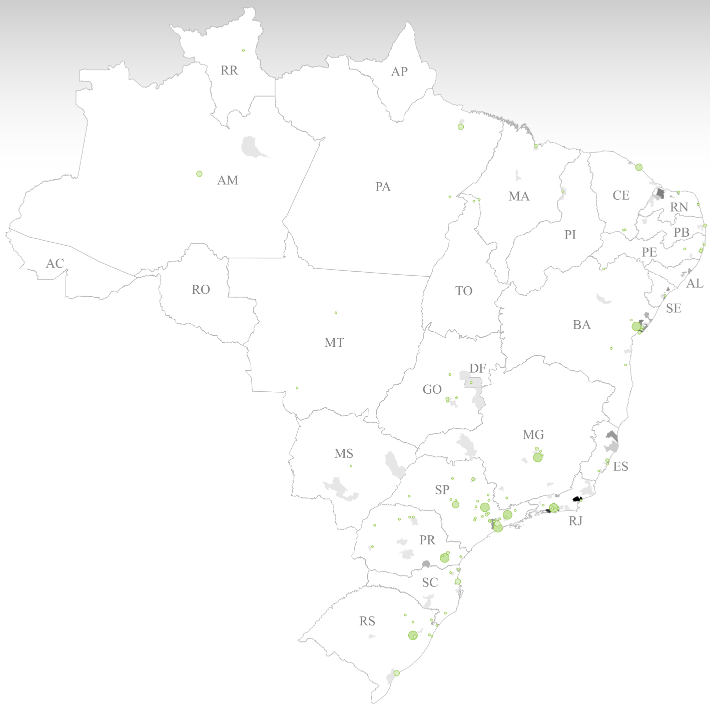


Formal Jobs - 2007

Sugarcane		Ethanol
	0 - 99	
	100 - 249	
	250 - 499	
	500 - 999	
	1,000 - 2,499	
	2,500 - 4,999	
	5,000 - 7,499	
	7,500 - 9.999	
	10,000 - 11,999	
	Over 12,000	

Source: Prepared from RAIS data (2007).

Figura 4 **Distribution of formal employment in petroleum and derivatives production**



Formal Jobs - 2007

Petroleum		Derivatives
	0 - 99	
	100 - 249	
	250 - 499	
	500 - 999	
	1,000 - 2,499	
	2,500 - 4,999	
	5,000 - 7,499	
	7,500 - 9,999	
	10,000 - 11,999	
	Over 12,000	

Source: Prepared from RAIS data (2007).

Petroleum and derivatives production activities are located in 196 municipalities (128 for petroleum production and 107 for derivatives production, with both activities being found in 39 municipalities). We can see that sugarcane and ethanol production activities are present in approximately six times more municipalities (1,086) than those having activities related to petroleum and derivatives production. This highlights how sugarcane and ethanol activities are much more widely spread. **Figures 5** and **6** illustrate, respectively, the distribution of formal employment in sugarcane and ethanol production, and in oil and derivatives production, in 2007.

The next section seeks to widen the discussion with respect the capacity of the four sectors to spread job creation.

3.3 The spread of job creation and the location quotient

3.3.1 Sugarcane

São Paulo is the state with the greatest number of people employed in sugarcane production. In 2008, the sector accounted for 255,851 formal jobs in the state, of which 136,345 were attributable to sugarcane for ethanol production . Sugarcane production is present in 410 (63.6%) of the 645 municipalities in the state. To identify the relative importance of jobs created by the sector in the municipalities, we estimated the location quotient for the 410 relevant municipalities. These were then grouped by QL range.

In 2008, São Paulo had 220 districts where the QL was greater than one, indicating that in 55.9% of the municipalities where the activity is to be found in the state, it constitutes a specialization. These 220 municipalities represent 35.5% of all municipalities in São Paulo. This shows that production and job creation are widespread.

Table 7 presents the main indicators for the 15 municipalities with the greatest number of sugarcane jobs in the state of São Paulo. Orindiuva was the municipality with the highest job QL (63.858). The average age of sugarcane workers in Orindiuva was 31.5 years, and the municipality registered annual per capita GDP of R$15,622 in 2006.

3.3.2 Ethanol

São Paulo is the state with the greatest number of people employed in ethanol production. In 2008, this activity created 63,983 formally-contracted jobs in the state.

Ethanol production is present in 80 (12.4%) of municipalities in the state. **Table 8** shows these municipalities distributed by range of location quotient. In 2008, São Paulo had 61 municipalities with QL greater than one, indicating productive specialization in 76.3% of the municipalities that have this activity, and in 9.46% of all municipalities in the state.

Table 9 shows the main indicators for the 15 leading São Paulo state municipalities in terms of employment related to ethanol production. Sebastianópolis do Sul had the best job QL (223.876) among these municipalities. The annual GDP per capita in Sebastianópolis do Sul was R$14,032 in 2006, and the average age of ethanol workers was 32.9 years.

Just as in sugarcane production, ethanol production also has a widespread impact, creating jobs in 61 municipalities of São Paulo where the QL is greater than one.

Table 7 **Indicators by municipality in São Paulo state**

Municipality	Jobs*	Job LQ	GDP per capita	Average Age
Paraguaçu Paulista	10,228	37.980	10,000	33.8
Pontal	9,585	38.938	15,374	32.2
Lençóis Paulista	8,145	17.649	26,043	35.2
Novo Horizonte	8,087	29.277	22,399	34.2
Promissão	6,857	55.512	9,478	30.5
Orindiuva	6,475	63.858	15,622	31.5
Catiguá	5,465	60.427	12,510	34.1
Miguelópolis	5,253	55.316	8,365	31.6
Guaíra	5,172	36.788	14,136	34.5
Clementina	4,937	9.598	15,520	32.0
Santa Adélia	4,866	19.290	15,871	33.1
Bocaina	4,825	23.915	20,238	34.7
Santa Cruz das Palmeiras	4,527	49.631	10,295	34.1
Florida Paulista	4,138	47.123	11,699	34.9
Pirassununga	3,907	39.686	9,701	31.0
Total for the state of São Paulo	255,851	-	-	34.0

Source: Prepared by the authors using data from the RAIS (2008) and the IBGE (2006).
* To estimate the number of sugarcane plantation workers that can be attributed to ethanol production in São Paulo state we used the proportional production mix

Table 8 **Municipalities in the state of São Paulo by band of location quotient, in 2008**

Location quotient	Number of municipalities
0 < QL< 1	19
1 < QL < 5	13
5 < QL< 10	10
10 < QL	36
Total districts: ethanol	80

Source: Prepared by the authors from RAIS data (2008).

3.3.3 Petroleum production

The state of Rio de Janeiro is the leading generator of employment in petroleum production, accounting for 61.97% of jobs in the sector. In 2008, this activity accounted for 42,820 formally-contracted jobs in the state.

Unlike ethanol production, which creates jobs in 80 municipalities in São Paulo, the leading producer state, petroleum production is present in just 14 municipalities in the state of Rio de Janeiro.

Table 10 shows these 14 municipalities distributed by band of location quotient. In 2008, the state of Rio de Janeiro had just two municipalities, Macaé and Três Rios, where the QL was greater than one, so indicating productive specialization in 2.17% of state municipalities and in 14.3% of the municipalities where the activity is present.

Table 11 presents the main indicators for the 14 municipalities where there is petroleum production in the state of Rio de Janeiro.

Macaé had the highest job QL (20.609). In 2008, the average age of a petroleum production worker in the municipality was 38, and the annual GDP per capita was R$40,281.

Indicators by municipal district in the state of São Paulo Table 9

Municipality	Jobs	Job LQ	GDP per capita	Average Age
Teodoro Sampaio	3,512	124.489	7,725.00	33.6
Guairá	3,484	53.554	15,871.00	33.2
Sebastianópolis do Sul	3,413	223.876	14,032.00	32.9
São Paulo	3,219	0.133	25,675.00	31.7
Iracemápolis	3,072	82.357	26,226.00	36.9
Sud Mennucci	2,834	158.833	13,742.00	32.7
Batatais	2,614	34.365	13,815.00	34.3
Narandiba	2,498	196.497	10,719.00	32.1
Parapuã	2,473	148.328	9,282.00	33.4
Valparaíso	2,448	61.239	11,562.00	30.9
Caiuá	2,377	205.741	10,561.00	32.8
Bento de Abreu	2,334	110.145	27,044.00	31.5
Tanabi	2,288	80.165	8,746.00	31.3
Junqueirópolis	2,205	84.91	9,641.00	34.7
Presidente Alves	2,177	213.997	14,357.00	35.2
State of São Paulo	65,983	-	-	33.2

Source: Prepared by the authors using data from the RAIS (2008) and IBGE (2006).

Table 10 Municipalities in the state of Rio de Janeiro by band of location quotient, in 2008

Location Quotient	Number of Municipalities
0 < LQ< 1	12
1 < LQ < 5	1
5 < LQ < 10	-
10 < LQ	1
Total municipalities: petroleum production	14

Source: Prepared by the authors from RAIS data (2008).

Table 11 Indicators by municipal district in the state of Rio de Janeiro

Municipality	Jobs	Job LQ	GDP per capita	Average Age
Macaé	25,319	20.609	40,281	38.0
Rio de Janeiro	15,538	0.627	20,851	41.0
Niterói	1,233	0.636	15,651	36.7
Três Rios	303	1.257	11,660	36.6
Duque de Caxias	156	0.088	26,392	46.0
Rio das Ostras	136	0.704	117,532	31.1
Angra dos Reis	69	0.167	24,250	47.3
Campos dos Goytacazes		0.02	53,797	36.7
Volta Redonda	20	0.027	23,269	35.8
Saquarema	12	0.083	9,185	28.2
Silva Jardim	5	0.134	6,022	23.8
Rio das Flores	4	0.125	20,955	47.8
Teresópolis	4	0.012	10,476	31.0
Rio Bonito	1	0.003	13,532	49.0
State of Rio de Janeiro	42,820	-	-	39.0

Source: Prepared by the authors using data from the RAIS (2008) and IBGE (2006).

Table 12 Municipalities in the state of São Paulo by band of location quotient, in 2008

Location Quotient	Number of Municipalities
0 < LQ < 1	9
1 < LQ < 5	10
5 < LQ < 10	2
10 < LQ	7
Total municipalities: petroleum derivatives production	28

Source: Prepared by the authors from RAIS data (2008).

Some caveats are necessary when analyzing the number of jobs and the presence of business establishments in the municipalities. The RAIS database reflects information provided by the company and attributes to each productive activity the company's registered location, as per its CNPJ number in the year of the declaration. This is considered in the RAIS as the business establishment. The company also provides information about where each employee works, which is not necessarily the same place as the location of the business establishment. The Rio de Janeiro municipality of Campos dos Goytacazes, for example, is significant in terms of creating jobs associated with petroleum, but does not have a high number of employees, because many of the workers registered there could be working in another municipality[xvi].

3.3.4 Petroleum derivatives

The state of São Paulo creates the greatest number of jobs associated with the production of petroleum derivatives. This activity created 6,544 formal jobs in the state in 2008 but was present in just 28 municipalities.

Table 12 shows municipalities distributed by band of location quotient. In 2008, São Paulo had 19 municipalities with QL greater than one, thus indicating productive specialization in 67.9% of the municipalities where this activity is present, but in just 2.95% of all municipalities in the state.

Table 13 shows the main indicators for the 15 largest job creators in the state of São Paulo.

Paulínia, besides having the largest number of jobs in the activity, had the highest job QL (76.159) amongst the districts. The average age of the worker was 37.5 years and the district had an annual GDP per capita of R$104,728.

3.4. Impact of substituting Type C gasoline with hydrous ethanol in Brazil

Tables 14 and 15 show the net effect on employment and total wages in the economy of the simulated increase in hydrous ethanol consumption[xvii], supposing a 15% increase in ethanol demand and an equivalent reduction in the consumption of Type C gasoline, as per the methodology described in Section 2 above. As the largest sugarcane, sugar and ethanol producing state the results for São Paulo are presented separately, with those for remaining states aggregated.

An increase of 15% in hydrous ethanol demand in the North-Northeast region, substituting Type C gasoline consumption, would produce a total employment increase of 67,843 jobs, distributed 632 jobs in São Paulo and 67,211 in the rest of Brazil. If the alteration were made in the Center-South region, then an additional 2,718 jobs would be created in São Paulo and 27,957 in other states, for a total of 30,674. If the substitution took place just in São Paulo, then the state itself would see 13,536 additional jobs created, with a further 5,647 in the rest of Brazil, making a total of 19,184. Finally, a 15% substitution in all states would potentially create 117,701 additional jobs, distributed 16,886 in São Paulo and 100,815 in the rest of the country.

A similar analysis was conducted to estimate the impact on total wages arising from a 15% increase in hydrous ethanol consumption with a corresponding decrease in Type C gasoline consumption. Table 15 shows that such a substitution in the North-Northeast region would increase total monthly wages in Brazil by R$98.27 million, distributed R$1.2 million in São Paulo and R$97.08 million in the rest of Brazil. If the change were made in the Center-South region, the total monthly wage increase would be R$92.01 million, distributed as shown in Table 15). However, a 15% substitution in São Paulo would increase total wages by R$45.63 million[xviii]. Taking the country as a whole, a 15% increase in hydrous ethanol consumption with a corresponding reduction in Type C gasoline demand would potentially increase total monthly wages by R$235.91 million, distributed R$92.87 million for São Paulo and R$143.05 million for the rest of Brazil.

Both scenarios (more jobs and higher wages) would be positive for the Brazilian economy.

Finally, to underscore the importance of hydrous ethanol in terms of its potential for increasing jobs and wages, as an exercise we simulated a 0.8% increase in Type C gasoline consumption, with a corresponding reduction in hydrous ethanol consumption[xix].

Table 13 **Indicators by municipality in the state of São Paulo**

Municipalities	Jobs	Job LQ	GDP per capita	Average Age
Paulínia	1,441	76.159	104,728	37.5
Cubatão	1,423	67.191	46,146	40.6
São José dos Campos	1,071	10.583	25,419	40.1
Lençóis Paulista	831	70.4	26,043	37.8
Mauá	711	22.732	12,325	38.8
Itupeva	192	19.5	28,650	35.7
Barueri	148	1.041	95,966	33.1
São Paulo	89	0.037	25,675	34.3
Piracicaba	76	1.221	18,650	37.2
Pederneiras	71	10.214	15,748	31.9
Presidente Prudente	66	2.18	13,527	40.4
Ribeirão Preto	63	0.654	20,139	32.8
Pindamonhangaba	55	3.764	20,828	31.4
Guarulhos	52	0.322	19,999	32.9
Catanduva	52	2.776	14,613	34.9
State of São Paulo	6,544	-	-	38.3

Source: Prepared by the authors using data from the RAIS (2008) and IBGE (2006).

The net result showed a negative impact with a reduction of 45,799 jobs and drop of R$120.2 million in total monthly wages.

We can therefore see impacts of a similar magnitude between the 0.8% increase in Type C gasoline consumption and the 10% increase in hydrous ethanol consumption. However, in the latter case it is a positive impact, with the creation of 78,467 jobs and an increase of R$157 million in monthly earnings. This comparison highlights the importance for job creation in Brazil of hydrous ethanol production relative to Type C gasoline.

4. Final considerations

This study presents a comparative analysis of social indicators related to the production of sugarcane, ethanol, petroleum and petroleum derivatives.

It was estimated that in 2008, 495,000 jobs were generated in two stages of the ethanol supply chain: 268,000 in sugarcane plantations, counting just the proportion of sugarcane destined for ethanol production; and 226,000 jobs in the industrial sector. In the same year the petrochemicals sector, including production of petroleum and petroleum derivatives, generated approximately 90,000 jobs. This corresponds to 18.2% of the jobs created by the ethanol and sugarcane sectors. Similarly, employment in these sectors was more widespread, consequently impacting creation of jobs and wealth in several states and municipalities in Brazil.

Impact on jobs of increasing demand for hydrous ethanol *(in R$ millions)* **Table 14**

Number of jobs created in 2004 by a 15% increase in hydrous ethanol demand, with an equivalent reduction in Type C gasoline consumption, considering direct, indirect and income effects.

Increases in hydrous ethanol consumption	15%			
Impact/ Shock	North-Northeast	South-Central	São Paulo	Brazil
Rest of Brazil	67,211	27,957	5,647	100,815
São Paulo	632	2,718	13,536	16,886
Brazil	67,843	30,674	19,184	117,701

Source: Research results.

Impact on wages of increasing demand for hydrous ethanol **Table 15**

Increase in aggregate monthly wages in 2004 resulting from a 15% increase in hydrous ethanol demand, with an equivalent reduction in Type C gasoline consumption, considering direct, indirect and income effects.

Increases in hydrous ethanol consumption	15%			
Impact/ Shock	North-Northeast	South-Central	São Paulo	Brazil
Rest of Brazil	97.08	77.93	-31.96	143.05
São Paulo	1.2	14.07	77.6	92.87
Brazil	98.27	92.01	45.63	235.91

Source: Research results.

Simulating a 15% increase in the consumption of hydrous ethanol as a substitute for Type C gasoline indicated strong potential for creating employment and income, with an increase of 117,701 jobs and R$235.91 million in monthly income. On the other hand, an increase in Type C gasoline consumption in place of hydrous ethanol showed unfavorable results, reducing employment and aggregate wage value in the Brazilian economy. In this situation there would be an estimated reduction of 46,000 jobs and R$120.2 million in monthly wages. These results show that public policies that encourage ethanol consumption can offer significant social and economic benefit.

Despite this potential for job creation in the sugar-ethanol sector, it should be noted that several studies suggest that in the next few years the sugarcane production sector will reduce its demand for agricultural workers because of increasing mechanization. At the same time the sector will demand better-qualified workers. Two observations should be made in this respect. First, the decrease in employment over time, and the change in employee profile, are consistent with the pattern of development seen in modern economies. Second, the decrease of direct employment in sugarcane harvesting and the consequent decrease in total sector payroll is a matter for concern because it will reduce the indirect employment that is created by sugarcane, ethanol and sugar production[xx]. However, if we consider the potential for job creation in a scenario of ethanol substituting gasoline, the prospect would the creation of additional jobs.

In terms of agricultural jobs, it is important to recognize that sugarcane employs a large number of poorly-educated workers. Without this opportunity for participating in the labor market, it would be difficult to absorb these workers in other sectors.

We would emphasize that policies to encourage ethanol production should be accompanied by a concern to address the problem of low education among sugarcane cutters. Given the growth of mechanized production, the need for more qualified workers is a predictable trend in sugarcane production for the coming years. Without public and private policies to help workers complete their formal schooling and undergo training or retraining, many people will lose their jobs in the face of technological advance, and they will not be easily absorbed into the other activities that will gain in prominence during this process.

The average number of years of schooling of sugarcane employees compared to the ethanol and petroleum sectors also explains a relevant part of the wage disparity between the sectors. This has important implications, because it is believed that a policy to reduce educational disparity among workers of the agricultural and industrial areas of the sugar-ethanol sector could – in addition to increasing productivity and wages –contribute to fighting income inequality and poverty existent within these sectors.

Another question that deserved attention was the degree to which sugarcane and ethanol production is geographically widespread. Based on the location quotient (QL) methodology and data from the RAIS, it can be seen that productive activities in the sugar-ethanol sector are located in rural areas of states, in particular the state of São Paulo, spreading out into small municipalities. At the same time, the production of petroleum and derivatives is highly concentrated in a few Brazilian cities, meaning that the sugar-ethanol sector gains prominence for its capacity to add dynamism to regional development. As a next step, studies should be conducted to determine causal and functional relationships between the presence of sugar-ethanol or petrochemical sectors in a specific Brazilian municipality and its socio-economic indicators, in order to understand the possible impacts on quality of life in such locations.

Finally, it is important that Brazil reinforces the participation of ethanol in the energy matrix, taking into account the positive social externalities for the entire population. In addition to its clean and renewable nature, ethanol production has the capacity to employ a large number of people with differing educational backgrounds and levels of qualification. It also stimulates regional development dynamics, given its widespread importance throughout several Brazilian states and municipalities.

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Explanatory Notes

[i] To extract RAIS data, the following CNAE codes were used: sugarcane: 01130; petroleum production: 06000 and 09106; petroleum derivatives production: 19217 and 19225; and ethanol: 1935. For the PNAD, the following codes were used: sugarcane: 01105; petroleum production: 11000; petroleum derivatives production: 23010; and ethanol: 23400.

[ii] The RAIS is an administration registry set up under Decree 76.900/75, under the responsibility of the Ministry of Labor. It was created for operational, control and statistical purposes. The declaration is annual and mandatory for all business establishments in Brazil, independent of having employees or not. Coverage exceeds 97% of the formal economy (MTE, 2006).

[iii] The PNAD is a system of annual household surveys conducted by the IBGE since 1967. It investigates several socio-economic characteristics of families and people in all Brazilian states. Certain variables such as general population characteristics, education, labor, income and housing are included every year, while others like migration, fertility, marriage, nutrition and health have variable frequency (IBGE, 2006).

[iv] Because the PNAD registers monthly incomes for September and a significant part of the population gets paid in early October, the appropriate index is obtained by calculating the geometric mean of the values of the INPC inflation index for September and October - as proposed by Corseuil and Foguel (2002).

[v] To simulate the demand shock in the input-output matrix, the “other regions of Brazil” were separated into the Center-South (excluding São Paulo) and the North-Northeast. This separation is also important because of the heterogeneity present in the economies of those regions, especially with regard to the products analyzed. The Center-South and North-Northeast have socio-economic characteristics that are recognizably different. However, the results for these regions were presented together, because the North-Northeast region is limited in its capacity to increase ethanol production and the demand shock applied to this region can be satisfied by another region.

[vi] GUILHOTO, J. J. M. (USP. Departamento de Economia – FEA, São Paulo). Personal memo. 2009.

[vii] The demand shock was applied in the Center-South, North-Northeast and São Paulo state, and was analyzed only for São Paulo state and the other regions of Brazil as a group. We calculated the increase in consumption of hydrous ethanol and the corresponding gasoline consumption in each state, then added together the states that comprise the regions analyzed.

[viii] The value of Type C gasoline consumption is greater than the value of the consumption equivalent to one million reais of hydrous ethanol if the relationship between Type C gasoline prices and hydrous ethanol (PG / PE) is greater than 1.428. This is because,

given that: $Vol_E = \frac{Valor_E}{P_E}$ and that: $Valor_G = Vol_E * 0,7 * P_G$. Substituting Vol_E em $Valor_G$

will result: $Valor_G = * 07 * \frac{P_G}{P_E}$. Where ***G*** is gasoline ***C*** and ***E*** is hydrous ethanol.

[ix] Kassouf and Ferro (2004) state that indicators of child labor in Brazilian agriculture fell between 1992 and 2001.

[x] Several studies point to the urgent need for training of this labor qualification. See Moraes (2007), Balsadi (2008) and Oliveira (2009), among others.

[xi] While the four sectors have different characteristics they were aggregated in this regression analysis because they had a high coefficient of determination (R2), and the t-test was significant for almost all parameters. Another model was adjusted, taking into account only the industrial activities – production of petroleum, derivatives and ethanol. For this model, the coefficient of determination was 59.48%. Hoffmann and Oliveira (2008) also estimated earnings formulas with two binaries distinguishing the ethanol industry, the sugar industry and sugarcane production (base), using data from PNAD 2006.

[xii] Having “b” as the coefficient, the percentage difference for each binary is 100[exp(b)–1]%.

[xiii] This model explains 71.2% of the variations of the income logarithm for people employed in the sugar-ethanol and petrochemical sectors. It is a very satisfactory result when compared with studies that use PNAD, given that important variables in determining personal earnings (such as ambition, creativity, entrepreneurship and material wealth) are difficult to measure, and are not obtained from these household surveys (Hoffmann, 2000, pg. 101).

[xiv] The concept of agriculture used by the author refers only to the farming activities contemplated by the PNAD, including temporary and permanent crops.

[xv] We adjusted the total number of jobs by the proportion of sugarcane destined to ethanol (53.3%) in the 2007/08 harvest.

[xvi] Another aspect that deserves attention is the presence of business establishments without employees, given that there is a requirement to provide the RAIS with a negative statement. Even if a company has no formal employees in the year of declaration, this fact must be reported. Such data can reflect a newly opened business that may not have started production, but appears in the RAIS database due to the requirement for annual registration, or firms in the process of closure (MTE, 2008).

[xvii] By “net effect” we mean the result for the increase in hydrous ethanol consumption subtracted from the result for the equivalent reduction in Type C gasoline consumption.

[xviii] The reduction in the value of income in the rest of Brazil due to an increase in demand in the State of São Paulo can be explained by the fact that the unit value of income (salary) paid by the industries most impacted by the increased consumption of hydrous ethanol is lower than those sectors impacted by the reduction of Type C gasoline.

[xix] A greater increase was not possible, because the equivalent reduction of ethanol would exceed the volume of ethanol consumed in some states.

[xx] Guilhoto et al. (2004) discuss the impact of mechanization on direct, indirect and induced employment in sectors that produce sugarcane, sugar and ethanol.

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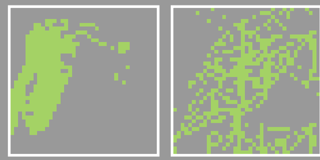

Contribution of Ethanol to Climate Change

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The use of low-carbon, renewable energy is an important strategy for mitigating emissions of greenhouse gases (GHG) and combating global warming. Sugarcane ethanol, which has a very favorable energy and emissions balance, is a commercially available alternative with the potential to expand rapidly in many countries and as new applications emerge. From a lifecycle perspective, sugarcane ethanol has the capacity, in Brazil, to reduce around 90% of GHG emissions when compared with gasoline.

In 2006 the reduction of GHG emissions attributable to the use of ethanol (as a gasoline substitute) reached 22% of final emissions for the transportation and electricity generation sectors in Brazil, and could reach 43% in 2020. In relation to Brazil's total energy consumption (electricity, industrial, transportation, residential, and others), large-scale consumption of ethanol avoided the equivalent of 10% of total emissions in 2006 and will reach 18% in 2020 (excluding agricultural and land-use changes). The potential for new uses (substituting other fossil fuels and increased exports) could considerably increase this share.

The emissions reductions to be sought globally through the coming decades make it possible

to study the "value" of GHG mitigations generated by ethanol (determined by the additional global cost of the appropriate set of technologies for a desired level of mitigation). This additional value of Brazilian ethanol is estimated at US$0.20 per liter of ethanol. In other words, each liter of ethanol used is equivalent to US$0.20 that would otherwise have to be spent on measures to mitigate greenhouse gas emissions, so reducing the investments that countries would need to make to control global warming.

An analysis of expectations for the post-Kyoto regime concludes that the debate persists over global reductions goals. Furthermore, the mechanisms for the management of emissions between countries (like the Clean Development Mechanism) are very limited, especially for renewable energies like ethanol.

For Brazil, it is necessary that international goals be adopted in a uniform manner, including China and India, to protect the competiveness of our industry. It is also necessary that a specific advantage – the fact that Brazil has one of the cleanest energy matrices in the world – be considered in international trade.

1. Introduction

The relationship between climate change and increasing concentrations of greenhouse gases in the atmosphere was irrefutably demonstrated in 2007 by the Intergovernmental Panel on Climate Change (IPCC). International negotiations to prevent the inherent problems are currently focused on trying to limit temperature increase in 2100 (to maybe 2º C) with emissions reduction distributed between industrial and developing countries. Negotiations for establishment of these rules are ongoing.

Given the size of the Brazilian program for ethanol use, it is important to verify, in the domestic and international context, its contribution to this global effort through the next decade. Knowledge of this contribution (and its value, in the context of other technologies and emission mitigation policies) is a necessary element in the set of facts to be considered in the development of Brazilian policy for these negotiations.

2. Greenhouse gas emission mitigation via the production and use of sugarcane ethanol

Assessments of GHG emission reduction attributable to the use of sugarcane ethanol have been made since 1992 (Macedo 1992). Gradual improvements have been made to the databases, and changes made due to variations in production and use technologies (Macedo 2007). More recently, work has been developed seeking harmonization between the methodologies used for various raw materials and products (sugarcane, corn, grains, wood, ethanol, biodiesel, etc.). These assessments are generally made for the production and fuel use cycle, and initially did not include effects of land-use change.

Adoption of the European Directive in December 2008 led to the "official" introduction of quantification of the direct effects of land-use change (LUC) in biofuel production. This quantification takes into account changes in carbon stocks (above and below the soil) and seeks to implement a relatively simple calculation.

Table 1 **Scenarios for ethanol demand** *In millions of m³ per year*

Year	2010		2015		2018		2020	
	Domestic mkt	Export	Domestic mkt	Export	Domestic mkt	Exp	Domestic mkt	Exp
UNICA (2008)	23	6	35	12			50	15
Mapa (2007)	20		28		30			
EPE (2007)	20	4	26	10			34	14
IE-UFRJ, scenario B (2006)							35	
Cepea (2007)		4,4		9,8				18

Given the absence of sufficient and reliable data for soil carbon levels in many regions this calculation is based on IPCC default parameters. In 2009, the Environmental Protection Agency (EPA) and California Air Resources Board (CARB) submitted proposals for discussion that included direct and indirect LUC effects in the United States.

The so-called "indirect effects" of LUC have been under discussion since 2008. These do occur, in certain cases, but the tools available for their evaluation (the models and the cause-and-effect relations for innumerable situations and locations) are clearly inadequate for the desired task. The European Directive has postponed decisions on the use of indirect effect assessments to at least the end of 2010, while in the United States the discussions have advanced considerably in relation to initial proposals.

2.1 Emissions avoided through the use of sugarcane ethanol: estimates for 2009 – 2020

Following are estimates for the reduction of GHG emissions attributable to using sugarcane ethanol as a substitute for gasoline. The process of calculation entails:

- Scenario 2009-2020 for ethanol fuel demand in Brazil and for export;
- Technological scenario for the period (assuming only the introduction of commercial technologies for electrical energy, and continuous progress in usage technologies);
- Specific emissions for these scenarios; composition for the total period.

Ethanol demand 2010-2020

Table 1 shows consumption estimates for the domestic and international markets during this decade, remembering that these scenarios are very susceptible to change, depending on the public policies adopted in coming years. This is particularly the case for developed countries, which have traditionally protected their markets with high import tariffs. An "export" scenario was included only to analyze expected mitigation. It is a "moderate" scenario (Cepea, 2007).

As shown in **Table 2**, a scenario was adopted for 2020 specifically to estimate the emissions avoided by the use of ethanol. This takes into account various scenarios and assumptions, together with the demand analysis that includes ethanol blended with Type A gasoline and the increase in the fleet of flex-fuel vehicles with a consequent rise in demand for hydrous ethanol (E-100).

Domestic and export demand for ethanol Table 2
In millions of m³ per year

	2010	2015	2020
Domestic Demand			
Anhydrous	6	6	5
Hydrous	17	29	45
Subtotal, domestic	23	35	50
Exports, anhydrous	5	10	15
Total	28	35	65

Technological scenario for the period

Technological developments in the period and their impact on GHG emissions are considered from a base point of the current situation for the average for mills, using 2006 parameters as defined from data available for the Center-South region (Macedo 2007). This study considers only technologies that will be commercially available in this horizon (i.e. by 2020), together with clearly identifiable trends, the most important of which is the use of sugarcane straw (up to 40%) and residual bagasse (up to 35%) to produce a surplus of electrical power via conventional high pressure (steam cycle) and co-generation systems (Seabra, 2008). Expected advances in agricultural and industrial productivity, and in conversion efficiency, are also included. In the agricultural area, we expect to see the optimized allocation of new varieties, the more rapid use of genetic modification in plants, and precision agriculture technology. We shall denote this technological stage as "Technology E" (with "E" for electricity). The penetration rates of the technology are estimated and introduced in the study, differentiating new mills from existing mills.

We did not take into account technologies currently under development that are expected to achieve significant penetration only after 2018, for example cellulosic hydrolysis. Estimates in this sense can be found in Macedo (2008) but are not essential for this study.

Basic agricultural and industrial data, along with data for transport, distribution, and final usage of ethanol for the base year 2006 and for "Technology E" in 2020, can be found in Macedo and Seabra (2008). Some of the main parameters are shown below, bearing in mind that for "Technology E," they are not averages for all mills:

Table 3 Production parameters for the period 2006-2020

	Tonnes cane/ha	Liters ethanol per tonne cane	Surplus kWH per tonne of cane	Area of sugarcane in millions of ha
2006, average	87	86.3	9.2	2.4
2020, Technology E	95	93.2	135	7.3

Table 4 Corresponding production of ethanol, electricity and sugarcane

	2006	2010	2015	2020
Ethanol, domestic market (M^3 millions)	14.2	23	35	50
Ethanol, export market (M^3 millions)	3.7	5	10	15
Sugarcane planted area (ha millions)	2.4	3.6	4,2	7.3
Sugarcane (tonnes millions)	207	318	385	697
Electricity (tWh/year)	1.9	2.9	20.3	52

Rates of penetration for Technology E were estimated taking into account that the technology is already partially in commercial use, being incorporated into almost all new mills (high pressure steam generation). However, it will take some years to reach 40% usage levels for sugarcane straw. The following hypotheses were therefore adopted:

- 2006-2010: as a conservative estimate, the conditions pertaining in 2006 were adopted, without complete new systems;
- 2011-2020: 80% of incremental production will use Technology E (electricity); and 3% of 2010-level production shifts to Technology E each year.

Thus, 35% of production will use Technology E by 2015, and 53% in 2020.

Reduction of GHG emissions during the period

a. Production cycle (without effects on land-use change)

The analysis of GHG emissions follows the standards currently used for biofuels, including CO_2, methane and N_2O, which are considered to be the most important GHGs in relation to agricultural production, industrial conversion, transportation, distribution, and final use of ethanol. There are still disagreements (albeit smaller today) about some points, notably over the different ways of calculating emissions and mitigation via by-products, and over some processing parameters. When reporting the results, we have always sought the best information available, with the greatest transparent.

Table 5

Avoided emissions

Specific emissions avoided by virtue of using ethanol, compared with gasoline, for average 2006 conditions and for Technology E in 2020; excluding impacts of land use change (tonnes CO_2e/m^3 ethanol)

Year	2006 (average)		Technology E (2020) (1)		
Final use of ethanol	E-100	E-25	E-100	FFV	E-25
Emissions during production	0.44	0.46	0.34	0.34	0.36
Emissions avoided	2.15	2.82	2.36	2.28	3.02
Surplus bagasse (2)	0.14	0.15	0.00	0.00	0.00
Surplus electricity (3)	0.03	0.03	0.38	0.38	0.40
Use of ethanol (4, 5)	1.98	2.64	1.98	1.90	2.64
Avoided emissions (net)	1.71	2.36	2.02	1.94	2.66

Notes: (1) Technology E: Process improvements + Electricity production (high pressure, bagasse + 40% straw). • (2) Substitution of oil-fired boilers (efficiency 92%; PCI) with boilers fired by bagasse (efficiency = 79%; PCI). • (3) This study used an emissions factor based on the average of factors of the build margin and the operating margin, for Brazil: ~268 t CO_2e/gWh. Emission factors of 579 t and 560 t CO_2e/gWh(e) for 2006 and 2020, respectively (based on IEA estimates, average world emissions, electricity), and emissions of natural gas-fired generating plants, can also be taken into consideration. • (4) Equivalencies: E-25: 1 L ethanol = 0.8 L Type A gasoline; E-100: 1 L ethanol = 0.74 L Type A gasoline; FFV: 1 L gasoline = 0.72 L E-25 = 0.66 L Type A gasoline. • (5) Gasoline, emissions of GHG: 2.64 kg CO_2e/m^3 gasoline.

The detailed analysis of the emissions – parameters, coefficients, default values used, database and its variation, and methodologies – for the current and Technology E cases can be found in the referenced work (Macedo and Seabra 2008, Macedo 2007). We note the inclusion of the average efficiency of motors, which in Brazil can be assessed based on many years of experience. Summarizing, for blends containing up to 10% of ethanol, we have 1 liter of ethanol = 1 liter of Type A gasoline (which becomes an 80% equivalence with E-25); while E-100 engines show an equivalence of 79% (1 liter of ethanol = 0.79 liters of Type C gasoline) – Cetesb (2008). For flex-fuel vehicles, in 2005, we have 1 liter of ethanol = 0.72 liters of E-25 (which is 66% of equivalence compared to Type A gasoline) – Joseph Jr. (2005); Cetesb (2008). The most interesting results are shown in Tabela 5.

b. Effect of land-use change

The direct effects of land-use change related to Brazilian sugarcane expansion have been analyzed in recent years. It can be shown that:

- Changes in land use to produce sugarcane for ethanol during the last 25 years in Brazil should be considered only for the period 2002-2009, because the production of ethanol remained constant at around 12 million m3 per year from 1984 through 2002 (Macedo and Seabra, 2008).
- The findings of several independent studies show that in this period the occupation of woodlands (cerrado/savannah, forests) was less than 2% of the total, with land-use changes involving principally existing pastureland and land used for annual crops (Nassar, 2008).

Table 6 **Alterations in carbon stocks by virtue of land use changes (LUC)**

Crop	Change in carbon stock (1)	Emissions (kg of CO_2e/m³ of ethanol)	
	(tonnes of carbon / ha)	2006	2020 electricity
Pasture – degraded	10	-302	-259
Pasture – natural	-5	157	134
Pasture – cultivated	-1	29	25
Soy	-2	61	52
Maize	11	-317	-272
Cotton	13	-384	-329
Cerrado (savannah)	-21	601	515
Open field	-29	859	737
Cerrado (dense)	-36	1040	891
LUC emissions (2)		-118	-109

Notes: (1) Based on average values for carbon stocks below and above the soil (only perennial). • (2) Distribution of LUC: 2006 – 50% pasture land (70% degraded, 30% natural); 50% annual crops (65% soy, 35% others); 2020 – 60% pasture land (70% degraded, 30% natural); 40% annual crops (65% soy, 35% others); Cerrado less than 1%.

- Information about carbon levels in the soil for the crops being substituted versus those for sugarcane do not differ greatly from the IPCC default levels, indicating that sugarcane cultivation without burning could increase the soil carbon balance for the majority of annual crop and pasture lands (Amaral, 2008).
- An analysis of the average current situation for the change of land-use to sugarcane without burning is summarized in **Table 6** (Macedo and Seabra, 2008), and indicates an increase in the soil carbon level. If the conditions of land-use change are maintained (and this is to be expected, assuming the intensification of livestock grazing) then the direct effect of the land use change will be positive.

Several studies now under way seek to improve the knowledge about soil carbon stocks in Brazil. In this study, however, to maintain our conservative posture, we have not yet included the positive results that have been obtained so far.

c. Results: avoided emissions

Tabela 7 shows total avoided emissions for selected years between 2006 and 2020. Two references are considered in regards to the avoided emissions for the substitution of electrical energy: an average between the build margin and the operating margin in Brazil (260 t CO_2e / gWh) and the value associated with natural gas plants (570 t CO_2e /gWh).

Thus, in the 11 years 2010 – 2020, total avoided emission would be 1,015 million tonnes of CO_2e, with an average of 92 million tonnes of CO_2e per year; or 7% more if the emissions from the substituted electricity are computed based on natural gas generation (a 12% increase in the last year).

2.2 Emissions avoided through ethanol use in the Brazilian context

The values of avoided emissions include the effects of ethanol and electricity. For comparison, we use GHG emissions for the transportation and electricity generation sectors in Brazil, estimated for 2005 and 2020 (EPE 2007). Here, as throughout this study, the computed electricity generation corresponds only to that portion of sugarcane used to produce ethanol; the sector generates almost as much again with the production of sugar.

Table 7 **Emissions avoided through the use of ethanol (in Brazil and exported)**
In millions of tonnes of CO_2e per year

	2006	2010	2015	2020
Mitigation (1)	36	55	91	133
Mitigation (2)	37	56	97	149

(1) Electricity: average of build and operating margins in Brazil (260 t CO_2e / gWh)
(2) Electricity: natural gas generating stations (570 t CO_2e / gWh)

In 2006, emissions mitigation with ethanol (and associated energy) represented 22% of final emissions of the two sectors, and could reach 43% by 2020.

Brazil's total annual emissions (related to energy production and use, across all sectors) were 350 million tonnes of CO_2e in 2006, forecast to reach 720 million tonnes of CO_2e in 2020 (EPE 2007), excluding emissions related to agriculture and changes in the use of land and forests. The ethanol sector avoided the equivalent of 10% of these emissions in 2006, and could avoid 18% in 2020.

3. The global context

Given that the warming caused by increased GHG emissions is a global problem, it is appropriate to put the emissions prevented by ethanol in this context. Anthropogenic emissions of the principal GHGs in 2005[i] were: 36 gigatonnes (Gt) of CO_2 (of which 75% from energy and 11% from land-use change); 6 Gt CO_2e of methane; 2.5 Gt CO_2e of N_2O; and about 0.8 Gt CO_2e of fluorinated gases.

The reference scenario (WEA 2008), maintaining policies in place in October 2008 (average values between various IPCC scenarios), points to GHG emissions growing from 44.2 Gt CO_2e (2005) to 54 Gt in 2020 and 59.6 Gt CO_2e by 2030. Emissions associated with energy correspond to 61%, 67%, and 68%, respectively, of these totals. The Brazilian ethanol sector contributed to a 0.1% reduction of these emissions in 2006, and could reach 0.25% in 2020.

The relationships between GHG emissions and climate are complex. Factors like carbon removal could partially neutralize the greenhouse effect (IPCC 2007-a). Under current conditions, the variation of 1 ppm CO_2 in the atmospheric concentration corresponds to 7.7 Gt CO_2e; but taking into account removal processes (oceans, atmosphere, soils) the corresponding emission would be 13.3 Gt CO_2e.

It is estimated that average global temperatures today are 0.76° C higher than the pre-industrial average, and the rate of growth has increased (0.19° C in the last 20 years).

Table 8 **Emissions by sector and mitigation through the use of ethanol**

In millions of tonnes of CO_2e per year

	Transportation (1)	Electrical energy (1)	Transportation +electricity	Emissions avoided: ethanol + electricity (2)
2006	140	20	160	36
2020	250	60	310	133

Notes: (1) Emissions include a certain quantity of ethanol in the mix (according to EPE estimates); they are therefore final emission values, according to the EPE (2007). • (2) Includes emissions avoided by virtue of exported ethanol.

Two scenarios considered (WEO 2008-a) for 2030 aim for GHG concentrations to stabilize at either 550 ppm of CO_2e, with a global temperature increase of 3° C and emissions reaching 33 Gt CO_2e; or 450 ppm, with a 2° C rise in temperature and an emissions increase of 25 Gt CO_2e. The potentially harmful effects of these levels of temperature rise are well modeled today (IPCC 2007-a).

Several models[ii] (Fischedick 2008) show that in the period 2000-2030 the most relevant mitigation technologies (for stabilization at 450-590 ppm CO_2) would be those of energy conservation and efficiency, followed by technologies related to renewable energy sources. Looking further ahead, to 2100, the same technologies will continue to be important, alongside others such as carbon capture and storage (CCS).

One important point is that in order to obtain adequate emissions reductions, all the technology options under consideration will be necessary. With regard to transportation (the case of ethanol), under the reference scenario global emissions will grow from 6.7 Gt CO_2e to 11.6 Gt CO^2e between 2002 and 2030. Existing options to increase efficiency and the use of biofuels could reduce this by 2.2 to 4.5 Gt CO_2e (IPCC 2007-c), but this potential mitigation would be partially offset by the increased use of non-conventional liquid fuels with higher CO_2 emissions. This means that transportation emissions will continue growing through 2030, even with the use (within their practical possibilities) of all mitigation options currently being analyzed.

Cost of emission mitigation in the world, and the additional value of ethanol

In the current scenario, climate changes will imply significant costs to countries, in terms of implementation and adaptation. The goal is to minimize this impact through the reduction of emissions, so minimizing damage (and the cost of adaptation). Uncertainties regarding adaption costs are clear: annual values were estimated by the IPCC in 2007 to be between US$40 billion and US$170 billion after 2030, but were recently revised to more than US$500 billion.

For just now, it is possible to estimate the average cost of tonnes of avoided carbon emissions, to achieve certain goals. For sugarcane ethanol, this cost is an indicator of its additional value (a non-market externality).

Cap and trade systems are seen as the most likely. In these systems, the cost of stabilizing emissions depends on the target (i.e. the concentration of CO_2), the baseline and the set of available technologies (Fischedick 2008). Ideally, the technological options to be used would start with the lowest-cost options. This was summarized in (IPCC 2007-a): "Studies indicate the necessity for a diversified portfolio; carbon prices in the range US$20-50/t CO_2e would be sufficient to drive large-scale fuel-switching and make both CCS and low-carbon power sources economically viable as technologies mature." Several studies have looked at specific aspects of the estimated costs. In general, there is a consensus that cost estimates are still very imprecise. There is insufficient knowledge about some specific costs (CCS, for example) for different scales and timeframes. It is difficult to analyze interdependent systems and there is large variation depending on location. Some recent results are:

- Considering the available technologies for electricity (including CCS with coal and natural gas), and compared to the base of 15.77 Gt CO_2e in 2030, emissions reduction could reach 4 Gt CO_2e with a carbon price of up to US$20/t CO_2e; 6.4 Gt CO_2e with a price of up to US$50/t CO_2e; and 7.2 Gt CO_2e with a price of US$100/t CO_2e. (IPCC 2007-b)
- Stabilization at 550 ppm CO_2 would correspond to a price of US$20-50/t CO_2e, between 2020 and 2030; but US$100/t would be necessary for 450 ppm CO_2. (IPCC 2007-a)
- It is possible to reduce emission by 55% by 2030 (leading to 550 ppm) with a price below 60 Euros/t CO_2e; and by 70% (for 450 ppm) with a price between 60 and 100 Euros/t CO_2e. (McKinsey 2009)
- There are two scenarios for 2050: maintain emissions at the same level as 2005 (with marginal costs of CO_2 mitigation up to US$50/t CO_2e), or reduce 2005 emissions by half by 2050 – in this more optimistic scenario some technologies would go to US$200/t CO_2e, but the average would stay between US$38 and US$117/t CO_2e). (IEA 2008)
- In the scenario of stabilization at 550 ppm CO_2, cap and trade would bring the price of CO_2 to US$90/t CO_2e in 2030 (OECD+), and US$40/t CO_2e in 2020. For stabilization at 450 ppm, the price would be up to US$180/t CO_2e in 2030. (WEO-2008-a)

From these indications, and considering the need to reduce the atmospheric concentration of CO_2 to 450 ppm, we have assumed a reference cost for mitigation of US$100/t CO_2e for the next 20 years. This cost is determined by the total emissions to be reduced, and from the cost and potential (varying by location and time) of the various technologies under consideration.

Considering the use of ethanol in substitution for gasoline and its excess electricity, the avoided mitigation cost of US$100/t CO_2e and the average value of mitigation (~2 t CO_2e/m^3 ethanol, see **Table 5**) create an additional value for ethanol of US$0.20 per liter. This additional value (that is to say, in addition to the equivalent value of the gasoline which it substitutes) is one of the externalities of ethanol use. While this externality is unremunerated, it should be taken into account when developing appropriate policies to promote the production and use of ethanol.

Possibilities for expansion of ethanol use in other sectors in Brazil

Ethanol could be used in other sectors in Brazil, so increasing its potential for emissions mitigation. While this possibility is not included in this assessment, we suggest some possibilities:

- The use of natural gas (NG) needs to be redirected to areas like industry and thermoelectric generation, where it is more appropriate than being used as vehicular natural gas (Compressed Natural Gas-CNG). In 2008, CNG use corresponded with about 4.5 million m^3 of ethanol (approximately 30% of the fuel ethanol used in the country).
- The consumption of diesel in isolated stand-alone generating systems was equivalent to 1.4 million m^3 of ethanol.

- The consumption of diesel just in the sugarcane agricultural sector was equivalent to about 2.2 million m^3 of ethanol.
- The use of ethanol substituting just 5% (by energy content) of diesel would require about 4 million m^3 of ethanol (this could occur as a priority in sectors like urban mass transportation).

Evolution of knowledge on climate change; trends and expectations for the post-Kyoto regime; ethanol in Brazil

Global climate change, caused by the increased concentration of CO_2 and other greenhouse gases in the atmosphere as a result of human activity, is "one of the greatest challenges of our times," according to the leaders of countries represented at the G-8 Major Economies Forum, held in L'Aquila, Italy, in July 2009.

Climate change and greenhouse gases

Global warming is caused by human activity that increase the atmospheric concentration of greenhouse gases: carbon dioxide (from the burning of fossil fuels, cement production, and deforestation); methane (anaerobic decomposition of organic material); nitrous oxide (nitrogenated fertilizers and the chemical industry); and certain industrial gases with halogen bases. The higher concentration of these gases produces a gradual warming of the Earth's surface, changing the dynamic of the oceans and the atmosphere. It is predicted that such changes will have various harmful effects. Ecosystems and human activity are adapted to the current climate, and the predicted climate change will be much quicker than the capacity of nature or humanity to adapt.

In 1988, the Intergovernmental Panel on Climate Change (IPCC) was created by the United Nations to assess the state of human knowledge about climate change, including scientific questions, impact estimates and possible response strategies. After the 1990 report, the rapid advance of knowledge about the topic made continuous reevaluation necessary. New reports were published in 1995, 2001 and 2007, and another is planned for 2013. The first report (1990) recorded an increase in the concentration of carbon dioxide in the atmosphere and predicted that the average global surface temperature would increase by about 3º C in 2100. The report also predicted that another decade would pass before climate change could be detected. The latest IPCC report in 2007 stated that man-made climate change had been unequivocally detected. Given that climate change includes natural effects (volcanic eruptions, solar variation, and El Niño), it is necessary to separate these out by using mathematical models. Current models and the increasing intensity of climate change allowed climate simulations for the past century. Comparing these with actual observation makes it possible to separate natural causes from human-induced climate change.

The cause-and-effect chain in the climate system starts with human decisions and actions, which lead to the emission of greenhouse gases. Increasing concentrations of these gases in the atmosphere leads to warming, higher temperatures, local and regional impacts from climate change and the associated harmful effects. The relationship between emissions and the increase in concentrations is dictated by the average lifetime of each gas in the atmosphere. The relationship between the increase in concentrations and the radiative strength is a function of the properties of each gas. The relationship between the radiative strength and the temperature increase is determined by the climatic sensitivity, which is the average increase in surface temperature each time the carbon dioxide concentration is doubled, and by the timescale of the vertical transfer of heat in the oceans. There is a complex relationship between temperature increase and the local and regional impacts of climate change, and as a consequence the harmful effects, but we can say that it is a monotonically increasing function of the rise in temperature.

We therefore know that stabilizing the temperature requires stabilization of the atmospheric concentration of greenhouse gases, which in turn requires stabilizing net anthropogenic emissions. "Net emissions" is a concept that takes into account the removal of carbon dioxide from the atmosphere, which is considered as negative emissions. The only greenhouse gas that lends itself to anthropogenic removal is carbon dioxide, which can be removed from the atmosphere by planting trees, or through capture and geological storage (in oil and gas wells or in saline aquifers), or by seeding the oceans with iron salts. These last two technologies are still under development. Given a temporal profile of future emissions, this corresponds to a single profile of increasing concentration and a single profile of rising temperature. The inverse is not true, however – there is more than one possible emissions profile that can achieve the same temperature increase. In this case, the tendency is to look for the emissions profile that corresponds to the lowest possible cost for the same result.

Reactions to climate change

Our knowledge about climate change has evolved slowly and gradually since 1990. In parallel, society has become more aware and there have been more positive actions from governments, businesses and individuals. The possible reactions – in addition of course to inaction – are mitigation and adaptation. Mitigation comprises actions to reduce net anthropogenic emissions of greenhouse gases. Adaptation relates to measures that reduce the harmful impacts of climate change. The preferred combination of inaction, mitigation, and adaptation can be summarized as the choice of a tolerable limit for climate change.

Reacting to the first IPCC report, the UN General Assembly in 1990 established a negotiating process that culminated in 1992 with the adoption of the text of a convention. In force since 1994, this convention sets as a goal the stabilization of atmospheric greenhouse gas concentrations at a safe level, although it did not specify this value. The convention also embodied the principle that all countries share a responsibility that is common, but differentiated in function by their respective capacities for action. At the first Conference of the Parties to the Convention (COP-1), in 1995, the assessment was that the commitments made by industrialized countries were inadequate to reach their goal of stabilizing the concentration of greenhouse gases in the atmosphere. This led to a mandate to negotiate what became the Kyoto Protocol, adopted in 1997 and in force since 2005.

In essence, the Kyoto Protocol established limits for national aggregate emissions for industrialized countries, national emission mitigation programs for all countries, and carbon market mechanisms to minimize the overall cost of emissions reductions. The first period for verification of compliance to Kyoto targets is 2008-2012. Limits for the second period are now under discussion.

At the same time, the 13th Conference of the Parties to the Convention (COP-13) in Bali, Indonesia, adopted a two-year plan of action generating decisions relating to an agreement that would be adopted at the COP-15 in Copenhagen at the end of 2009. This would be broader than the Kyoto Protocol and would seek to achieve the goal of the Convention, stabilizing atmospheric concentrations of greenhouse gases[iii].

The international negotiation process, taking place under the aegis of the Kyoto Protocol, is moving to define new emissions limits for industrialized countries through 2020. It is reasonable to assume that these values will be defined only at the end of the other front the negotiations. The limits under the Kyoto Protocol are also important because they will have a direct impact on the market value of carbon credits under Clean Development Mechanism (CDM).

On the other front of the negotiations, under the aegis of the Convention but outside the scope of the Kyoto Protocol, the goal is to establish a longer-term regime that could lead to meeting the goal of the Convention. Although the goal of the Convention mentions the stabilization of greenhouse gas concentrations in the atmosphere, the tendency today is to look for a limit to temperature increase – a variable that is more directly related to the magnitude of the harmful impacts of climate change. Also, as we have seen, there is more than one temporal profile for concentrations and emissions that generates the same result. This introduces an additional degree of flexibility and therefore tends to minimize the costs of mitigation.

Although the official negotiations take place in the Conferences of the Parties to the Convention, several high level meetings tend to include the question of climate change on their agendas, seeking to build the consensus that is necessary for the success of the official conferences. The most recent such meeting was the Major Economies Forum (MEF). This saw consensus between the 14 participating countries that climate change should be limited to a temperature increase of 2º C at the end of the century.

A limit for the increase in temperature (for example, 2º C) would imply the need to reduce net global anthropogenic emissions of greenhouse gas by approximately 60% in comparison to 1990 levels. As a first suggestion, the main industrialized countries in the G8 (including the European Union) at the same event outlined an effort to reduce their emissions by 80%, so allowing developing nations to act more slowly. Although these projections made four decades in advance are subject to many uncertainties, and still have not been adopted, they point to an important change in the global energy matrix with impacts for all countries.

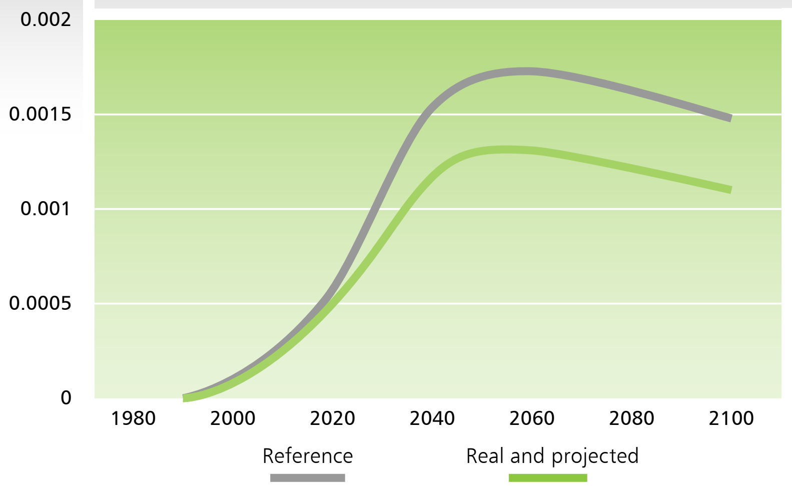
Biofuels; Ethanol in Brazil and Climate Change

Global studies (Pacala 2004) show that renewable biofuels are a necessary part of this transformation. It will not be possible to reach the desired goal for limiting the increase in temperature without a significant increase in the participation of renewable biofuels in the new energy matrix.

It is interesting to consider the impact on global temperature increase caused by the introduction in Brazil of fuel ethanol to replace gasoline. To do this we must first establish a baseline. It has been common to use as a baseline a "business as usual" scenario that corresponds to what would occur if no action were taken to reduce emissions. This emissions scenario is adopted by the IPCC and is based on demographic projections, the intensity of energy use and the technology used for its generation. This is done for the whole world, although it may sometimes be compiled regionally. In the case of individual projects, such as those in the CDM, the baseline is constructed using an approved methodology that seeks to establish the most plausible scenario. The "business as usual" (BAU) baseline scenarios are hypothetical, or counterfactual – future scenarios that could happen, but have not happened – and therefore are not subject to objective demonstration or verification. Furthermore, these scenarios lend themselves to manipulation.

The only way to avoid these problems is to adopt a fixed and measurable reference. The trend in the Convention and especially in the Kyoto Protocol is to adopt 1990 emissions as the fixed reference. The above-mentioned need to reduce global emissions by 60% refers to 1990 levels.

Figure 1 **Increase in the average global surface temperature resulting from the use of ethanol and gasoline in Brazil: 1990 to 2030** *In °C*



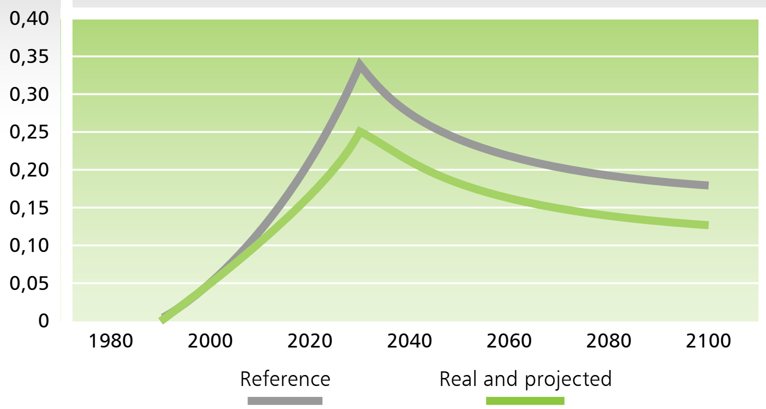
Reference: volume of ethanol held constant at 1990 level, from 1990 to 2030. • **Real and project**: real consumption (1990-2008) and projected (2008-2030).

Using 1990 as a base year – it has been adopted as a benchmark in international negotiations – we can calculate the contribution to climate change resulting from the use of Type A gasoline and ethanol for a certain period, for example, between 1990 and 2030. This benchmark implies holding constant during the period the volume of ethanol produced in 1990 (11.8 million cubic meters), with the fuel consumption of Otto Cycle engines being complemented by gasoline up to the levels of real demand for 1990-2008 and projected demand for 2008-2030 (EPE 2007). Based on this benchmark we can calculate the effect of ethanol, measured by consumption of ethanol and gasoline (real, from 1990 to 2008, and projected from 2008 to 2030).

Figure 1 shows the increase in the average global surface temperature, indicating the magnitude of climate change from that date. **Figure 2** shows the increase in the atmospheric concentration of carbon dioxide. The calculation takes into account the emissions relating to ethanol and gasoline (as shown in **Table 5**), the dynamics of the process of CO_2 absorption by the Earth, and the result of global warming itself in the increase of temperature.

The forecast horizon is 2100, which is the year normally adopted by the IPCC and in political negotiations about the future regime of climate change. Note that we have used only official data to the horizon for which they are available (2030), to avoid any pre-judgment of what will happen after that date (zero emissions from 2030 to 2100). Interestingly, while Brazil's National Climate Change Plan (PNMC) provides for mitigation measures, and thus for limiting greenhouse gas emissions, the government's detailed energy plan foresees the resumption of exponential growth in Type C gasoline consumption as of 2020, maintaining a constant ratio between consumption of ethanol and Type C gasoline. It does not include the proportional increase in ethanol consumption that would seem to be compatible with the goals of the PNMC.

Figure 2 **Impact on the concentration of CO_2 in the atmosphere resulting from the use of ethanol and gasoline in Brazil 1990 to 2030** *Concentration of CO_2 in PPM*



Reference: volume of ethanol held constant at 1990 level, from 1990 to 2030. • **Real and project**: real consumption (1990-2008) and projected (2008-2030).

Prospects for international negotiations

The trends in international negotiations are:

- Limiting temperature increase in 2100 to 2º C;
- Industrialized countries reduce emissions by 80%, compared to 1990 levels;
- Emerging countries reduce emissions in comparison to current trend;
- Special consideration for least developed countries.

Physical considerations allow us to state that, to achieve temperature stabilization, we must first stabilize the concentration of carbon dioxide (and other GHG) in the atmosphere. To stabilize the concentration of carbon dioxide in the atmosphere, it will be necessary to reduce net anthropogenic emissions to a level 60% below that recorded in 1990. This reasoning allows us to estimate the level of emissions possible in developing countries that, taken together with the 80% reduction in emissions of industrialized countries, will result in a 60% reduction in global emissions. Given that emissions from industrialized countries represented three-quarters of global emissions in 1990; the proposals under consideration today lead us to conclude that emerging countries must limit their emissions to 1990 levels.

There are no indications of how to divide this limit amongst emerging countries. Assuming, however, for purposes of illustration, that each country acts individually, we can conclude that Brazil should adopt measures in its national planning to stabilize emissions at 1990 levels. Energy planning in its current form does not indicate measures in this manner, and it is therefore reasonable to assume that this planning needs to be revised to match the declared objectives of national policy and the PNMC.

The options for limiting greenhouse gas emissions can, in general, be classified in three main groups:

I Regulatory policies and measures that require the adoption of certain practices, for example energy efficiency standards, the outright prohibition of certain practices, and so on. In general, measures like these tend to be the least efficient because they increase the cost to society of measures to contain emissions;

II Fiscal measures, ranging from a tax on greenhouse gas emissions – a "carbon tax" – to tax incentives (effectively negative taxes) and the provision of credit on favorable terms for enterprises that result in reduced emissions;

III Mechanisms to limit and trade emissions (cap-and-trade), under which the imposition of emission limits is accompanied by the preparation of certificates that allow for emissions at levels compatible with the desired limits, coupled with permission to trade such certificates. This system is currently used in the European Union, where it is known as the European Union Emissions Trading System. Under certain conditions to control emissions from stationary sources, with available technology, this scheme can result in minimizing costs for society as a whole, because the market is responsible for ensuring that reductions will occur where their marginal costs are lowest.

There is also an innovative tendency to combine the second and third approaches, as for example in the Waxmann-Markey Bill, approved by the U.S. House of Representatives, where permits are auctioned rather than handed out free. Brazil's Secretary for Economic Policy at the Ministry of Finance has expressed interest in this model.

In addition to the debates about global targets for temperature increase (and thus for overall emissions), the allocation of these targets amongst countries or groups of countries, and the list of possible domestic policies to be adopted by countries in general and Brazil in particular, two other questions remain. One relates to international mechanisms by which emissions limitations can be re-allocated among countries – the international carbon trade; the other is the relative competitiveness of Brazil.

The international debate about the international carbon market is still extremely limited. The existing mechanism within the ambit of the Kyoto Protocol, the Clean Development Mechanism, has its limitations, in particular with respect to renewable energy and ethanol.

As for international targets, these need to be adopted uniformly, including China and India, in order to protect the competitiveness of Brazilian industry.

Brazil's advantages, such as its relatively clean energy matrix, should also be incorporated. It is necessary to quantify and transfer this in order for it to be translated into advantages in international trade.

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Explanatory Notes

[i] Sources: WEO 2008, EPA data for the IEA, IEA databases and IPCC 2007.
[ii] Image, Ipac, AIM and Message.
[iii] This study was concluded before the COP-15 meeting in Copenhagen.


04

Ethanol and Health

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Paulo Afonso de André

This study shows that even a partial substitution of petroleum derivatives by ethanol in the vehicle fleet in the São Paulo metropolitan region would save hundreds of lives and prevent thousands of hospitalizations, saving public coffers hundreds of millions of dollars.

The impacts of air pollution on health are well known in the scientific community. Fuel replacement is equivalent to a reduction in ozone formation (ethanol instead of gasoline) and particulate emissions (ethanol instead of diesel). Furthermore, the use of ethanol reduces greenhouse gas emission and helps combat global warming.

Over 12,000 hospitalizations and 875 deaths would be avoided per year in a scenario of total oil and diesel replacement by ethanol in Greater São Paulo. During this period, public coffers would save nearly US$190 million.

A more realistic goal – using ethanol in the bus fleet – would result in the reduction of 1,350 hospitalizations per year due to ailments caused by diesel-generated pollution. In this way more than US$3.8 million would be saved each year. Also, 220 deaths would be avoided per year, equivalent to half the number of deaths from tuberculosis in the region in 2007.

Pollutants considered in the analysis were fine particulate matter and ozone. These pollutants were chosen because they exceed the recommended limits of the World Health Organization and are considered the main challenges in the area of air pollution in Brazil.

Greater São Paulo was chosen for the study because of the availability of good quality observational data on health and the environmental. Since air pollution is recognized as a problem that affects other densely-populated regions, the results of this study can be extrapolated to other areas with similar characteristics.

Another aspect that should be emphasized is that the results are underestimated, because health affects are only measured in terms of hospital admissions and mortality. This is due to the availability of official information. However, it is known that these cases represent a minority of adverse health events and do not take into account diseases that do not require hospital care or cause death. In other words, the impact is even more serious than the numbers presented in the simulation.

Presentation of the problem

Mankind is central to prospection and marketing in the oil, gas and renewable fuels industry. The availability of energy that can be stored and "packaged" into fuel tanks or gas drums has opened the way for mechanized mobility. Hydrocarbons contained in petroleum have made possible the development of new products and compounds that have changed the format and efficiency of several items of equipments and the production of new medicines. More importantly, the availability of energy and new compounds has allowed society to incorporate new attitudes and patterns of consumption, creating habits that require ever-increasing energy production. These new habits have become part of daily life and any change to the energy matrix or the way that we generate and consume energy do not seem to be feasible and efficient in the short term. Changes are happening slowly, and are subject not only to environmental but also to economic decisions.

In this scenario, we are now confronted with extremely relevant issues for the energy industry. In our view, the following are the most important points:

a What are the energy alternatives that will reconcile society's increased energy demand with questions of efficiency, price and sustainability? The concentration of oil and gas production in some critical regions of the planet has led to various moments of tension in recent decades, impacting the price of these products in the international market. An expanded group of feasible energy alternatives is the best antidote to these difficulties.

b What are the energy sources that imply least environmental impact, be it at a global scale (minimizing the effects of climate change) or at a regional scale (minimizing adverse effects of fuel production and emissions)? Global warming from the emission of CO_2 and other greenhouse gases is an issue that has moved beyond the technical sphere of academia and industry to impact the daily life of ordinary people. The same can be said for the adverse effects of vehicular emissions, which have been the object of increasingly restrictive political control in order to safeguard human health. As a result of these problems, created through the consumption of fossil fuels by industry and transportation, there is a growing sentiment in society that we should reduce pollution emissions from stationary and mobile sources, which will affect the future market for these fuels. It is important to note that, at the current technological level and for most uses of oil and gas (and their derivatives), no significant reduction in emissions can be achieved just by technological improvement of the industrial process or of motor engineering. It must necessarily consider fuel composition as a determinant factor. A clear example of this is diesel vehicles, where the catalytic converter technology is dependent on the fuel formulation.

c How can we transform the energy generation process into one of the tools that helps to achieve socio-economic equality between rich and poor nations, and also reduces social and health inequalities within a country? Energy production is a source of wealth. In general, the choice of new energy sources is made in terms of cost-effectiveness, determined from the point of view of the productive process. Activities related to fuel production, distribution and trade produce impacts on human life. **Table 1** presents a summary comparison between the potential risks to human health due to the use of petroleum-based fuels and some biofuels (ethanol and biodiesel).

The analysis in **Table 1** shows that risk to human health is inevitable at every stage of fuel production. What matters is choosing the alternative with the smallest impact. It is also important to implement and develop new practices that ensure processes have maximum sustainability, taking into account environmental, economic and social aspects (for example, the elimination of sugarcane burning prior to the harvest).

The above-mentioned set of situations indicates that mankind and the fuel production industry have forged such close bonds that they have sealed their fate in an implicit pact. The future of mankind depends on increasing the production of clean and sustainable energy sources, while the future of the energy market will depend on its ability to meet the needs of mankind through sources that ensure climate stability, with the least possible damage to human health, and that lead to a future with less socio-economic inequality. In other words, by including sustainability and a lower risk to health and the environment, the price of new fuels will depend, in the near future, on the incorporation of values that go beyond the costs of prospection, production, refining and distribution. The incorporation of questions related to the impact on humans of the new energy alternatives that Brazil has adopted could add new value to these fuels and provide information that may assist the strategic planning of energy markets in the coming decades.

Comparison of potential risks to human health Table 1

	Petroleum	Biofuels
Production	Water and soil contamination from production waste or leaks	Water and soil contamination from pesticides and production waste
	CO_2 emissions (flaring)	
	Fugitive emissions	Straw burning (ethanol)
	Work conditions: onboard work on platforms, contamination from chemicals present at refineries	Work conditions: exhaustion, inhalation of gases and particles after straw burning
Transport and Storage	Leaks (during transport, tanks and pipelines)	Increased solubility of leak plume
	Fugitive emissions	Fugitive emissions
Emissions	Atmospheric pollutants (particles, hydrocarbons, volatile organic compounds precursor of O_3)	Atmospheric pollutants (carbonyl compounds in the case of ethanol, NO_2 and long-chain hydrocarbons such as acrolein in biodiesel)
	Increased greenhouse gas emissions	Variable greenhouse gas emissions balance, depending on the grid

General considerations about the relation between atmospheric pollution and human health

The assessment of the impact of energy sources on health requires the availability of information at a series of interconnected levels, as shown in **Figure 1**.

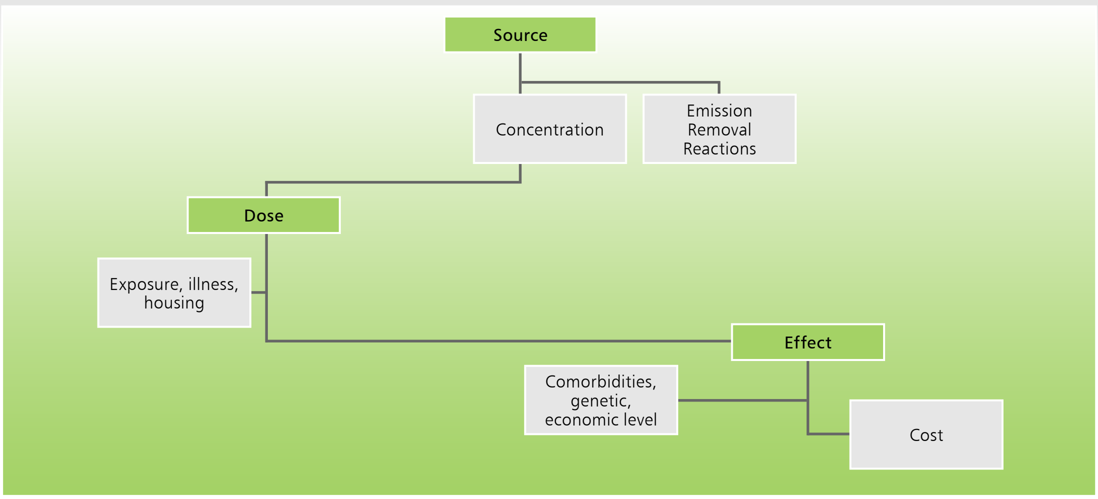
Each element in **Figure 1** represents critical information for determining environmental risk.

One key point is the characterization of the emission source, with its chemical composition and emission rates. In some situations the emission source is known, as in the case of vehicular, industrial or agricultural emissions. However, there are situations in which the emission source is unknown, as in the case of surface water pollution in a major hydrographic basin.

We must also consider various aspects related to dispersion and reactions in the environment. Primary pollutants are those emitted directly by the source – discharge points of liquid effluents, industrial smoke-stacks, automotive tail pipes, and re-suspension from the soil, for example. Secondary pollutants are produced in the environment from chemical reactions, and have primary pollutants as their precursors. In this group ozone and secondary aerosol particles are significant.

Pollutants with local effects are those with a very short average life and that affect mainly the area surrounding their source. Pollutants with mesoscale effect are those with an average life of hours or days, affecting larger regions because they can be carried by winds, convection or water. Pollutants with regional impacts are those that reach their highest concentrations many miles from their point of formation. Aero-

Figure 1 Algorithm for evaluation of environmental risk



Source: Adapted from Kovats and cols, 2005.

sol particles generated by fires in the Amazon affect the Southeast a few days after being formed. This means that pollutants with a regional impact are those that are formed or carried a great distance from their source or from the origin of their precursors. Pollutants with global effects are generally atmospheric in nature, and can be carried long distances in the troposphere or reach the stratosphere via vertical convection. CH_4 (methane) and CO_2 (carbon dioxide) are examples of this type of pollutant, and participate in global temperature change.

The physical characteristics of the source, the type of pollutant emitted and its associated emission rate, reactions that occur in the atmosphere and the phenomena of transportation and removal are all crucial to defining the environmental concentrations of pollutants.

Concentration is not the only factor that determines the dose received by any specific individual or segment of the population. Factors that significantly alter the received dose include the time spent near sources of atmospheric emission, the level of physical activity, comorbidities that alter absorption, metabolism or rate of absorption of environmental pollutants and socio-economic factors that alter housing conditions in a way that allows greater penetration of pollutants inside homes.

On the other hand, the adverse effects on health for a given dose of pollutants will depend on factors related to individual susceptibility. The adverse effect of environmental pollutants will be modulated by factors such as age, nutritional state, socio-economic level, pre-existing diseases and polymorphism of detoxifying genes. The effect of pollutants on health also depends on time of exposure. Depending on the type of pollutant, the dose and the individual characteristics of the subject some adverse effects are manifested acutely (hours or days after exposure), while others are seen only after long periods of exposure (the so-called chronic effects). Increases in mortality associated with situations of excessive accumulation of atmospheric pollutants is a typical example of the acute effects of pollutants. Indoor pollution from cigarette smoke, decreased intelligence from lead exposure, and most of the pollutants that cause cancer are examples of how the magnitude of health damage can be accurately assessed only after prolonged periods of exposure.

It is also important to establish limits for the health effects that will be assessed. Health effects on the population due to exposure to ambient pollutants are varied. Intensities and latency periods are different, and include: behavioral and cognitive effects; pulmonary and systemic inflammation; alterations to airway caliber, vascular tone and heart rate control; reproductive changes; morbidity and mortality from cardiac and respiratory diseases; and increased incidence of cancer; among others. Given the multiplicity of possible outcomes, it is necessary to define adverse health effects in an objective way. Based on this definition, we can then select which events are useful to determine the impact that an environmental change will have on the population that is exposed to it.

Although the concept of adverse or detrimental effects to human health is widely used to define measures of risk assessment or environmental management, a precise definition of the boundaries between a finding that is statistically significant and a change that will in fact result in relevant health effects still requires further definition. A description and analysis of current definitions can be found in **Annex 1**.

The definition of adverse health effects must necessarily be accompanied by a characterization of the most susceptible groups. Increased susceptibility to pollutants depends on individual, housing and socio-economic factors. Among those of an individual nature, the most important are age, associated morbidities, and genetic characteristics. The extremes of the age pyramid have been identified as prime targets for the adverse effects of air pollutants, especially in the segments below five and above 65 years of age. Associated morbidities such as asthma, chronic bronchitis, atherosclerosis, diabetes mellitus, cardiomyopathies and cardiac arrhythmias are among the pathological conditions known to be more susceptible to air pollution effects.

Living conditions affect the dose received and, consequently, the susceptibility to pollutants. In large urban centers, there are areas where the generation and dispersion of pollutants leads to ambient pollution levels that are significantly higher than the urban average. Places that present a greater risk to residents are those adjacent to major traffic corridors, low-lying regions in urban centers, areas with high buildings, and areas subject to constant traffic jams. For example, measurement of inhalable fine particulate matter carried out under the Costa e Silva elevated highway in São Paulo showed levels three times greater than city averages.

The type of construction also affects the degree of pollution penetration inside homes. Older buildings that lack air conditioning tend to have greater air pollution penetration. We must also take into account that contributions from internal sources can significantly deteriorate air quality in homes. Socio-economic conditions also interfere with the susceptibility to air pollutants. In São Paulo, it was shown that, given the same variation of ambient pollution (expressed in terms of inhalable particulate matter, PM10), mortality is higher in neighborhoods with worse socio-economic indicators (Martins et al, 2004).

Factors that determine the greater vulnerability of the underprivileged to air pollutants can be divided into two main categories: events related to health conditions and access to care and medication, and conditions that foster greater exposure to pollutants. In the first category, we know that the less fortunate segment of the population has worse health due to deficient sanitation and nutrition, lack of access to medical services, and lower purchasing power to buy medication when ill. The second category – greater exposure – has been recognized as a relevant factor in the relationship between air pollution and health.

The relationship between social exclusion and greater exposure to pollutants occurs both at continental levels and within individual communities. Dirtier industrial processes, vehicles with obsolete technology, and fuels with higher concentrations of contaminants are found more frequently in developing countries. To a lesser degree, it is common within a given community for the professions that lead to greater exposure to pollutants (street workers, for example) to be performed by the most needy segments of the population. Similarly, it is more common for disadvantaged groups to live in houses beside roads with high traffic, and to use firewood or waste for cooking. We can thus see that the greater vulnerability of poorer social groups to air pollution is determined both by worse basic conditions of health and access to health infrastructure, and also by greater exposure to pollution.

Impacts of sugarcane ethanol production on human health

It is appropriate to emphasize that the analysis of health effects reported in this chapter will be based on the effects of atmospheric emissions, in particular for emitted pollutants and the emission of greenhouse gases. For comparative purposes, the effects observed in the case of ethanol will be compared to those present in the current alternative, i.e., petroleum derivatives.

Fuel production is strongly associated with air emissions that have the potential to interfere with human health. In São Paulo State, the current practice of burning off sugarcane straw in order to manually harvest sugarcane has been associated with increased morbidity caused by respiratory diseases in adults and children, and cardiovascular diseases in adults. Health effects appear to be strongly dependent on the fraction of particulate emissions, and have sufficient magnitude to constitute a significant public health problem for those exposed to them. As a result of these impacts, a protocol was signed in 2007 between the Environmental Secretariat of São Paulo State (SMA), and the Brazilian Sugarcane Industry Association (UNICA), establishing a progressive reduction in plantation burning with a corresponding increase in mechanized harvest. According to the SMA, mechanization accounted for 49.1% of the 2008-2009 harvest. According to the protocol, all areas with slopes of less than 12% will be mechanized by 2014. Vegetation cover in São Paulo will increase as a result of reforestation in areas where the slopes are too steep for mechanized harvest, for example along river banks.

Activities related to petroleum production and refining are harmful to human health. Several epidemiological studies have reported an increase in cases of respiratory diseases, cardiovascular diseases and tumors (leukemia and cancers of the central nervous system) in areas near refineries and petrochemical plants. Recent studies in the Paraíba Valley in São Paulo showed increased rates of change in biomarkers in the vicinity of the oil refinery, along with increased rates of cardiovascular disease and cancer. Organic compounds in the gaseous and particulate phases of emissions from refineries and petrochemical complexes are mutagenic and lend biological plausibility to the toxicological and epidemiological findings outlined above.

The set of information concerning the production process shows that the nature of chemical compounds and the severity of health findings indicate that sugarcane production is significant in terms of atmospheric emissions. This points to the need to reduce or end sugarcane straw burning prior to harvest.

Climate change and public health

Sugarcane ethanol has significant advantages over petroleum-based fuels in terms of greenhouse gas emissions. This question – the health consequences of predicted climate change due to global warming – deserves some special consideration.

Medical literature has been devoting increasing attention to the potential impacts of climate change on human health. Within this scenario, biofuels such as ethanol may also help reduce health impacts due to global warming, because they are more neutral in terms of greenhouse gas emissions compared to petroleum-derived fuels: the balance between the absorption of CO_2 during plant growth and emissions during production and fuel burning is almost neutral, while the elimination of straw burning, among other advances, further reduces emissions. This document focuses on three aspects of the relationship between health and climate change: food security, water shortages and heat stress.

Food security is one of the most evident problems of global warming. Climate models project that, maintaining the current rate of warming, areas of Brazil such as the semi-arid region of the Northeast may present a process of desertification. Paradoxically, increased levels of atmospheric CO_2 may cause some crops, especially in the South, Southeast and Midwest of the country, to increase in productivity if water is available. If these forecasts come true, there will be an increase in social and economic inequality, with migration from new desert areas and an increase in the poverty belt around major cities. This process will tend to be more intense in regions with a greater proportion of family or small farms, which will be less able to make the necessary adjustments.

The quality and quantity of water available for human consumption are crucial determinants in the relationship between health and illness. Infectious diseases transmitted via water are among the leading causes of morbidity and mortality worldwide. The desertification process in the semi-arid region will exacerbate water shortages in the area. Moreover, climate changes are causing rainfall in the Northeast to occur in greater intensity at the beginning of the rainy season, petering out later in this season. The example of 2009 is a clear indicator of this phenomenon. Systems of storage tanks and ponds were compromised around the flooded areas. This could have led to water shortages if rains had been insufficient, as well as to contamination of reservoirs by human and animal waste. In coastal regions, the rise in sea level points to increased salinity of aquifers, with the consequent reduction in the quantity and quality of water. If this situation persists, it is forecast that global warming will increase morbidity and mortality from waterborne diseases, while forcing the migration of the population from affected regions.

Finally, it is appropriate to discuss thermal stress. Our bodies are maintained in a narrow temperature range around 37° C, independent of the temperature range that the external environment imposes on us. The fine control of body temperature is the result of the body's thermal regulatory centers, and the adaptation of our clothing and dwellings. Each population has a range of thermal comfort, and this varies for different regions. When the external environment presents temperatures outside of this comfort zone, health indicators such as hospital consultations and excess mortality start to rise. A schematic representation, which translates empirically what happens in São Paulo, is shown in **Figure 3**.

Figure 3 shows that the relationship between excess mortality from temperature extremes is not linear, but increases disproportionately with extremes of minimum daily temperature. The range of thermal comfort can be defined as lying between a minimum daily temperature of 10 and 20 degrees centigrade, with excess mortality caused by waves of cold and heat. In the case of São Paulo, the effect of a cold spell is more intense than that observed with heat waves. In a cold city, the opposite occurs, i.e., heat waves have a greater impact on health. Those most affected are people whose mechanisms of adaptation are less efficient – children (respiratory disease) and the elderly (respiratory diseases in cold spells and cardiovascular diseases in heat waves). Social and economic factors also modify the effects of extreme temperatures. Lower income dwellings offer greater "permeability" to external temperature variations, while the reduced vegetation rates in the poorest regions of the city increase the local daily temperature range and are responsible for the greater impact of thermal extremes among the poorest members of a community.

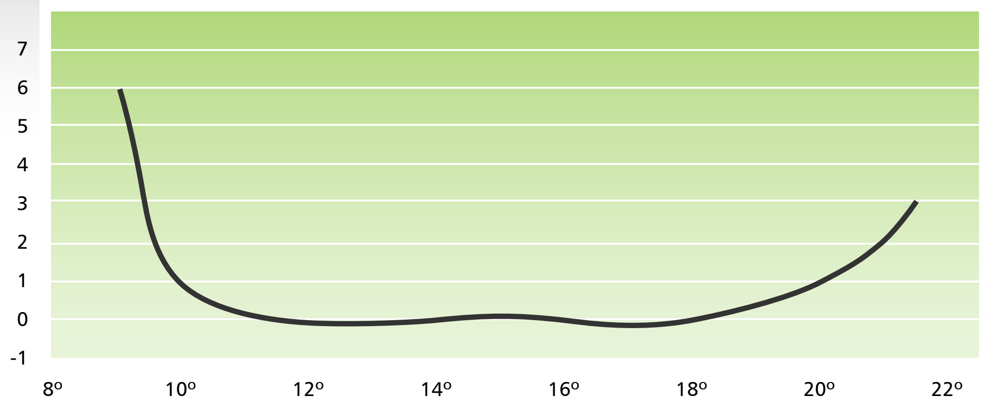
Some other aspects of the relationship between global warming and disease – such as possible increased spread of infectious diseases transmitted by insects, and natural disasters such as floods and landslides caused by extreme rainfall – also significant, but are not addressed at this time due to space limitations.

Impact of fuel ethanol from the perspective of accidents during transportation and storage

Leakage of oil and its derivatives is a major source of environmental accidents, with notable environmental impacts. Hydrocarbons and metals present in petroleum can be consumed by people and produce adverse health effects by contaminating water on the surface or deep underground, or by entering the food chain cycle. The expected effects are reproductive disturbances, changes in bone marrow function (damaging the formation of red blood cells – anemia – and white blood cells – low immunity) and increased risks of developing cancer, especially leukemia and lymphomas. Ethanol's chemical structure and greater capacity to break down in the natural environment implies virtually zero risk of the changes just described. One

Figure 3

Representation of additional deaths attributable to extremes of minimum temperatures in the city of São Paulo *Additional deaths per day / Minimum temperature in centigrade*



downside of ethanol comes with fuel storage at filling stations, given the increased permeability of gasoline in soil when it is mixed with ethanol (McDowell et al, 2003). In other words, the addition of ethanol to gasoline increases the plume dispersion of gasoline in the soil, increasing the risk of surface water contamination in the case of a filling station leak. This situation deserves greater attention in terms of monitoring tank sealing at filling stations in urban areas. And what about the risk of inhalation?

Health effects of emissions by ethanol powered vehicles

We know intuitively that, regardless of the fuel used, automotive emissions contain compounds that have potential effects on human health. Inhalation offers a gateway for these compounds, given that an adult's lungs have an alveolar surface of around 70 square meters, and a barrier of cells with an average thickness of less than one thousandth of a millimeter is interposed between our internal environment (the inside of alveolar capillaries) and the external environment. As the air passes through approximately 30 centimeters of airways, it must be heated to 37° C, reach a relative humidity of around 90% and be filtered of microorganisms and ambient pollutants. The arrival in the alveolar territory of chemical compounds, both in the gaseous state or adhering to soot particles, gives rise to a possible local or systemic inflammatory response as these compounds access the bloodstream. It is therefore imperative that the analysis of health effects of emissions from ethanol-powered vehicles be conducted in comparison to the emission from vehicles powered by gasoline or diesel.

Laboratory studies with rodents in the 1980s showed that emissions from light vehicles running on ethanol were less toxic than those from gasoline-powered engines, in tests for both acute and chronic toxicity. Ethanol emissions produced lower levels of lung inflammation and of mutations. In these studies, the lower toxicity of ethanol emissions was attributed to the type of organic compounds emitted.

In the case of emissions from ethanol-powered engines, the organic compounds are almost entirely ethanol, accounting for 70%, and aldehydes, amounting to 10% (this fraction comprised 85% acetaldehyde and 14% formaldehyde). Gasoline engines on the other hand emit a whole family of volatile compounds and polycyclic aromatic hydrocarbons with high toxic and carcinogenic potential. This approach, while useful as an initial step, does not take into account photochemical processes that can occur in the so-called "real world", i.e. in the atmosphere of big cities. It is extremely important to analyze the formation of secondary pollutants, especially ozone and other compounds of the photochemical oxidants family formed by the interaction of primary pollutants with solar radiation.

An increased level of aldehydes (acetaldehyde and formaldehyde) in the atmosphere is undeniably one of the consequences of using fuel ethanol. On the other hand, formaldehyde is the most characteristic aldehyde in vehicular emissions from the use of petroleum and its byproducts, notably diesel. It is important to look in more detail here at the behavior and toxicity of atmospheric aldehydes, both from the perspective of their direct toxicity, as well as their potential for ozone formation.

Structure and metabolism of aldehydes

Aldehydes are highly reactive organic substances. They contain a carbonyl group (double bond between carbon and oxygen atoms), and have a high affinity with lipids, proteins and DNA (Comeap, 2000)[i]. Aldehydes can be divided into three classes based on their structure and reactivity with organic substrates (Comeap, 2000):

a Simple or saturated aldehydes: the metabolism of these aldehydes happens through the oxidation of their carboxylic acids (via aldehyde dehydrogenase) or by reducing the alcohol dehydrogenase. Links with thiol groups, as well as links with several proteins, including those that make up DNA, also occur and explain the carcinogenic potential of these aldehydes. The aldehydes of interest in this study – formaldehyde and acetaldehyde – are representatives of this category of aldehydes.

b Unsaturated α,β-aldehydes (for example, acrolein): these aldehydes bind to substrates such as glutathione or cysteine, and oxidize after these links. As in the previous case, this class of aldehydes can bind to amino groups of DNA, and may lead to the development of mutations.

c Halogenated or modified aldehydes (benzoaldehyde): the metabolism of these aldehydes depends on the nature of their functional group; some can be oxidized (for example, benzoaldehyde, furfural, malodialdehyde) while others are predominantly conjugated with glutathione, cysteine or serine.

Sources of aldehydes in the external environment of large cities

In outdoor areas of large cities, the different classes of aldehydes described above are produced by vehicle emissions, biomass burning or through photochemical reactions (Miller et al, 2001). In the atmosphere of large urban centers, the relative contribution to aldehydes production of direct emissions and photochemical processes will depend on the rate of emission from anthropogenic sources and climatic conditions.

The emission of aldehydes in urban environments is the result of incomplete oxidation of vehicle fuel, be that gasoline, gasohol, ethanol, natural gas or diesel (Abrantes et al, 2005; Durbin et al, 2007; Kado et al 2005; Martins et al 2008). In the polluted atmosphere of large cities, the main precursors of aldehydes are hydrocarbons, alcohols, ethers and aromatic compounds of anthropogenic origin, subjected to the action of ozone or OH, HO_2 and NO_3 radicals (Andrade et al, 2002).

In the city of São Paulo, carbonyl directly emitted by vehicles predominates in the morning, with greater participation of photochemical processes in the afternoon (Miller et al, 2001). Usually in the morning, the concentration of acetaldehyde is higher than that of formaldehyde; this behavior is reversed in the afternoon after photochemical processes.

Aldehydes as ozone precursors

In addition to their direct toxicity, atmospheric aldehydes can contribute to the formation of ozone, one of the pollutants most associated with adverse effects for human health. The basic aspects of the photochemical reactions related to aldehydes and ozone are of great importance to understanding the consequences of using different fuels, and are presented in **Annex 2** (aldehydes as precursors of ozone). Further details can be found in specific literature (Carter, 1994; Saldiva et al, 2005).

Effects of formaldehyde and acetaldehyde on human health

The vast majority of our knowledge about the effects of formaldehyde and acetaldehyde on human health comes from the occupational area or from a context of external environments. This information is of little value when one takes into account the scope of the current study, which has as its main objective the analysis of aldehydes in an ambient context. The detailed survey of the medical literature did not reveal the existence of population-based studies, relating ambient concentrations of formaldehyde and acetaldehyde to indicators of morbidity or mortality.

There are major problems with transposition of data from occupational studies to an ambient context. For a start, there are significant differences in the degree of concentration of aldehydes in the ambient study; this tends to be much greater in the working environment. On the other hand, the susceptibility of exposed populations tends to be different. There is much less frequency in the working environment of those individuals who are most prone to suffer greater adverse effects when exposed to ambient levels of atmospheric pollutants, such as the elderly, children or patients with severe asthma or cardiovascular diseases.

In this scenario, the estimated risk of the adverse effects of formaldehyde and acetaldehyde on indicators of morbidity – in other words, the induction or worsening of disease – presents as a limiting aspect the fact that symptoms or abnormalities observed in humans or experimental animals were observed in ambient concentrations much greater than those found in Brazilian cities.

The U.S. Environmental Protection Agency (EPA) has not defined a reference concentration for chronic inhalation of formaldehyde (Iris, 1990)[ii]. Based on studies with rodents, the EPA has identified cancer risk from exposure to formaldehyde through inhalation, establishing the unit of risk for inhalation at 1.3×10^{-5} per $\mu g/m^3$. This means that lifetime exposure to a concentration of 1 $\mu g/m^3$ leads to an additional 1.3 cancer cases per 100,000 inhabitants. The same situation occurs for acetaldehyde, which does not have a set safety standard for chronic inhalation, except for the risk of developing tumors (Iris, 1991). In the case of acetaldehyde, lifetime exposure to a concentration of 1 $\mu g/m^3$ leads to an excess of 2.2 x 10-6 per 1 $\mu g/m^3$. This means that lifetime exposure to a concentration of 1 $\mu g/m^3$ creates an additional 2.2 cancer cases per one million inhabitants.

Effects of ozone on human health

As noted earlier, aldehydes are important precursors of ozone formation. In this case, unlike the situation for formaldehyde and acetaldehyde, there is a solid mass of population-targeted information relating ambient variations of ozone to adverse health outcomes.

Studies using controlled inhalation, both in animals and in humans, indicate that ozone has the potential to cause adverse effects to human health, such as:

- Short-duration exposure produces inflammation of the respiratory tract, mainly in the upper airways and in the transition region between the respiratory bronchioles and alveoli;
- Studies in intoxication chambers demonstrate that the ozone levels present in large Brazilian cities (160 $\mu g/m^3$) are capable of inducing significant pulmonary inflammation in both humans and animals; this is established a few hours after the end of exposure;
- Ozone inhalation can induce a systemic inflammatory response that is characterized by the activation of serum levels of complement and acute-phase proteins;
- Ozone inhalation impairs pulmonary defenses through the functional impairment of the mucociliary system, reducing the activity of alveolar macrophages and impairing activation of circulating lymphocytes;
- Ambient levels of ozone cause increased bronchial reactivity;
- Repeated inhalation of ozone leads to a degree of adaptation by the recipient, through an increase in production of anti-oxidant substances by the respiratory tract. However, we must caution that this “adaptation” does not prevent the development of pulmonary inflammation, especially in terminal bronchiolar units;
- Some host factors modulate the magnitude of the response to ozone, such as age, respiratory co-morbidity, and genetic factors that modulate the synthesis of anti-oxidant substances through the respiratory tract.

a Effects of ozone on morbidity indicators

There is convincing evidence that ambient levels of ozone are associated with increased morbidity in the exposed population. The indicators of morbidity most consistently associated with ambient ozone variations are school absence, hospitalization for asthma and respiratory infections in emergency rooms, and episodes of worsening chronic obstructive pulmonary disease.

Romieu et al (1992) showed a 20% increase in infant day care absences due to respiratory infections in Mexico City, when ozone levels remained above 260 $\mu g/m^3$ for two consecutive days. A study of first grade students in 12 Californian cities found that an increase of 40 $\mu g/m^3$ of ozone was associated with an increase of 62.9% in general absences, 82.9% for respiratory diseases, and 45.1% for diseases of the lower respiratory tract (Gilliland et al, 2001). A Nevada study found a 13% increase in absence of first graders with eight-hour increments of 100 $\mu g/m^3$ in average ozone concentration (Chen et al, 2000). And a study conducted with first grade Korean students showed that an increase of 32 $\mu g/m^3$ was related to an increase of 8% in absences (Park et al, 2002). These studies suggest that data for school absences can constitute an extremely sensitive instrument to detect acute effects of ozone on the infant population.

Monitoring the severity of asthma in children is another approach that has been used successfully to determine the adverse effects of ozone. A study in New Haven, Connecticut, showed that an increase of 100 $\mu g/m^3$ in hourly ozone levels was associated with increases of 35% in cases of wheezing and 47% in cases of respiratory symptoms (Gent et al, 2003). In a cohort study of 846 asthmatic children, an increase of 30 $\mu g/m^3$ was associated with morning respiratory symptoms (16%), followed by reduction of peak expiratory flow (Mortimer et al, 2000, 2002).

With regard to hospital admissions, the magnitude of the effects of ozone on the exposed population depends on the climate in the region where the study is conducted and on the type of indicator used. Given the large number of publications on this subject, **Table 3** summarizes the expected effects of different concentrations of ozone on hospital admissions.

b Effects of ozone on mortality

Contrary to the situation for particulate material, the relationship between ozone and mortality is less clear. This is because the magnitude of the effects was significantly affected by the specifications of the statistical models employed or the geographical location of the community being studied. However, studies conducted in various cities and more recent meta-analyses show that there are acute effects of variations in ozone and mortality of the exposed population, with an average coefficient of 0.256% in excess deaths for a 10 $\mu g/m^3$ increase of ozone. A summary of these studies can be seen in **Table 4**.

As for chronic effects, exposure to ozone has been linked to reduced lung function in children. However, the association with decreased life expectancy and increased risk for developing cancer has not yet been clarified.

Ambient concentrations of aldehydes in Brazilian cities

The research available in the scientific literature is somewhat disappointing, with a relatively small number of atmospheric aldehyde measurements. Taken together, these studies show that these measurements were a result of the initiative of research groups interested in the subject, rather than any systematic attempt at ambient monitoring of air quality for the purpose of safeguarding public health. This is a concern in a country such as ours, where mobile sources have high potential for emission of atmospheric aldehydes, given the wide use of ethanol, natural gas and diesel.

Table 5 shows available data for measurements of atmospheric concentrations of formaldehyde and acetaldehyde in some Brazilian cities.

Figures 4 and **5** show temporal variation of formaldehyde and acetaldehyde measurements in cities where data could be found in the literature. The compiled data does not permit a clear trace of the changes over the past 20 years. Moreover, the most recent data is from 2003, and so does not reflect the impact of flex-fuel vehicle growth, as well as the high rate of conversion of vehicles to natural gas.

Table 3

Estimate of the expected increase in hospital admissions for respiratory diseases compared to changes in the ambient ozone level

Expected increase of hospital admissions due to respiratory illness	O_3 concentration ($\mu g/m^3$)	
	1-hour average	8-hour Average
5%	30	25
10%	60	50
20%	120	100

Table 4

Summary of representative studies that link acute variations of ozone with mortality

Location of study	Findings	Reference
95 North American cities	20 $\mu g/m^3$ of ozone was associated with increments of 0.52% in total mortality and 0.64% in cardio-respiratory mortality.	Bell et al, 2004
23 European cities	An increase of 10 $\mu g/m^3$ was associated with an increase of 0.33% in overall mortality, including 0.45% of cardiovascular mortality and 1.13% in respiratory mortality.	Gryparis et al, 2004
Meta-analysis of studies conducted in seven European cities	An increase of 10 $\mu g/m^3$ was associated with an increase of 0.3% in overall mortality and 0.4% of mortality from cardiovascular diseases.	Anderson et al, 2004
14 U.S. cities	AAn increase of 20 $\mu g/m^3$ in the hourly ozone average was associated with an increase of 0.23% in respiratory mortality.	Schwartz, 2005
Meta-analysis of 39 time-series studies in the United States	An increase of 10 $\mu g/m^3$ was associated with an increase of 1.1% in mortality from cardiovascular disease.	Bell et al, 2005
Meta-analysis of 43 studies conducted in different parts of the world, with seven additional North American studies	An increase of 20-$\mu g/m^3$ in the hourly ozone average was associated with an increase of 0.39% in overall mortality.	Ito et al, 2005
Meta-analysis of 28 North American studies	Increase of 0.21% in overall mortality for an increase of 10 $\mu g/m^3$ in the average concentration of ozone.	Levy et al, 2005

As can be seen in **Table 5** and **Figures 4** and **5**, there is a larger set of data for the cities of Rio de Janeiro and São Paulo. Consolidating the measurements for these two cities, the ambient values of acetaldehyde and formaldehyde are those shown in **Table 5**. Generally speaking, the formaldehyde/acetaldehyde ratio in these two cities is about 0.5. Moreover, the concentrations of formaldehyde and acetaldehyde in Rio de Janeiro and São Paulo are much higher than those observed in other cities around the world, even those of similar size.

Estimated health effects of aldehydes

As mentioned earlier, there are no Brazilian or international studies linking ambient variations of formaldehyde and acetaldehyde to population morbidity indicators. What has been established is a numeric indicator for the risk of developing cancer, especially in the respiratory tract, as a result of ambient concentrations of these aldehydes.

Table 5 **Descriptive statistics of the measurements available in the literature on ambient levels (in $\mu g/m^3$) of formaldehyde and acetaldehyde in the atmosphere of Brazilian cities**

City		Formaldehyde	Acetaldehyde
São Paulo	N	17	17
	Average	11.7	24.3
	Median	8.8	18.8
	Minimum	1.6	5.0
	Maximum	28.8	54.8
	DP	8.1	16.6
Rio de Janeiro	N	8	8
	Average	11.7	26.2
	Median	8.9	10.7
	Minimum	2.3	3.4
	Maximum	33.0	86.3
	DP	9.7	31.6
Londrina	N	4	4
	Average	5.7	4.7
	Median	5.7	3.8
	Minimum	1.2	0.8
	Maximum	9.9	10.2
	DP	3.6	4.2
Porto Alegre	N	3	3
	Average	11.5	14.9
	Median	9.0	6.9
	Minimum	5.7	6.3
	Maximum	19.6	31.7
	DP	7.3	14.5
Salvador	N	3	3
	Average	15.5	19.0
	Median	13.7	11.3
	Minimum	3.6	6.3
	Maximum	29.1	39.6
	DP	12.8	17.9

Source: Monteiro et al, 2001; Andrade et al, 2002; Pinto et al; 2007, Martins et al, 2006.

According to census projections, the adult population (aged 20 years and over) in the metropolitan region of São Paulo is 12,674,944 inhabitants. Considering the unitary risk of developing cancer estimated for formaldehyde (1.3 x 10^{-5} cases per $\mu g/m^3$), and the average concentration of formaldehyde obtained from measurements in the literature (**Table 5**), we can estimate that approximately 1,928 and 678 cancer cases are due to

Figure 4

Average values and corresponding standard errors of formaldehyde concentrations measured in Brazilian cities between the years 1985 and 2003. *Formaldehyde ($\mu g/m^3$)*

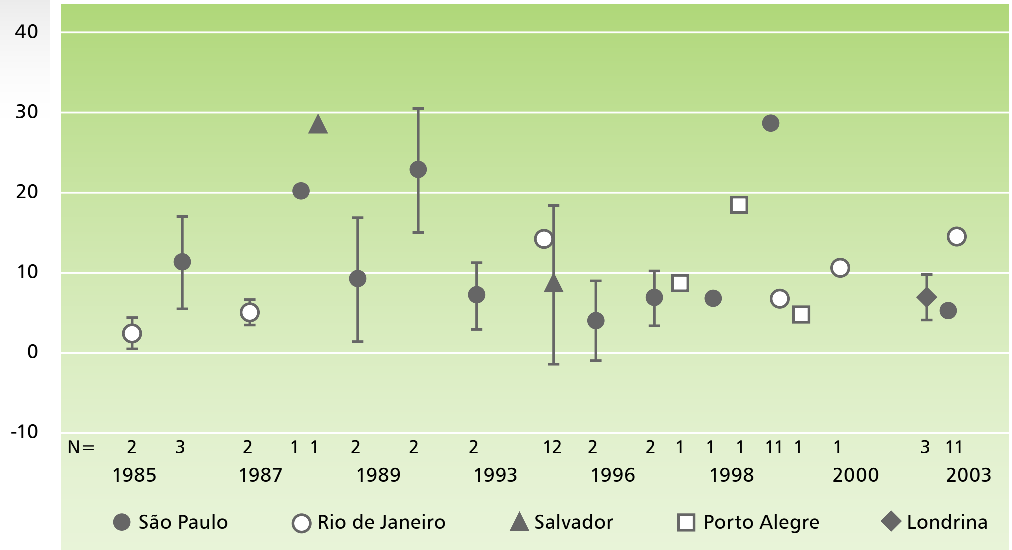
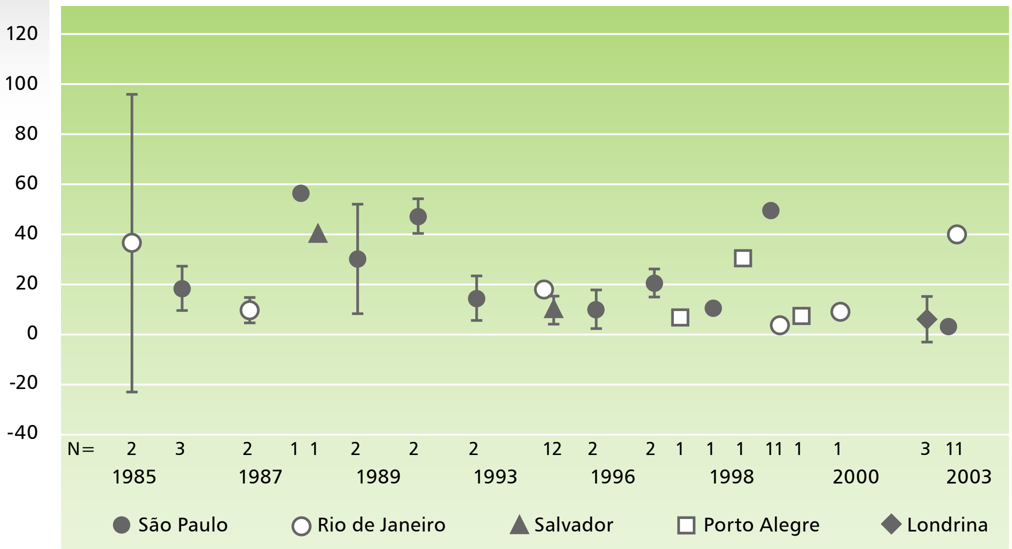


Figure 5

Average values and corresponding standard errors of acetaldehyde concentration measured in Brazilian cities between the years 1985 to 2003. *Acetaldehyde ($\mu g/m^3$)*



ambient concentrations of formaldehyde and acetaldehyde, respectively, in the metropolitan region of São Paulo. Considering that the average life of residents is about 70 years, and taking into account that population data was obtained for residents aged 20 years and over, then we can say that 52 new cases of cancer caused by concentrations of both aldehydes are observed in São Paulo each year.

Another possibility is to estimate the effects of aldehydes on health in the context of their potential for ozone formation. This type of approach has the advantage of offering a certain degree of support for the creation of vehicle emission standards directed to control ozone. Only one detailed study has been done in Brazil of vehicular emission factors for volatile organic compounds for vehicles in urban traffic conditions (a study of tunnels conducted by Martins et al, 2006). The results of this study are shown in **Table 6**. The same table also presents respective values of maximum incremental reactivity (MIR) for each of the compounds evaluated in the study, together with the estimated potential for ozone formation for each compound, defined as the product of emission factors (in g.km-1) multiplied by their respective MIR.

Volatile organic compounds have different levels of reactivity, which means they may have different potentials for forming ozone and other photochemical oxidants. These differences in the effects ozone formation are referred to as "VOC reactivity". The effect of the variation in VOC emission on ozone formation in a particular episode will depend on the magnitude of the variation of the emission. The MIR scale was developed by Carter (1994) and is based on averages for the increase in reactivity, calculated for various scenarios based on chamber studies and box type models. NOx concentrations have a considerable effect

Table 6 **Values of ambient concentrations of formaldehyde and acetaldehyde obtained in different cities of the world** *(in µg/m³)*

	Formaldehyde	Acetaldehyde
Los Angeles	1.8-13	1.8-16.5
Denver	2.8-4,8	1.,8-3
Atlanta	3.3	3.7
México	43.5	4.7-5.7
Copenhague	0.3-8	0.3-33
Paris	5-40	3.7-16.5
Grenoble	3.1-22	3.6-18
Roma	10.2-21.2	5.3-12.1
Londres	5.0-32.5	2.9-5.3
Leipzig	1.6-12.5	0.7-2.3
Urawa (Japão)	3.1-14.2	2.4-12.5
Algéria	5.2-27.1	2.6-10.3
Cairo	40	–
Hong-Kong	4.9	2.4

Source: according to data reported by Cecinato et al, 2002.

on VOC reactivities. In conditions of high NOx concentration, VOC reactivities are relatively insensitive to other conditions of the study scenario. However, in conditions of low NOx concentration, relative reactivities tend to be more sensitive to other ambient conditions.

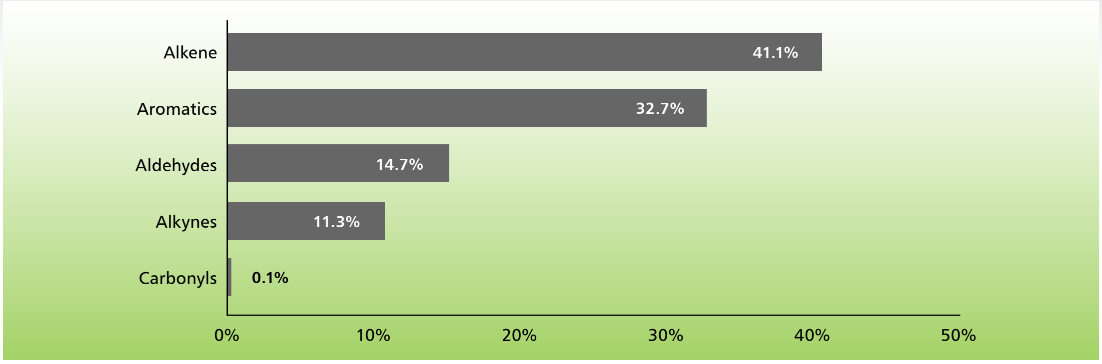
Potential for ozone formation can be represented graphically via the combination of different types of volatile organic compounds, as shown in **Figure 6**. Volatile organic compounds measured in this study represent a fraction of the total VOCs actually emitted. Thus, there is a significant part not included in the experiments. Therefore, the figures presented in **Figure 6** refer to the percentage of total VOCs measured in the interior of the tunnels.

It is important to note that the tunnels study was conducted in São Paulo in 2004, thus preceding the significant increase in flex-fuel vehicles observed in recent years. It is also important to point out that the measurements taken in the study by Martins et al (2006) represent a fraction of total volatile organic compounds emitted. In these conditions, the 14.7% potential for ozone formation attributed to aldehydes represents an over-estimation.

According to Cetesb data, annual averages for one-hour maximum ozone concentrations are around 90 $\mu g/m^3$ in São Paulo. As shown in **Figure 6**, all aldehydes together represent approximately 14.7% of the potential for ozone formation among the VOCs analyzed. The study by Grosjean et al (2002) shows that formaldehyde and acetaldehyde are the dominant aldehydes for ozone formation. If percentages attributable to aldehydes in ozone formation shown in **Figure 6** are applied to ambient concentrations measured in São Paulo, the annual averages for maximum one-hour ozone concentration would be 7.7 $\mu g/m^3$ produced by acetaldehyde and 5.6 $\mu g/m^3$ produced by formaldehyde. The estimated adverse events attributed under this scenario to direct and indirect effects of formaldehyde and acetaldehyde, for the metropolitan region of São Paulo, are presented in **Table 8**.

Figure 6 **Relative maximum potential for ozone formation of the classes of volatile organic compounds emitted by automotive sources**

Value determined by multiplying the emission rate (in g.km-1) by the respective MIR



Source: Andrade and cols, 2006.

Biofuels policy as a tool to promote public health

From what has been presented so far, we see that the process of fuel production generates pollutants that are associated with significant damage to health. Given the body of evidence about the adverse health impacts for sugar workers and the residents of towns surrounding the sugarcane plantations it is important to incorporate harvest mechanization into ethanol production, so avoiding the adverse impacts of emissions coming from straw burning (Ribeiro H., 2009).

When we look at the products of vehicular emission, acetaldehyde and formaldehyde represent a "new fact" in the use of ethanol as a light vehicle fuel, given their potential to form ozone. This is particularly important for the atmosphere in Brazilian cities that have high levels of NO_2, a situation implying that ozone formation becomes highly dependent on the increasing carbonyl concentration.

The use of ethanol as a fuel for heavy vehicles would also promote changes in the profile of emissions. With respect to aldehydes, the use of ethanol means exchanging formaldehyde emissions (a characteristic of diesel) for acetaldehyde (ethanol). More importantly, emissions of ethanol-fueled vehicles are much lower than those of the vehicles currently in use in Brazil, meaning that the emission of existing particulate matter from this automotive source would drop to virtually zero.

Each of the above cases deserves separate consideration. For the case of light vehicles that use ethanol as fuel, the increase in emissions of aldehydes is accompanied by a reduction of other volatile organic compounds associated with gasoline emissions. To simplify matters, we shall outline a situation of exchanging acetaldehyde for benzene, toluene and xylene, which are the volatile organic compounds most associated with petroleum derivatives. Considering the emission rates determined in tunnels (Martins & Andrade, 2008a) and presented in Table 7, we can infer that the potential for ozone formation of aromatic compounds (typical of petroleum products) is 6.3 times greater than that of acetaldehyde. Considering that aromatic compounds and olefins have ozone formation potential estimated from tunnel measurements of about 32.7% and 41.1%, respectively, and taking into account only the reduction of aromatic compounds, we can infer that using ethanol to replace gasoline would reduce the potential for ozone formation by about two times the current gasoline formulation. These results are consistent with those found in Martins and Andrade (2006) who – based on simulations with Eulerian photochemical models – obtained significant reductions in ozone

Table 8

Lethal effects

Estimate of the additional number of events that can be attributed to the direct effects (cases of cancer) and indirect effects (premature death from ozone formation) in the São Paulo metropolitan region, taking as a base estimates by Cetesb of direct emissions of the vehicle fleet and environmental measures of ozone.

São Paulo	Formaldehyde	Acetaldehyde	**Total**
Cancer	38	14	**52**
Premature death	120	169	**289**

Pollution in tunnels in São Paulo Table 7

Emission factors of volatile organic compounds emitted by vehicular sources, calculated from averages in tunnels in São Paulo, and the potential for ozone formation under maximum conditions defined as the product of multiplying the emissions factor by the respective MIR of each compound (gO_3/km)

Type	MIR	Emission (mg/Km)	Potential for ozone formation
toluene	2.7	134.5	363.15
1-butene	8.9	113.9	1013.71
n-pentane	1.04	87.9	91.42
cyclohexane	1.28	81.3	104.06
benzene	0.42	78.3	32.89
n-butane	1.02	74.9	76.4
M+p-xylene	7.4	62	458.8
n-hexane	0.98	60.1	58.9
1,2,4-trimethylbenzene	8.8	52.5	462
formaldehyde	7.2	48.4	348.48
acetaldehyde	5.5	45.7	251.35
o-xylene	6.5	44.4	288.6
n-heptane	0.81	41.1	33.29
1-ethyl-4-methylbenzene	8.8	32	281.6
ethylbenzene	2.7	31.1	83.97
n-octane	0.6	29.3	17.58
methylpentane	1.5	28.7	43.05
aldehydes >C2	6.3	24.9	156.87
n-nonane	0.54	22.6	12.2
isobutane	1.21	20.9	25.29
1,3,5-trimethylbenzene	10.1	20.8	210.08
1-pentene	6.2	19.6	121.52
3-methylhexane	1.4	19.5	27.3
1-ethyl-3-methylbenzene	2.7	19.3	52.11
cumene	6.5	17.9	116.35
1-ethyl-2-methylbenzene	8.8	16.4	144.32
decanoic acid	0.46	14	6.44
n-propylbenzene	2.1	12.2	25.62
methylcyclopentane	2.8	11.2	31.36
n-undecanoic acid	0.42	9.6	4.03
acetone	0.56	9.3	5.21
methylcyclohexane	1.8	9.2	16.56
1-methylethyl benzene	3	8.3	24.9
2,3-dimethylpentane	1.31	7.9	10.35
isoprene	9.1	7.6	69.16
2-butanone	1.02	6.9	7.04
1-hexene	4.4	6.8	29.92
n-dodecanoic acid	0.38	6.2	2.36
Styrene	2.2	5.7	12.54
2,2-dimethylbutane	0.82	4	3.28
2.4-dimethylpentane	1.5	3.7	5.55
2,3-dimethylhexane	1.31	3.3	4.32

Source: Martins et al, 2006.

production when considering a fictional scenario to replace all gasoline with ethanol in the light vehicle fleet. Various scenarios were considered for different gasoline formulas with reduced aromatics and olefins, but even so the use of ethanol had the effect of a greater reduction in ozone production.

Particulate matter also merits detailed analysis. An analysis of filters containing fine particulate matter, conducted over the past three years and associated with receptor modeling, indicates that diesel vehicle emissions account for about 25% of ambient concentrations of this pollutant in the cities of São Paulo and Rio de Janeiro. Since particulate matter emissions from heavy vehicles running on ethanol are practically nonexistent, the use of ethanol as fuel for heavy vehicles offers significant potential for reducing fine particulate matter, which is clearly associated with adverse health effects.

With respect to mortality, long-term studies conducted by Pope and colleagues (Pope et al, 2002) indicate that an increase of 10 $\mu g/m^3$ in the annual average of fine particulate matter leads to a 6% increase in general mortality.

As for morbidity, several epidemiological studies available in the literature relate morbid effects with both respiratory and cardio-vascular diseases for different age groups of the population, principally in terms of hospital admissions.

Given that we know the epidemiological coefficients for ozone and fine particulate matter, we can calculate the expected variations in health outcomes for changes in pollutant concentration levels by using **equation 12**:

$$[Events\ (MPolt)] = [\exp\ (\beta*(MPolt)-1]\ *\ Total\ Events$$

where **Events** is the total number of morbid outcomes associated with ambient exposure;
MPolt is the average change in pollutant concentration;
exp is the exponential function;
β is the regression coefficient obtained through epidemiologic studies; and
Total Events is the total number of morbid outcomes in the period under review.

Estimated ambient concentrations in scenarios for fuel substitution

We need data on health outcomes in order to apply the function described in **equation 12**. Figures regarding mortality and hospital admissions under the public health system, as well as the coverage rate of the private health care system, can be obtained from DATASUS databases. The relationship between remuneration of hospital admissions paid for by the public system and those paid for by the private health system were obtained from the São Paulo Hospital das Clinicas. Ambient concentrations of ozone, the availability of ethanol and gasoline in the metropolitan region of São Paulo, and the composition of gasohol (gasoline blended with ethanol) are available on the website of Cetesb, the São Paulo State environmental agency, while the concentrations of inhalable fine particulate matter are at the stage of being published.

As ozone is not a pollutant emitted directly by vehicles, but results from the photochemical reaction of several so-called precursor gases that are emitted by vehicles, among other sources, we shall consider the study by Martins and Andrade (2008b). This study used modeling and simulation to estimate a reduction of 29 mg/m^3 in the ambient concentration of ozone if all gasoline were to be substituted by ethanol in the São Paulo vehicle fleet. Scenarios for the partial replacement of gasoline by ethanol therefore use a proportional reduction of this ozone concentration.

Thus, the partial replacement of gasoline with ethanol would reduce the direct vehicular emission of precursor gases, and be potentially capable of reducing the ozone concentration in the same proportion to the maximum reduction estimated in the above-mentioned study. Were ethanol to be used by the diesel fleet, this would promote a direct reduction in fine particle emissions.

Based on the above assumptions, we can estimate the reduction in expected deaths and hospital admissions, avoided by ozone reduction, due to ethanol use in the scenarios of 5%, 10%, 15% and 100% gasoline replacement, and the reduction in expected deaths and hospital admissions avoided by the reduction of fine particulate matter under scenarios of 5%, 10%, 15%, 50% and 100% ethanol use in the heavy vehicle fleet.

Table 9 presents the impacts on the ambient concentration of inhalable fine particulate matter (MP2.5) for the diesel/ethanol scenarios, and ozone for the gasoline/ethanol scenarios.

As shown in Table 9, scenarios for ethanol use in place of diesel allow us to estimate a reduction in the ambient concentration of inhalable fine particulate matter of 2% to 25%, depending on the replacement scenario. When ethanol replaces gasoline, then depending on the replacement scenario we can expected a decrease of 2% to 30% in the ambient concentrations of ozone (due to precursors).

Estimated health costs avoided through environmental improvement

Establishing priorities for health prevention and management implies the need to estimate the cost of adverse effects of diseases. It is also important as an instrument for public management. Several approaches can be used to achieve this goal, the most direct one being to estimate the expenditure on direct investments in the health system and of expenditure lost due to the consequences of disease.

There are various approaches to determining environmental costs, and more specifically the public health costs arising from a particular environmental variation, which in the case of this study is a change in air quality.

The allocation of economic value to natural resources is based on principles of neoclassical economics, where the approach is to assign monetary values to social and environmental losses that result from ambient degradation. Thus, the idea of attributing economic value seeks to treat the social costs and benefits provided by the environment as an economic agent (Pearce, 1987).

The most accurate way to measure the impact of air pollution in a given region is to conduct epidemiological studies to establish dose-response functions that correlate morbidity and mortality in susceptible populations with ambient air concentrations.

Several methods have been used in various studies to put a value on health costs associated with ambient pollution. These methods can be grouped into two broad categories. The first approach – defensive expenditure – includes methods that measure only direct income loss (lost wages and additional costs). These do not include inconvenience, suffering, loss of leisure and other intangible impacts on individuals and on family well-being, and may well disregard or seriously underestimate the health costs of people who are not part of the labor market. This approach therefore indicates only the lower limit of the social costs of pollution and underestimates the total cost for individuals. The second broad approach – quota valuation – includes methods that attempt to capture the willingness of individuals to pay to avoid or reduce the risk of death or disease.

The cost of illness approach is applied to morbidity. Direct morbidity costs can be divided into two categories: medical expenses for treatment of ailments (cost of hospital care and out-patient treatment) and loss of wages during hospitalization, days missed at work and other times when activities are significantly restricted due to illness.

The preventive cost approach constitutes an attempt to infer the minimum amount that people are willing to pay to reduce health risks, and are calculated based on the amount that people living in polluted areas spend on preventive measures. For example, expenditure on bottled water to avoid water-borne diseases, or installation of air filters to prevent indoor air pollution.

Table 9

Scenarios for the reduction of particulate material

Expected behavior of a 2.5 PM concentration for scenarios of replacement of diesel by ethanol in the heavy vehicle fleet, and in the ozone concentration for scenarios for the substitution of gasoline by ethanol in the light vehicle fleet in the São Paulo Metropolitan Region.

Fuel substitution scenario	Environmental expectation for the pollutant concentration	Expected variation
5% of diesel by ethanol	Reduction in the 2.5 PM from direct emission	Up to 2%
10% of diesel by ethanol	Reduction in the 2.5 PM from direct emission	Up to 3%
15% of diesel by ethanol	Reduction in the 2.5 PM from direct emission	Up to 4%
50% of diesel by ethanol	Reduction in the 2.5 PM from direct emission	Up to 13%
100% of diesel by ethanol	Reduction in the 2.5 PM from direct emission	Up to 25%
5% of gasoline by ethanol	Potential reduction of ozone from precursor emissions	Up to 2%
10% of gasoline by ethanol	Potential reduction of ozone from precursor emissions	Up to 3%
15% of gasoline by ethanol	Potential reduction of ozone from precursor emissions	Up to 5%
100% of gasoline by ethanol	Potential reduction of ozone from precursor emissions	Up to 30%

The contingency value approach uses survey data to determine how much people are willing to pay to reduce the risk of premature death from disease. Studies on contingency valuation produced Values of a Statistical Life (VSL) that are relatively lower than the wage differential, ranging from US$1.2 million to US$9.7 million per statistical life (IEI, 1992; U.S. EPA, 1997).

The technique of calculating the economic value of health impacts used to make this estimate was based on evidence from epidemiological studies and economic theory, developed by the World Health Organization (WHO) and by Harvard University. It is called the Disability-Adjusted Life Year (DALY), implying the years of life lost or lived with disability (Murray and Lopez, 1996). This method is based on studies that associate an ambient factor (in this case pollution) with a health indicator (hospital admissions and mortality) to estimate how many years each adverse health event has impacted the population. In other words, how many years of life each affected person has lived with temporary or permanent disability – defined as health status less than perfect – and how many years of life were lost, relative to their life expectancy, by each person suffering premature death. The years of life indicator can be converted into a monetary base for the purpose of a cost-benefit evaluation (Miraglia, 2002).

Techniques to place an economic value on health impacts constitute a tool for evaluating projects and policies for public health and pollution control, lending support to the decision making process.

In this sense, estimating potential health costs that could be avoided by virtue of ambient improvement in air quality arising from the adoption of scenarios to use ethanol in place of gasoline in light vehicles, and in place of diesel in heavy vehicles, provide this analysis with an important parameter for benchmarking biofuels policy.

Mortality – annual avoided costs

Tabela 10 shows total annual deaths that would potentially be avoided through the use of ethanol in the various scenarios, due to improvements in ambient concentrations of ozone and fine particulate matter, together with the related value of avoided mortality costs. The calculation of value of deaths avoided by the reductions in concentrations of ozone and fine particulate matter were obtained from the average values of years of life lost due to ambient concentrations of air pollutants in São Paulo (Miraglia et al, 2005) applied to scenarios for potential mortality reductions (Table 9) and using the current rates of life expectancy of the population (IBGE, 2008).

As can be seen in Table 10, the potential for avoided mortality through the introduction of ethanol into the energy matrix can be translated into annual economic benefits ranging from US$1 million to US$133 million, respectively, for scenarios of ethanol replacing 5% of gasoline, and 100% of diesel. These values point to the magnitude of potential benefits that could come from the implementation of a biofuel policy for the Metropolitan Region of São Paulo, even under the conservative scenarios.

Morbidity – annual avoided costs

The estimate of morbidity detailed here takes into account only those costs associated with hospital admissions for diseases and population age groups that are most consistently associated with air pollution, namely, hospital admissions for respiratory diseases for children up to four years of age and adults over 40 years of age, and cardiovascular disease only for adults over 40 years of age. This estimate may therefore be considered conservative, by omitting other less frequent outcomes and other age groups, but it is in line with the criteria commonly used in this type of estimate.

Table 11 shows the benefit in terms of morbidity reduction that would arise as a result of using ethanol in place of gasoline and diesel. It also presents estimates of value for each fleet replacement scenario, using the methodology described.

Conservative estimates therefore indicate that using ethanol in the replacement scenarios described above would create a morbidity reduction that, translated into economic benefits, would range from US$0.6 million to $19.8 million annually for the scenarios of ethanol replacing 5% diesel and 100% of gasoline, respectively, and considering only the Metropolitan Region of São Paulo.

Final thoughts, and an analysis of uncertainties

This chapter assumes that impacts on human health should be part of the life cycle analysis of fuels. The exposure of entire populations to atmospheric emissions, both in the fuel production process as well as from vehicle emissions in major metropolitan areas, clearly points in that direction. In the case of ethanol, both positive and negative characteristics have been identified for its use as an alternative to fossil fuels.

Table 10 **Potential annual variation in mortality by scenarios of ethanol addition in the metropolitan region of São Paulo and its economic assessment**

Scenario for substitution of fuels	Annual Mortality		
	Diagnosis	Quantity	US$ million
5% of diesel by ethanol	Reduction	37	6.63
10% of diesel by ethanol	Reduction	75	13.45
15% of diesel by ethanol	Reduction	112	20.08
50% of diesel by ethanol	Reduction	373	66.89
100% of diesel by ethanol	Reduction	745	133.60
5% of gasoline by ethanol	Reduction	6	1.07
10% of gasoline by ethanol	Reduction	13	2.33
15% of gasoline by ethanol	Reduction	19	3.40
100% of gasoline by ethanol	Reduction	130	23.31

The main negative aspects in the ethanol production process are the process of burning off straw during harvest, and the question of water balance during the plant's growing cycle, together with the problems of mono-culture and land use. Fortunately, the industry can significantly reduce this trend via self regulation. The assessment of the current impacts of sugarcane straw burning is based on the few studies that have been conducted in São Paulo. The absence of an efficient monitoring network in rural areas complicates an in-depth analysis of this issue. Burning sugarcane straw also undermines bio-ethanol's efficiency in the balance of greenhouse gases. Considering these two points – local effects of pollutants and global effects on climate – the conclusion must be that there is no environmental or human health argument to justify straw burning prior to harvest.

With regards to the effects of vehicle emissions, ethanol has advantages over both gasoline and diesel. This is evidenced by the favorable balance in terms of global climate change, and also as a factor in reducing tropospheric ozone production (when used as a substitute for gasoline) and aerosol (substituting diesel). Given the quality of petroleum derivative fuels sold in Brazil today, ethanol constitutes an alternative within the list of measures and possible improvements in terms of air quality and reduced health impacts of air pollution. One of the most significant aspects, in our view, is using ethanol in bus fleets in major urban centers.

The impact of ethanol on ozone production is one of the key points in the discussion about the health effects of ethanol emissions. Given the current formulation of Brazilian gasoline, current vehicle technology, and the scenario of high concentrations of nitrogen oxides in Brazilian cities, our projections are that fuel ethanol reduces tropospheric ozone formation. In this case, there are some degrees of uncertainty. The most significant limitation here is the lack of historical and consolidated data for ambient concentrations of aldehydes in the regions under study. The available data relate to sampling periods with different sampling times and were usually performed in isolated spots. It is regrettable that Brazil, where the last three decades have seen significant changes in the matrix of automotive fuels, has paid so little attention to ambient measurement of aldehydes. Another limiting aspect of the study is the shortage of data for auto-

Table 11 **Annual potential variation of morbidity under scenarios for the addition of ethanol in the São Paulo Metropolitan Region, and respective economic values**

Scenario for substitution of fuels	Annual morbidity Hospitalizations (SUS and private)		
	Diagnosis	Quantity	US$ million
5% of diesel by ethanol	Reduction	224	0.63
10% of diesel by ethanol	Reduction	450	1.26
15% of diesel by ethanol	Reduction	675	1.89
50% of diesel by ethanol	Reduction	2,270	6.38
100% of diesel by ethanol	Reduction	4,588	12.86
5% of gasoline by ethanol	Reduction	398	0.98
10% of gasoline by ethanol	Reduction	795	1.96
15% of gasoline by ethanol	Reduction	1,193	2.95
100% of gasoline by ethanol	Reduction	8,002	19.79

motive emissions based on measurements in the field, such as the tunnels experiments mentioned earlier. Significant changes in fleet profile – the introduction of flex-fuel vehicles and the significant conversion of part of the fleet to vehicles running on natural gas – could not be considered in this study, a step that would have allowed health risks to be broken down by sectors of the vehicle fleet.

The two above-mentioned factors prevent the creation of photochemical models with the accuracy needed to assess the contribution of different fuels to the production of aldehydes and ozone. It is therefore necessary to obtain this key information to reduce the uncertainty of the estimates and, as a consequence, to support the development of consistent public policies in the areas of air pollution and public health in urban centers.

There is also a lack of studies on the effects of biofuels use on the emissions of heavy vehicles, with respect to the behavior of the engine and the filter system for particulate matter. There are many studies regarding changes in emissions of nitrogen oxides and fine particles due to the use of biofuels in heavy vehicle engines.

The calculation of the economic value of environmental benefits translated into health indicators shows a favorable scenario for implementing such a change in the current energy matrix, increasing resources for other investments which should prioritize the health of populations exposed to air pollutants, as well as rail transportation.

Concept of adverse or harmful effect on human health

Annex 1

The most widely adopted definition used to describe an adverse health effect is the one approved by the American Thoracic Society (1995). This defines a health impact as "a significant medical event, characterized by one or more of the following factors: **1)** interference with the normal activity of the affected individuals; **2)** episodic respiratory illness; **3)** incapacitating illness; **4)** permanent respiratory disease; **5)** progressive respiratory dysfunction."

In 2000, in light of new scientific knowledge, the American Thoracic Society expanded the scope of its previous definition, incorporating the following events: biomarkers, quality of life, physiological effects, symptoms, increased demand for medical care and finally, mortality (American Thoracic Society, 2000). More recently, in 2004, the American Cardiology Society (Brook et al, 2004) published a document acknowledging air pollution as a risk factor for aggravating cardiovascular diseases, in particular acute myocardial infarction, congestive heart failure, and the development of arrhythmias.

Studies with data from the American Cancer Society (Pope et al, 2002) include lung cancer as an indicator of the effects of air pollution. Finally, reproductive alterations such as low birth weight, miscarriage and abnormal sex ratio at birth have also been incorporated into the set of indicators of significant adverse effects of air pollution.

As mentioned above, several adverse effects of air pollution on human health can be identified. Some of them are acutely apparent, manifesting just hours or days after exposure, while others become evident only after long periods of exposure. Both the acute and chronic effects may exhibit different levels of severity, ranging from vague discomfort to death – the outcome of greatest severity. Some examples may help to better clarify these ideas. Increases in air pollution will cause cognitive alterations or non-specific irritability in a large fraction of the population. A smaller proportion of exposed individuals will present increases in plasma markers and lung inflammation, indicating the presence of subclinical inflammation. In an even smaller proportion of the population, this inflammation may cause functional alterations such as increased blood pressure, mild disturbance of autonomic heart control or a reduction in indicators of lung function. At a greater level of severity, chronic users of medication to control respiratory and cardiac diseases (for example, asthma and hypertension) will need larger amounts of drugs to control their conditions. There will be those who, unable to control the changes by themselves, consult a doctor or, in more serious cases, will receive treatment at first aid posts or hospitals. Finally, a fraction of those affected will die the same day, or a few days later, due to the effects of the pollution to which they were exposed (**Figure 2**).

Most studies that use severe outcomes, such as respiratory hospitalizations and mortality, to assess acute pollution effects are likely to have human health and air pollution related coefficients that undermine the real effects, since events that affect quality of life, such as impaired control of chronic diseases, are not accounted for by the lack of mandatory reporting of such issues.

Annex 1 **Concept of adverse or harmful effect on human health**

Long-term studies that monitor population groups for extended periods of time recognized that pollution effects could only be detected after years of exposure. Similar to the effects of cigarettes, which only manifest after years of tobacco consumption, pollution presents, to a lesser extent, some of the same chronic effects. **Table 2** shows the relationship of some chronic effects of air pollution.

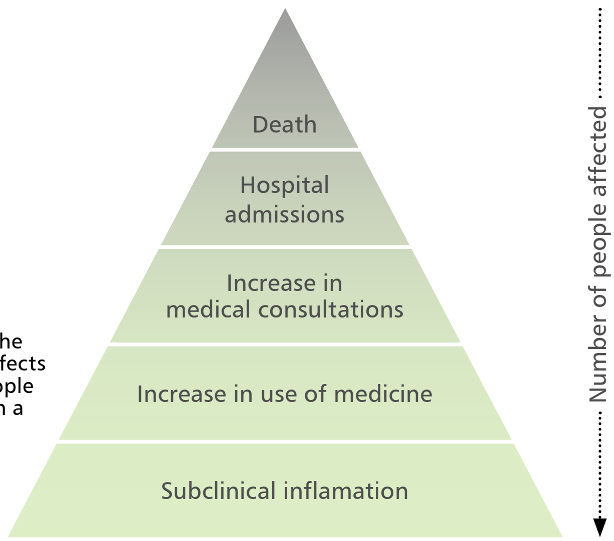


Figure 2 Diagrammatic representation of the relationship between the severity of pollution effects and the number of people affected by pollution in a given community.

Source: adapted from American Thoracic Society, 2000.

Table 2 **Some of the secondary outcomes most consistently reported in the literature as relating to chronic exposure to air pollutants**

Increased respiratory symptoms	Worsening of arterial atherosclerotic
Reduced lung function	Increased frequency of abortions
Reduction of birth weight	Higher incidence of pulmonary neoplasms
Greater incidence of obstructive pulmonary disease	Loss of years of life due to cardio-respiratory diseases

Source: adapted from WHO, 2006.

Aldehydes as ozone precursors

Annex 2

The general simplified equations governing photochemical atmospheric pollution can be summarized as follows:

NO_2 is dissociated by the action of ultraviolet rays forming NO and atomic oxygen;

$$(1) \quad NO_2 + h\nu\ (\lambda \leq 430\ nm) \rightarrow NO + O$$

The oxygen atom combines with one molecule of oxygen to form ozone;

$$(2) \quad O + O_2 \rightarrow O_3$$

Ozone is decomposed by the reaction with NO, forming NO_2 and one oxygen molecule;

$$(3) \quad NO + O_3 \rightarrow NO_2 + O_2$$

The process described in reactions **1** to **3** is photostationary. In other words, the balance of ozone production is close to zero. However, the atmosphere of major cities favors the disruption of photostationary cycle, allowing the generation of significant amounts of ozone, as clearly shown by environmental measurements taken in Brazilian urban centers. The reaction of NO with peroxides is the greatest cause of photochemical imbalance, as shown in reaction **4**;

$$(4) \quad NO + RO_2\cdot \rightarrow NO_2 + RO$$

Atmospheric peroxides are formed by the oxidation of several organic compounds, as shown in the following equations, which illustrate possible outcomes of the oxidation of an alkene;

$$(5) \quad RCHCHR + O \rightarrow RCH_2\cdot + RCO\cdot \quad \text{(generation of free radicals)}$$

$$(6) \quad RCH_2\cdot + O_2 \rightarrow RCH_2O_2 \quad \text{(generation of peroxides)}$$

$$(7) \quad RCH_2O\cdot + O_2 \rightarrow RCHO + HO_2\cdot \quad \text{(generation of aldehydes)}$$

$$(8) \quad RCH_2O_2\cdot + NO_2 \rightarrow RCH_2O_2NO_2 \quad \text{(generation of organic nitrates)}$$

The group of above-mentioned reactions exemplifies some of the possibilities by which volatile organic compounds (VOCs), such as aldehydes, can be generated or interfere with the stationary photochemical equilibrium, allowing the formation of ozone. The process can be summarized as follows: in the absence of VOCs, the amount of ozone formed in the troposphere is very low; the presence of VOCs can consume NO or convert NO to NO2, creating the real possibility of the formation of ozone, according to the following general formulas:

$$(9) \quad VOC + OH\cdot \rightarrow RO_2\cdot + intermediate\ products$$

$$(10) \quad RO_2\cdot + NO \rightarrow NO_2 + free\ radicals$$

$$(11) \quad radicals \rightarrow OH\cdot + intermediate\ products$$

Annex 2 Aldehydes as Ozone Precursors

Under the conditions set out above, the process of ozone formation is dependent on the amount of VOCs available in the troposphere, as well as the amount of OH radicals or other chemical species with which VOCs can interact (Carter, 1994). The influence of VOCs on ozone formation depends on the amount of NOx available. If NOx levels are sufficiently high, the amount of VOCs is the limiting factor for ozone formation. In these conditions, when NOx concentrations are high, the NOx inhibits the formation of ozone because the reaction of OH with NO_2 limits the formation of reactive species in the atmosphere. On the other hand, when NOx concentrations are low, ozone formation is dependent on the availability of NOx, causing the increase in the concentration of NOx to increase the rate of ozone formation.

These equations explain the sequence of ozone formation. However, at night and close to large sources of NO (for example high-traffic zones), ozone concentrations are reduced via processes of removal of O_3 by the reaction with NO [**equation 3**].

During the day this reaction is generally balanced by the photolysis of NO_2 [**equation 1**]. However in the vicinity of large emissions of NO the net result is the conversion of O3 to NO_2. In the vicinity of such sources, ozone is consumed and can become higher as the plume moves with the wind (plume aging). As there is no photolysis of NO_2 at night, this [**equation 3**] leads to ozone removal.

The classification between systems with saturation of NOx and sensitive to NOx (NOx-limited) is determined by the chemistry of hydroxyl radical (OH) and hydroperoxide (HO_2) and peroxyl radicals in organic RO_2 form.

The atmosphere manifests a system that is sensitive to NOx (NOx-limited) when peroxides and carboxylic acids represent the dominant radical sink. In this case, the ambient concentrations of HO_2 and RO_2 will be determined by the balance between free radical sources and reactions for the formation of peroxides and carboxylic acids.

Since the rate of peroxide formation is quadratic in HO_2, ambient concentrations of HO_2 and RO_2 vary only slightly in response to changes in NOx and VOC. The rate of ozone formation is determined by the reaction of HO_2 and RO_2 with NO. In polluted regions the rate of ozone formation is generally little affected by variations in VOC. In more remote areas, the rate of ozone formation also increases with the increase in concentration of VOCs.

NOx-saturated regimes (VOC-limited) occur when nitric acid is the dominant radical sink. In this case, ambient concentrations of OH will be determined by the balance between free radicals and the reaction of OH with NO_2. Since the rate of nitric acid formation increases with NO_2, the ambient OH decreases with the increase of NO_2. The rate of ozone formation is determined by the rate of VOC and CO reaction with OH. This rate increases with increasing VOC and decreases with increasing NOx.

The division between regimes that are sensitive to NOx (NOx-limited) or to VOCs (VOC-limited) is closely related to the ratio of the sum of VOCs with NO_2, bearing in mind that the sums are weighted by the reactivity of the VOCs.

The ratio of free radicals to the rate of nitric acid formation is proportional to the ratio of the sum of all VOCs (weighted by reactivity with OH) with NO_2. When this ratio is high, the peroxides become the dominant radical sink and conditions are sensitive to NOx. When this ratio is low, nitric acid becomes the dominant radical sink and conditions are of NOx saturation. Ozone photolysis is the greatest source of the hydroxyl radical (OH) in the troposphere of remote regions, meaning that an increase in O_3 will produce more OH, resulting in a decrease in the lifetime of many trace species such as methane and hydrochlorofluorocarbons (HCFCs), which are species of great importance to physical and chemical processes in the stratosphere.

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Explanatory Notes

[i] Comeap (Committee on the Medical Effects of Air Pollution).
[ii] Iris (Integrated Risk Information System).

05

Sugar-Ethanol Bioelectricity in the Electricity Matrix

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Bioelectricity related to the production of sugar and ethanol has exceptional potential to play a strategic role in the expansion of the national electrical power system. This is because it is highly complementary to hydroelectricity, allows for distribution close to centers of consumption, and offers significant socio-economic and environmental benefits.

Bioelectricity produced from bagasse complements hydropower because it provides electricity during the driest months of the year. In 2008, the country's potential hydraulic energy (ENA in Portuguese) was between 80 to 90 GW av from January to March, falling to between 30 to 40 GW av in the period June to November, while sugarcane crushing in the Center-South region was above 80% of its maximum value in the period May through September. It is important to note that the potential for annual production of bioelectricity is almost 15,000 MW av by the end of the decade, representing approximately 15% of Brazilian national demand.

New hydropower dams increase the need for this complementarity, given the significant reduction in their reservoir capacity as a result of physical and environmental restrictions. With the construction of new dams in the North of Brazil (including Belo Monte), the ENA will be close to 120 GW av from January to April, but will not exceed 40 GW av between July and October.

This complementary characteristic of bioelectricity and hydroelectricity can play a strategic role in helping the country maintain a clean and renewable energy matrix, avoiding the need to use

fossil fuel powered thermoelectric stations as a backup. Estimates from the National Electricity System Operator (ONS in Portuguese) indicate that every GW av of bioelectricity injected into the National Interconnected System (SIN in Portuguese) can economize 4% of the reservoirs in the Southeast/Center-South electricity sub-system during the dry season.

The A-3 and A-5 auctions for new energy (open to projects of all sources) held in 2007 and 2008 used criteria and rules that favored oil-fired thermoelectrics, which have high costs of generation. Of the thermoelectric plants contracted, 98.9% were powered by fossil fuels (63% by oil) and just 1.1% by bagasse.

Sugarcane bioelectricity offers environmental benefits (reduction in the emission of greenhouse gases), economic benefits (job creation), and the guarantee of electrical energy supply (with decentralization). However, this competitive advantage is not being given adequately value by the current rules for energy auctions.

We recommend contracting energy through specific actions for each source, or auctions that are specific for generation during the dry season, and the formulation of a specific industrial policy that can create better conditions for power plants to connect to the grid and sell energy.

1. Introduction

The Brazilian electricity matrix is based predominantly on hydropower. This gives the country a privileged position vis-à-vis the rest of the world in matters of environmental sustainability. Most countries nowadays are seeking to increase the participation of renewable energy sources in their electricity matrixes in order to expand their energy supply while reducing their greenhouse gas emissions.

However, Brazil's unique matrix should not prevent the country from investing in alternative and renewable energy sources like sugarcane bioelectricity. An adequate understanding of the dynamics of introducing renewable and alternative energy sources into the national energy matrix requires an acknowledgment that the current model, based on hydropower plants with large reservoirs, is coming to an end. Limiting factors are physical questions and the attitude of environmental authorities, who will only license new hydroelectricity power plants that have small reservoirs. This means that diversification of national generating capacity is both necessary and inevitable within the growth of the Brazilian electricity system through the next few decades, with particular emphasis on energy sources that complement hydropower.

Given this process of evolution, it is important to analyze which alternative energy resources should be prioritized in the coming years.

One strategic option for Brazil's energy future is contracting energy sources that are complementary to hydropower, and that simultaneously contribute to maintaining Brazil's clean energy matrix. Sugarcane bioelectricity is outstanding among such sources, mainly thanks to the following characteristics:

I Costs competitiveness
II Seasonal complementarity in relation to the rainfall pattern
III Maturity of the sugar and ethanol industry
IV Contribution to reduction of GHG emissions
V Proximity to demand centers

The goal of this paper is to analyze and demonstrate the importance of sugarcane bioelectricity for maintaining the key characteristics of the electricity matrix, ensuring: reliable supply; national economic competitiveness, and environmental sustainability. Sugarcane bioelectricity offers the advantages inherent in a renewable energy source, generated through an efficient co-generation process, using as its primary energy source residual biomass from ethanol and sugar production. On the other hand, bioelectricity offers additional advantages for Brazil, such as the creation of income and employment in rural areas, stimulus for the capital goods industry, and a positive impact on the trade balance – the import coefficient is close to zero, avoiding not only the importation of equipment, but also of fuel.

This study is divided into two parts. The first is dedicated to an analysis of the transition currently underway in the Brazilian energy matrix, and the growing need to develop energy sources that are complementary to hydroelectric power, while the second part looks at bioelectricity as a complementary and competitive source for the Brazilian energy matrix, while also presenting a brief study of its environmental sustainability. Finally, we present conclusions that in general terms demonstrate bioelectricity's high degree of competitiveness, provided that current criteria for contracting energy are reviewed, as are the externalities of bioelectricity in comparison to other energy sources.

2. Transformation of the Brazilian generation matrix

Hydroelectric power plants constitute more than 80% of Brazil's energy generating capacity[i]. In terms of effective generation, around 90% of the Brazilian electricity supply comes from hydropower plants, as shown in **Table 1**. Brazil is second only to Norway in terms of hydropower participation within total capacity, as shown in **Table 2**.

The preponderance of hydropower in the Brazilian energy matrix ensures the supply of electricity at competitive prices[ii] and with reduced levels of carbon emissions[iii]. However, it is important to understand how the

Participation of hydropower in total generation – Brazil *In %* **Table 1**

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008
Percentage (%)	94.11	89.65	90.97	92.14	88.63	92.45	91.81	92.78	88.61

Source: site of ONS (National Electricity System Operator); operational history.

Participation of hydropower in total installed generating capacity – selected countries *In 2006* **Table 2**

Countries	Participation percentage (%)
Norway	98.5
Brazil	83.2
Venezuela	72
Canada	58
Sweden	43.1
Russia	17.6
India	15.3
China	15.2
Japan	8.7
USA	7.4
Rest of the World	14.3
World Mean	16.4

Source: IEA (2008).

Brazilian electricity generating sector manages to supply such a high percentage of total demand even though it is subject to irregular precipitation and seasonal variation of the rivers. Graph 1 shows the seasonal behavior of average river flows. We can see that potential hydraulic energy (ENA)[iv] exceeded 89,000 MW av in February, compared with an average of 30,000 MW av in September[v]. Another relevant fact is the comparison between the average ENA and the load. During the dry season, between May and November, the ENA is around 38,000 MW av while the load of the National Interconnected System (SIN) is around 51,000 MW av (2008 data).

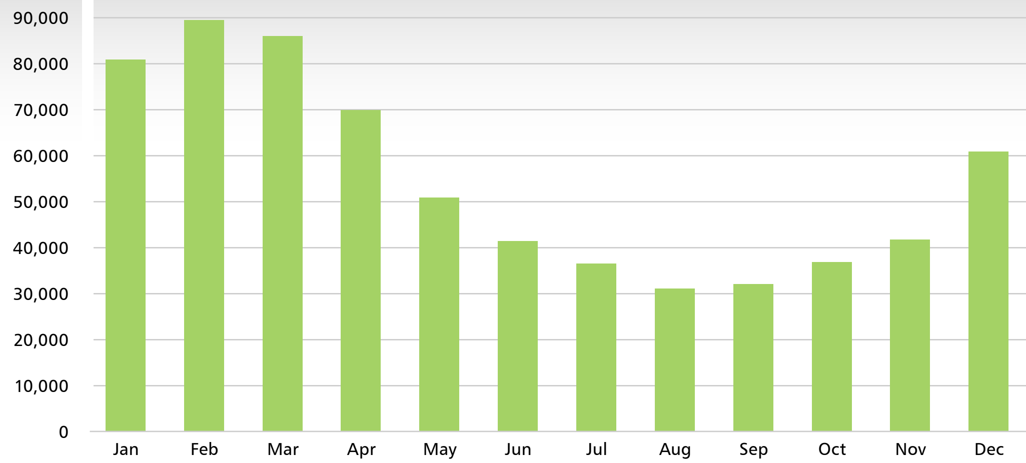
Up until now, it has only been possible to exploit Brazil's great hydropower potential with the construction of dams that have large reservoirs. The uncertainties related to seasonal river flows have been reduced by storing water during the wet season for its eventual use during the dry season. The potential energy of water in the reservoirs (called Stored Energy or SE) allows for the constant generation of energy throughout the year, or even for a few years.

Although Brazil has so far developed only 30% of its total hydroelectric potential[vi], the current model based on power plants with large reservoirs is drawing to an end. Installed hydroelectric capacity will grow in the coming years with small increases in the energy storage capacity of the system. This will reduce the ability to regularize energy supply during the year, as shown in **Graph 2**.

There are both physical and environmental restrictions on the construction of new reservoirs. Physical limitations lie mainly in the fact that the majority of potential hydropower sites in the Brazilian altiplano have now been developed, and remaining sites lie mainly in the flatter North region. It is difficult to build hydropower stations with substantial regulatory reservoirs in a region where the topography is predominantly smooth. It would be possible to flood large areas, but given the gentle slopes even large reservoirs would afford only modest energy storage. There are also environmental restrictions. Brazilian environmental legislation has become much tougher since the introduction of the new Constitution in 1988, and

Graph 1 • **Potential hydraulic energy**

Historic average; includes SIN subsystems (2008 configuration) in thousands of MW average



Source: ONS website (www.ons.org.br). Data assembled by GESEL/IE/UFRJ from the operation's historic databank in 2008.

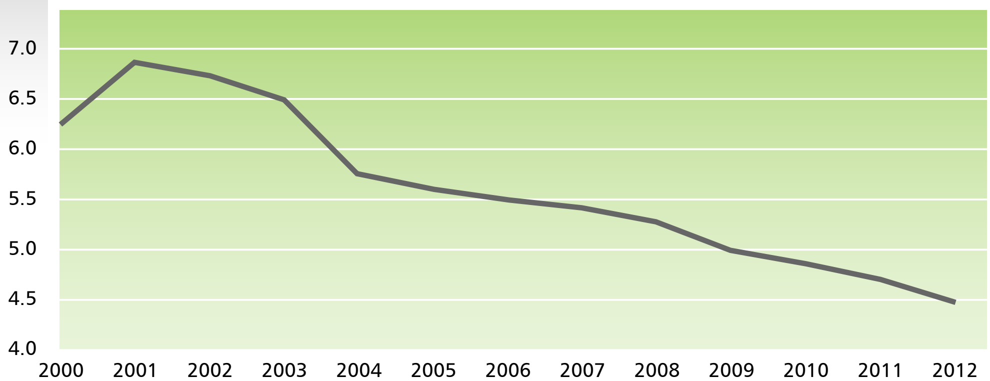
environmental authorities limit the construction of new reservoirs and even expansion of the country's hydroelectric capacity.

Given the physical and environmental restrictions mentioned above, the new hydropower plants now being built or planned have essentially run-of-river characteristics, without significant storage reservoirs. The sites on the Madeira River that recently went to tender are representative of this trend: the new reservoirs will occupy an area only slightly larger than is normally flooded during the rainy season. Belo Monte and the stations on the Tapajós and Teles-Pires rivers will follow the same general pattern. The inevitable consequence will be less ability to regulate the river flow and reduced hydropower generation.

The decreased ability to regularize the power supply by using large reservoirs will lead to growing difficulty in meeting energy demand from hydropower sources alone during the dry season. This allows us to conclude that the Brazilian electricity sector faces the challenge of complementing the existing hydropower plants with generators that operate efficiently during the dry season. Contracts for generation that complements hydropower capacity have given preference to thermoelectric plants burning fossil fuels, which in most cases have poor technical and economic efficiency. These power plants have low fixed costs, but high variable costs of generation. The logic of contracting power from such plants is to provide a backup for the hydropower capacity, because expectations are that they have a low probability of being dispatched. However, with the reduced ability of reservoirs to maintain constant power supply, these thermoelectric power plants will be dispatched more frequently than the original prediction, above all during the dry season. When the thermoelectric generators cease to play the role of simple back-up during moments of lower rainfall, their operational cost with lower technical and economic efficiency will prove to be excessive.

The Brazilian power sector therefore requires new generating stations that will complement the hydro stations with the technical and economic profile to supply base load during the dry season. Among the alternatives to complement hydropower generation, sugarcane bioelectricity is the most efficient.

Graph 2 **Change in reservoir capability to regularize generation** *Maximum stored energy/load*



Source: Chipp, Hermes. Operational procedures to ensure SIN energy supply. Presentation at GESEL-IE-UFRJ, Rio de Janeiro, July 9th, 2008.

3. Characteristics and benefits of sugarcane bioelectricity

Guaranteeing security of supply coupled with environmental sustainability will require investment in alternative and renewable sources as well as efficient processes of generation. Bioelectricity fits this premise because it is generated from biomass left over from sugar and ethanol production. Because it uses waste as its primary energy source, bioelectricity is, by definition, a renewable, efficient and sustainable source of energy. It is energy produced via co-generation, a process that ensures a significant degree of efficiency[vii]. Moreover, most of it is produced in São Paulo and neighboring states, which is the country's main region for electricity demand. This constitutes another plus in terms of economic and electricity efficiency, by reducing transmission costs and losses.

However, these benefits have not been adequately and correctly priced in at Brazil's auctions for new energy. Auction results indicate bioelectricity's apparent lack of competitiveness in comparison to other sources of energy. The supposed lack of competitiveness is the result of unfavorable auction methodology, which does not correctly value the benefits that bioelectricity offers to the Brazilian electricity system thanks to its natural complementation of the hydropower generation system.

Sugarcane bioelectricity is an energy source that contributes to the security of Brazilian electricity supply by diversifying the matrix and above all by complementing hydropower production, besides being environmentally sustainable. Unlike other forms of thermal energy production, bioelectricity is carbon neutral. This is a highly desirable characteristic that has not been properly valued at auctions.

3.1 Potential and costs of bioelectricity

According to Corrêa Neto and Ramón (2002), the sugar-energy sector is traditionally self-sufficient in terms of energy, meeting 98% of its energy demand by burning sugarcane bagasse. Co-generation provides the thermal, mechanical and electrical energy needed for the production of ethanol and sugar. However, this self-sufficiency has traditionally been ensured via inefficient production processes that yield just enough energy to supply the mill itself.

According to Dantas (2008), the decision to adopt low-efficiency cogeneration technologies was aimed at maximizing bagasse incineration, given the difficulties of storing the product and the low market value of raw bagasse. There was also no commercial interest in investing in more efficient power plants that would be able to export surplus energy to the grid.

Until the early 1990s, the Brazilian energy sector was organized in vertically integrated monopolies with centralized energy production. Regulations did not permit entities other than the concessionaires to sell energy. This arrangement lasted until the mid 1990s, when independent energy producers were allowed. This created a legal structure that allowed sugar and ethanol plants to "export" electricity to the grid, so creating the scenario for investment in efficient co-generation plants, aiming to sell surplus energy.

Although the sugarcane sector has long had the technical potential to sell its surplus energy, it is only recently that this has become possible from a commercial point of view. It is thus important to look at how bioelectricity can contribute to the Brazilian energy supply in the coming decades.

Bioelectricity generation potential is a function of the sugarcane harvest, because the amount of harvested sugarcane will determine the amount of residual biomass available for bioelectricity generation. The potential also depends on the technology used, which determines the efficiency of the conversion of biomass into electrical energy.

Following the ethanol industry boom, lead by the Proálcool program in the 1980s, and the cycle of sugar expansion in the 1990s, the last few years have seen a new growth phase for the sugar and ethanol industry. Prospects now point to further increases in the supply of sugar and ethanol in coming years. Estimates indicate Brazilian sugarcane production will increase from the current 550 million tonnes to exceed one billion tonnes of crushed sugarcane per harvest within 10 years. In addition to the expansion of sugarcane production, another fact will increase the amount of biomass available as an input for energy generation: the end of pre-harvest burning[viii] will allow sugarcane straw to be used as a primary energy source alongside bagasse.

With respect to cogeneration technology, sugar and ethanol plants have traditionally used counter-pressure cycles that ensured only the energy self-sufficiency of the plants themselves. Even within this configuration, however, some modifications, principally the use of high-pressure cauldrons, make it possible to achieve considerable energy efficiency, generating around 40 kWh per tonne of processed sugarcane (Corrêa Neto and Ramón, 2002).

New greenfield projects are currently adopting extraction-condensation technology, which allows for production of significant energy surpluses at low costs. This technology can generate up to 96 kWh per tonne of processed sugarcane, of which an average of 80 kWh can be exported. These numbers take into account only bagasse use, but with the incineration of straw not burned in the plantation (with the end of manual harvesting), it is possible to reach up to 200 kWh per tonne of processed sugarcane (Kitayama, 2008). The cost of investment in this technology is around R$3,000 per installed kW. Table 3 shows data for the short, medium and long term potential for bioelectricity generation, assuming all sugar and ethanol plants adopt the best technology.

The estimates of bioelectricity potential are based on extraction-condensation technology that has already been fully mastered and is economically viable. However, the development of biomass gasification technology – which has already been mastered in the technical sense but is not yet commercially viable – could represent a major leap forward in the potential for bioelectricity generation. This technology is capable of producing up to 270 kWh of surplus energy per tonne of processed cane.

Dantas and Castro (2008) state that the development of cellulosic ethanol could negatively impact the future supply of bioelectricity, because it may offer an alternate economic use for biomass. However, based on recent projections for the ethanol and electricity markets, the authors have assumed that investments in cogeneration will not be reduced. Rather, they are likely to be increased, especially if specific policies are adopted, for example auctions for new energy separated by source. The 2008 auction for Reserve Energy is an example.

However, because the potential for bioelectricity generation is calculated in relation to the total harvest, it is important to analyze the situation of existing sugar and ethanol plants, which need to be retrofitted to generate electricity more efficiently. These plants must replace part of their equipment to adopt more modern cogeneration technologies. It is a question of replacing functioning equipment, which may have a considerable remaining service life and that already ensures energy self-sufficiency for the plant. Realizing the generating potential of these plants therefore requires an auction price cap higher than that applied to greenfield projects. According to Castro (2008) and based on pre-crisis economic parameters in September 2008, while new projects are viable selling energy an average price of R$155/MWh, retrofitted projects need an average price of R$180/MWh to be viable. It should be noted that the sugar-energy sector has a heterogeneous production structure and these values may have a high standard deviation, especially when factoring in the costs of connection to the electricity grid, which is the responsibility of the bioelectricity entrepreneur.

3.2 Bioelectricity complementing the Brazilian electricity system, and externalities

The mere fact of incorporating bioelectricity into the system on a scale compatible with its potential would contribute to increasing the security of Brazilian electricity supply by virtue of diversifying the energy matrix. However, the most favorable characteristic of sugarcane bioelectricity for the Brazilian electricity system security is its complementary quality in relation to rainfall patterns in the Center-South region, where 70% of Brazilian reservoir capacity is concentrated. The sugar-energy harvest takes place between April and November, coinciding with the dry season in the Center-South region. Graph 3 compares the sugarcane crushing pattern with natural hydropower energy flow, demonstrating the complementarity of bioelectricity and hydropower.

Because sugarcane bioelectricity generation is concentrated during the dry season, it constitutes an energy source of great relevance to complement the installed hydropower base. It is effectively a “winter energy”. According to the ONS, every 1,000 MW av of bioelectricity injected into the interconnected system during the dry season is equivalent to a 4% saving of reservoirs in the Center-South subsystem.

Table 3 **Estimates of sugarcane bioelectricity potential***

Harvest	Sugarcane (in millions of tonnes)	Generation potential (in MW av)
2012/13	696	9,642
2015/16	829	11,484
2020/21	1038	14,379

* These estimates assume the use of extraction-condensation technology, with the use of 75% of available bagasse and 50% of available straw.
Source: Prepared by Gesel/IE/UFRJ from UNICA data.

3.3 Economic viability

Despite all the acknowledged benefits of incorporating bioelectricity in the electricity matrix, there are doubts and arguments about its viability and economic competitiveness. The main argument is that if bioelectricity were competitive, it would already be sold in the new energy auctions. However, the methodology used at auctions for contacting new energy does not necessarily select the best generation projects, as discussed by Castro et al (2009a).

Table 4 presents information that demonstrates the need for a more detailed analysis regarding the apparent lack of competitiveness of bioelectricity.

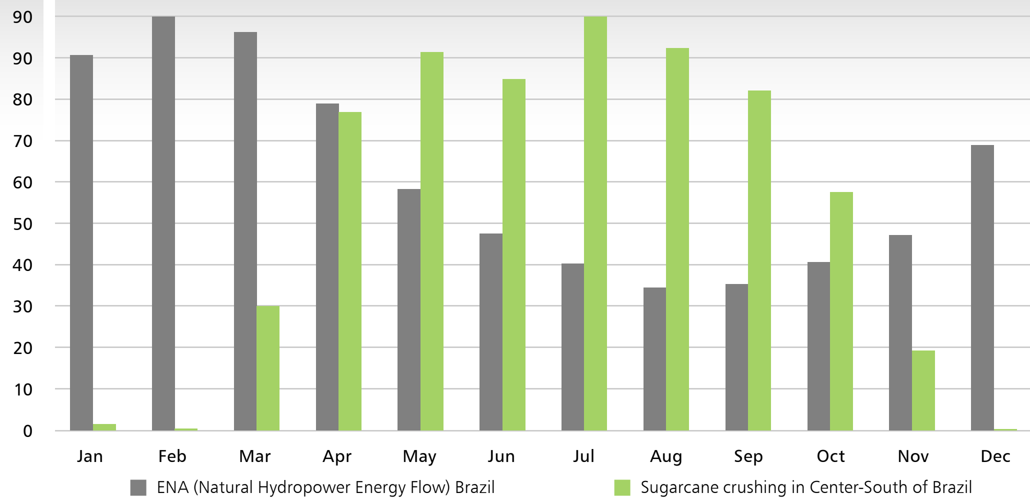
This table shows that 71.1% of contracted thermoelectric power had variable cost greater than R$200 in July of 2009, to which must be added to the fixed costs of the generating station. Given this data, it is fair to question whether a biomass generator with a fixed generation cost of R$155 per MWh or even R$180 for a retrofitted mill really constitutes a threat to the rates structure.

It is important to note that, to obtain the cost of these generating stations that are dispatched in order of merit, one cannot simply add the fixed and variable costs, because these stations were contracted as backup, with estimated dispatch for a small number of hours per year. It is because of this methodology – low fixed cost, high variable cost and infrequent dispatch – that these plants appear competitive at auctions. However, in a hydroelectric system with declining regulatory capacity, where complementary generation

Graph 3

Complementarity of hydroelectricity and the sugar-energy sector

As a % of the month with the greatest supply



Source: ONS (www.ons.org.br) website and UNICA. Data prepared from 2008 operational history (ENA) and sugarcane crushing in the 2007/2008 harvest in the Center-South of Brazil.

will be increasingly necessary (especially during the dry season), these power plants are not the best option. They will prove to be much more expensive for the system than sugarcane bioelectricity thermal plants that operate inflexibly with no variable costs.

3.4 Environmental sustainability: GHG emissions

The Brazilian energy matrix, and particularly the electricity matrix, has unique characteristics in terms of reduced environmental impact, especially with regard to emission of greenhouse gases (GHG). However, this cannot be used as an argument for contracting dirty and polluting energy sources.

The energy sector has the greatest responsibility for global greenhouse gas emissions, with 48.8% of the worldwide total. **Table 5** compares the Brazilian emissions profile with that of other countries, illustrating the differences. It can be seen that most Brazilian emissions come under the heading of "Land use, land-use change and forestry (LULUCF)", which includes burning. Emissions from the Brazilian energy sector account for only 8.8% of the country's total.

Because bioelectricity is a renewable source of energy, it is neutral in GHG emissions. This is a marked contrast to the significant emissions of thermal energy generation with fossil fuels, as shown in **Table 6**.

Based on an estimated potential total of 14,379 MW av of bioelectricity for export in the 2020/21 harvest, we can calculate the equivalent generation of 125,960 GWh. Production of this same energy by coal-fired power plants would create total emissions of 100.7 million tonnes of CO_2. Were this generation from oil-

Table 4 Variable unit cost (VUC) of thermal generation in the National Interconnected System (SIN)

In 2009

VUC (R$/MWH)	Available power (MWa)	% Total
up to 100	1,536	6.80%
100 to 150	3,655	1.30%
150 to 200	1,313	5.80%
200 to 250	6,386	28.40%
250 to 300	2,723	12.10%
300 to 400	3,561	15.90%
400 to 600	1,643	7.30%
more than 600	1,637	7.30%
Total	22,454	100%

Source: ONS, PMO of July 2009.

fired stations, emissions would be 69.3 million tonnes of CO_2. Even with combined-cycle natural gas plants, emissions would be 50.4 million tonnes of CO_2. We can therefore clearly see the importance of bioelectricity for maintaining a matrix with reduced carbon intensity, and so contributing to climate change mitigation.

3.5 Source of distributed generation and additional benefits of bioelectricity

Bioelectricity counts as a source of distributed generation by virtue of being located in the Center-South region, close to the country's principal demand centers. This proximity reduces the need for expansion of transmission, which constitutes both an environmental benefit (reduction of losses in the transmission system) and an economic benefit (less need for investment in the expansion of the transmission system). Bioelectricity can even be injected directly into the distribution network, without any need to reinforce the very high tension basic grid. We can thus see that bioelectricity is compatible with the new technological paradigm of the electricity sector, which places great emphasis on the exploitation of niches for distributed generation.

Emission profiles of selected countries *In percentage, 2005 data*

Table 5

Region/ Country	Energy	Transporta-tion	Industrial processes	Agriculture	LULUCF	Waste	Total
World	48.8	11.8	3.4	13.8	18.6	3.6	100
Annex 1	63.3	18.6	3.6	8.2	-	6.2	100
Non- Annex 1	36.9	6.1	3.2	15.6	35.1	3	100
China	64.6	4.6	7.9	21.4	-1	2.5	100
India	52.3	6.8	3.5	34.8	-2.2	4.8	100
Indonesia	7.9	2	0.5	4	83.6	1.9	100
South Korea	68.8	17.5	9.2	2.8	0.2	1.6	100
Brazil	8.8	5.7	1.5	20.1	62	1.8	100
Mexico	50.5	16.6	3.5	8.2	15.8	5.3	100
South Africa	73.7	9.6	2.7	10.7	0.5	2.9	100

Source: Souza and Azevedo (2006).
* Land use, land-use change and forestry

GHG emissions by different sources *In kg per MWh*

Table 6

Energy source	CO_2 emissions (in Kg per MWh)
Natural Gas (open cycle)	440
Natural Gas (combined cycle)	400
Oil	550
Coal	800
Hydroelectricity	25
Wind Power	28

Source: European Union (2007).

Furthermore, the Brazilian capital goods industry is ready to provide the necessary equipment for the construction of cogeneration plants. In this sense, investments in new, more efficient, cogeneration plants – notably retrofit conversions – do not require substantial importation of equipment, thus saving hard currency and providing a boost to the Brazilian industrial sector.

On the other hand, bioelectricity uses a nationally-produced primary energy source, as opposed to other types of generation that require imported fuel. In this sense not only there are foreign exchange savings, but also the price volatility of energy is reduced. This becomes clear in the contracts arising from the auctions for new energy: the cost of generation using oil, coal and natural gas is indexed to the international spot price of these energy inputs, while bioelectricity is indexed to the Broad Consumer Price Index (IPCA).

▶ 4. Conclusions

The Brazilian electricity matrix is going through a phase of transition, facing the increasing need to complement hydropower generation with other options to generate electricity efficiently during the dry season. Bioelectricity is an energy source that is intrinsically complementary to hydro generation, because the sugarcane harvest coincides with the dry season.

The cycle of expansion of the sugar-energy sector, together with the gradual end of burning sugarcane, ensures the necessary biomass for significant bioelectricity generation in the coming years. This justifies investments in technology that allows bioelectricity to be incorporated into the Brazilian electricity matrix.

The apparent lack of competitiveness of bioelectricity at auctions for new energy is the consequence of existing criteria for contracting energy, that do not correctly take into account all the benefits of bioelectricity for the Brazilian electricity system. In this sense, merely the reasons restricted to the "energy world" would be sufficient to justify the incorporation of bioelectricity into the Brazilian electricity matrix in a scale compatible with its potential. However, besides reasons of energy, there is the relevant fact that bioelectricity is a renewable energy source in a world that demands measures to reduce greenhouse gas emissions, and so mitigate climate change.

These reasons justify modifying the policy of contracting energy via auctions for the regulated market. Adoption of auctions by specific type of energy source, or auctions specifically for base-load generation during the dry season, would seem to be a more efficient alternative than auctions that are open to any type of project, and which have not been stimulating the efficient contracting of new projects. This guideline would be one of the most important components for a public bioelectricity policy.

Another point to be addressed via public policy is the creation of conditions for existing sugar and ethanol mills to be connected to the grid and sell energy. Sugar and ethanol mills are geographically dispersed; many are far away from sub-stations capable of receiving the energy produced. This means that access to the grid becomes an obstacle to the incorporation into the system of new bioelectricity generation ventures. The solution found for this problem around the time of the Reserve Energy Auction – the design of a collection grid to serve various projects in the same region – was certainly a step in the right direction. However, given that the financial commitment to build the collection grid had to be made before the auction, this was not an ideal alternative. Bearing in mind the competitiveness of bioelectricity, studies are recommended to reinforce the grid in regions where there is high production potential, even before confirming that mills in the region have been successful at energy auctions.

In summary, the following are important points for a public policy for the sugarcane bioelectricity sector: 1) give appropriate value to the seasonal complementarities of bioelectricity at auctions for new energy; 2) hold regular auctions restricted to this source, or at least to sources that are compatible with it; and 3) plan the expansion of transmission systems in a way that effectively allows for incorporation of bioelectricity into the generation matrix.

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Explanatory Notes

[i] Includes the Paraguayan half of Itaipu.
[ii] Competitiveness at the generation level, as shown in auctions for the Rio Madeira dams. Final electricity prices in Brazil are not low for a number of reasons that are beyond the scope of this paper.
[iii] CO_2 emissions by the Brazilian energy matrix per tonne equivalent of petroleum are 1.57, compared to 2.36 for the global energy matrix. Hydroelectricity and the large-scale use of ethanol are among the factors responsible for reducing carbon intensity in the Brazilian matrix.
[iv] Hydraulic energy in rivers, available for energy purposes.
[v] These numbers include only those rivers that already have hydropower stations.
[vi] Brazil hydropower generation potential is estimated at approximately 260 GW.
[vii] Cogeneration can be defined as the simultaneous production from the same primary energy source of thermal and mechanical energy that can be converted into electricity.
[viii] The Agro-Environmental Protocol in the State of São Paulo contemplates the end of sugarcane burning and manual harvesting in flat areas by 2014. Over 50% of the harvest is already mechanized. Therefore, even though part of the cane will be left on the soil to protect it, there will be a significant increase in the biomass available for energy use.

06

Ethanol as a Fuel

Francisco Nigro

Alfred Szwarc

Flex-fuel vehicles were launched in 2003 and currently account for about 90% of new sales, constituting the high point of Brazilian ethanol's success story this decade. This doesn't mean that there is no room for improvement in terms of gains in energy efficiency and environmental performance. On the contrary, significant technological advance is possible, provided the necessary public policies are adopted.

At the start of the Proálcool Program the development of ethanol engines was directed towards increasing energy efficiency, which reached a maximum of 16% higher than that of gasoline vehicles. Development in the 1980s was geared towards control of pollutant emission and the energy advantage of ethanol fell through the 1990s as the industry invested more in gasoline vehicle technology, responding to the drop in oil prices.

Vehicle manufacturers have different strategies for the development of flex-fuel engines. In general, however, adequate use is still not made of ethanol's greater latent heat of vaporization and higher octane for reducing consumption. At the same time gasoline consumption has improved, so that in official tests of flex-fuel vehicles the energy advantage of ethanol has been virtually annulled. In tests conducted by specialized magazines, however, ethanol has shown significantly higher energy efficiency compared to gasoline. This indicates a need to think about how standardized consumption tests could be made more representative of typical usage.

While the technologies to improve energy efficiency of flex-fuel engines are well known, their development is largely determined by technical and economic questions that depend on how

much consumers are willing to pay for the benefits. In Brazil, popular models have production volumes that can support intensive engineering development, but they are very sensitive to price increases.

Brazil was a pioneer when it launched flex-fuel motorcycles in 2009. These build on the solutions that were developed in the 1980s for ethanol-powered motorcycles. They are innovative, low-cost vehicles that could represent an export opportunity. Some of the innovations adopted in four-wheel vehicles could also be used for motorcycles.

Finally, there are great opportunities for using ethanol as a substitute for diesel, particularly in the sugar-energy sector and in the urban transportation of passengers and cargo, where it is desirable to use clean and renewable fuels. In such cases, the use of ethanol in captive fleets permits the development of technical solutions that are optimized for ethanol. Due to the social character of urban passenger transport, there is potential for tax incentives that improve its viability. Technological alternatives now under development point to four options: a) the conversion of diesel engines into Otto Cycle engines; b) the use of ethanol with an additive; c) the use of vaporized ethanol in diesel engines; and d) blends of ethanol and diesel with a co-solvent.

Despite the success of ethanol, public policies are needed to reinforce Brazilian technological capability for the efficient and sustainable use of the fuel. Such policies would include training human resources for research and development, stimulus for domestic automotive engineering, and incentives for consumers.

1. Introduction

Brazilian use of ethanol as a vehicle fuel grew sharply from 1975 with the establishment of the National Ethanol Program, known in Portuguese as Proálcool. This program initially encouraged the production of anhydrous ethanol (AEAC) to be blended into gasoline up to a level of 20%, then as of 1977 Proálcool also began to promote the use of pure hydrous ethanol (AEHC) as vehicle fuel.

Given the initial resistance by automakers to producing all-ethanol vehicles, the initial strategy for Proálcool was to disseminate the technology for converting gasoline engines to run on hydrous ethanol. Engine rebore workshops were selected to carry out conversions, backed up by a network of Technology Support Centers (CATs). These centers were based on research institutes and public universities in various states. The goal was to make conversion techniques uniform and consistent, in line with a study presented by the São Paulo State Institute for Technological Research (IPT – Castro et al. 1982). The CATs certified interested companies of proven technical competence to perform engine conversions and helped develop and approve conversion procedures by certified companies.

Although this period of engine conversion, and the demonstration fleets that were established at the time, helped spur consumer interest in the use of hydrous ethanol, it was only in 1979 that the program really took off, with the factory production of new ethanol-powered vehicles. This followed an agreement between Proálcool and Anfavea (the National Association of Automotive Vehicle Manufacturers).

The main vector for the development of ethanol engine technology at this time was increasing energy efficiency. This was consistent with the strategic and economic factors that led to creation of Proálcool. Environmental concerns were not a priority, although ethanol's characteristic as a renewable fuel had been recognized and was cited as an important quality. In the same context, the search began around 1980 for alternatives to replace the large-scale use of diesel in agricultural machinery, freight and public passenger transport.

In addition to the above-mentioned questions, ethanol's environmental and social characteristics started gaining importance around the mid-eighties. From an automotive engineering standpoint, technology development was driven primarily by environmental requirements for pollutant emission control and end-user satisfaction, with energy efficiency often taking a back seat.

This chapter seeks to analyze the evolution of Brazilian technology for using ethanol as a fuel, pointing out the main technological challenges to be overcome to make fuel ethanol more competitive and suggesting public policy measures that can help overcome these challenges. We give special attention to flex-fuel vehicle technologies and to replacing diesel fuel with ethanol, especially in terms of energy efficiency and technical feasibility.

Considering that over the past hundred years the internal combustion engine has been developed and refined to run on gasoline and diesel, and that these fuels have also been better adapted to their respective engines, the approach used in this paper to explain the evolution of ethanol engine technology will be based on a comparative evaluation of the properties of ethanol with those of petroleum derivatives.

Currently, the technological fuel-engine interface – which historically developed as a symbiotic relationship between the automotive and oil refining industries – is being challenged by renewed interest in biofuels, particularly ethanol. However, considering the global context in which the auto industry operates, petroleum derivatives still account for 97% of fuel consumed by engines. The feasibility of any alternative fuel is therefore heavily dependent on using the industrial infrastructure already established for transporting, storing and distributing gasoline and diesel. This important economic and structural question represents the main competitive advantage of renewable fuels in comparison to other alternative sources of energy for the transportation sector, and justifies the approach used here to promote the growing use of ethanol through technological development, rather than as a disruptive technology.

▶ 2. Flex-fuel vehicles

2.1 Historical context, origins and principles of operation

To facilitate an understanding of the technical questions that lay behind the development of ethanol engines and the emergence of flex-fuel engines, it is necessary to consider the main similarities and differences between ethanol and petroleum derivatives from the perspective of their use in internal combustion engines.

One key difference is the high oxygen content of ethanol (35% by mass). This would initially indicate a calorific value around 65% of that of oil derivatives, together with the possibility of a cleaner burn in the engine. Another important feature of ethanol, associated with its short molecular chain, is its considerable volatility and high resistance to spontaneous ignition. These features make it suitable for spark-plug ignition (Otto engines). It is important to note that as a pure substance, ethanol has a constant distillation temperature of 78 °C at atmospheric pressure, whereas gasoline, which is a mixture of over 500 hydrocarbon chains typically containing five to 12 carbons, undergoes distillation usually between 30 °C to 220 °C. This characteristic is used as a parameter for design of Otto engines.

Ideally, Otto engines require a homogeneous mixture of fuel vapor and air in a stoichiometric (chemically ideal) proportion. This is compressed in the combustion chamber. The engine induces ignition by a spark from the spark plug and combustion occurs by flame propagation, without the occurrence of auto-ignition. Fuels that are more resistant to auto-ignition make it possible to the increase of the compression ratio of the engine and consequently its energy efficiency. Octane rating is a measure of resistance to auto-ignition of fuels in Otto engines. It is measured in a special engine under standardized conditions, and the values for ethanol are significantly higher than those for gasoline.[i] This characteristic makes it possible to add ethanol to gasoline to increase its octane rating, a fact that allowed Brazil to become one of the first countries to eliminate tetraethyl lead, a substance known for its high toxicity, such as anti-knock additive in gasoline. Adding ethanol to gasoline also contributed to eliminating the need to increase the presence of aromatic hydrocarbons in gasoline in refinery operations, a practice frequently used to increase octane rating, but which has the disadvantage of increasing the toxicity of both the fuel and its combustion byproducts.

Given its considerable volatility, low lubricity and high resistance to auto-ignition, ethanol is traditionally not used as a fuel in compression ignition motors (Diesel Cycle). In this type of engine, air is compressed before the fuel is injected at the right time via a high-pressure system, and auto-ignites. The air-fuel mixture is heterogeneous, which facilitates the formation of particulate matter in the exhaust fumes, and the injection system is normally lubricated by the fuel itself, which to this end requires specific characteristics of viscosity and lubricity.

Ethanol is completely miscible with gasoline and water, and is sold in Brazil as anhydrous ethanol (AEAC) or hydrous ethanol (AEHC) containing 5-6% of water by volume. AEAC is mixed with Type A gasoline in a quantity that can vary between 20% to 25% ± 1% in volume to form Type C gasoline, which is sold at filling stations. AEAC concentration in gasoline is set by the Inter-ministerial Sugar and Ethanol Commission (CIMA) in function of supply and demand conditions for the product in the market, and has been held at 25% in recent years. Given that Type A gasoline is not miscible with water, the stability of the ternary mixture depends on the proportion of the components. Fortunately, when Type C gasoline is mixed with AEHC the mixture is stable even at temperatures down to -10 °C. This means that flex-fuel vehicles can be used without restriction in Brazil (Neto et al., 1993).

Another property of ethanol that is quite different from petroleum is the latent heat of vaporization. For ethanol this corresponds to 3.2% of its calorific value, while for petroleum derivatives it is about 0.7%.

As mentioned above, spark-ignition engines require a mixture of air and fuel vapor that is close to the stoichiometric ratio in order to function properly, with low emission of pollutants. This means that the amount of ethanol required to fully utilize the same amount of air is much higher than that for gasoline, which in turn means that an ethanol engine fuel system has to supply a quantity of fuel about 60% higher than in a gasoline engine of equivalent power.

Finally, it should be noted that all components of the fuel system must be made of materials that offer chemical compatibility with the fuel to be used. Various materials were substituted in the 1980s, mainly plastics, rubber and metallic substances used to protect surfaces that were incompatible with ethanol. More recently the automotive sector has only used materials that are compatible with both ethanol and petroleum derivatives.

The rebore industry converted gasoline engines to use AEHC, with the technology comprising the following elements: increase of engine compression ratios by lowering cylinder heads and replacing pistons; recalibration of carburetors for ethanol; alteration of centrifugal advance and vacuum curves in the distributor to ensure optimal spark timing for ethanol combustion; use of spark plugs with lower operating temperature than gasoline ones; and installation of an auxiliary cold start system with gasoline injection into the intake manifold. Some models also received heated intake manifolds, using either the engine's cooling water or its exhaust gases. This facilitated ethanol vaporization and allowed for better use of the corresponding energy. To prevent the higher compression ratio generating undue mechanical stress, the fuel-air mixture was less enriched than that used in gasoline-powered engines at full power[ii], thus maintaining the torque and horsepower of the original engine. This helped decrease consumption. In order to maintain compatibility between ethanol and the materials used in the fuel supply system, elastomeric seals and some ferrous and plastic components of the system were changed and carburetors received anti-corrosion protection. To receive certification, engine conversions had to demonstrate: maintenance of the engine torque curve at full power with no more than a 25% increase in AEHC consumption by volume when compared to the original engine using 'gasohol' (gasoline with up to 20% ethanol); calibration of the mixture and timing advance to ensure that, when operating under partial load (25%, 50% and 75% of full load) over the entire range of engine speeds, consumption was at most 6% greater than minimum consumption at each operating point.

When taking into account the calorific value of the fuels, we can see that the energy efficiency obtained by using ethanol at full load was about 25% higher than gasoline. This gain was possible because at that time the gasoline/air mixture at full load was very rich – excess gasoline of up to 15% compared to the stoichiometric mixture to ensure a rich mix even in a cylinder receiving less fuel – and the compression ratio in engines running on Brazilian gasoline was less than 8:1. Moreover, the reference gasoline engine used was a normal production engine, while the converted engine was specially calibrated using a dynamometer, a fact that could explain perhaps 5% of the efficiency gain. The increase in compression ratio for values up to 12:1 implied an efficiency increase of around 7%, while the use of latent heat of ethanol vaporization accounted for about 2%.

As reported by the IPT in the already-mentioned study, the consumption of vehicles converted to ethanol, measured in field tests and on a chassis dynamometer, was around 20% higher by volume than that of normal production cars, albeit with loss of drivability.

On the other hand, the engines of new ethanol-powered cars produced by automakers since 1979 have taken advantage of ethanol characteristics that increase torque and power, with carburetors calibrated to use a rich mixture at full load and a lean mixture on partial loads.

The fuel consumption of vehicles produced during the period in which ethanol-powered cars accounted for more than 90% of new vehicle sales can be compared by using data from the Fuel Economy Program (Programa de Economia de Combustíveis – PECO)[iii] signed between the Federal Government – represented by the Ministry of Industry and Commerce and the Ministry of Mines and Energy – and automakers, represented by Anfavea. Implemented by the Secretariat of Industrial Technology (STI/MIC), from 1983 to 1986 the program published a booklet entitled The Right Choice – A Consumption Guide to Your Car, which contained average consumption values for new cars sold at that time. Measurements were carried out in accordance with ABNT NBR 7024, a standard created at that time and called "Light on-road motor vehicles – Measurement of fuel consumption – Test method". For example, the consumption of one of the most popular ethanol-powered models (1985, 830 kg weight and engine rated at 43.9 kW) was 11.2 liters/100 km (8.9 km /liter) in the city and 7.7 liters/100 km (13.0 km/l) on the highway. The average increase in consumption of ethanol powered vehicles when compared to the equivalent gasoline model was 25% by volume, which implies an energy gain of 16% in favor of ethanol, although it should be noted that tests were performed in pre-heated engines. Under these average vehicular operation conditions, the increased compression ratio possibly accounted for around 6%, the leaner mixture for about 7% and the use of the greater latent heat of ethanol vaporization for 1%. Another factor worth mentioning is that ethanol-powered models were more modern than gasoline ones. As such, they incorporated incremental developments in advance of the gasoline models.

At that time, according to Cetesb[iv], average emissions of ethanol-powered vehicles were: carbon monoxide (CO) - 16.9 g/km, hydrocarbons (HC) - 1.6 g/km, nitrogen oxides (NOx) – 1.2 g/km, and aldehydes (RCHO) - 0.18 g/km. Gasoline-powered vehicles meanwhile emitted considerably more, with the exception of aldehydes: CO - 28 g/km; HC - 2.4 g/km; NOx - 1.6 g/km, and RCHO - 0.05 g/km.

After 1989, there were some market shortages due to insufficient supply of ethanol, coinciding with a drop in oil prices and the opening of the domestic car market for imported vehicles, most of which were gasoline-powered. Consequently, the demand for ethanol cars fell sharply, and from 1995 it remained below 5%.

Environmental concerns were becoming increasingly important during that period, and Cetesb developed techniques for measuring vehicle pollutants. This culminated in the creation of Proconve, the Program to Control Motor Vehicle Air Pollution, established by Conama Resolution No. 18/86 and subsequently consolidated by Law No. 8723/93 and complementary regulations. The program was run by Ibama, with Cetesb as its technical agent, and limited new vehicle emissions in progressively stricter stages. Following the introduction of the legislation, vehicle development came to be dominated by emission targets for regulated pollutant, while aspects such as cost and energy efficiency became secondary. With the start of Stage L-3 in January 1997, three-way catalyzers became necessary to achieve maximum limits of CO (2 g/km), HC (0.3 g/m), NOx (0.6 g/km), and RCHO (0.03 g/km). This led to the use of stoichiometric mixtures in both ethanol and gasoline engines. The negative impact was greater on fuel consumption of ethanol-powered vehicles than gasoline vehicles, since the higher speed of propagation of the laminar flame in ethanol and the higher compression ratios of the engines allowed for the use of leaner mixtures than in gasoline engines with partial loads.

As of 1999, ethanol prices once again became competitive against gasoline in the Brazilian market. Ethanol-powered vehicles were available, and new all-ethanol engines were developed. However, sales did not pick up, because there was a lack of consumer trust.

It was in this context that the first Brazilian flex-fuel vehicle was launched in March 2003, capable of running on hydrous ethanol, Type C gasoline or any mixture of the two. This gave motorists the freedom to choose their fuel at each fill-up, taking into account cost and availability.

Alternative fuels research in the United States, Europe and Japan in the early 1980s (Pefley et al., 1980) had already led to development of prototypes, anticipating the possibility of using ethanol, methanol or gasoline in the same engine. These prototypes took advantage of the flexibility of electronic fuel injection systems that were starting to be used on a commercial scale, controlled by feedback of the sensor signal that measured the oxygen content in exhaust gases.

The first flex-fuel vehicles developed by automakers came from Ford in the United States in 1984 and were used in demonstration programs of flex-fuel technology. General Motors launched the first commercial flex-fuel vehicle in the United States in 1992, the Lumina van, with a capacitive sensor for measuring the ethanol content in the fuel.

The flex-fuel vehicle fleet in the United States grew strongly, stimulated by several U.S. government regulations and tax incentives[v]. This was despite the lack of fuel supply infrastructure. It is worth mentioning that U.S. flex-fuel vehicles accept as limiting fuels gasoline with zero ethanol (E0) and gasoline with 85% anhydrous ethanol (E85).

In Brazil, the first studies were developed by Bosch in 1990, as described by Conti, 2002, at a seminar organized by the IPT in March 2000. The first prototype vehicle using the Motronic Flex Fuel system was presented by Castro et al (1994). In 2000, Magneti Marelli presented its Flex-fuel Sensor Software system (SFS) System[vi]. This constituted an innovation in that it did not require the additional capacitive sensor used by the Bosch system to detect the percentage of blended ethanol; instead this was replaced by the oxygen sensor already used to control pollutant emissions. As a simpler, cheaper and more reliable system, it became the preferred choice for automakers. Moreover, the federal government allowed flex-fuel vehicles to enjoy the same IPI tax rates as alcohol vehicles (lower than gasoline vehicles), a factor that offset the investment in technological development and allowed the technology to be deployed throughout Brazil.

The operating principle of flex-fuel technology used in Brazil is based on the oxygen content sensor in the exhaust gas (lambda probe), an item that is already required to meet Proconve Phase L-3 emission standards. As previously mentioned, the air/fuel mixture must be maintained at its stoichiometric or ideal level so that the three-way catalyzer can dramatically reduce HC, CO, NOx and RCHO. The function of the lambda probe is to instruct the engine's electronic control unit (ECU) to inject more or less fuel if the mixture is too lean or too rich (having less or more fuel), thus keeping the fuel stoichiometrically correct for combustion. Moreover, in order to accurately detect the engine operating point (percentage of load and rotation), additional sensors measure engine rotation and the intake air flow and report this to the ECU.

Given that the values of the stoichiometric ratios of air/ethanol and air/gasoline are known and are stored in the ECU memory, it is possible to calculate the ethanol ratio in the fuel being injected into the engine – the ECU infers the amount of fuel being injected to maintain the stoichiometric air/fuel mixture from the length of time that the injectors need to be kept open. Based on this calculated content, other engine operating parameters whose optimal values depend on the ethanol content in the fuel are controlled. These include ignition timing; the need for gasoline injection at a cold start; the amounts that need to be injected to meet transitory engine response in hot and cold conditions and strategies to improve the efficiency of the catalyzer.

Another fundamental aspect for the rapid introduction and development of flex-fuel technology in Brazil was the immediate incorporation of improvements made previously to ethanol engine, in terms of material compatibility, degree of ignition heat, fuel pump and filter system, and cold start, among others.

2.2 Development of the technology in Brazil

The introduction of flex-fuel engine technology in Brazil was initially based on the concept of not modifying the original gasoline engine. In the first generation, therefore, attention was focused almost exclusively on system functionality and meeting emission requirements, with little concern paid to ethanol consumption. The compression ratio of engines using Type C gasoline was maintained, and gains in torque and power deriving from the use of ethanol were around 2%. During the second generation, compression ratios rose by about one percentage point compared to Type C gasoline engines, representing the search for greater equilibrium in the development of an engine for both fuels. Gains in horsepower and torque for ethanol were in the range of 3% to 4%. New catalyzers and spark plugs appropriate for the new compression ratios were also introduced. In the third generation, some automakers with greater experience in the development of ethanol engines adopted in some models compression ratios close to the maximum acceptable for ethanol, with torque gains of over 5% when using ethanol.

Table 1 was adapted from a presentation made by a Volkswagen representative[vii] at the 2009 Ethanol Summit, and summarizes the progress of the technology in the vision of this automaker. Note that Volkswagen's fourth generation technology has a cold start system with ethanol pre-heating, so eliminating the need for an auxiliary gasoline fuel tank.

While this division into generations helps visualize the general trends, each engine model has its own characteristics and limitations. It may thus be impracticable in some cases to apply the whole concept of second generation.

Three data sources can be used to compare the latest developments in fuel consumption of new ethanol-powered cars with that of cars running on Type C gasoline: Reports of Production Emission Values[viii], the Brazilian Vehicle Labeling Program, and specialized magazines.

Table 1 Evolution of flex-fuel technology, according to Volkswagen

Generation	Market entry	Engine compression ratios	Power gains with ethanol	Torque gains with ethanol	Loss of mileage with ethanol	Cold start with gasoline
1st	2003	10.1 – 10.8	2.1%	2.1%	25% - 35%	Yes
2nd	2006	10.8 – 13.0	4.4%	3.2%	25% - 35%	Yes
3rd	2008	11.0– 13.0	5.6%	9.3%	25% - 30%	Yes
4th	2009	11.0 – 13.0	5.6%	9.3%	25% - 30%	No

2.2.1. Reports of production emission values (RVEP)

In addition to consumption data obtained from measurements to certify that pollutant emissions are within current limits, there is a database of engine fuel consumption generated by emission tests carried out by automakers to ensure that production remains in compliance with the environmental legislation. This data is reported by automakers via the Reports of Production Emission Values (Relatórios de Valores de Emissão da Produção – RVEP) submitted to Cetesb and Ibama, and corresponds to a minimum of 0.2% of new vehicles sold. This allows for a solid statistical comparison, despite vehicles being tested before they are run in. Vehicle emission values are measured at the exhaust pipe according to the NBR 6601 urban cycle and refer to the following regulated pollutants: CO, HC, NOx and RCHO. Some automakers also report results for carbon dioxide (CO_2) emissions and in these cases, it is possible to calculate fuel consumption. It should be noted that NBR 7024, which standardizes the measurement of fuel consumption, uses the same urban cycle as NBR 6601, while also providing a specific highway cycle.

Cetesb has published[ix] factors for average emissions for new vehicles, including CO_2, since 2002, as shown in **Table 2**. Average emission values are calculated as a weighted average for the number of vehicles sold for each model. The values for consumption of Type C gasoline and ethanol, presented in **Table 2** and referring to the urban cycle, were recalculated according to NBR 7024. The numbers relative to ethanol are slightly different to those shown in the Cetesb report, which does not correct the calculation formula.

When the lower calorific value and the specific mass of Type C gasoline and hydrous ethanol used in emissions tests are taken into consideration, in accordance with the Technical Regulations of the Brazilian Vehicle Labeling Program[x], it can be seen that 1.443 liters of ethanol is energetically equivalent to 1.0 liters of Type C gasoline. The last column of the table was calculated based on energy density values used in the Labeling Program (28.99 MJ/L for Type C gasoline and 20.09 MJ/L for hydrous ethanol). This allows for a comparison in terms of average energy consumption of new vehicles for each fuel since 2002. It is worth mentioning that the Type C gasoline used in tests contains 22% of anhydrous ethanol by volume, while that currently sold in Brazil should contain 25±1% of AEAC. This results in an energy equivalence of 1.426±0.006 liters of AEHC for 1.0 liter of Type C gasoline.

Looking at the results of the last column in the table, and in particular those referring to flex-fuel vehicles operating with both fuels from 2003 through 2007, it can be seen that in those cases where any variation of energy consumption was detected, the difference was less than 1%. This indicates that, on average, flex-fuel vehicles are still not sufficiently developed to take advantage of the greater latent heat of vaporization and the higher octane rating of ethanol to achieve a significant difference in energy consumption.

As for pollutant emission, flex-fuel vehicles operating on ethanol on average emitted values greater than those emitted when operating with gasoline. This is shown in **Table 3**, prepared with Cetesb data that was calculated from RVEP reports. The limiting values for each year were calculated based on the limits for Proconve Phases L-3 and L-4, where starting dates for Phase L-4 were: 40% in 2005, 70% in 2006 and 100% in 2007. Aldehydes emission when operating with ethanol is approximately five times greater than in gasoline operation, although the nature and toxicity of the aldehydes are very different for the two fuels, and are more favorable for ethanol. Of the three main pollutants that should be reduced by the emission control system (CO, HC and NOx), HC has on average been the most critical. Given that the balance between oxidation reactions and reductions in the catalytic converter[xi] can be altered by slightly changing the stoichiometry of the air/fuel mixture, the coefficient here called the "Limit Fraction" was introduced. This is calculated as the average value of relations between the three pollutants and their respective limits. This coefficient indicates that, as the years pass, there has been a reduction in the difference between the results with both fuels. This is a result of greater attention given by automakers to ethanol operation. The coefficient also indicates that, in the past two years, the average emission of these three pollutants in the case of gasoline operation appears to tend towards 90% of emissions with ethanol.

One aspect that should be highlighted is that this data refers to new vehicles. However, emissions also depend on the deterioration of catalyzers, which is faster with gasoline than ethanol. Emissions also depend on the quality of fuels at pumps. Emission results for flex fuel models sold in 2009, which meet Proconve

Table 2 Average factors for emissions and fuel consumption for new light vehicle

Model	Fuel	CO g/km	HC g/km	NOx g/km	RCHO g/km	CO_2 g/km	Mileage km/liter	Consumption MJ/km
2002	Gasoline C	0.43	0.11	0.12	0.004	198	10.93	2.65
	Ethanol	0.74	0.16	0.08	0.017	191	7.47	2.69
2003	Gasoline C	0.40	0.11	0.12	0.004	194	11.15	2.60
	Ethanol	0.77	0.16	0.09	0.019	183	7.79	2.58
	Flex-Gasoline C	0.50	0.05	0.04	0.004	210	10.31	2.81
	Flex-Ethanol	0.51	0.15	0.14	0.020	200	7.15	2.81
2004	Gasoline C	0.35	0.11	0.09	0.004	190	11.39	2.55
	Ethanol	0.82	0.17	0.08	0.016	160	8.89	2.26
	Flex-Gasoline C	0.39	0.08	0.05	0.003	201	10.77	2.69
	Flex-Ethanol	0.46	0.14	0.14	0.014	190	7.52	2.67
2005	Gasoline C	0.34	0.10	0.09	0.004	192	11.28	2.57
	Ethanol	0.82	0.17	0.08	0.016	160	8.89	2.26
	Flex-Gasoline C	0.45	0.11	0.05	0.003	188	11.50	2.52
	Flex-Ethanol	0.39	0.14	0.10	0.014	180	7.94	2.53
2006	Gasoline C	0.33	0.08	0.08	0.002	192	11.28	2.57
	Ethanol	0.67	0.12	0.05	0.014	200	7.14	2.81
	Flex-Gasoline C	0.48	0.10	0.05	0.003	185	11.69	2.48
	Flex-Ethanol	0.47	0.11	0.07	0.014	177	8.08	2.49
2007	Gasoline C	0.33	0.08	0.08	0.002	192	11.28	2.57
	Flex-Gasoline C	0.48	0.10	0.05	0.003	185	11.69	2.48
	Flex-Ethanol	0.47	0.11	0.07	0.014	177	8.08	2.49

Phase L-5, were recently released by Anfavea[xii]. In general, these indicate values that are more favorable for ethanol operation. It should be noted that the observed differences are small, in absolute terms, and the vehicles easily meet current emission limits.

To illustrate the comparative evolution of consumption ethanol and gasoline vehicles, two sets of real data obtained from the Reports of Production Emission Values will be discussed.

Figure 1 presents semiannual average fuel consumption results from 1998 to 2003 for typical vehicles equipped with an engine designed specifically for Type C gasoline or ethanol, and then started using flex technology beginning in 2003. The error bars indicate a 95% average confidence interval. Large confidence intervals are associated with a reduced number of vehicles tested in the six-month period and, therefore, a low production of that model. The available data indicate that automakers have preferentially tested flex models with gasoline. This fact increases the uncertainty of average values for operations using ethanol. It is important to mention that vehicles of the same model and submitted to same emissions cycle can present consumption variations of up to 15%, while the standard deviation of the consumption distribution is around 3% of the average value.

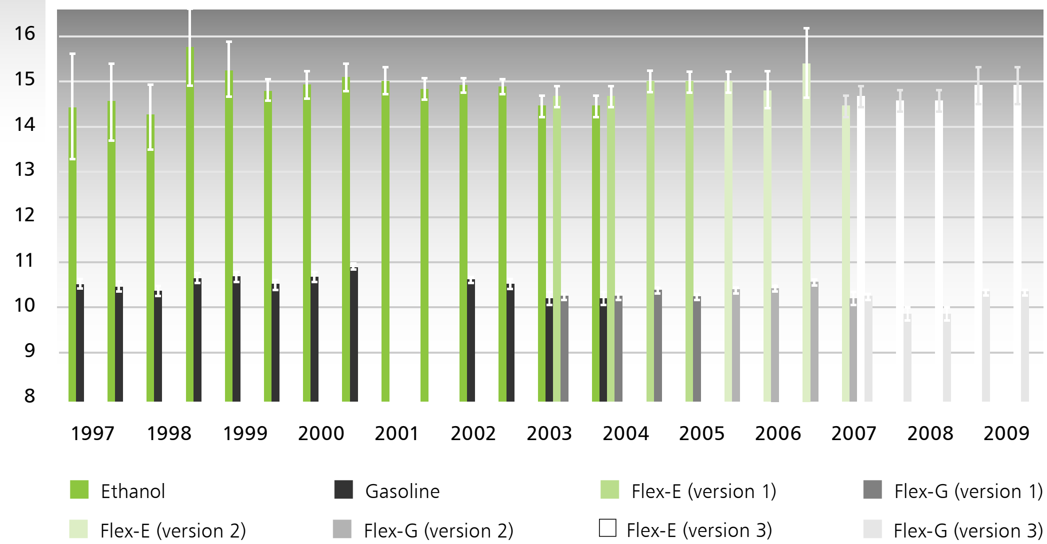
Table 3 **Average factors of flex-fuel vehicle emissions compared to limit values**

Model	Fuel	CO g/km	HC g/km	NOx g/km	Limit fraction	RCHO g/km
2003	Weighted Limit Gasoline C Ethanol	2.0 0.50 0.51	0.30 0.05 0.15	0.60 0.04 0.14	100% 16% 33%	0.030 0.004 0.020
2004	Weighted Limit Gasoline C Ethanol	2.0 0.39 0.46	0.30 0.08 0.14	0.60 0.05 0.14	100% 18% 31%	0.030 0.003 0.014
2005	Weighted Limit Gasoline C Ethanol	2.0 0.45 0.39	0.24 0.11 0.14	0.46 0.05 0.10	100% 26% 33%	0.030 0.003 0.014
2006	Weighted Limit Gasoline C Ethanol	2.0 0.48 0.47	0.20 0.10 0.11	0.36 0.05 0.07	100% 29% 33%	0.030 0.003 0.014
2007	Weighted Limit Gasoline C Ethanol	2.0 0.48 0.47	0.16 0.10 0.11	0.25 0.05 0.07	100% 36% 40%	0.030 0.003 0.014

Considering the set of results of the versions dedicated to ethanol and gasoline, the average energy bonus for ethanol models was 2.2±0.5%. This advantage disappears in the comparative performance of the first flex-fuel vehicles, which maintained the compression ratio used in the gasoline version almost unaltered and where ethanol consumption increases 3.6±1.0% and gasoline increases 1.4±0.4%. Therefore, in this case, the flex-fuel vehicle led to a loss in energy output in operations with ethanol and gasoline. In the second generation of flex-fuel vehicles, with higher compression ratios and an improved engine management system, the initial energy output with ethanol was practically regained, but there was an increase in energy output for operations with gasoline. The energy advantage for ethanol therefore remained inexistent.

Figura 2 refers to a production model with a one-liter engine. It shows the average consumption results for specific ethanol and gasoline versions until the first semester of 2005, then average results of two generations of flex-fuel motors. Similar to the previous case, there is an energy advantage for ethanol between the dedicated versions, which in this case averages 4.3±0.4%. We can also see that the more recent models clearly present lower consumption for ethanol as well as gasoline. In the first generation of flex-fuel ve-

Figure 1 **Fuel consumption for a typical 1.6 liter model** *Urban cycle – Consumption in liters/100 km*

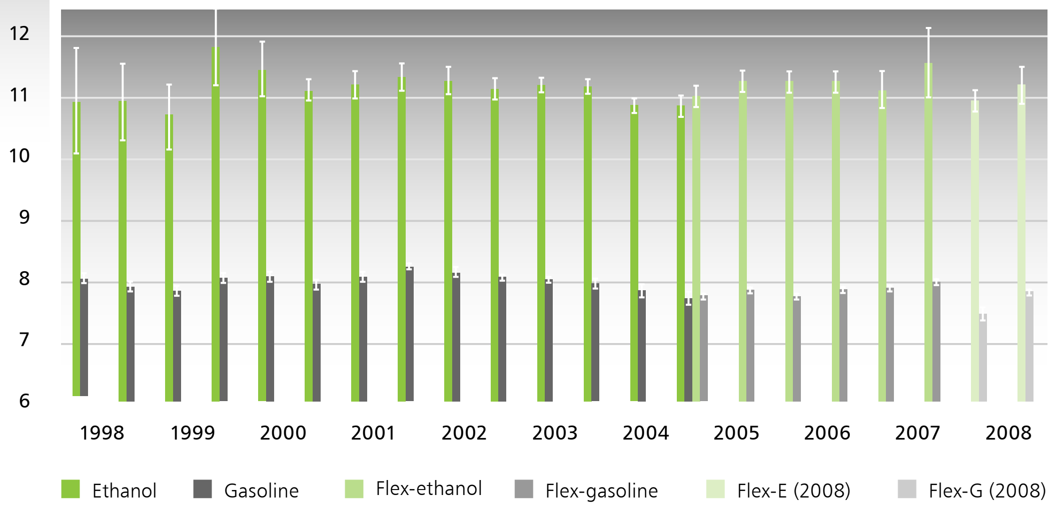


hicles, with compression ratios similar to gasoline engines, the energy advantage of ethanol was reduced by 0.6±0.8%, because of the increase in ethanol consumption. Despite reduced ethanol consumption in the more recent generation where the engine compression ratios are similar to vehicles dedicated to ethanol, the consumption of gasoline was also reduced, leaving the energy advantage of ethanol in average 1.5±0.8%.

For flex-fuel vehicles (that even in 2008 maintained the same compression ratio as gasoline engines), we can see an increase in energy consumption of approximately 2% in urban cycle, when using ethanol.

Recapping the general situation observed, based on the RVEP reports – after the introduction of Proconve Phase L-3, when three-way catalyzers became mandatory with a stoichiometric calibration of the fuel blend, there was an energy output gain of approximately 4% for vehicles dedicated exclusively to ethanol in comparison with those dedicated to Type C gasoline. This was for operation in an urban cycle that includes a phase of cold start and motor heating. With the introduction of first generation flex-fuel technology (maintaining compression ratios of gasoline engines) the energy output advantage of ethanol was practi-

Figure 2 **Fuel consumption for 1.0 liter model** *Urban cycle – consumption in liters/100 km*



cally zero. There was even a small increase in consumption when using gasoline. For some vehicles that had been available only in gasoline versions, the introduction of the first-generation flex-fuel version, in general, implied a small increase in gasoline consumption, of the order of 1%, while energy consumption with ethanol was approximately 2% higher. With the following generations of flex-fuel technology, employing compression ratios closer to ethanol engines, a signification reduction in consumption was observed when running on ethanol. There were also reductions in gasoline consumption, so that the energy gain with ethanol remained between zero and 2%.

2.2.2. Brazilian Vehicle Labeling Program

As mentioned earlier, another important source of current data on flex-fuel vehicle consumption is the Brazilian Vehicle Labeling Program[xiii], coordinated and regulated by Inmetro (Brazil's National Institute of Metrology, Standardization and Industrial Quality) with voluntary participation of the main automakers in the country. The program, established at the end of 2008, published urban and highway cycle fuel consumption results for vehicle models submitted by the automakers, using Norm ABNT NBR 7024: 2006 "Light Motor Vehicle – Fuel Consumption Measurement – Test Method". **Annex 1** publishes the first results of the Program, while **Annex 2** presents complimentary data on vehicle motorization (collected in specialized magazines) and variation of energy consumption between ethanol and gasoline.

Looking at the information about vehicle motorization, we can see that automakers have different strategies regarding flex-fuel vehicles. Chevrolet and Volkswagen are using high compression ratios, corresponding to what has come to be called the "third generation", while Fiat and Honda in most of their models are maintaining the compression ratios of gasoline engines. Exceptions to this pattern are Fiat's Mille Way Economy and Honda's Civic which are using intermediate compression ratios. The relation between the energy consumption of ethanol and gasoline varies significantly between different models. On average, however, it is unfavorable for ethanol by about 2%. The results presented show that, even in 1.0 liter models of the so-called third generation, in general, there is no energy advantage for ethanol. It is important to highlight that, for now, the Vehicle Labeling Program is voluntary and based on values declared by automakers, based on regulatory tests of models. These data differ significantly (by 5% to 10%) from the average results in the Reports of Production Emission Values.

According to the Vehicle Labeling Program, it is acceptable for any vehicle randomly selected from the automaker's stock to present fuel consumption values up to 10% higher than those declared. Should the difference be between 10% and 20%, two other units shall be selected, and if the average of the three differs from the declared value by less than 10%, the result will be considered as acceptable. We should note, therefore, that the declared values include not only aspects of average consumption distribution, but mainly of the standard deviation.

It is interesting to compare the consumption results of 1985 ethanol-only models with 2009 flex-fuel models operating on ethanol. Despite the power/weight ratio having increased by 10% and vehicle pollution being reduced 20-fold, we can see that for vehicles of the same weight, consumption was reduced by approximately 20% in the urban cycle and around 5% in the highway cycle. These facts show that there was an evolution in the energy efficiency of ethanol-powered vehicles in the past 24 years, but that it was approximately 15% less than the evolution of gasoline vehicles. Also, the incorporation of electronic systems employing mapped ignition and multipoint fuel injection with mixture control via feedback, have made possible a more significant gain in the urban cycle rather than the highway cycle – remembering that in 1985, engines car worked with lean mixtures during the highway cycle.

2.2.3. Specialized magazines

Several specialized vehicle magazines conduct their own evaluations of fuel consumption of models launched by the automakers. These publications apply their own usage cycles and test procedures that to a certain extent represent the average use of vehicles. **Table 4** shows results from *Autoesporte*[xiv] magazine for common models, so offering a comparison with the values published by the Vehicle Labeling Program.

Table 4 Comparison of data: ***Autoesporte Magazine*** **and the Vehicle Labeling Program**

Model	Km/Liter						Variation of energy consumption Ethanol / Gasoline		
	Urban Cycle		Highway cycle		Autoesporte Cycle				
	Ethanol	Gasoline	Ethanol	Gasoline	Ethanol	Gasoline	Urban	Road	Autoesporte
Celta 1.0L	10.0	14.5	12.8	17.8	11.2	14.4	0.5%	-3.6%	-9.8%
Mille 1.0 Economy	10.8	15.7	13.2	19.2	12.7	14.4	0.7%	0.8%	-20.5%
Palio 1.4L	8.8	13.0	10.8	16.0	10.0	13.2	2.4%	2.7%	-7.4%
Corsa 1.4L	8.6	13.0	11.7	18.0	11.4	14.6	4.8%	6.6%	-10.2%
Gol 1.0	9.5	13.9	13.5	19.9	12.6	14.4	1.4%	2.2%	-19.9%
Gol 1.6	9.1	13.4	13.2	19.3	9.0	12.2	2.0%	1.3%	-4.9%
Polo 1.6	9.5	13.8	14.9	21.2	8.7	11.3	0.7%	-1.4%	-8.9%
Civic 1.8 Automatic	8.2	12.0	12.8	18.6	9.1	11.6	1.4%	0.7%	-10.6%

Annex 1

Results of the Brazilian Vehicle Labeling Program – 2009

Marque	Model	Version	Engine	Transmission No. of gears Manual (M) Automatic (A)	Ar Cond. Yes (Y) No (N)	Steering Hydraulic (H) Manual (M) Electric (E) Electric-Hydraulic (EH)	Fuel Ethanol (E) Gasoline (G) Flex (F)	Km/L				2009 Classification	Inmetro Classification Area (m²)
								Urban cycle		Highway cycle			
								Ethanol (km/l)	Gasoline (km/l)	Ethanol (km/l)	Gasoline (km/l)		
Chevrolet	Celta 2P	Life, Spirit and Super	1.0 L	M5	N	M	F	10.0	14.5	12.8	17.8	C	< 6.5
Chevrolet	Celta 4P	Life, Spirit and Super	1.0 L	M5	N	M	F	10.0	14.5	12.8	17.8	C	
Chevrolet	Celta 4P	Life, Spirit and Super	1.4 L	M5	N	M	F	9.6	14.2	12.8	19.1	C	
FIAT	Mille Way Economy	1.0 Flex	1.0 8V Fire	M5	N	M	F	10.8	15.7	13.2	19.2	A	
FIAT	Palio 2P Novo ELX	1.4 Flex	1.4 8V Fire HP	M5	S	H	F	8.8	13.0	10.8	16.0	E	
FIAT	Palio 4P Novo ELX	1.4 Flex	1.4 8V Fire HP	M5	S	H	F	8.8	13.0	10.8	16.0	E	
FIAT	Palio 2P Novo 1.8R	Flex	1.8 8V	M5	S	H	F	7.7	11.2	10.1	15.0	E	
FIAT	Palio 4P Novo 1.8R	Flex	1.8 8V	M5	S	H	F	7.7	11.2	10.1	15.0	E	
KIA	Picanto	EX3, LX3	1.0	M5	S	E	G		16.2		21.0	A	
KIA	Picanto	EX3, LX3	1.0	A4	S	E	G		15.8		20.8	A	
Chevrolet	Classic	Life, Spirit and Super	1.0 L	M5	S	H	F	8.7	13.0	12.0	18.0	D	6.5 to 7.0
Chevrolet	Corsa	Joy, Maxx and Premium	1.4 L	M5	S	H	F	8.6	13.0	11.7	18.0	D	
Chevrolet	Prisma	Joy and Maxx	1.0 L	M5	N	M	F	9.7	14.4	12.8	18.4	B	
Chevrolet	Prisma	Joy and Maxx	1.4 L	M5	S	H	F	9.0	13.4	12.4	18.6	C	
FIAT	Idea	ELX 1.4 Flex	1.4 8V Fire	M5	S	H	F	8.1	11.8	10.8	15.7	E	
FIAT	Punto	1.4 Flex	1.4 8V Fire HP	M5	N	H	F	8.9	13.2	11.2	17.0	C	
FIAT	Siena	Novo HLX 1.8 Flex	1.8 8V	M5	S	H	F	7.8	11.7	10.3	15.6	E	
HONDA	Fit	LX, LXL	1.4L – 16V	M5	S	E	F	9.8	14.8	12.3	18.6	A	
HONDA	Fit	LX, LXL	1.4L – 16V	A5	S	E	F	9.2	14.0	11.8	18.2	B	
HONDA	Fit	EX, EXL	1.5L – 16V	M5	S	E	F	9.2	13.7	11.6	17.3	C	
HONDA	Fit	EX, EXL	1.5L – 16V	A5	S	E	F	9.0	13.5	12.0	17.6	C	
VOLKSWAGEN	Gol	1.0L	1.0	M5	S	H	F	9.5	13.9	13.5	19.9	A	
VOLKSWAGEN	Gol	1.6L, 1.6 power	1.6	M5	S	H	F	9.1	13.4	13.2	19.3	B	
VOLKSWAGEN	Polo	BlueMotion	1.6	M5	S	E-H	F	9.5	13.8	14.9	21.2	A	
HONDA	Civic	LXS	1.8L – 16V	M5	S	H	F	8.3	12.3	11.8	17.5		7.0 to 8.0
HONDA	Civic	LXS, EXS	1.8L – 16V	A5	S	H	F	8.2	12.0	12.8	18.6		
VOLKSWAGEN	Voyage	1.0L	1.0	M5	S	H	F	9.5	13.9	13.5	19.9		
VOLKSWAGEN	Voyage	1.6L, 1.6 Trend, 1.6 Comf.	1.6	M5	S	H	F	9.1	13.4	13.2	19.3		
FIAT	Linea	T-JET 1.4 16V TURBO	1.4 16V T-JET	M5	S	H	G		11.5		14.3		> 8.0
KIA	Carnival	EX2, LX2	3.8	A5	S	H	G		7.8		10.6		
FIAT	Strada	Nova Trekking 1.4 Flex	1.4 8V Fire HP	M5	N	H	F	8.9	13.2	10.5	15.7		

Annex 2

Results of the Brazilian Vehicle Labeling Program – 2009

Marque	Model	Cylinders Diameter	Pistons Course	Compres-sion rate	Maximum power Ethanol / Gasoline	Rotation at maximum power	Piston velocity at maximum power	Maximum torque ethanol / gasoline	Rotation at maximum torque	Vehicle weight	Fuel tank	Maximum power	Power / weight	Energy consumption of AEHC / Type C gasoline	
		(mm)	(mm)		(CV)	(rpm)	(m/s)	(m.kgf)	(rpm)	(kg)	(litro)	(CV)	(kW/ton)	Urban cycle	Highway cycle
Chevrolet	Celta 2P	71,1	62,9	12,6	78/77	6400	13,4	9.7/9.5	5200	860	54	78,0	66,7	0,5%	-3,6%
Chevrolet	Celta 4P	71,1	62,9	12,6	78/77	6400	13,4	9.7/9.5	5200	890	54	78,0	64,5	0,5%	-3,6%
Chevrolet	Celta 4P	77,6	73,4	12,4	105/99	6000	14,7	13.4/13.2	2800	890	54	105,0	86,8	2,5%	3,4%
Fiat	Mille Way Econ.	70	64,5	11,6	65/66	6000	12,9	9.2/9.1	2500	830	50	66,0	58,5	0,7%	0,8%
Fiat	Palio 2P ELX	72	84	10,35	86/85	5750	16,1	12.5/12.4	3500	981	48	86,0	64,5	2,4%	2,7%
Fiat	Palio 4P ELX	72	84	10,35	86/85	5750	16,1	12.5/12.4	3500	981	48	86,0	64,5	2,4%	2,7%
Fiat	Palio 2P 1.8R	82	85	10,5	114/112	5500	15,6	18.5/17.8	2800	1025	48	114,0	81,8	0,8%	2,9%
Fiat	Palio 4P 1.8R	82	85	10,5	114/112	5500	15,6	18.5/17.8	2800	1025	48	114,0	81,8	0,8%	2,9%
Kia	Picanto	67	77	10,1	64	5500	14,1	9,4	2800	840	35	64,0	56,1		
Kia	Picanto	67	77	10,1	64	5500	14,1	9,4	2800	840	35	64,0	56,1		
Chevrolet	Classic	71,1	62,9	12,6	78/77	6400	13,4	9.7/9.5	5200	920	54	78,0	62,4	3,6%	3,9%
Chevrolet	Corsa	77,6	73,4	12,4	105/99	6000	14,7	13.4/13.2	2800	1045	44	105,0	73,9	4,8%	6,6%
Chevrolet	Prisma	71,1	62,9	12,6	78/77	6400	13,4	9.7/9.5	5200	921	54	78,0	62,3	2,9%	-0,4%
Chevrolet	Prisma	77,6	73,4	12,4	105/99	6000	14,7	13.4/13.2	2800	921	54	105,0	83,9	3,2%	3,9%
Fiat	Idea	72	84	10,35	86/85	5750	16,1	12.5/12.4	3500	1180	48	86,0	53,6	1,0%	0,7%
Fiat	Punto	72	84	10,35	86/85	5750	16,1	12.5/12.4	3500	1090	60	86,0	58,1	2,8%	5,2%
Fiat	Siena	82	85	10,5	114/112	5500	15,6	18.5/17.8	2800	1080	48	114,0	77,7	3,9%	5,0%
Honda	Fit	73	80	10,5	101/100	6000	16,0	13/13	4800	1116	42	101,0	66,6	4,7%	4,8%
Honda	Fit	73	80	10,5	101/100	6000	16,0	13/13	4800	1116	42	101,0	66,6	5,5%	6,9%
Honda	Fit	73	89,4	10,4	116/115	6000	17,9	14.8/14.8	4800	1141	42	116,0	74,8	3,2%	3,4%
Honda	Fit	73	89,4	10,4	116/115	6000	17,9	14.8/14.8	4800	1141	42	116,0	74,8	3,9%	1,6%
Volkswagen	Gol	67,1	70,6	13	76/72	6250	14,7	10.6/9.7	3850	934	55	76,0	59,9	1,4%	2,2%
Volkswagen	Gol	76,5	86,9	12,1	104/101	5250	15,2	15.6/15.4	2500	944	55	104,0	81,1	2,0%	1,3%
Volkswagen	Polo	76,5	86,9	12,1	104/101	5250	15,2	15.6/15.4	2500	1079	45	104,0	70,9	0,7%	-1,4%
Honda	Civic	81	87,3	11,5	140/138	6200	18,0	17.7/17.5	4300/5000	1260	50	140,0	81,8	2,7%	2,8%
Honda	Civic	81	87,3	11,5	140/138	6200	18,0	17.7/17.5	4300/5000	1260	50	140,0	81,8	1,4%	0,7%
Volkswagen	Voyage	67,1	70,6	13	76/72	6250	14,7	10.6/9.7	3850	970	55	76,0	57,7	1,4%	2,2%
Volkswagen	Voyage	76,5	86,9	12,1	104/101	5250	15,2	15.6/15.4	2500	1021	55	104,0	75,0	2,0%	1,3%
Fiat	Linea	72	84	9,8	152	5500	15,4	21,1	2250/4500	1305	60	152,0	85,7		
Kia	Carnival	96	87	10,4	242	6000	17,4	35	3500		80	242,0			
Fiat	Strada	72	84	10,35	86/85	5750	16,1	12.5/12.4	3500	1051	58	86,0	60,2	2,8%	3,6%

Although consumption results published by Autoesporte show a certain correlation with the results from the Vehicle Labeling Program, there is a significant discrepancy in the differences in energy consumption between ethanol and gasoline in corresponding cycles. While the cycles of the standardized and laboratory tests reveal energy consumption for ethanol that was on average 1.5% higher than gasoline, in the tests conducted by the specialized magazine, in conditions more representative of normal use it was 11% lower than gasoline.

It is worth noting that the difference in energy density between the Type C gasoline sold in filling stations and that used in standardized consumption and emissions tests was taken into account in the calculation of energy consumption. The average reduction in energy consumption of ethanol in relation to gasoline was 7.5% if we consider the results of all flex-fuel vehicle models tested and published by the magazine, including first generation vehicles. Similarly reduced results are obtained if we analyze data from the Folha de S. Paulo newspaper or the Carsale.uol website, both of which are based on street and road tests conducted by the Mauá Institute of Technology. This suggests that even though the field tests may lack the rigor of ABNT NBR: 7024, they point to some lack of representativeness in the standardized testing. Two possible explanations for these differences between ethanol and gasoline energy consumption in the cycles are: the difference in the length of the cycles, and consequently the different weight of cold starts and cold-phase operation; and the non-use, during the normalized cycle, of the greater torque of engines operating with ethanol to reduce gear change rotations.

Summarizing all the official results for vehicle consumption since the mid-1980s, based on existing standardization, we can say that ethanol vehicles have undergone significant development in the urban cycle (20%) and less significant in the highway cycle (5%), while gaining a 10% increase in the power to weight ratio of the vehicle and an enormous reduction in pollutant emission per kilometer. This reduction is estimated at: CO – 36 times; HC – 15 times; NOx – 17 times; and RCHO – 11 times. Nevertheless, these gains were considerably lower than those obtained by gasoline-powered vehicles, which started the period with high levels of consumption and pollutant emission.

In the past 24 years, therefore, the original advantages of ethanol engines in 1985 – energy efficiency 15% greater and pollutant emission 30% lower than gasoline engines – were annulled or became disadvantages. Energy consumption of new ethanol vehicles is on average 2% higher than for corresponding gasoline models. Besides that, the average emission of CO, HC and NOx pollutants after the catalyzer in new vehicles, not yet run in, is approximately 10% greater with ethanol than gasoline, while aldehyde emissions are 4.6 times greater than with gasoline. It should be noted that results for CO, HC and NOx emissions published by Anfavea for 2009 models, taking into account the official results of testing of models and the effect of 80,000 km durability for catalyzers, are in general favorable towards ethanol.

The practical results of vehicle consumption, as tested and published by specialized automobile magazines, point to significantly greater energy efficiency when using ethanol rather than gasoline. This suggests the need to ask if the standardized test is indeed representative of "average use" in Brazil and what should be done to make it so. One aspect that could be incorporated, within the context of ABNT NBR: 7024, would be permission for gear shift rotations to be different in ethanol and gasoline operations with the same flex-fuel vehicle.

2.3. Future possibilities

Conceptually speaking, the limit to development of a flex-fuel engine is the one that guarantees that for each specific blend with which the engine can operate, there will be the same performance, consumption, pollutant emission and durability that would be achieved with a hypothetical engine that had been optimized for each specific blend. However, adopting a more pragmatic view, the evolution of flex-fuel technology is determined by technical and economic considerations that depend on how much consumers are willing to pay when purchasing a certain model, to obtain the benefits of fuel savings, difference in performance or pollutant emission during the useful life of the vehicle. In Brazil, models aimed at the bottom end of the market enjoy production volumes that can support intensive engineering development, but they are also the market segment where market pressure imposes restrictions on any price increase that would be caused by the addition of parts or components. Below, we discuss technologies that, if used, would promote the evolution of flex-fuel vehicles towards a conceptual "optimum", but without considering the economic feasibility of their implementation.

Given that the development of the basic engine designs generally takes place outside of Brazil, and is based on gasoline engines, and these are then adapted into flex-fuel engines, the following discussions start from the perspective of making flex-fuel vehicles more suitable for ethanol.

The factor that most complicates the use of ethanol in spark ignition engines, and which is in most urgent need of improvement, is the question of cold start and cold operation. The limited volatility of ethanol at low temperatures makes it difficult to comply with emission limits stipulated in the more recent phases of Proconve, while at the same time reducing ethanol mileage when compared to gasoline. We have a step in the right direction with the solution of electrically heating the fuel and improving its vaporization by using injectors that have holes of a smaller area (a greater number of holes or an increase in injector pressure) to avoid the injection of gasoline during cold start. This system was introduced by Volkswagen in its fourth generation flex-fuel vehicles, with the Polo E-Flex. Innovations expected for the next generation of flex-fuel vehicles include the use of oxygen sensors that start responding at lower temperatures, as well as catalytic converters installed closer to the exhaust valves so that they heat up faster. Other innovative technological solutions may appear to reduce the heating time of the combustion chamber and to further speed up the start of operation of the catalyzer.

Another important characteristic that differentiates ethanol from gasoline, and that should be better exploited in flex-fuel vehicles, is its greater resistance to auto-combustion. This higher octane rating makes it possible to increase the engine compression ratio and obtain greater thermal output. The use of systems that allow for varying the opening and closing angles of the intake valves would make it possible to vary the engine's effective compression ratio, so making better use of the auto-combustion limit of the specific fuel being used. The use of smaller engines burning more fuel in applications typically handled by larger engines could be an excellent way to take advantage of ethanol's high-octane rating and latent heat of vaporization. Direct injection of ethanol into the combustion chamber, besides facilitating cold start as mentioned earlier, would allow us to make intelligent use of ethanol's resistance to auto-combustion. This could be simply via the injector in the combustion chamber, or combined with an injector at the entry port of each cylinder (Cohn et al., 2008). Specialists estimate that the adoption of this concept could bring consumption savings of 20% to 30%. The introduction of intake manifolds with heating controlled according to the proportion of ethanol in the fuel, together with control of the water temperature in the engine, are likely to become more common in future generations of flex-fuel vehicles as a way to make better use of ethanol's vaporization characteristics.

Another aspect that requires attention in the search to reduce fuel consumption in flex-fuel engines is the use of more dilute mixtures in the combustion chamber through the use of exhaust gas recirculation (EGR) valves. This will make better use of ethanol's flame-propagation properties, without altering the stoichiometric mixture necessary for the proper functioning of the three-way catalyzers.

3. Flex-fuel motorcycles

3.1 Technology and concepts

The two-wheel market has grown rapidly in Brazil, and is dominated by smaller motorcycles (100 cc to 250 cc) running on Type C gasoline. Data from the National Traffic Department (Denatran) and the Brazilian Association of Manufacturers of Motorcycles, Mopeds, Scooters, Bicycles and Similar Vehicles (Abraciclo), indicates that 1,925,514 new motorcycles (including scooters and mopeds) were registered in the country in 2008. This was an increase of 12.7% over 2007 and took the national two-wheel fleet to 13,084,148. Assuming average consumption of 27 km/l, annual average mileage of 9,000 km and a 25% blend of anhydrous ethanol in Type C gasoline, this fleet therefore consumed approximately 1.1 billion liters of ethanol in 2008. However, this scenario for ethanol consumption could change rapidly with the introduction of flex-fuel engines, as happened in the four-wheel segment. Six years after VW's Gol Total Flex automobile was launched, Honda in March 2009 launched the CG 150 Titan Mix, a flex-fuel version of their most popular motorbike, the CG 150 Titan, which sold 442,000 units in 2008 (23% of total two-wheel sales in the country).

The Titan Mix version captured 12.3% of total national two-wheel sales in its first four months, with 66,700 units sold from March to June 2009. The success of the world's first flex-fuel motorcycle was to be expected, because it offers the rider freedom to choose which fuel – gasoline or ethanol – he uses according to his own requirements, with economic considerations paramount. Data from field research conducted by UNICA in 2008 with over 500 motorcycle users showed that approximately 15% of them had already used or were currently using just ethanol in their vehicles. The group surveyed comprised mainly motorcycle couriers and people regularly using motorcycles for their daily transportation. This group proved to be very sensitive to fuel price, a fact that was leading a significant number to make amateur conversions so that they could run just on ethanol.

Small motorbike engines are normally very simple – single-cylinder, four-stroke, air-cooled, with valve command on the cylinder head with the rocker arm and fuel supplied through a basic carburetor. This favors amateur conversions for ethanol use, effected by changing the original carburetor jet for one with a larger caliber, so allowing higher volumes of ethanol in the engine, and adjustment to tick-over and air intake settings. However, these conversions frequently result in combustion failures, loss of performance, inefficient fuel use, increased pollutant emissions and premature wear of the carburetor and other components that are not appropriate for the use of hydrous ethanol.

The flex-fuel motorcycle responds to market demands and avoids the need for this type of conversion, offering satisfactory usage results. It represents a technological advance on some of the solutions developed in 1982 for the ethanol-powered CG 125 motorbike that was produced in Brazil. The tank's internal nozzle has a flame-prevention screen to avoid fire spreading from outside to inside the tank; the secondary fuel filter has a higher retention capacity and so avoids rapid clogging of the pump; the start-up system was adjusted to meet the needs of cold start using ethanol; and the internal treatment of the tank, fuel pump and fuel gauge potentiometer were changed to be compatible with ethanol use.

Unlike its ethanol predecessor, which had a secondary gasoline tank for cold start at any temperature, the flex-fuel version requires that the motorcycle tank (16.1 liters) contain about 20% of gasoline to ensure cold start at ambient temperatures below 15o C. The motorcycle has an alert lamp mechanism on its dashboard to help the rider with respect to cold start.

While the Titan Mix flex-fuel system is conceptually similar to that adopted in four-wheel flex-fuel vehicles, it is simpler, coordinated by an engine electronic control module (ECM). This is connected to sensors that monitor engine performance and convey information on the fuel blend being used. The sensors register the pressure in the intake manifold, the position of the throttle, the intake air temperature, the temperature of the lubricating oil and the oxygen content in the engine exhaust gas. Based on the data provided by these sensors, the ECM selects one of the following operating programs:

Program 1: Tank fueled with gasoline;
Program 2: Tank contains gasoline and ethanol in equal proportions;
Program 3: Tank contains a greater quantity of ethanol;
Program 4: Tank only fueled with ethanol.

Table 5 **Pollutant emission of the CG 150 Titan Mix flex-fuel motorcycle**

Pollutant	Promot 3 emission limit (g/km)	Emissions (g/km)		Difference in emissions and limits of Promot 3 (%)	
		Gasoline	Ethanol	Gasoline	Ethanol
CO	2.0	0.658	0.444	-67.1%	-77.8%
HC	0.80	0.146	0.143	-81.8%	-82.1%
NOx	0.15	0.068	0.102	-54.7%	-32.0%

The oxygen sensor is located in the engine exhaust manifold, and is the main item responsible for the operation of this system. Based on the selected program, the ECM transmits this information to the injector nozzle, which has eight holes, while the conventional gasoline version has six. This supplies the appropriate quantity of fuel for combustion and regulates the ignition timing – advancing it in the case of ethanol and retarding it for gasoline.

The CG 150 Titan flex-fuel motorbike is equipped with a catalytic converter to reduce pollutant gas emissions. As can be seen in **Table 5**, it easily meets emission limits established by the third phase of Brazil's Promot (Air Pollution Control Program for Motorcycles and Similar Vehicles) which is equivalent to the current phase of European legislation.

Given that Promot does not establish limits for aldehyde emissions, this pollutant is still not regulated. However, extrapolating from observations of four-wheel flex-fuel vehicles, equipped with electronic injection and catalytic converters, aldehyde emissions must be low: 0.03 g/km or less.

Adopting the strategy of not altering the 9.5:1 compression ratio used in the gasoline engine, the flex-fuel version offers slight increase in power and torque when using ethanol. While the motorcycle develops 1.32 kgf.m of torque at 6,500 RPM and 14.2 CV of power at 8,500 RPM when running on gasoline, these values increase to 1.45 kgf.m and 14.3 CV, respectively, when using ethanol. With respect to fuel consumption, Honda and specialized magazines inform that with ethanol it is possible to reach 27 to 29 km/liter (3.7 to 3.4 liters per 100 km), while gasoline consumption varies from 35 to 39 km/l (2.9 to 2.6 1/100 km). This corresponds to consumption approximately 30% greater with ethanol, which implies an energy bonus of around 7%.

In addition to Honda, system makers such as Delphi and Magneti Marelli have announced the development of flex-fuel technology for motorcycles. Considering the good market response to Honda's initiative, it is likely that flex-fuel technology can enjoy the same success in the two-wheel market as it has with four-wheeled vehicles. Given that we are talking about a low-cost vehicle and an innovative concept, then besides supplying the domestic market this could represent an interesting opportunity for export to several countries, with potential to encourage ethanol consumption in other markets.

3.2. Evolution of the application

As in all cases where technological innovations are adopted in a new application, there has to be a learning curve before the technology reaches maturity. In the case of flex-fuel motorcycles it is still too early to say what directions the technology might take. However, it is clear that some of the innovations adopted in four-wheel vehicles could also be applicable to motorcycles. Examples of incremental improvements that could be applied quickly include increasing the compression ratio and refining engine operation maps to optimize fuel injection and ignition.

4. Diesel substitution

4.1 Initial considerations

When it comes to the use of petroleum derivatives in internal combustion engines, the competitive advantages of compression ignition (Diesel Cycle) engines for heavy-duty applications and operations requiring greater power are well established; as are the advantages of spark ignition (Otto Cycle) engines in applications requiring lower power and less intensive use. Given that the cost of diesel and gasoline per unit of energy are about the same, these differences are due mainly to the greater energy efficiency of diesel engines (about 20% compared to Otto Cycle engines for vehicular applications), set against the lower manufacturing costs of Otto Cycle engines for the same range of power.

With respect to the emission of local air pollutants, while a diesel engine emits a lower mass of pollutants per unit of work done, the systems for post-combustion treatment of exhaust gases make applications with spark ignition engines less polluting per unit of work done than those with compression ignition engines. In particular, much of the pollution in large urban centers is attributed to the emission of nitrogen oxides and particulate matter from vehicles with diesel engines. In contrast, the emission of greenhouse gases per unit of work done is lower for compression ignition engines than for spark ignition engines, due to the greater efficiency of the former when both are running on the petroleum derivatives for which they were designed. On the other hand, as already mentioned, the physical and chemical properties of ethanol, particularly the volatility and greater resistance to auto-combustion, make it an ideal fuel for spark ignition engines, in the same way that vegetable oils and their derivatives such as biodiesel are more suitable for compression ignition engines. It is worth noting that when Otto Cycle engines are optimized for ethanol, their energy efficiency is higher than when optimized for gasoline. In the case of Diesel Cycle engines, the energy efficiency varies little when they are optimized for different fuels, although depending on the fuel there may be considerable difficulties in adapting the engine. For ethanol, significant changes are needed, while for biodiesel almost nothing needs to be done.

Therefore, if we imagine a global market for liquid engine fuels that is in reasonable equilibrium and dominated by gasoline and diesel, it would make more sense to use ethanol as a gasoline substitute and extract a higher percentage of diesel oil from petroleum to use in compression ignition engines. Given that in most countries, taxes on gasoline (used mostly in individual transport) are higher than taxes on diesel (used mostly in public and freight transportation), we can conclude that the global market offers little scope for using ethanol in applications currently dominated by diesel.

However, domestic markets are far from perfect or in equilibrium, and ethanol has an excellent property that is fundamental in greenhouse gas mitigation policies – it significantly reduces carbon emissions. This creates opportunities to use ethanol to replace diesel, either partially or totally.

In Brazil, and especially in the State of São Paulo, the price relationship between ethanol, gasoline and diesel is such that this possibility cannot be ruled out. From an energy standpoint, it takes 1.72 liters of hydrous ethanol or 1.22 liters of Type C gasoline to replace 1 liter of diesel. Thus, assuming that in the medium term the price of diesel will be maintained in the range of 85% to 90% of the price of Type C gasoline, then whenever the pump price of ethanol drops below 49% to 52% of the gasoline price, there is economic – but not necessarily technical – potential for consumers to use ethanol instead of diesel. Recently, this limit has been exceeded, which reinforces the interest in substitution. It is worth mentioning that the price relation between hydrous ethanol and Type C gasoline that make it economically attractive to use ethanol in a flex-fuel vehicle is 70%. This clearly demonstrates how far the market has been from equilibrium.

When we consider the pre-tax selling price of hydrous ethanol and the purchase price of diesel by ethanol producers, the opportunity for substitution becomes clearer. It appears to be economically advantageous when the ethanol/gasoline price ratio at filling stations falls below the 77% - 81% range, for the same reasons that we saw for the diesel/Type C gasoline price. These limits are around 65% even when ethanol is used in spark ignition engines, which have lower energy efficiency than compression-ignition engines. This shows that there is great economic potential for the replacement of diesel by ethanol in the sugar and ethanol sector, and this potential could possibly be even higher than that for the substitution of Type C gasoline by ethanol in flex-fuel vehicles.

Within this reality of prices, we can clearly see the need to develop alternative techniques for ethanol use as a diesel replacement. In June 2009, average prices of fuels per unit of energy at distributors in São Paulo were: hydrous ethanol, R$44/GJ[xv]; diesel, R$52/GJ; and biodiesel, R$70/GJ[xvi]. The high incentive for biodiesel illustrates the importance that has been given to achieving a renewable substitute for diesel, which in this case can be used in the existing fleet.

Three typical applications for using ethanol in diesel engines were seen as most promising. They are:

- buses, minibuses and vans for urban passenger transport;
- small trucks and urban delivery vans;
- agricultural machines and vehicles transporting cargo in the sugar and ethanol industry.

4.2. Buses, minibuses and vans for urban passenger transport

The first application offers the advantage of having its use restricted to captive fleets, with the added benefit of reducing the emission of local pollutants and noise in urban environments. It is therefore potentially suitable for being the object of tax incentives or legal requirements that facilitate its adoption. In this context, São Paulo's Municipal Law 14.933/2009, which establishes the city's Climate Change Policy, has amongst its goals a reduction of at least 10% a year in fossil fuel use in all public transportation operating under public contract in the city, so that by 2018 only use renewable fuels are used.

4.3. Small trucks and urban delivery vans

The second application presents advantages similar to those mentioned above, in terms of captive fleets and the reduction of pollution and noise in the urban environment. However, it is essentially a private activity, which makes action by public authorities more difficult. One technical advantage is the fact that their diesel engines are smaller and can therefore be more easily replaced by Otto Cycle engines with economic advantages, as outlined in the initial considerations.

4.4. Agricultural machinery and vehicles for transporting cargo in the sugar and ethanol industry

The third application demonstrates undeniable economic viability. It thus offers some margin for developing technical solutions that are optimized for ethanol, and which could subsequently be used in other applications.

4.5. Alternative technologies and potential development

4.5.1 Transformation of heavy diesel engines into Otto Cycle engines

The option that offers least technological risk for substituting diesel with ethanol is the replacement of ignition compression engines with spark ignition engines. Although this solution was widely adopted in the 1980s, above all in the sugar and ethanol sector, there is currently no commercial supply in the Brazilian market of Otto Cycle engines large enough to be used in typical diesel engines applications.

The solution implies transforming original diesel engines into ethanol-powered Otto Cycle engines, and is relatively cheap. The following modifications are required: alteration of the pistons to reduce compression ratio to levels compatible with ethanol; replacement of the diesel high-pressure injection system for an ignition system where spark plugs are installed in the injector nozzle housings; adaptation of an Otto Cycle low pressure injection system, with the injectors in the intake manifold installed next to the cylinder intakes; installation of a throttle valve to control the air intake flow; installation of sensors for oxygen, combustion, and absolute intake pressure; use of an Electronic Control Unit (ECU) programmed according to the fuel and ignition; and advance of engine ignition timing. Given that the exhaust temperatures in Otto Cycle engines are higher than in diesel engines, changes to the exhaust valves and the valve seatings may also be needed.

The possibility of using stoichiometric mixture and a three-way catalytic converter ensure meeting strict pollutant emission limits, while the lower noise of the Otto Cycle engine is an advantage in many applications.

The disadvantage of this alternative is the increase in energy consumption due to the lower efficiency of Otto Cycle engines compared to diesel. This disadvantage increases for engines with larger piston diameters, in applications where there are large variations in load and rotation and ones with a high degree of turbo–compression, and can vary from about 15% to 40% depending on use. Applications in large urban buses operating on routes with low average speed are likely to approach the higher limit. Applications such as farm machinery that do not require three-way catalytic converters can use a leaner air/fuel mixture and reduce the disadvantage by about 7%.

MWM International and FPT are developing solutions of this type for motor in the 60kW and 200kW ranges, respectively. Expectations are that these engines will cost less than the originals, thanks to the elimination of high-pressure injection systems and because emission controls in the next phase of Conama will be much more complex for diesel engines than for spark ignition engines[xvii].

New options are being researched, mainly overseas, for example low temperature combustion processes (Homogeneous Charge Compression Ignition and Controlled Auto Ignition – HCCI and CAI), direct injection into the chamber, and water injection, among others. These may eventually help reduce the energy cost of changing the cycle.

4.5.2 Ethanol with an additive in diesel engines

Another alternative that avoids sacrificing the greater energy efficiency and robustness of compression ignition engines is to use ethanol directly in Diesel Cycle motors. To do this, hydrous ethanol must receive an additive to gain the necessary lubricity that ensures the durability of the fuel injection system and ensure self-combustion of the fuel injected into the engine's combustion chamber.

This option was tried a lot in Brazil during the 1980s, using ignition stimulants based on organic nitrates and lubricants based on castor oil. Scania and Mercedes Benz suggested alternatives. The Swedish company conducted field tests with buses and trucks that were sold in Brazil at the time, and later carried on this development in Sweden. From 1990 to 2007, Scania sold 600 urban buses that operate in Stockholm and other cities in Sweden using hydrous ethanol and an additive of the ethylene glycol type. The engines have a special Bosch injection system and initially had a 24:1 compression ratio.[xviii]

The low level of pollutant emission has allowed these vehicles to continued meeting European environmental requirements. Third-generation engines with 28:1 compression ratios easily meet Euro V legislation requirements and EEV (Environmentally Enhanced Vehicle) legislation, which is more restrictive than Euro V.

Demonstrations and tests of this technology were conducted within a European Union initiative called the BEST Project (Bio-Ethanol for Sustainable Transport). Coordinated by the city of Stockholm, BEST involved nine cities including São Paulo in several countries. Energy consumption of ethanol on the demonstration bus was shown to be equivalent to a diesel-powered control vehicle.

The current cost of the additive and the need to use a modified engine are the main disadvantages of the technology. However, given that it is already being used in urban buses, there is a great opportunity to make it viable via the previously mentioned Law No. 14.933/2009.

4.5.3 Vaporized ethanol in diesel engines

The use of ethanol as a partial substitute for diesel can be achieved by injecting ethanol via the intake air of a diesel engine, as if it were an Otto Cycle engine, while at the same time reducing the quantity of diesel oil injected into the combustion chamber. This option has the advantage of being reversible, but presents some technical difficulties that limit the proportion of diesel that can be substituted. In situations where an engine is operating at low load, and combustion therefore uses only a small fraction of the air drawn in, part of the ethanol is not burned and is expelled from the chamber via the exhaust valve. In high load situations that imply high pressures and temperatures within the combustion chamber, ethanol is subject to detonation, because diesel engine compression ratios are very high for ethanol. It is therefore essential to have precise control over the amount of ethanol injected for each condition of engine load and speed, and to coordinate this with the amount of diesel.

Both Bosch and Delphi, which supply fuel injection and control systems for Otto Cycle and Diesel Cycle engines, have been working on developing this alternative for engine makers. Both companies use two fuel tanks and two separate injection systems that only interact electronically, meaning that there is no need to develop complex new physical systems.

The percentage of diesel that can be efficiently substituted depends on the individual cylinder capacity of the engine and the intensity of turbo-charging used in the application. Dynamometer bench tests conducted by Bosch with a 2.8 liter, four-cylinder turbo-charged engine showed a substitution rate ranging between 12% and 57%, depending on the operating point[xix].

The use of detonation sensors and possibly a throttle valve in the intake manifold can increase the substitution rates for this option.

4.5.4 Blends of ethanol, diesel and co-solvents

Another possibility for the partial replacement of diesel is the preparation of diesel-ethanol blends, using a co-solvent or emulsifying agent to counter the low miscibility of ethanol in diesel. Field and laboratory tests have shown that the original injection systems of diesel engines are quite sensitive to the presence of ethanol, leading to wear or pitting in some components. Depending on the engine configuration, the serious problem of vapor lock can also occur, cutting fuel supply to the engine. Since ethanol is miscible in biodiesel, which in general has few limitations as a fuel for diesel engine, a mixture of the two biofuels can be tried, using the lubricating properties of biodiesel and the clean combustion properties of ethanol. However, the elevation of vapor pressure of the fuel caused by the ethanol blend can lead to cavitation in the injection system. As mentioned earlier, the cost of biodiesel per unit of energy is far superior to that of diesel, which limits the scope of this alternative.

5. Public policies to accelerate the development of fuel ethanol applications in vehicles and engines

The success of Brazilian ethanol as a renewable substitute for gasoline vehicle fuel is a source of great pride and creates expectations that the country could enjoy a possible new role in the international context of greenhouse gas emission reduction. However, when we compare the detailed evolution of energy and environmental efficiency in the use of ethanol and gasoline as vehicle fuels over the past 30 years, we can see that there is much room for improvement.

In this context, there is a need for public policies that reinforce the establishment of domestic technologic competence focused on using ethanol as a vehicle fuel, so preventing barriers to its use from neutralizing the efficiency gains in ethanol production.

5.1. Challenges to the development of engine technology in Brazil

As we saw in the section on ethanol-powered passenger vehicles, during the first half of the 1980s these vehicles enjoyed significant advantages over gasoline-powered cars, both in terms of energy efficiency and local pollutant emissions. Today, however, these advantages have been practically zeroed or have even become minor disadvantages.

This turn of events is not difficult to understand, when we recall that the automotive industry is composed of multinational companies and that renewable fuels represent only a small fraction of fuels consumed globally by the transportation sector. It is natural, therefore, that technological developments aimed at reducing fuel consumption and pollutant emission in the past 30 years were aimed essentially at petroleum derivatives. The relative importance of Brazil in the global automobile market was small and the use of ethanol as vehicle fuel was seen as just a local solution. With the adoption by the United States of a program for ethanol production and its use as the country's main gasoline substitute, engineering for ethanol applications has gained new momentum.

Renewable fuels today represent 19% (by energy content) of fuels used in the Brazilian transport sector. Brazil aims to become an international leader and to serve as example for other countries in the production and use of renewable fuels. Brazilian engineering therefore faces two challenges. The first is to adapt for ethanol the various technologies that have been developed for petroleum derivatives. The second is to pursue technological development based on the specific properties of ethanol to make it a more competitive fuel, so helping prevent new legislation that could the use of ethanol in global markets.

Given that Brazil today accounts for 4% of global new vehicles sales and that Brazilian auto engineering represents an even smaller fraction of the global sector, it is a huge challenge and one that needs the support of public policies to be overcome.

5.2. Common policies for the development of the various alternatives

To develop world class competence in Brazil, dedicated to the use of ethanol as a vehicle fuel, the country needs to establish public policies that act at three different levels: the training of technical competence (principally human resources) for research and development; stimulus for and strengthening of domestic auto engineering; and incentives for the final consumer to attribute value to the energy efficiency and environmental sustainability that ethanol seeks to achieve. This last area of action should be specific to each ethanol application.

5.2.1. Training of researchers

Basic research into new combustion processes in engines and new fuels takes place in universities and technology institutes located in countries that are leaders in the automobile industry. These centers train engineers who will be dedicated to the research and development of new engines that ensure the technological evolution of the sector.

If Brazil is to lead development for using ethanol as an internal combustion engine fuel it is essential to encourage research groups in universities and institutes that can train competent researchers in the field. Possible topics to be developed include: combustion kinetics of ethanol engines; visualization and simulation of combustion in engines; development and control of HCCI and CAI processes; and special catalyzers for the products of ethanol combustion; among others. Training researchers and, mainly, the structuring of a combustion engine research program should be the object of a public policy focused on a partnership between research institutes, universities and the auto industry. Given that financial resources are limited, it is important to concentrate efforts on more specialized and better equipped institutes to avoid the dispersion of these resources into projects with little or no practical return.

5.2.2. Support for the development of motor engineering

Automakers and their main suppliers in Brazil are global companies that seek to incorporate specific regional factors into their strategies. For this reason, several of these companies have established their renewable fuels development centers within their Brazilian subsidiaries – a fact that should be taken advantage of and encouraged by means of public policies that aim at strengthening automobile engineering specifically in the use of ethanol. Even though basic engine units, engine control systems and catalyzers are developed abroad for gasoline engines, their adaption for ethanol generally takes place in Brazil. A significant part of the developments that are applied to flex-fuel engines are the work of parts and systems suppliers to the OEMs.

Public policies that encourage financing for the development of ethanol engine components and systems, similar to the Funtec program run by the Brazilian Development Bank (BNDES), would help attract other competence centers in the ethanol field to the country. Projects should involve various players in the supply chain together with research institutes or universities, in order to build up domestic know-how. The focus could be on items such as catalyzers, piston rings, fuel pumps, injection nozzles, cold start systems and the like, specifically for ethanol.

5.3. Specific aspects

5.3.1. Flex-fuel vehicles

The Vehicle Labeling Program, currently coordinated by Inmetro, is a way to promote healthy competition between automakers by giving public recognition to – and so informing consumers about – the vehicles with the greatest energy efficiency. However, this program does not differentiate between renewable and fossil fuels – a fact that could end up favoring imported vehicles that have been optimized for gasoline. However, under the current rules of the program, if an OEM launches an ethanol-powered model, this will enjoy an advantage of around 3% due to ethanol's higher octane rating, and this could possibly reward the vehicle with a higher classification.

A economy classification program for ethanol, ignoring gasoline results, with the possible participation of organizations such as the IPT and Cetesb, and with wide publication of the results, would emphasize the aspects of optimization that it is desired to promote.

There should be incentives for OEMs and final consumers in order to promote the desired energy efficiency and environmental sustainability. One incentive that could be adopted, and that has shown to be effective in other countries, is selective tax relief based on the level of fuel economy and emission reduction.

A public policy to promote fleet renewal would be effective in reducing emissions of greenhouse gases and local pollutants, and would bring indirect benefits by increasing energy efficiency in ethanol use, because new generations of flex-fuel vehicles would be developed. It is worth mentioning that with CO_2 valued at US$20 per tonne, the average annual reduction in CO_2 emissions for each flex-fuel vehicle in Brazil could justify an IPVA (annual road license tax) 1% lower for flex-fuel vehicles compared to their gasoline equivalent, assuming the flex-fuel vehicle runs on ethanol 65% of the time.

Public policies to encourage the export of flex-fuel technology would reinforce the development of Brazilian motor engineering, and this would help improve the use of ethanol as a fuel. Exporting flex-fuel vehicles to developing countries that import petroleum and derivatives could help open new markets for ethanol exports and/or help in transforming ethanol into a commodity.

5.3.2. Flex-fuel motorcycles

A public policy focusing on renewing the motorcycle fleet, with replacement by flex-fuel motorcycles, would bring direct benefits in terms of reduction of greenhouse gas emissions, plus indirect benefits through the development of technology to use ethanol in smaller engines. The same logic that applies to IPVA reduction for flex-fuel four-wheel vehicles could be applied to flex-fuel motorcycles, as well as a public policy to encourage exports.

5.3.3. Diesel substitution

There should be encouragement for environmental legislation aimed at reducing CO_2 emissions to include clauses relative to the transportation sector, both collective and individual. Even conservative values for the CO_2 emissions avoided by transportation vehicles that do not use fossil fuels can justify tax reductions of 5% to 10% on the IPI and ICMS taxes levied on new vehicles. Other options for support could include direct subsidies for a fixed period and the purchase of old vehicles to remove them from circulation.

Given that substituting ethanol for diesel is much more economically attractive in the sugar and ethanol industry than in any other sector of the economy, the credibility to promote this alternative in other markets can be harmed if the sugar and ethanol sector does not set an example.

As a move to facilitate the development of technological alternatives that will initially be applied in the sugar and ethanol sector, we suggested that the sector should use its combined purchasing power in a co-ordinated manner to encourage suppliers to develop projects involving agricultural machinery and trucks.

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Explanatory Notes

[i] Brazilian law does not establish the octane level of Type A gasoline, but for Type C gasoline the octane level is based on the Anti-Knock Index (AKI – Índice Antidetonante, IAD), with the following minimum values: gasoline: AKI 87; premium gasoline: AKI 91; "Podium" gasoline: AKI 95. In comparison, ethanol has AKI 99.5 (calculation of AKI values for ethanol – RON and MON – from Owen, K. and Coley, T., Automotive Fuels Reference Book, pp. 591, second edition, Society of Automotive Engineers, 1995.
[ii] Reducing the amount of fuel in relation to the theoretical quantity of air for complete combustion.
[iii] STI/MIC, Fuel Economy Program for Light Vehicles with Otto Cycle Engines, Brasilia, 1983.
[iv] Report on Air Quality in the State of São Paulo, 2007. State Government of Sao Paulo - Department of the Environment - Cetesb, 2008.
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[viii] In accordance with Conama Resolution No. 299 of October, 2001.
[ix] Report on Air Quality in the State of São Paulo, 2007. State Government of São Paulo - Secretariat of the Environment - Cetesb, 2008.
[x] "Regulation on Conformity Assessment for Light Passenger Vehicles and Light Commercial Vehicles with Otto Cycle Engines" - Annex to Inmetro Decree No. 391/2008.
[xi] System that treats exhaust gases. Also known as a catalyzer.
[xii] http://www.Anfavea.com.br/emissoes.html.
[xiii] Inmetro Instruction No. 391 - 04/11/2008 – "Regulation on Assessment of Conformity of Passenger Vehicles and Light Commercial Vehicles with Otto Cycle Engines".
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[xviii] Moreira, JR – "The BEST Project and the expansion of the ethanol industry in Brazil" - Presentation at panel entitled "Ethanol: New option for Diesel Engines" - Ethanol Summit 2009, São Paulo, June 2009.
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07

International Biofuels Policies

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Rafael Schechtman

Global biofuels production is growing, reaching approximately 80 billion liters in 2008, of which 67 billion was ethanol. Supply increased by 18.6% per year between 2000 and 2008 for ethanol, and 37.3% for biodiesel. This is a market where the most important producers of ethanol are the United States (34 billion liters in 2008) and Brazil (27 billion liters); the two countries together accounting for about 80% of world production.

Despite the increase in production, experience in several countries shows that in general the use of biofuels is not yet competitive with petroleum products, and depends on public policies. These policies do not tend to succeed where petroleum derivatives are subsidized or where the tax burden does not include the costs of the externalities of fossil fuel production and use.

All countries (except Brazil, in the case of ethanol) have policies to encourage biofuels consumption. These are justified by a number of factors, including greater energy security, reduction of environmental impacts and the creation of new markets for agricultural products.

Three main instruments exist to promote the use of biofuels: command and control mechanisms (regulatory standards, including mandatory consumption); economic measures (financial incentives, differential taxation, tradable certificates); and import restrictions.

The United States, for example, applies both regulatory standards and financial incentives, establishing mandatory volumes for renewable fuels. It is important that regulations take into account the rate of emissions reduction attributable to replacing fossil fuel with biofuel. Today, a 10% blend of ethanol in gasoline is mandatory in some U.S. states. In addition, there are tax incentives to promote the use of U.S. corn-based ethanol and tariff barriers to imports from Brazil.

The European Union uses much more biodiesel and accounts for two thirds of world production of this fuel, which receives strong incentives. In the medium term, given the restrictions on domestic supply, the EU is likely to import larger quantities of ethanol to meet growing consumption. Today, Brazilian ethanol faces tax barriers to enter the EU.

This study also analyzes biofuels policies in Sweden, Britain and Germany. In Sweden, where ethanol use is promoted compulsorily, half of new light vehicle models were offered in flex versions in 2008. The UK, which until 2010 promoted biodiesel and ethanol via tax incentives, will introduce increasing mandatory quotas for biofuel sales. And Germany, which in 2008 produced 17% of the world's biodiesel from canola, ended tax breaks for the majority of cases, preferring to impose quotas.

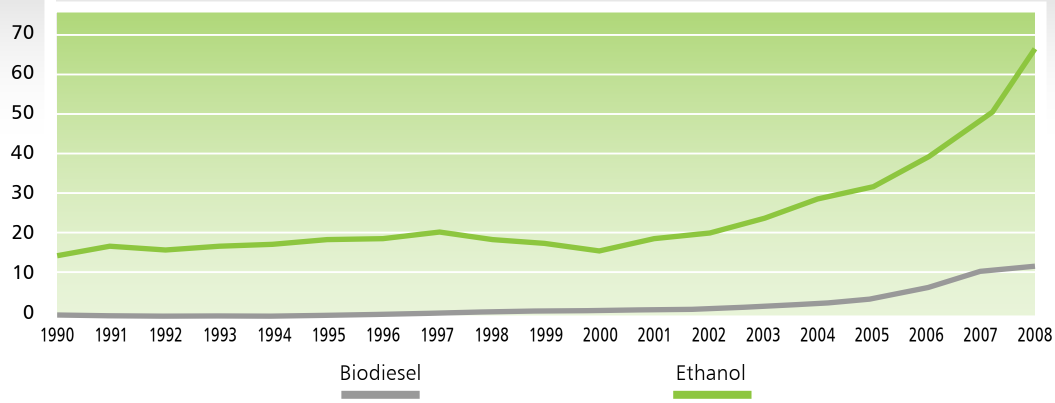
▶ Introduction

The global biofuels market grew at surprising rates during the last decade. As can be seen in **Graph 1**, between 2000 and 2008, the annual growth of ethanol production averaged 18.6%, while for biodiesel growth averaged 37.3%.

As shown in **Table 1**, 67 billion liters of ethanol and 12 billion liters of biodiesel were produced in 2008, a volume equivalent to approximately 920,000 barrels/day of petroleum, or 1.1% of the global production of fossil fuels. The United States leads the global production of ethanol, followed by Brazil. Together, these countries were responsible for nearly 90% of global ethanol production. Germany was the largest producer of biodiesel, with its 2.2 billion liter output representing 17% of global production. Production of biodiesel has been dominated by member-states of the European Union (EU), which together produced 8 billion liters, or two-thirds of global production.

The performance of the biofuels market reflects both the implementation of policies in several countries to promote its production and use, and its improving competitiveness compared to fossil fuels. This stems from falling production costs, due to technology gains, as well as the rising petroleum price until 2008. Even so, production costs for biofuels are greater than those for petroleum derivatives. Biofuels are not competitive with fossil fuels at market prices, except in a few cases such as Brazilian ethanol. Hence, the majority of promotional policies are justified on the grounds that biofuels bring non-market benefits.

Graph 1 **Annual growth of global ethanol and biodiesel production** *In billions of liters*



Source: Prepared by the authors from Fulton, L. et al. (2004) for 1990–2000 data; EIA (2009a) for 2001–2007; and REN21 (2009) for 2008.

These benefits include:

a *Increase in national security of energy supply*

Petroleum has finite reserves and highly volatile prices. Seeking to minimize dependence on this fuel is therefore crucial for many countries. Biofuels have great potential for directly substituting petroleum derivatives in the short term and without great investments in infrastructure or technological changes in vehicle motors. Ethanol can be used when mixed with gasoline in proportions of up to 15%[i] without significant alterations to vehicle engines, and in greater proportions in modified vehicles. Modern diesel engines can run on mixtures of up to 100% biodiesel, while older models accept up to 20% biodiesel with small modifications. Unlike other candidates to substitute petroleum derivatives, such as natural gas (CNG), hydrogen and electricity, the biofuels distribution and retail chain can more easily use the existing infrastructure for oil derivatives. In addition, biofuels can be produced domestically; if imported, they can come from diverse regions that do not manifest the instabilities that currently plague several oil producing countries.

b *Reduction of global and local environmental impacts*

The substitution of oil derivatives by biofuels is positive for local air quality. Biodiesel emissions, for example, contain less carbon monoxide, sulfur oxides and particulate matter than diesel emissions. Biofuels are less toxic than fossil fuels and their production processes are less aggressive to the environment, while waste material from their production can be recycled and even used to generate electricity, as in the case of Brazilian sugarcane ethanol.

Global production of ethanol and biodiesel in 2008 *In billions of liters* Table 1

	Ethanol	Biodiesel	Total
United States	34.0	2.0	36.0
Brazil	**27.0**	**1.2**	**28.2**
France	1.2	1.6	2.8
Germany	0.5	2.2	2.7
China	1.9	0.1	2.0
Argentina	0.0	1.2	1.2
Canada	0.9	0.1	1.0
Spain	0.4	0.3	0.7
Thailand	0.3	0.4	0.7
Others	0.5	2.7	3.2
Global Total	**67.0**	**12.0**	**79.0**

Source: Prepared by the authors from REN21 (2009).

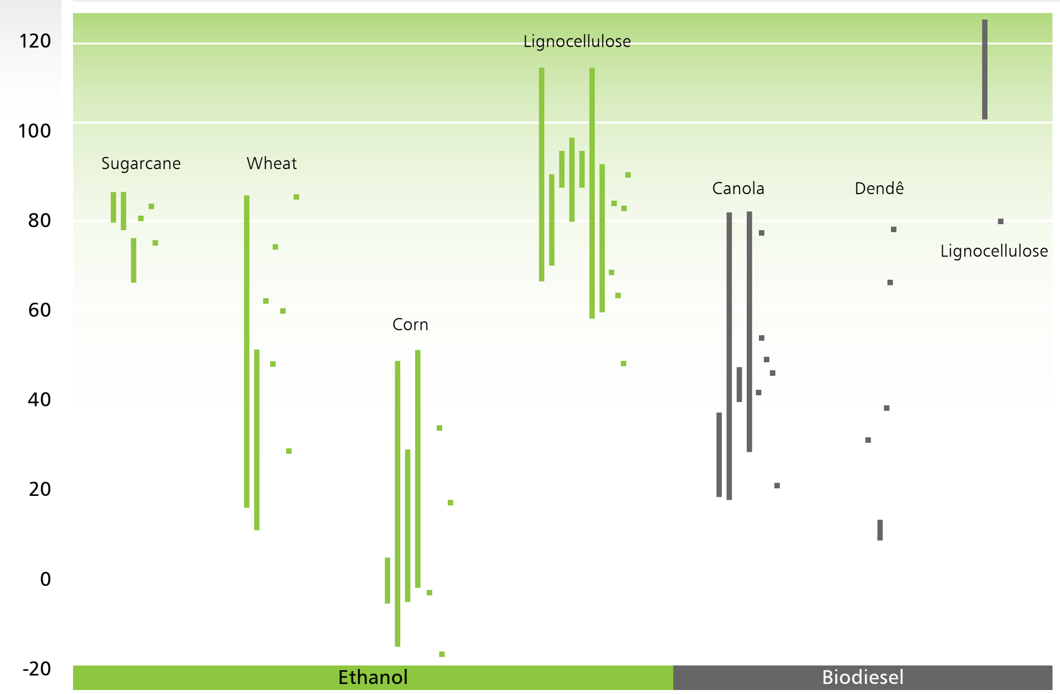
Because they produce less greenhouse gas (GHG) emissions than gasoline and diesel, ethanol and biodiesel are important options for mitigating climate change. This is particularly true for countries that need to reduce their emissions to comply with the Kyoto Protocol. According to a 2008 study by the OECD looking at lifecycle emissions[ii] of GHG from various biofuels produced by different technological paths, sugarcane ethanol emits, on average, 85% less GHG than gasoline (see **Graph 2**). This can exceed 100% if the use of byproducts of the sugar-ethanol industry is considered, for example the generation of bioelectricity. Wheat ethanol offers more modest results, reducing emissions between 30% and 50%, while corn ethanol provides an average reduction of 20%.

Studies show differing results for biodiesel produced with existing technologies in Europe, using canola vegetable oil. However, the OECD study indicates probable emission reduction values of between 40% and 55%. According to the OECD, research data on Dendê biodiesel is scarce. Some cases point to reductions of up to 80%, although in other cases where the crop has been grown in areas where tropical forest was burned down, there may be an increase of emissions.

Graph 2

Less greenhouse effect *Reduction in (%)*

Reduction of net greenhouse gas emissions for technology paths for biofuels production compared to gasoline and diesel (with no change in land use)



Source: REN21 (2009).

For the second-generation technology paths, the production of both ethanol and biodiesel from biomass lignocellulose can lead to emission reductions greater than 100%. However, these paths are not yet commercially available.

c *Creation of new markets for agricultural products*

Biofuels production creates new demands in agriculture and brings benefits to rural areas by improving product prices and increasing regional income. Other benefits include the development of new agricultural and production technologies and the possibility of exporting new items, for example new technologies and renewable products. There is, however, great concern that crops destined for biofuels production may occupy or dislocate areas destined for food production. These crops may even be diverted to biofuel production. This is particularly true when fiscal incentives for biofuels distort the relative market prices.

d *Stimulus for regional and national development*

Biofuels production can also promote economic activity, development and job creation, especially in rural areas that are generally less developed than urban areas. Other benefits can also be created for the country, such as the technological development of agricultural sectors and biofuel production. Also, the country can expand its range of export options, adding new technologies and renewable fuels.

This study analyzes international policy experiences for promotion and use of biofuels in an attempt to identify the barriers and opportunities for exporting Brazilian ethanol. In item 1, we analyze automotive fossil fuel prices in several countries with the aim of identifying space within pricing policies to adopt financial incentives for biofuels. Item 2 evaluates policies to promote production and consumption in selected countries, seeking to identify the dimensions of the ethanol market in these countries and the barriers to Brazilian ethanol. Finally, item 3 summarizes and complements the main considerations and results of this paper.

▶ 1 Analysis of international automotive fuel prices

An analysis of the internal pricing policies of automotive fossil fuels used in different countries is essential for an understanding of the impact of policies aimed at promoting biofuels.

Consumer prices for petroleum derivatives include several cost factors, profit margins and taxes incurred along the supply chain from the wells to the gas stations. These include the costs of petroleum prospection, production, transportation and refining, then the cost of distribution and retail sale of derivatives, plus companies´ profit margins and taxes in both the oil producing and derivative consuming countries.

In general, international gasoline and diesel prices follow the price of a barrel of petroleum. With the elevation of petroleum prices until the middle of 2008 and its subsequent decline, it would be logical that consumer prices followed a similar pattern, at least to a certain extent. However, it can be seen that in some countries the prices did not follow the variation of the international price of petroleum. The explanation for this lies in the different policies of countries to set domestic prices and taxes.

Three basic mechanisms are used in policies to establish domestic prices: (**I**) *ad hoc* decisions; (**II**) automatic adjustments determined by formulas; and (**III**) market prices. The first mechanism is what occurs when prices are adjusted by the government or by oil companies that are directly or indirectly controlled by the government, as a function of political or macroeconomic concerns. Readjustments are usually made at irregular intervals of time, using non-transparent criteria, and this leads to prices that move out of step with international ones. China, India and Indonesia are examples of countries that use such a mechanism. Under Brazilian law, gasoline and diesel prices are free, but in the last few years diesel and gasoline price adjustments made by Petrobras have used this mechanism, either for political interests of the government or for the economic interest of the government-controlled corporation.

The second mechanism – used for example in Malaysia and Vietnam – is based on formulas that are predefined by the government or the national petrol company. These formulas readjust prices automatically, at pre-defined periodic intervals, based on the behavior of international prices. Compared with an ad hoc system, readjustment by this mechanism has the advantage that domestic prices follow the international market, albeit with some delay, in addition to being transparent and predictable.

Finally, under the third mechanism, adopted in the majority of countries that are members of the Organization for Economic Cooperation and Development (OECD)[iii], prices are a consequence of the interplay of market forces. In these countries, the role of the government is restricted to taxing fossil fuels.

Generally speaking, two types of taxes are levied on automotive fuels in consuming countries: specific tributes for fuels (excise taxes or duties, and transportation taxes), for example Brazil's federal fuel levy known as the CIDE (literally, the Contribution of Intervention in the Economic Domain); and value added taxes (VAT), which also apply to the sale of other products – the Brazilian ICMS state-level tax is an example. The specific taxes have fixed values and apply to volumes sold, while VAT is fixed as a percentage of the final price of fuels, and therefore impacts the selling price. There are also taxes on the ownership and use of vehicles, such as Brazil's IPVA, and the congestion taxes that are used in some European countries, but these do not affect the final price of fuels.

In a comparison between fuel prices – with and without taxation – in OECD countries, the Institut Français des Relations Internationales (IFRI) showed that tax-free prices do not reveal significant variations, given that oil derivatives are commodities (Davoust, R., 2008). The IFRI thus demonstrated that the differences between consumer prices are caused mainly by national tax policies, while differences in costs and margins have little influence compared to taxes.

This same conclusion was reached by GTZ (now GIZ) in a series of studies of consumer prices and tax levels for diesel and gasoline in several countries since 1991 (GTZ, 2009). Based on the level of tax in final consumer prices for gasoline and diesel, GTZ (GTZ, 2009) grouped countries in four categories, as shown in **Graph 3** and **Graph 4**[iv]:

Category **1** – countries with high tax incentives[v]: These are countries where consumer prices for derivatives are below the international oil price. In other words, product prices do not cover the opportunity cost of oil and the costs of derivatives production. In general these are oil-producing countries where the cost of derivatives production is subsidized by the national oil industry and fuel prices are used to control inflation and avoid public dissatisfaction. Examples include Venezuela, Libya and Saudi Arabia. Biofuels penetration in such countries is practically impossible. Given their abundant low-cost oil, only non-market objectives such as local and global environmental questions could motivate any biofuel promotion policy.

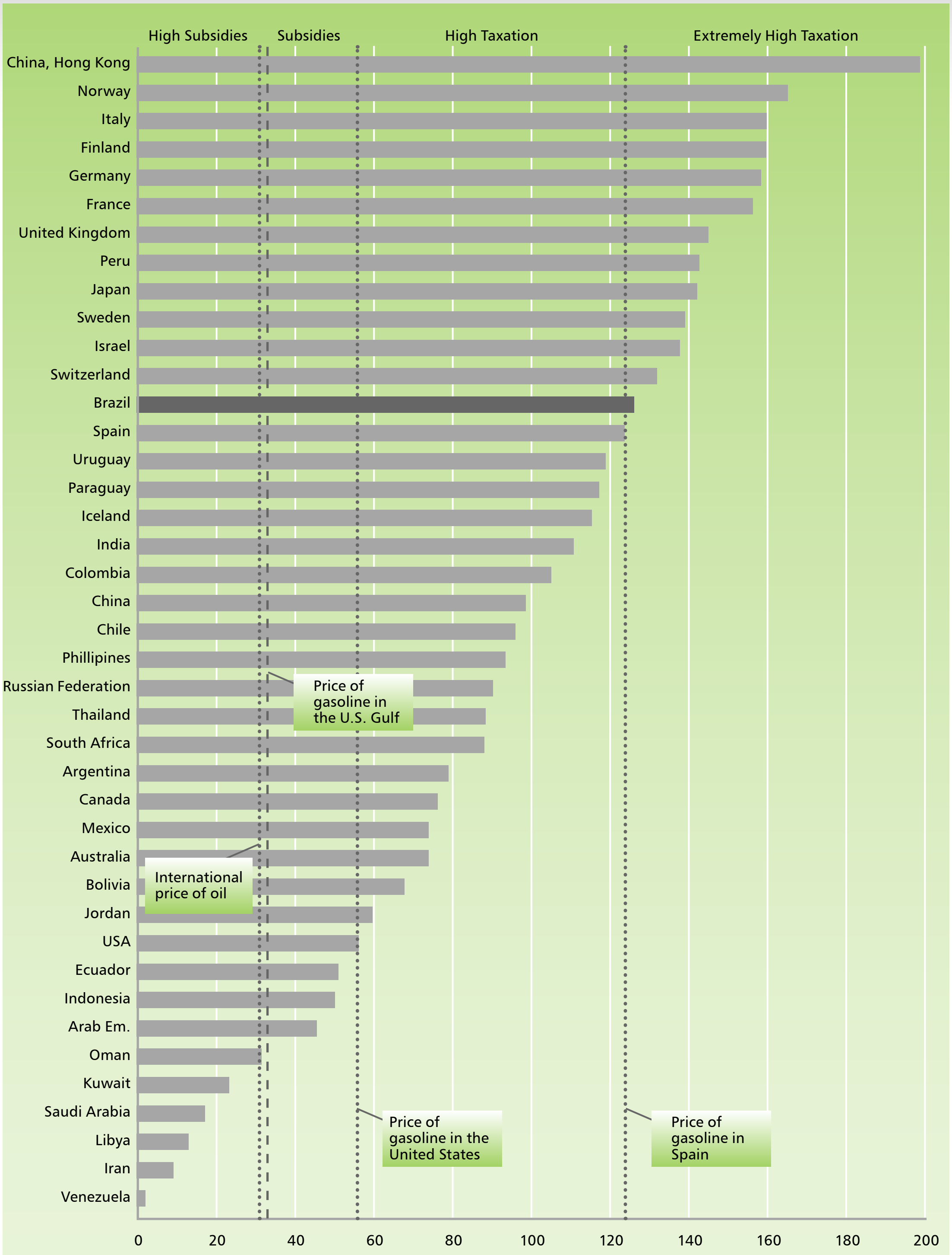
Category **2** – countries with tax incentives: These are countries where diesel and gasoline consumer prices are above international oil prices but below the selling price in the United States[vi], which is a country that practices market prices for derivatives with a minimum of tax. Fuel prices in these countries cover the raw material costs but receive tax incentives to cover other costs in the supply chain. As shown in **Graph 3** and **Graph 4**, in some of these countries gasoline and diesel prices are below market prices practiced in the Gulf of Mexico. As in Category 1, this group also includes oil-producing countries where significant tax incentives would be necessary for biofuels promotion, which would only be justified by non-market objectives.

Category **3** –countries with high taxation[vii]: These are countries where prices lie between the U.S. and those practiced in Spain, which in November 2008 had the lowest derivatives prices of countries in the EU-15[viii]. In addition to Spain's own taxes, fuel prices in that country are impacted by the mandatory minimum values of VAT and the specific taxes on fuels that apply to every EU member. Taxation in countries within this category exceeds US$0.10/liter and has other purposes in addition to road construction and maintenance. In some countries in the category, fuel prices are not a result of market forces; rather they are established ad hoc by the government or an oil company controlled by the government. In this case, derivatives sales generate more income than is required to cover production and distribution costs. Appropriation of this income by the government has the same role as taxation. Concession of tax incentives would be necessary for biofuels to be viable in these countries.

Category **4** –countries with very high taxation: These are countries where prices are above the level in Spain. In these countries, fuel taxation has many objectives such as constructing and maintaining roads, generating income, encouraging efficiency in the transportation sector and internalizing the environmental costs of the production and use of fuels and vehicles. These countries offer high potential for the introduction of biofuels without requiring elevated tax incentives.

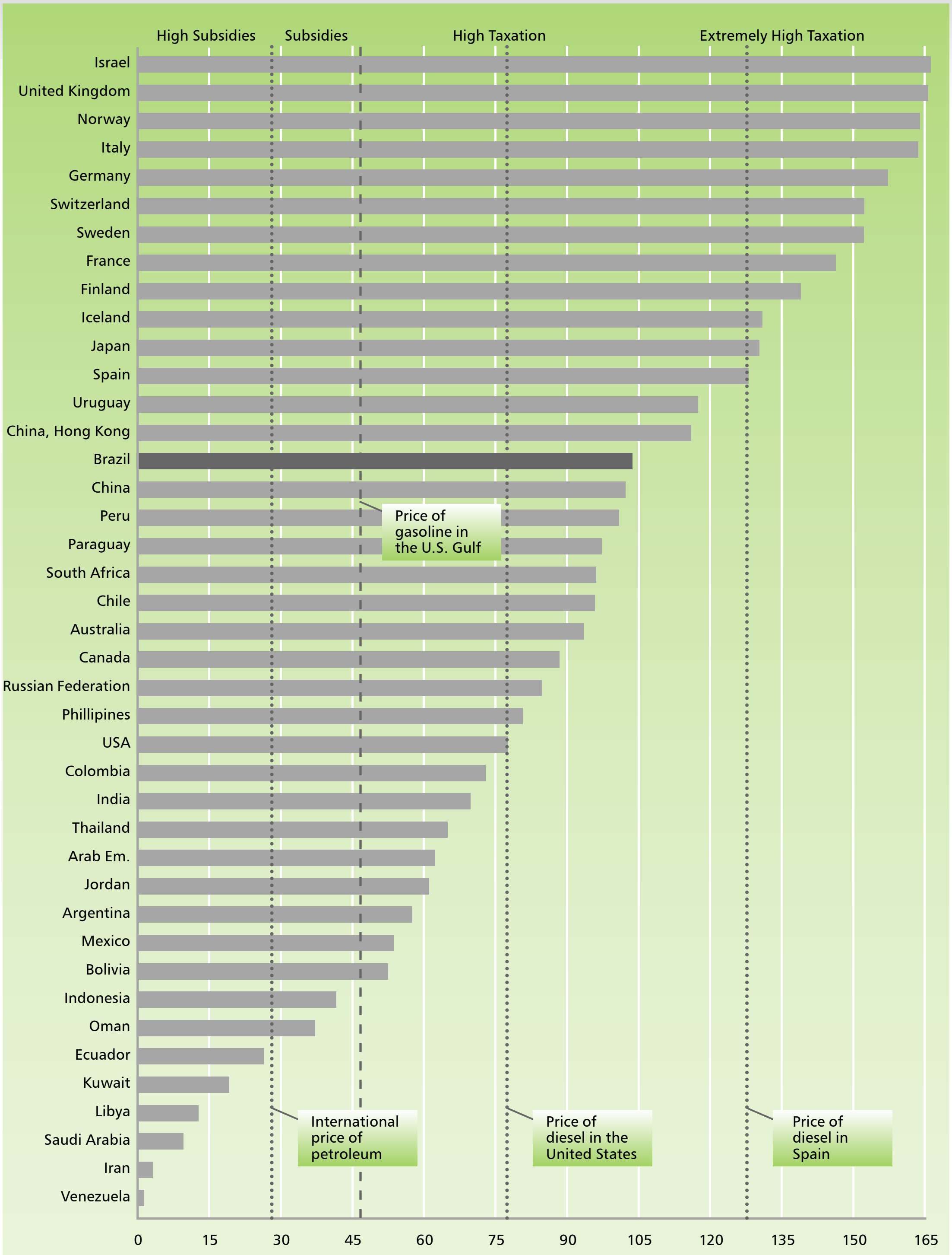
The last survey of gasoline and diesel prices in 172 countries undertaken by GTZ in November of 2008 (GTZ, 2009) indicated that, in the case of gasoline, eight countries fell into category 1; 12 into category 2; 86 into

Graph 3 **Comparison of consumer prices for gasoline** *US cents/liter; November 2008*



Source: Prepared by the authors from GTZ (2009).

Comparison of consumer prices for diesel *US cents/liter; November 2008* Graph 4



Source: Prepared by the authors from GTZ (2009).

category 3; and 66 into category 4. Diesel, on the other hand, saw 12 countries in category 1; 30 in category 2; 81 in category 3; and 49 in category 4. In that month, Brazil fell into category 4 for gasoline and category 3 for diesel. It must be remembered, however, that the GTZ survey was conducted after the beginning of the global economic crisis, when free-market prices of these derivatives were in free fall around the world, but Petrobras had not made any adjustment to domestic prices.

2 Analysis of international policies for biofuels promotion

Many countries have in recent decades found that using biofuels for automotive purposes represents a contribution to the solution of important issues, such as: (I) increasing energy efficiency and flexibility, and diversifying available energy sources; (II) improving the country's ability to rapidly respond to emergency situations that affect fuel supply, such as price shocks or temporary interruption of supply for security reasons; (III) promoting the use of energy sources that are renewable and less harmful to the environment, especially with respect to GHG emissions; and (IV) exploiting the country's comparative advantages, promoting development and the exportation of new technologies and products.

Governments have adopted three main instruments to promote the use of biofuels: instruments of command and control; economic instruments; and import restrictions. Instruments of command and control have been applied since the 1980s, and are regulatory standards that imply, for example, a requirement for biofuel mixtures or the production of vehicles for its use. This category also includes vehicle emission standards, fuel specifications and minimum efficiency standards for vehicles.

Economic instruments include financial incentives, special tax structures and negotiable certificates for biofuel mixtures. Financial incentives and special tax structures have been used in several countries since the beginning of the 1990s as a way to achieve environmental goals. They can take the form of tax credits, government tax incentives or loans with special conditions, and their purpose is to reduce the cost of producing alternative fuels and acquiring vehicles that run on them. In general, financial incentives and regulatory standards are applied together.

Special tax structures are conceived to place a greater tax burden on fossil fuels. They are usually applied via policy changes that create or increase taxes on pollutant sources and agents, according to the externalities that these produce. Environmental taxes differ from financial incentives in two ways. First of all, they do not imply cost for the government; on the contrary, they generate funds that can be used to reduce other taxes or to finance environmental and social programs. The second difference relates to the signal sent to consumers about the externalities involved in vehicle use, which are internalized by the tax. Faced with higher prices, the consumer adjusts his demand or chooses to use less pollutant technologies or fuels.

The use of certificates has been adopted in environmental programs in the United States and European countries, together with regulatory standards. These standards require, for example, that electricity distributors or generators or, alternatively, consumers themselves, use a minimum percentage of renewable fuels to meet the demand of electricity. The imposition of standards is accompanied by the introduction of negotiable certificates that are supplied to the agents according to their fulfillment of the required standards. This means that agents who can acquire renewable energy more cheaply can sell their surplus certificates to others that face higher costs in meeting their targets.

Import restrictions are geared to protecting domestic biofuel producers, in particular via the introduction of import tariffs or restrictions on the concession of financial incentives for imported products. This barrier has low economic efficiency because it imposes greater costs on the consumer by creating a market reserve and limiting competition among suppliers. The fact is that if there were no restrictions on international commerce, there would be a faster fall in biofuel costs and economic efficiency would increase, so helping speed up the reduction of fossil fuel use.

In the following pages, we discuss the application of these policies in the United States and the European Union. The United States was chosen because of the size of its market for vehicle fuel, both fossil and renewable, especially in the case of ethanol. The country also represents a good example of the application of regulatory standards and financial incentives to promote the production and use of biofuel.

Policies in effect in the European Union are discussed via the analysis of the situation in three member states: Sweden, the United Kingdom and Germany. While Sweden does not have a large fuel market compared to the other countries analyzed, it has one of the most ambitious biofuel promotion policies, especially for ethanol. Thanks to its relatively small fuel market – together with its high level of economic and social development, and the environmental awareness of its population – this country has introduced innovative policies to reduce, if not eliminate, the use of fossil fuels.

The United Kingdom, on the other hand, is a relevant example of the use of a biofuels program supported by the introduction of blend certificates.

Germany was selected because of its incentive policies for biodiesel. These place Germany first among biodiesel producers and consumers. The country's programs initially provided heavy subsidies for biodiesel use, but have now entered a new phase with the use of regulatory standards and economic instruments.

Finally, we discuss the history of Brazilian policies for ethanol promotion and indicate the necessary requirements for implanting a new national biofuel policy.

2.1 Biofuel policies in the United States

The United States has since 2005 occupied first place in the global production of ethanol, followed by Brazil. American ethanol is produced almost entirely from corn and is consumed domestically, above all as an oxygenator mixed with gasoline in proportions up to 10%. In 2009, ethanol consumption in the U.S. was 40.7 billion liters, representing almost 8.5% of the fuel market for Otto cycle vehicles.

The United States is a good example of the combined application of regulatory standards and financial incentives to promote biofuels. The 2005 Energy Policy Act (EPAct 2005) constitutes extensive legislation on energy, and establishes in Section 1501 a mandate for refineries, blenders, distributors and importers to add renewable fuels to gasoline. The Renewable Fuel Standard (RFS1) provided that the use of renewable fuels – which began in 2006, at four billion gallons or approximately 15 billion liters annually – should progress to 7.5 billion gallons by 2012. The regulation and implementation of this mandate is the responsibility of the Environmental Protection Agency (EPA), which must also define the percentage renewable fuel blend in gasoline, based on the gasoline demand in the country each year.

In December of 2007, the U.S. Congress passed the Energy Independence and Security Act (EISA), creating a new program which became known as RFS2. Once again, the EPA was given the responsibility of regulating the alterations. On May 26th, 2009, the agency submitted for public hearing a document entitled Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program. The hearing deadline was September 25th 2009, but the EPA only officially published the final version of the RFS2 regulation on March 26th, 2010, over two years after Congress created RFS2. This delay was caused by the great controversy generated about how to calculate emissions associated with biofuels production.

One important change introduced by RFS2 was the increase in mandatory volumes of renewable fuels. As shown in **Graph 5**, the new program extended the timeline for increasing the use of renewable fuels to reach 136 billion liters in 2022. RFS2 also establishes that a growing proportion of the annual volume of renewable fuels consumed must be advanced biofuels, and they must include minimum volumes of cellulosic biofuel and biodiesel produced from biomass. Although there is a significant increase in renewable fuel volumes, RFS2 allows for the possible substitution of all types of fuels in all types of vehicles including locomotives, vessels and aircrafts, as well as fuels used in stand-alone engines, whereas RFS1 provided only for the substitution of gasoline.

In order to be classified as a renewable fuel, advanced biofuel, cellulosic biofuel or biomass biofuel, and thereby qualify for inclusion in the respective annual volumes, the fuels must achieve minimum percentage lifecycle reductions of GHG emissions compared to the gasoline and diesel used in the United States in 2005. According to EISA, renewable fuels produced in mills whose construction was started after December 19th, 2007 must achieve minimum emission reductions of 20%, while advanced biofuels and biodiesel must reach 50% and cellulosic ethanol 60%.

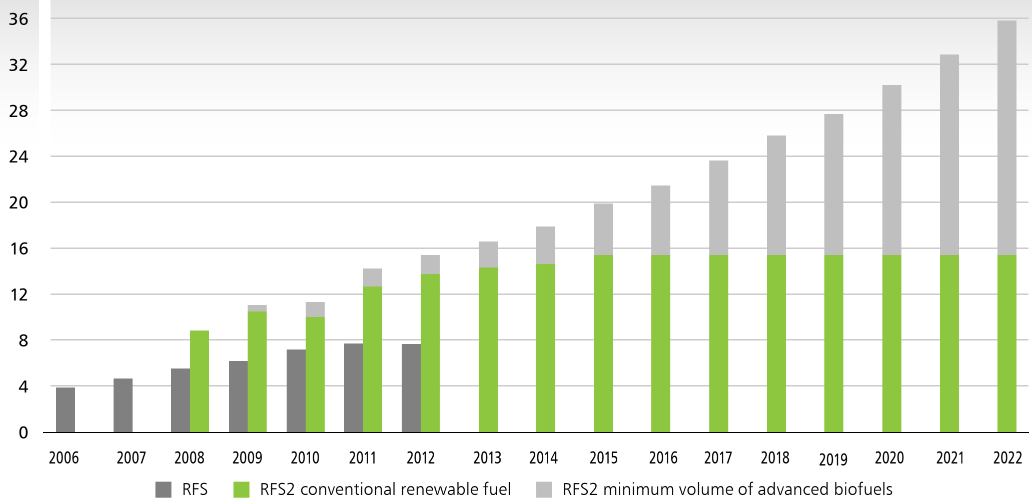
To determine the emission reductions generated by biofuels, the EPA relies on its own analysis and also the best available scientific models. It has incorporated many changes to the model initially proposed, based on public comments and the formal revision process undertaken by the agency. EPA analyses consider emissions throughout a fuel's lifecycle. This includes emissions caused by direct and indirect land use change (ILUC) in other countries that are caused by the production of renewable fuels in the United States. Because a fuel's lifecycle GHG emissions occur over the course of time, the EPA presented two proposals to take account of the temporal nature of emissions: analysis for a 30-year horizon, without weighting present and future emissions; and an analysis for a 100-year horizon, in which future emissions are discounted at an annual rate of 2%. In the end, however, the EPA decided to only use the 30-year horizon, without any discount.

Final regulations for RFS2 were announced in February 2010 and the EPA designated sugarcane ethanol as an advanced biofuel, capable of reducing greenhouse gas emissions by at least 50% compared to gasoline. The EPA also confirmed that Brazilian ethanol achieves GHG emission reductions that exceed the minimum requirements for all categories. The EPA's calculation shows an average reduction of 61% when compared to gasoline, using a 30-year period to compensate emissions related to indirect effects of land use (ILUC). Corn ethanol reduces emissions by 21% using best industry practices (i.e. electricity generated with natural gas), but the American average is still well below that, as shown in **Graph 6**.

The status achieved by Brazilian sugarcane ethanol undoubtedly opens windows of opportunity for this biofuel, given the uncertainties that surround the ability of the United States to produce advanced biofuel on a commercial scale in the short term.

This means that the criteria for emission reductions established by the EPA to classify biofuels, if maintained, open a window of opportunity for Brazilian ethanol, given that the deficit of American ethanol would lend weight to the argument of those people – including many in several U.S. states – who defend the reduction or even elimination of the current import taxes on the Brazilian product.

Graph 5 **Comparison between required volumes of renewable fuels in RFS and in RFS2**
*In billions gallons**



Source: Prepared by the authors from EPA (2009) and RFA (2009a). • *one gallon = 3.791 liters

In addition to RFS2, U.S. federal and state laws dealing with air quality and fuel specifications also have played a determinant role in the country's use of ethanol. At the federal level, the 1990 Clean Air Act (CAA 1990) mandated the use of oxygenated gasoline (reformulated gasoline) in some regions of the country, aiming to reduce emissions of carbon monoxide. Gasoline suppliers initially opted for the addition of methyl tert-butyl-ether (MTBE) to gasoline as an oxygenator because it is cheaper than U.S. ethanol, until evidence showed that MTBE poses a risk of groundwater contamination and is carcinogenic. Several U.S. states therefore banned its use, leading to a rapid acceleration in the use of ethanol as a substitute.

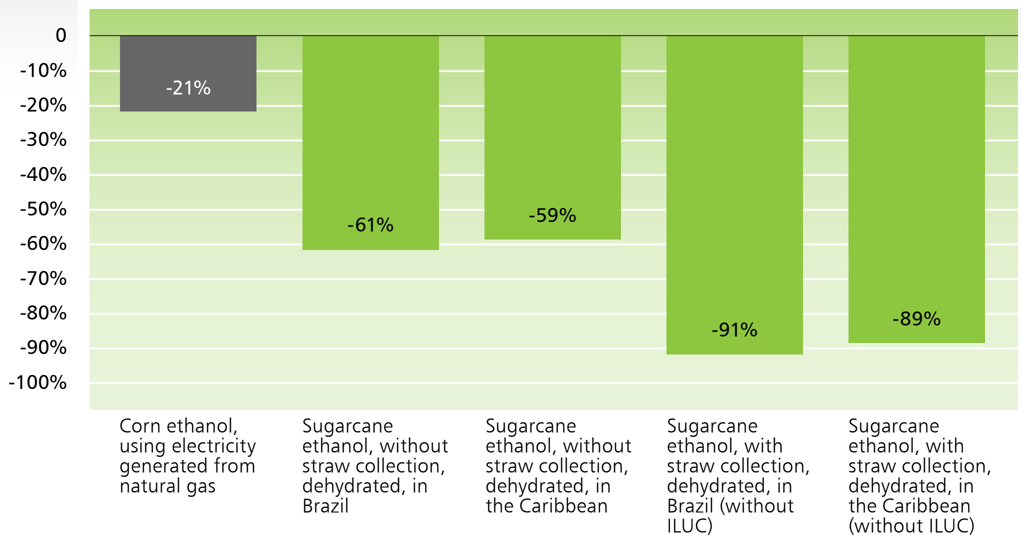
Thanks to environmental legislation, the addition of 10% ethanol in gasoline (E10) has now become mandatory in several U.S. states[ix], and is optional in all others. The blend of up to 10% is found at regular fueling stations. A voluntary 85% ethanol blend (E85) is also used, but is found in a few stations, in part because very few vehicles have the compatible technology to use it. On the other hand, the biodiesel blend with diesel in proportions from 2% to 100% is optional in all states.

To support the mandatory measures established under U.S. law, federal programs provide tax credits to fuel blenders and biofuel producers, as summarized in **Table 2**. Incentive values are significant. According to Koplow (2009), tax incentives applicable to conventional ethanol could add up to US$0.60 to US$0.79 per gallon in April 2009, while the amount for cellulosic ethanol was US$2.26 to US$2.46/gallon. As for

Graph 6

Lower greenhouse gas emissions

Average reduction of greenhouse gas emissions in the lifecycle of corn ethanol and sugarcane ethanol, including emissions from direct and indirect land-use change (LUC and ILUC), with 0% discount and a 30-year horizon



Source: U.S. Environmental Protection Agency (March 2010), prepared by the authors.

biodiesel, the sum of tax incentives could reach US$2.22 to US$2.65 per gallon. By way of comparison, the average price of U.S. gasoline in April 2009 was US$2.049 per gallon and diesel US$2.225 per gallon, including federal and state taxes that on average totaled US$0.47 to US$0.514 per gallon.

Although the incentive given to gasoline blenders (VEETC) does not discriminate the source of ethanol, the U.S. product is favored by the application of customs taxes on imports. An *ad valorem* tariff of 2.5% is levied on imported ethanol, which is low when compared to the rates prevailing in other countries, but in addition there is an extraordinary tax of US$0.54 per gallon, which exceeds by 20% the US$0.45 per gallon VEETC credit. Only the ethanol from countries that have concluded bilateral trade agreements with the United States is excluded from this tax; such countries include members of the North American Free Trade Agreement (NAFTA) and those included in trade preference programs created by Congress, such as the Caribbean Basin Initiative and the Andean Trade Preference. Ethanol imported from Brazil does not fit into any of these situations, and is therefore fully taxed.

In April of 2009, the Energy Information Agency of the United States published the Updated Annual Energy Outlook 2009[x] (Updated AEO 09). The document provides a reference scenario for the country's energy sector, taking into account the new global economic situation, together with the effects that the American Recovery and Reinvestment Act of 2009 (ARRA 09) may have on the U.S. economy and its energy market.

Enacted in February of 2009, ARRA 09 includes a package of measures from the U.S. government to stimulate the U.S. economy and minimize the effects of the crisis. Among the various measures are several aimed at increasing energy efficiency, reducing carbon emissions and increasing domestic energy production. Examples include improvements in buildings heating systems, setting minimum consumption standards for manufacturers and importers of motor vehicles, encouraging the acquisition of electric and hybrid vehicles, the use of renewable fuels and the use of light diesel vehicles. On the supply side, ARRA 2009 aims to increase domestic production of petroleum and natural gas, both onshore and offshore.

According to the updated projections of the AEO 2009, presented in **Table 3**, there would be a drop in gasoline consumption in the United States in 2009 due to the global economic crisis. The growth trajectory would resume in 2010 and 2011, with the return of economic growth. In 2012, however, the measures contained in ARRA 09 could impact the transportation sector, resulting in a drop in gasoline consumption which remains through the end of the analysis horizon. Ethanol consumption in the country, however, receives a positive impact from ARRA 09, caused by the increase in the volumetric percentage of the ethanol blend in gasoline, which grew from 7% in 2008 to 10% in 2010, remaining at that level until 2030.

The measures contained in ARRA 09 also have a positive impact on domestic production of ethanol. The increase in production of this biofuel will reverse the present deficit, which is met by imports, and generate an exportable surplus. This surplus will prevail through 2015, when domestic production again becomes insufficient to meet demand, causing a new cycle of ethanol imports that increase in the period 2015 – 2030 and reach 7.8 million m3, or 16% of ethanol demand, in 2022.

Table 2 **Main federal incentives for biofuels in the United States**

Incentives	Commentary	Value
Volumetric Ethanol Excise Tax Credit (VEETC). Promulgated by the America Jobs Act (2004). Replaced the partial exemption of automotive fuels established in the Energy Tax Act of 1978.	Credit for blenders when paying the excise tax on fuels. Calculated on the volume of ethanol of any origin, including imported, mixed to gasoline. There are no restrictions as to the size of the factory, market prices or social or environmental impacts for the production of methanol.	US$0.45 per gallon since January 1st, 2009 (it was US$0.51 per gallon until then). Values in introductory programs varied between US$0.40 and US$0.60 per gallon from 1978 to 2004.
Volumetric Biodiesel Excise Tax Credit (VBETC). Promulgated by the America Jobs Creation Act (2004). Most recent modifications included in the Emergency Economic Stabilization Act of 2008 (EESA).	Credit for blenders when paying the excise tax on fuels. Excludes biodiesel that is not produced or sold in the United States, or produced by co-processing in refineries. Includes biodiesel produced by any process and not only by etherification of vegetable and animal oils, except by co-processing in petroleum refining.	US$1.00 per gallon for every source. Originally, US$1.00 per gallon for vegetable and animal grease and US$0.50 for recycled oils.
Renewable Biodiesel Tax Credit. Promulgated by the American Jobs Creation Act (2004).	Credit for the producer on the payment of income tax. Originally, a tax credit parallel to the VBTEC for producers who, for whatever reason, could not reclaim the specific tax credit for fuels. In April 2007, its application was extended to include biodiesel produced by thermal depolymerization, which was not covered by the VBTEC.	US$1.00 per gallon for every source. Originally, US$1.00 per gallon for vegetable oils and animal grease and US$0.50 per gallon for recycled oils.
Small Producer Tax Credit. Initially authorized by the Omnibus Budget Reconciliation Act (1990). The Energy Policy Act (2005) doubled the annual production capacity of plants eligible for fiscal incentive from 30 million to 60 million gallons.	Credit for the producer on the payment of income tax. Any type of ethanol and biodiesel. Applicable only to factories with annual capacity of up to 60 million gallons.	US$0.10 per gallon for the first 15 million gallons per year. Producers of cellulose ethanol can claim credit on all 60 million gallons.
Production Tax Credit for Cellulosic Ethanol. Authorized by the 2008 Farm Bill.	Applicable only to the production of cellulosic ethanol.	US$1.01 per gallon, discounting VEETC if the production is destined to a gasoline blend and the Small Producer Tax Credit in case of small producers.

Source: Prepared by the authors from DOE (2009), RFA (2009b) and Koplow (2009).

This scenario, if it occurs, represents an opportunity for Brazilian ethanol exports, in particular if one considers that the EIA study does not take into consideration the sustainability criteria established by RFS2, which restrict the use of much of the ethanol currently produced in the United States.

2.2 Biofuel policies in the European Union

The group of member states in the European Union (EU) constitutes the world's greatest producer and consumer of biodiesel. The trade bloc began using biodiesel in the 1990s, in the transportation sector, motivated by the rise in oil prices. Biodiesel production later made great progress driven by the Blair House Agreement[xi] of 1992 and by strong fiscal incentives, principally in Germany.

In 2003, as a response to concerns about climate change and energy security, the EU approved Directive 2003/30[xii]. This laid out non-compulsory goals for fossil fuel substitution by biofuels to be pursued by the member states through 2010. As shown in **Table 4**, while biofuel participation has grown rapidly in the EU, it was not enough for the bloc to achieve the goals defined in the guidelines. This happened mainly because the goals were non-compulsory, with each state being responsible for deciding which measures it would adopt to meet those goals.

Faced with the EU's poor performance in combating GHG emissions, not just in transportation but in other sectors of the economy, on April 6th, 2009 the European Union Council approved the Energy and Climate Change Package (CCP), containing a new strategy to deal with the issue of energy and climate change. The section of this package that sets policy for renewable energy is called The Renewable Energy Directive (RED); it was published on June 5th, 2009 and came into effect 20 days later. RED policies must be implemented by EU member states in an 18-month period following its publication – in other words, by November 2010 – when they should be incorporated in member states' domestic legislation. Member states were also required to submit their national action plans by June 2010.

The CCP establishes the so-called "20/20/20" landmarks to be achieved by 2020:

I A 20% reduction in GHG emissions compared to 1990 levels.
II A 20% improvement in energy efficiency compared to current projections for 2020.
III A 20% participation of renewable energy in the EU's energy consumption matrix. It is mandatory for every member state that part of this renewable energy participation be obtained through the minimum level of 10% renewable energy consumption in transportation.

It is important to note that, while the 20% participation of renewable energy in total energy consumption is an overall target for the EU, different objectives were set for each member state in light of their current economic situation and potential for economic growth. Hence, some states should reach goals higher than 20%, while others may reach lower targets. The goal for renewable energy participation in Sweden, for

Table 3

Ethanol and gasoline in the United States

Consumption of gasoline; consumption, production and importation of ethanol in the United States; in millions of m³, according to EIA projections

Year	Consumption of gasoline with ethanol	Consumption of ethanol mixed with gasoline	Percentage of ethanol in gasoline	Consumption of ethanol as E85	Domestic production of Ethanol	Net importing of Ethanol
2006	537.0	21.1	4%	0.0	18.5	2.7
2007	538.9	25.9	5%	0.0	24.7	1.3
2008	520.2	36.0	7%	0.0	34.9	1.2
2009	514.1	39.6	8%	0.0	39.9	-0.3
2010	547.4	49.0	9%	0.1	49.7	-0.6
2011	560.8	55.1	10%	0.1	56.2	-0.9
2012	559.4	55.0	10%	0.1	55.2	-0.1
2013	555.6	54.7	10%	0.1	54.8	-0.1
2014	550.2	54.1	10%	0.1	54.3	-0.1
2015	542.1	53.4	10%	2.3	55.5	0.1
2016	533.1	52.5	10%	5.4	57.8	0.2
2017	525.9	51.8	10%	7.3	58.9	0.2
2018	516.9	50.8	10%	11.5	61.0	1.3
2019	510.9	50.1	10%	16.1	63.3	2.9
2020	502.9	49.6	10%	22.1	69.2	2.5
2021	497.3	49.7	10%	25.8	73.5	2.0
2022	486.8	48.1	10%	35.2	79.4	3.9
2023	487.1	48.2	10%	35.0	81.3	1.8
2024	489.2	48.9	10%	33.5	80.6	1.8
2025	488.7	48.4	10%	35.0	80.7	2.7
2026	488.9	48.0	10%	36.2	81.3	2.9
2027	482.1	47.9	10%	44.3	87.8	4.4
2028	481.8	47.8	10%	46.3	88.8	5.3
2029	476.6	49.5	10%	50.3	92.0	7.8
2030	478.1	48.2	10%	51.7	93.4	6.5

Source: Prepared by the authors from EIA (2009b).

example, is 49%, while in Malta it is just 10%. The goals in Germany, France, the United Kingdom and Italy, the largest European economies, are 18%, 23%, 15% and 17%, respectively.

The special attention given by the CCP to transportation is due to projections indicating that the sector will be responsible for the greatest share of growth in energy consumption. It thus requires the greatest discipline.

One important topic within RED refers to the sustainability criteria of biofuels that are used to reach the 10% goal. The three main criteria are:

I From the autumn of 2010 onwards, lifecycle GHG emissions of biofuels should be at least 35% lower than those of the fossil fuels they replace. GHG emissions reduction should be at least 50% from 2017 onwards, increasing to 60% when biofuels are produced in new installations.
II Biofuels should not be produced from raw materials obtained in areas of high biodiversity, such as primary forests and areas with native vegetation.
III Agriculture raw materials produced in the EU should be produced according to correct agricultural and environmental practices established by the EU's Common Agricultural Policy (CAP)[xiii].

Transportation fuel consumption in the European Union *In thousands of TPE* **Table 4**

Fuel	2006r	2007r	2008e	2009p	2010p
Total biofuels	5,910	7,940	9,320	10,340	12,650
Biodiesel	4,110	5,900	7,160	8,170	9,980
Pure vegetal oil	920	660	370	100	100
Ethanol	880	1,380	1,790	2,070	2,560
Conversion biomass – liquid (BtL)	-	-	-	2	8
Total fossil fuel	293,531	295,667	297,900	300,160	302,470
Diesel	183,702	189,596	192,250	194,940	197,670
Gasoline	109,829	106,071	105,650	105,220	104,800
Total fuels	299,440	303,610	307,220	310,510	315,120
Biofuels participation	1.97%	2.62%	3.03%	3.33%	4.00%
Target in Directive 2003/2030	2.75%	3.50%	4.25%	5.00%	5.75%

Notes: r- revised; e- estimated; p- projected. • *Source:* Prepared by the authors from Flach, B. (2009).

Given the technological preference for diesel motors in the EU and the longstanding tradition in the production of biodiesel, ethanol accounted for just 19% of biofuel consumption within the bloc in 2008. As shown in **Table 5**, ethanol consumption in the EU in 2008 was approximately 3.71 million m^3, of which 3.55 million m^3 was destined for the transportation sector and the remainder to stock formation. Countries with the greatest consumption of ethanol were France (1.1 million m^3), Germany (0.75 million m^3), and Sweden (0.43 million m^3). In fourth place were the United Kingdom and the Benelux bloc, with 0.28 million m^3 each. As shown in **Table 5**, consumption in the EU is projected to grow by an average of 16% per year between 2008 and 2010.

Ethanol production in the EU totaled 2.66 million m^3 in 2008, with the main producers being France (0.80 million), Germany (0.58 million), Spain (0.30 million) and Poland (0.22 million). The main raw material used in the production of ethanol was wheat (3.2 million tonnes), followed by sugar (1.0 million tonnes), corn (1.6 million tonnes) and barley and rye (0.5 million tonnes). According to the estimates presented in **Table 5**, ethanol production in the bloc should grow, on average, by 20% per year between 2008 and 2010.

In 2008, the EU's deficit between ethanol consumption and production required imports totaling 1.1 million m^3. Main importers were the United Kingdom, Sweden and the Benelux counties, acquiring the fuel from Brazil, Argentina, Costa Rica, Venezuela, Peru and Guatemala. Even though production grew by more than consumption between 2008 and 2010, ethanol imports will still be necessary and are projected to grow by 7% per year, on average, reaching 1.27 million m^3, or 25% of the product's consumption, by the end of the period.

It can be forecast that, in the medium term, the EU is likely to import growing quantities of ethanol due to two factors: (**I**) growth in demand to meet the goals for renewable fuel use imposed by CCP; and (**II**) limitations on domestic supply, given the biofuels sustainability criteria imposed by the RED. These criteria are unlikely to be met by the ethanol produced from the raw materials used in the EU. This creates a window of opportunity for Brazilian ethanol exports, at least until technologies for production of cellulosic ethanol reach maturity.

Table 5 **Supply and demand of ethanol in the European Union** *In thousands of m^3*

	2006[r]	2007[r]	2008[e]	2009[p]	2010[p]	Average annual growth
Installed capacity	2,220	3,800	5,960	6,720	8,870	41.4%
Production	1,635	1,840	2,660	3,040	3,800	23.5%
Exports	38	44	51	57	63	13.5%
Imports	230	1,000	1,105	1,115	1,270	53.3%
Consumption	1,825	2,795	3,715	4,100	5,010	28.7%

Notes: r - revised; e - estimated; p - projected. • *Source:* Prepared by the authors from Flach, B. (2009).

However, Brazilian ethanol currently faces tax barriers to enter the EU. The bloc establishes two import tax rates for ethanol: €0.192 per liter for non-denatured ethanol and €0.102/liter for denatured ethanol. These taxes, however, do not apply to countries included in the "Everything But Arms" initiative for Least Developed Countries nor to those African, Caribbean and Pacific nations covered by the Cotonou Agreement, which are exempt from any taxation. The Brazilian product therefore faces the higher of the two taxes, given that Brazil exports mainly non-denatured ethanol and the majority of EU member-states allow only this type of ethanol to be blended with gasoline.

Concern about biofuel imports to meet goals for GHG emission reductions in the transportation sector has been expressed by the European Commission (EC) in a series of policy documents. In the documents "An EU Strategy for Biofuels" (EC, 2006) and "Renewable Energy Road Map" (EC, 2007), the Commission proposes a search for the "appropriate development of both domestic production as well as the increase for importation opportunities". In the latter document, the EC declares that "if it becomes clear that the EU's supply of sustainable biofuels becomes restricted, the EU must be prepared to examine if greater access to the market should be an option to aid development of the market". According to these documents, the Doha Development Round and the free trade agreement between the EU and Mercosul will have impact on the additional opening up of the ethanol market. (Flach, B., 2009).

However, some factors may reduce the forecast importation into the European market. The preference that EU consumers have shown in the last two decades for diesel vehicles indicates an obstacle to the growth of gasoline consumption, which would stimulate an increase in ethanol consumed in the bloc. There is also competition from the growing biofuel production in countries favored by EU custom tax exemption programs.

Taxes on automotive fuels in Sweden in 2009 Table 6

Fuel	Consumption tax (SEK/l)	CO_2 (SEK/l)	SO2 (SEK/l)	VAT (%)
Conventional Gasoline	3.08	2.44	0	25
Diesel	1.33	3.01	0	25
Ethanol and biodiesel	0	0	0	0

Notes: SEK 1 = US$ 0.14, average exchange rate in August 2009. • *Source:* Prepared by the authors from Dahlbacka, B. (2009).

2.3 Biofuel policies in Sweden

Sweden was one of the first countries in the EU to adopt economic instruments in its environmental policies. As far back as 1991, the country introduced environmental taxes on all types of energy, including automotive fuels. As shown in **Table 6**, in addition to VAT Sweden targets gasoline with a specific consumption tax and a CO_2 emissions tax. Diesel faced yet another tax on SO_2 emissions but this became inoperative when the country began using diesel with ultra-low sulfur content (below five ppm). At the same time, ethanol and biodiesel enjoy total tax exemption, without which their prices would not be competitive.

Ethanol is used in Sweden as a compulsory additive to gasoline in an E5 blend. There is also an optional E85, which in winter months can be reduced to E75. Ethanol can also replace diesel in the form of optional ED95[xiv]. Biodiesel has been allowed since 2006 in a diesel blend up to 5%.

Sweden is Europe's greatest promoter of the use of E85 and flex-fueled vehicles. In the last few years, the government has granted incentives for the acquisition of flex-fuel vehicles, including a purchase bonus of SEK10,000 (approximately US$1,400), discounted insurance, lower licensing fees, free parking places in most major cities and exemption from the traffic congestion tax charged in Stockholm[xv].

In 2008, 50% of new light vehicle models were offered in flex-fuel versions and 25% of vehicle sales were flex-fuel. The Swedish government expects that the flex-fuel fleet will reach 300,000 units by the end of 2010, and that E85 will represent 10% of the country's automotive fuel market by 2012 (Christiansen, R.C., 2009).

In addition to the tax incentives for ethanol, the country's flex-fuel fleet is served by an infrastructure of approximately 1,400 stations offering E85, with that number predicted grow to 2,000 by the end of 2009. The Swedish government has already spent €69 million (US$91 million) setting up this infrastructure (Christiansen, R.C., 2009).

Even with tax exemption, the insufficient production volume and the high cost of European ethanol have undermined its competitiveness compared to traditional fuels. To supply the market and reduce the cost of the product, the European Commission has since 2008 been authorizing Sekab to import Brazilian ethanol with a reduced import tax. To make this possible, Brazilian ethanol used in the E85 blend is classed as a chemical, so attracting a lower import tax. However, this concession is being renewed yearly, and the fear that it could be cancelled at any moment creates insecurity for car buyers. This fear is aggravated by the fact that European ethanol producers oppose the concession given to Sweden. If European producers succeed in ending the tax reduction for Brazilian ethanol, placing it back in the agricultural product category, ethanol would cease to be competitive in Sweden and consumers would go back to using gasoline and diesel, or would at least reduce their consumption of biofuels.

Sweden is looking for alternatives to importing ethanol from Brazil. One option is supporting ethanol production projects in countries that benefit from tax-free entry into the EU through the "Everything But Arms" initiative for Least Developed Countries and the Cotonou Agreement with African, Caribbean and

Pacific countries. An experiment is taking place in Ghana, where a 150,000 m^3 capacity plant will be built by Brazil's Constran S/A group. The Brazilian Development Bank (BNDES) will concede partial financing of US$260 million, out of the project's total US$306 million investment (Energy Daily, 2008).

2.4 Biofuel policies in the United Kingdom

The United Kingdom started promoting biodiesel in 2002, to be consumed pure or in a diesel blend. Biodiesel was granted a reduction of £0.20 per liter (US$0.30 per liter) in the specific automotive fuel tax (£0.5035 per liter in 2008). Taking into account the 15% VAT, the reduction implies an advantage for the consumer of almost £0.24 per liter. In 2005, the reduction was extended to ethanol used in E85 or blended with gasoline in any proportion.

In 2008 the government announced that this reduction would end in April 2010, as of when biofuels will be taxed like other automotive fuels. Replacing the tax reduction policy, the Renewable Transport Fuel Obligation (RTFO) Order 2007 constitutes one of the UK's main policies for reducing GHG emission in the transportation sector. RTFO took effect on April 15th 2008, and seeks to reduce by 2.6 to 3.0 million tonnes per year the carbon gas emission of the transportation sector.

Inspired by a similar program that promotes the use of renewable sources in UK electricity generation, RTFO requires the larger agents (those supplying more than 450,000 liters of fossil fuels per year) to sell a minimum quota of ethanol and biodiesel. During the first year when RTFO was in force, from April 15th 2008 to April 14th 2009, the mandatory quota was set at 2.5%, rising to 3.25% between 2009 and 2010, 3.5% between 2010 and 2011, 4.0% between 2011 and 2012, 4.5% between 2012 and 2013, and 5.0% between 2013 and 2014[xvi].

Companies participating in the program were separated into two groups: those that supply more than 450,000 liters of fossil fuels per year, and are therefore required to participate by registering in RTFO; and those that supply volumes below this yearly limit, or which supply only biofuels. These can participate voluntarily by registering with the RTFO.

The Renewable Fuels Agency (RFA) was created to manage the RTFO. It supplies companies registered with the RTFO, either compulsorily or voluntarily, with Renewable Transport Fuel Certificates (RTFC) corresponding to the volume of biofuel they sold, substantiated by the payment of the relevant specific fuel tax. Companies are allowed to negotiate certificates between themselves.

Each annual period runs from April 15th of one year to April 14th of the next. At the end of each period, companies must prove to the RFA that they possess a number of certificates corresponding to the mandatory quota of that period. Companies that do not prove ownership of these certificates will have two options: (**I**) pay a fine (a buy-out penalty); or (**II**)) acquire RTFCs from other companies. Collected fines will go to a buy-out fund. Companies that are obliged to participate in the RTFO and have excess certificates can sell these to the RFA, while companies that participate voluntarily will be able to sell the agency all their certificates. The RFA buys these certificates at a price that depends on the amount accumulated in the buy-out fund. The value of the buy-out penalty was set at £0.15 per liter of non-supplied biofuel, increasing to £0.30 starting April 15th 2010.

To replace the tax incentive of £0.20/liter (extinct as of 2010), the UK government plans to set up a system to compensate biofuels according to the carbon emissions avoided in their production and use. Starting April 15th 2011, this system would reward only those biofuels that are produced from raw materials that meet sustainability standards deemed appropriate.

2.5 Biofuel policies in Germany

Germany is currently the world's largest producer and consumer of biodiesel. In 2007, it had installed capacity to produce 4.2 million tonnes a year, mainly from canola oil, and was responsible for 17% of global production. However, in that same year Germany produced just 0.54 million m^3 of ethanol, a tiny fraction of the worldwide production of 52 million m^3.

The country began using biodiesel in 1991, when the first production plant was built in Aschach, Austria. Because biodiesel was so much more expensive than diesel, its sale became feasible only with a favorable tax structure that exempted it from taxes on fossil fuels, such as the eco-tax (Ökosteuer) that is applicable to all energy sources, and the specific tax on mineral oils (Mineralölsteuer).

Initially, biodiesel was sold only in its pure form (B100). Filling station pumps had two nozzles, one for diesel and one for biodiesel, so allowing the consumer to decide his own mixture. This strategy could be implemented immediately thanks to the coincidental prohibition in the country of leaded gasoline sales, which freed up the distribution and retail infrastructure of the banned gasoline for use by the new fuel, so avoiding major investments. In addition to B100, biodiesel mixtures with percentages between 2% and 20% are common in Germany, while ethanol is blended into gasoline in a 5% proportion. E85, on the other hand, has a very small market, with just 30 filling stations offering it in 2007.

The government began encouraging the use of biodiesel in 1999, increasing the specific tax on fossil fuels. Petroleum prices began to rise in the same period, making biodiesel more and more competitive. This led to a consumption boom, with biodiesel sales growing by an average of 24% per year between 2000 and 2003. In 2002 there were 1,500 filling stations selling B100, about 10% of the country's fuel outlets. Biodiesel sales in 2003 totaled 755,000 m^3, representing 2.3% of total fossil diesel consumption in Germany, then about 33 million m^3 (Wittke, F. and Ziesing, H., 2004). In 2005, biodiesel could be found at 1,900 retail outlets and it enjoyed 3.75% participation compared to total diesel sales; almost twice the level required in Directive 2003/30. German biodiesel consumption in 2007 was 3.9 million m^3, representing 35% of worldwide biodiesel consumption and almost 10% of diesel consumption in the country (Federal Ministry of Economics and Technology, 2009).

With the rapid growth in consumption, fiscal exemption granted to biofuels[xvii] reached approximately US$3 billion in 2006 (Godoy, J., 2007) and began weighing on the country's budget. To remedy this situation, Germany introduced new biofuels legislation in the shape of the Energy Taxation Law and the Biofuels Quota Law, which took effect in August 2006 and January 2007 respectively. Under the new legislation, biofuels face the same specific taxes as fossil fuels, with the exemptions replaced by discounts to be requested from the government after sale. As shown in **Table 7**, the discounts given to biofuels used in blends were abolished in 2007[xviii], while discounts for pure biofuels except E85 were progressively reduced, with their extinction predicted for 2015. E85 continues to benefit from total exemption, as do second-generation biodiesel and ethanol.

To compensate for the higher taxes, the Biofuels Quota Law imposed mandatory biofuels sales quotas on fuel suppliers. These quotas are related to the total sales of petroleum derivatives, with individual sub-quotas for sales of gasoline and diesel. **Table 8** shows the biofuels quotas and sub-quotas that must be met by 2015. The quotas and sub-quotas are based on the energy content of the fuels, rather than volume.

Quotas can be met by selling biofuels pure or in blends of petroleum derivatives, and compliance requirements for these obligations can be transferred from one supplier to another by means of a formal contract. However, lack of compliance renders the supplier liable to a fine based on the amount of energy he failed to supply to meet his quota, and on the marginal cost of producing one unit of energy from biodiesel or ethanol[xix].

Introduction of the new legislation had two adverse impacts on the German biofuels industry (Mabee, W.E. et al., 2009). The first was a drop in national production. After reaching a peak of 3.56 billion liters in 2007, biodiesel production fell by 12% in 2008, to 3.18 billion. In March of 2008, biodiesel production plants had 85% of unused capacity, and half the companies in the sector either suspended operations or went bankrupt; with 14% of filling stations stopping selling the fuel. The situation improved only slightly in the summers of 2008 and 2009 as fuel prices increased, but still remained well below the production peak of 2007.

The second impact was an increase in biofuels imports. Up to 2005, domestic production was close to domestic consumption. This balance changed starting 2006, with imports increasing to supply 66% of the biofuel required to meet the quota legislation.

The situation led the government to send the German parliament the Amendment for Promotion of Biofuels in October of 2008. Parliament approved this amendment the following April, and it was awaiting publishing in the Federal Gazette to take effect. In addition to altering existing legislation for biodiesel tax and quotas (see **Table 7** and **Table 8**), the amendment also required the government to ensure that sustain-

Table 7

Discounts of specific taxes for biofuels in Germany

In Euro cents per liter

Year	Ethanol		ETBE	Biodiesel		Vegetal oil		Biofuels (2nd generation)(3)	
	E85(1)	Blend	Blend	B100	Blend	Puro	Blend	BTL(4)	Ethanol cellulose
2004	65.05	65.05	65,05	47.04	47.04	47.04	47.04		
2005	65.05	65.05	65,05	47.04	47.04	47.04	47.04		
2006(2)	65.05	0.00	0	38.04	32.04	47.04	47.04		
2007	65.05	0.00	0	38.04	0.00	47.04	0.00	47.04	65.05
2008	65.05	0.00	0	33.64	0.00	38.89	0.00	47.04	65.05
2009	65.05	0.00	0	27.34/ 30.34(5)	0.00	30.49	0.00	47.04	65.05
2010	65.05	0.00	0	21.04/ 24.04(5)	0.00	22.09	0.00	47.04	65.05
2011	65.05	0.00	0	14.74/ 17.74(5)	0.00	14.74	0.00	47.04	65.05
2012	65.05	0.00	0	2.14/ 5.14(5)	0.00	2.14	0.00	47.04	65.05
2013	65.05	0.00	0	2.14	0.00	2.14	0.00	47.04	65.05
2014	65.05	0.00	0	2.14	0.00	2.14	0.00	47.04	65.05
2015	65.05	0.00	0	2.00	0.00	2	0	47.04	65.05

Notes: (1) E85 exempted until 2015. • (2) Tax altered starting August 1st 2006. • (3) Situation of second-generation biofuels will be examined annually. • (4) Biomass conversion to liquid. • (5) New values fixed by the Amendment for the Promotion of Biofuels in 2009.
Source: Prepared by the authors from Mabee, W. E., et al. (2009).

Table 8

Energy percentages of biofuel blend quotas in Germany

Year	Gasoline + Diesel	Gasoline	Diesel
2007	n.a.	1.2%	4.4%
2008	n.a.	2.0%	4.4%
2009	6.25% / 5.25% (*)	2.8%	4.4%
2010	6.75% / 6.25% (*)	3.6%	4.4%
2011	7.00% / 6.25% (*)	3.6%	4.4%
2012	7.25% / 6.25% (*)	3.6%	4.4%
2013	7.50% / 6.25% (*)	3.6%	4.4%
2014	7.75% / 6.25% (*)	3.6%	4.4%
Quotas required for climate protection*:			
2015 / 2016	3% reduction in GHG emissions using biofuels		
2017 / 2019	4.5% reduction in GHG emissions using biofuels		
2020	7% reduction in GHG emissions using biofuels		

Note: (*) New values fixed by the Amendment for Biofuel Promotion in 2009; n.a. – not applicable.
Source: Prepared by the authors from Mabee, W. et al. (2009).

able standards are observed in the production, distribution and use of biofuels. The amendment introduced significant changes in the principles governing biofuels promotion beginning in 2015, establishing that the use of biofuels would no longer be based on mandatory quotas but would serve to reduce GHG emissions caused by the use of fossil fuels in transportation. With this amendment in force, the use of biofuels is likely to grow more slowly than previously predicted.

▶ 3 Final considerations

The worldwide production and use of biofuels has grown rapidly in recent years, motivated by concern about climate change and by questions of energy security and safety that become relevant in the context of potential petroleum depletion. The United States and Brazil are the world's largest producers of ethanol, while biodiesel production is dominated by EU countries, in particular Germany. While GHG emission reduction is a more or less common objective of all these policies, other reasons for promoting the production and use of biofuels include energy security, reduced fossil fuel consumption, local environmental impacts, rural development and increasing potential exports.

In most countries, however, biofuels are not very competitive, economically speaking, compared to petroleum derivatives. Even with the recent rise in the price of oil and its derivatives, many biofuels are still not very competitive, given that the prices for agricultural commodities and the inputs used in their production have also risen sharply. Consequently, with the exception of a few countries, the production and use of biofuels, and indeed of most new alternative energy sources, depend on public policies.

The success of these policies is related to the existing price structure in each country. Policies are unlikely to succeed when promoted in countries where petroleum derivatives prices are subsidized or carry a tax burden that does not cover the costs of externalities in the production and use of fossil fuels. Similarly, in countries where fuel prices are established ad hoc, the lack of price predictability erodes the viability of required investments for agricultural production and the installation of infrastructure for the distribution, retail sale and use of biofuels, unless substantial fiscal incentives or mandatory measures are introduced.

While public policies aimed at biofuels promotion can have several formats, they are based on three instruments: (i) financial support in the form of tax exemption or reduction, or the concession of direct fiscal incentives for agents in the supply chain or for biofuel consumers; (ii) mandatory quotas that require a minimum participation of biofuels in the automotive fuel matrix; and (iii) commercial restrictions in the form of custom taxes on biofuel imports to protect domestic production.

Measures of financial support impact the public budget, either through income loss due to fiscal waivers or additional expense through fiscal incentives. These therefore represent a transfer from taxpayers to the producers or users of biofuels. The United States is an example of a country that subsidizes producers and blenders, whereas Sweden grants tax exemption to biofuels. The United Kingdom abandoned fiscal waivers, while Germany has been progressively reducing this practice.

Mandatory quotas can be accompanied by fines on fuel suppliers who fail to comply with requirements, or blend certificates that can be traded between suppliers that exceed their quotas and others that fail to reach them. These measures do not impact the public budget, but imply greater costs for users who transfer income to agents in the biofuels supply chain. The United States, the United Kingdom and Germany all apply mandatory quotas in their biofuels promotion policies. In the United Kingdom, the adoption of quotas is accompanied by certificate emissions, while in Germany the obligation can be transferred to other suppliers.

Restrictions imposed on biofuel importation protect domestic production against foreign producers who are more efficient or who enjoy comparative advantages that reduce production costs. These measures limit the prospects for development of more competitive suppliers in other countries and impose a transfer from consumers to domestic producers. The United States and EU countries impose custom duties on biofuels imports. However, the analyses presented in this study suggest that the future demand for ethanol in these countries is unlikely to be met without importation. This is even more the case when taking into account that the sustainability criteria established by the United States and the EU in their energy policies for fossil fuel substitution restrict the use of certain technological production paths existing in these countries.

The prospect for internationalizing the use of biofuels creates opportunities not only for exporting raw material, but also technology. For Brazil to maintain its leadership in the ethanol market, it is vital to open up importing markets, grant incentives for investment in research and development, seek technological innovation that secures competitive production, create new uses for the product, and encourage the market for byproducts.

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Explanatory Notes

[i] Some studies question the technical viability of using gasoline blended with more than 10% of ethanol without modifying vehicle systems. Among the contentious issues are the increase in emissions of nitrogen oxide and aldehydes, and the increase in consumption, along with the reduction in the durability of vehicle components such as catalytic converters. UNICA questioned these findings in a letter sent to the U.S. Environmental Protection Agency (UNICA, 2009a).

[ii] The lifecycle analysis of fuels calculates greenhouse gas emissions originating from the prospection, production, distribution, and final use of fuels. In the case of biofuels, it also includes emissions resulting from the direct or indirect alteration to land-use in other countries as a result of the production of renewable fuels.

[iii] OECD member countries include Australia, Canada, the United States, South Korea, Mexico, Japan, New Zealand, Turkey and 22 European countries.

[iv] The graphs are presented to illustrate the classification of countries according to the level of fiscal incentives and taxation. Depending on the reference period for the prices, the relative positions of the countries may change, including their position within the categories.

[v] For purposes of this paper, a fuel is considered to be subsidized when its consumer price is lower than a reference (benchmark) price that represents an estimate of an "economic price" calculated using commercial fundamentals.

[vi] The retail prices of fuels shown for the United States include industry costs and profits margins, value added tax, and a specific fuel tax of approximately US$0.10 per liter that goes towards the maintenance and building of roads. Because it does not include other forms of specific taxation, the US price is adopted as a reference for the minimum price of derivatives without fiscal incentives.

[vii] For purposes of this paper, we consider a fuel to be taxed when its consumer price is higher than its reference (benchmark) price which represents an estimated "economic price" calculated according to commercial fundamentals.

[viii] The EU-15 comprises the initial member countries of the EU, who joined before the accession of 10 new countries on May 1, 2004.

[ix] Florida, Hawaii, Iowa, Kansas, Louisiana, Minnesota, Missouri, Montana, Oregon and Washington.

[x] An Updated Annual Energy Outlook 2009 Reference Case Reflecting Provisions of the American Recovery and Reinvestment Act and Recent Changes in the Economic Outlook (EIA, 2009b).

[xi] The Blair House Agreement of 1992 allowed the EU to produce oil seeds for non-food purposes up to the equivalent to one million tonnes of soy.

[xii] The official name of the Directive on the Promotion of the Use of Biofuels and Other Renewable Fuels for Transport.

[xiii] The CAP is a system of a fiscal incentives and agricultural programs in the EU, which in 2006 consumed 48% of the EU's €49.8 billion budget. The CAP takes a three-pronged approach: i) the unification of markets for the free movement of agricultural products within the EU; (ii) financial solidarity with regards to all the costs of CAP, which are financed by a communal treasury supported by import tariffs and contributions from European countries; and iii) community preference, so that EU products enjoy preferential treatment over imports.

[xiv] Developed by Sekap (Svensk Etanolkemi AB), one of the largest producers, importers, and vendors of ethanol in Europe, ED95 is an ethanol blend with a 5% ignition additive that is used in buses and trucks with adapted diesel engines.

[xv] The congestion tariff in Stockholm is applied to vehicles entering and exiting the city.

[xvi] The Renewable Transport Fuel Obligation Order 2007 originally stipulated an increase in the obligation from 2.5% in 2008-09 to 3.75% in 2009-10, and to 5% in 2010-11. These percentages were changed by the Renewable Transport Fuel Obligation (Amendment) Order 2009, which came into operation on April 15, 2009.

[xvii] In March 2009, specific tariffs on fossil fuels in Germany were €0.4704/liter for low-sulfur diesel and €0.6545/liter for unleaded gasoline. In addition to these tributes, there was also 19% VAT on the final price of all fuels, fossil or not. The sum of the taxes on fossil fuels averages €1.03 per liter for diesel and €1.22 per liter for gasoline.

[xviii] The difference of €0.02 between the tax for vegetable oil and diesel serves to compensate for the lower caloric value of vegetable oil.

[xix] In December 2006, these values were €16/GJ for biodiesel and €38/J for ethanol.

08

Ethanol Market and Competition

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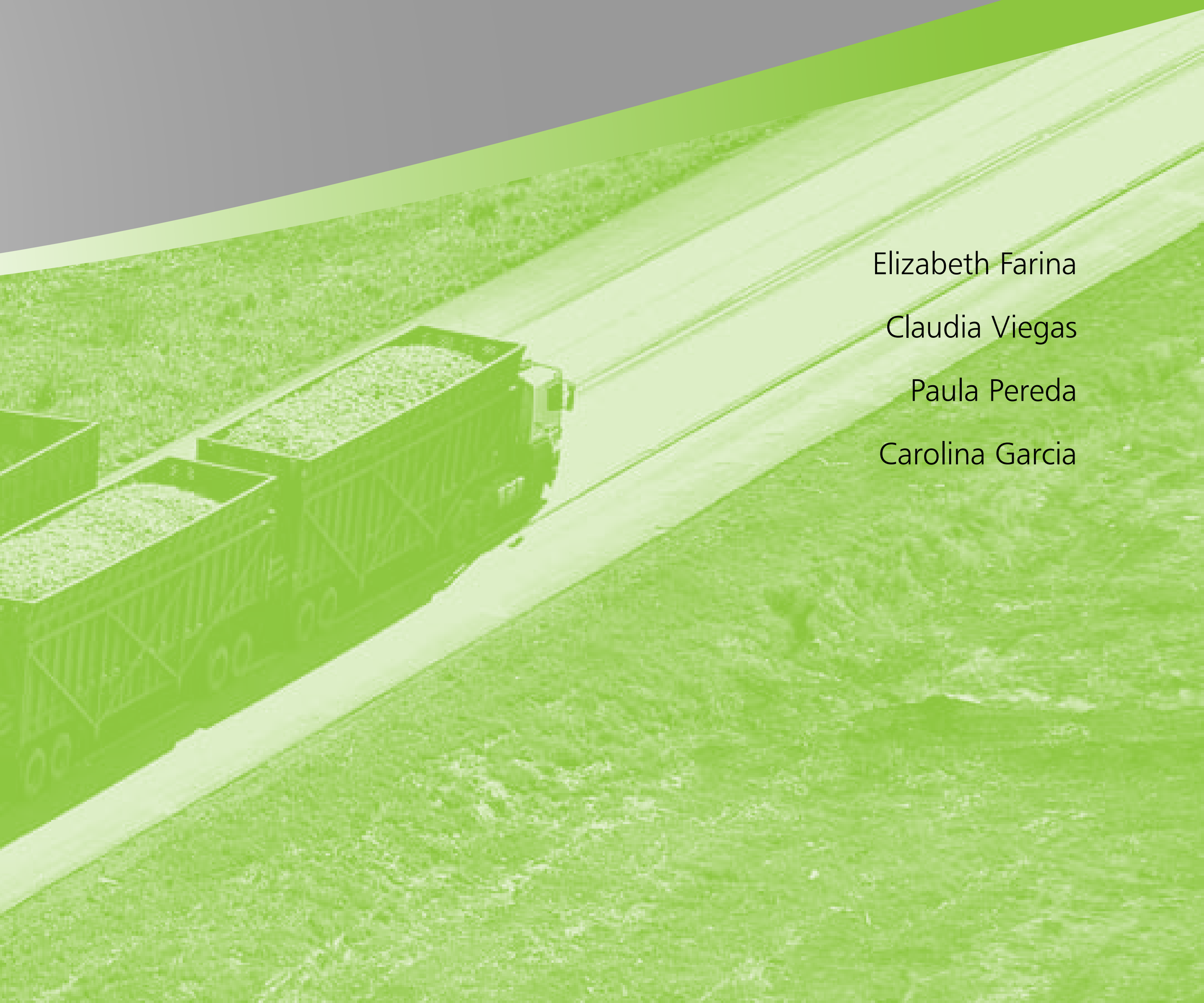
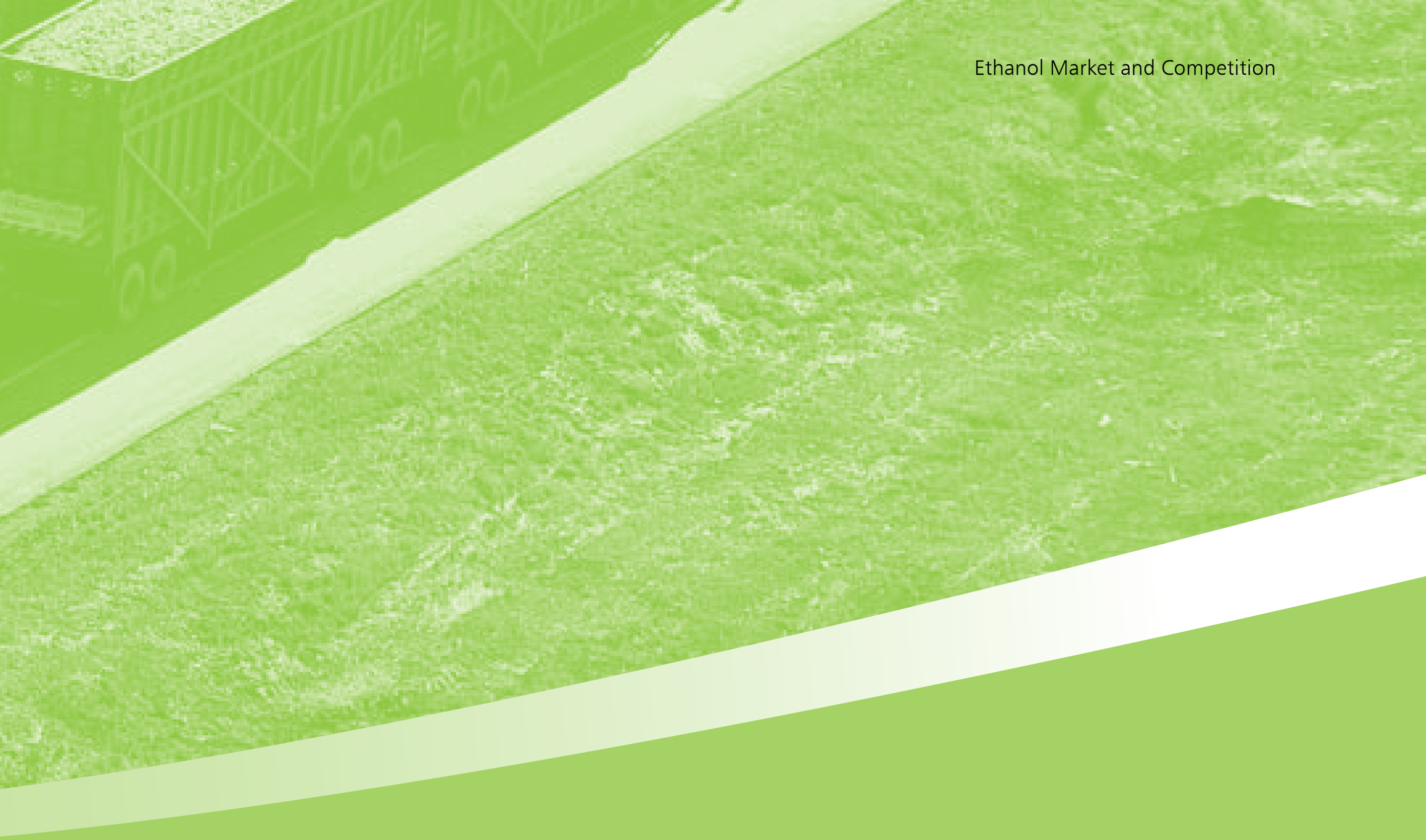


To a greater or lesser extent, fuel production and distribution has historically been regulated in every country in the world. The availability of energy is strategic for any economy, and the reliance on non-renewable sources represents challenges that are not trivial for public policy.

Despite their seasonality and the possibility of harvest failures, renewable sources help to mitigate the problems caused by dependence on fossil fuels.

In Brazil, ethanol production takes place within a relatively dispersed market. In this context, the question that must be asked is: does this ensure an adequate supply of ethanol? The answer depends, in part, on the policies adopted for petroleum derivatives, and in the case of Brazil, this in turn depends on Petrobras' pricing policy for derivatives. However, since it is clearly shown that hydrous ethanol consumers are more price-sensitive than those of Type C gasoline, we can conclude that in terms of public policies for ethanol, the price variable is adequate for regulating the market.



With respect to anhydrous ethanol, the variation of the mandatory blend – which must lie between 20% to 25% – has so far been an efficient way to reduce price volatility in the Type C gasoline market in times of scarcity. Changes in the blend percentage are justified only by harvest failures that endanger the supply of anhydrous ethanol for blending into Type C gasoline. This policy should not be used to address seasonal variations, because unjustified changes increase business risk and the sustainability of ethanol production.

Among various priority measures, this paper defends the following: establishment of technical criteria to monitor the market with the aim of identifying harvest failures; allowing agents a wider range of action to increase liquidity in the market; and intensification of mechanisms for maintaining private stocks of ethanol.

Improving the operation of the market with a minimum of intervention is the most efficient way to correctly stimulate the sustainable expansion of production.

1 Introduction

It is essential to understand the supply chain for anhydrous and hydrous ethanol if we are to examine competition patterns observed throughout all levels of the liquid fuels sector in Brazil, together with the consequences for domestic market supply and for public policy.

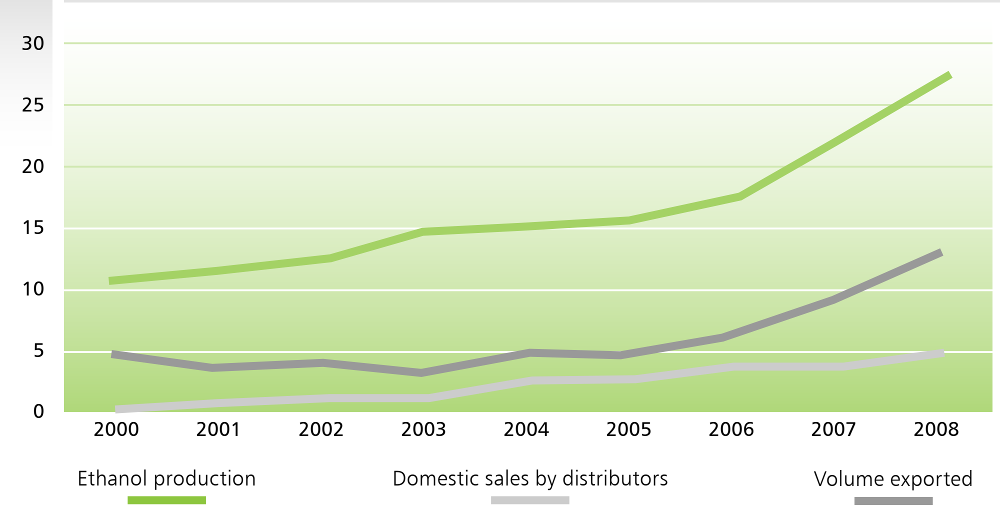
Figure 1 illustrates the flows within the entire agri-industrial system of the sugarcane business. This present study focuses on the ethanol production subsystem, even though the inter-relationship with the sugar subsystem is essential to understanding the dynamics of the former.

With the aim of discussing the possible outlines of a public policy for the ethanol market, this article is structured as follows:

Section 2 presents general aspects of the biofuels market in Brazil, highlighting the relationships between sugar and ethanol, gasoline and hydrous ethanol, and anhydrous and hydrous ethanol. In **section 3**, the ethanol supply chain is studied, examining the competitive environment and concentration in different segments in the supply chain. **Section 4** is dedicated to estimating the domestic demand of hydrous ethanol and Type C gasoline. **Section 5** looks at the impacts of variations in the price of anhydrous ethanol on variations in the gasoline price and calculates by how much production has to fall to constitute a situation of risk for anhydrous ethanol supply.

In conclusion, this paper discusses the role and the outlines of a public policy that would encourage renewable energy production, in particular sugarcane ethanol, and guarantees regular supply of the market.

Graph 1 **Production, exports and domestic sales of ethanol** *In billions liters*



Source: UNICA. ANP. Prepared by the authors.

▶ 2 General characteristics of the Brazilian biofuels market

Brazilian ethanol production has been boosted by growth in domestic consumption, most notably with the arrival of flex-fuel vehicles in 2003 – see **Graph 1**. Until 2003, the market was sustained by a mandatory blend of anhydrous ethanol in gasoline and by an aging fleet of ethanol-powered vehicles. Things changed in 2004, as shown in **Table 1**. In 2004, flex-fuel vehicles represented 2% of the fleet; in 2008 they were equivalent to 31%. The result was rapid growth in the demand for hydrous ethanol, which overtook Type C gasoline sales in 2009.

2.1 Relation between sugar and ethanol

The sugar and ethanol markets compete for the same raw material input, namely planted and crushed sugarcane. From the supply side, therefore, they could be considered as competing products. This relationship is beneficial for the producer, who can count on alternatives in the event of demand/supply shocks for the product. It acts as a reducer of business risk, given that these products are independent on the demand side, that is, they are independent from the consumer's point of view.

Sugar and ethanol production reacts to relative prices and technical characteristics. Sugar mills with attached distilleries can direct cane juice from crushing to the production of sugar or ethanol, depending on the relative profitability of the two products. The decision also depends on rainfall. During rainy periods, the sugar content of the cane is low and it is preferable to produce as much ethanol as possible, reducing sugar production to a necessary minimum, with the opposite happening during dry periods. However, production plants have a pre-determined volume of cane to crush during the harvest and limited capacity

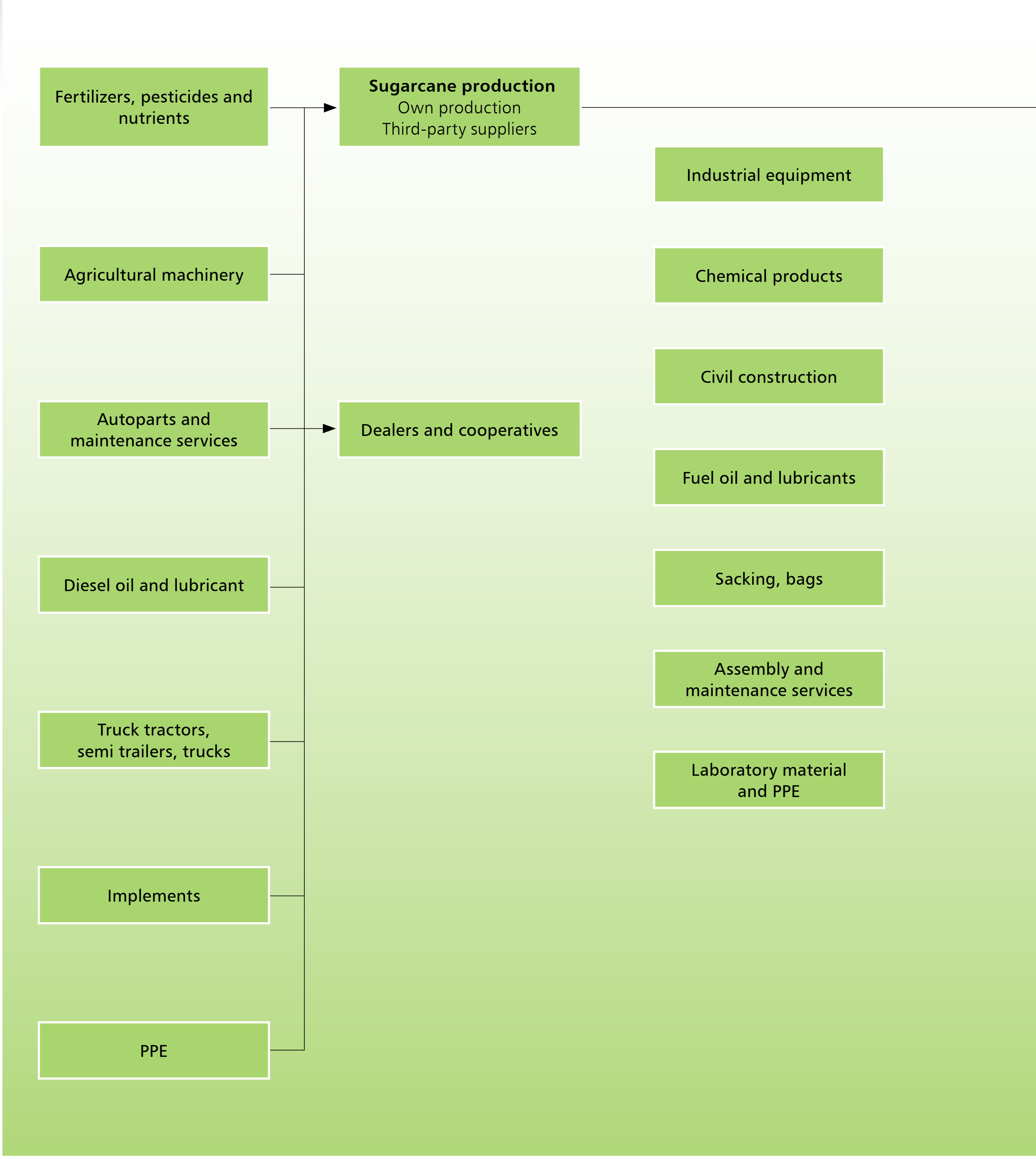
Table 1 **Light vehicle fleet** *In units*

Year	Flex-fuel	Gasoline	Ethanol	Total
2000		12,171,156	3,088,471	15,259,627
2001		13,259,902	2,704,089	15,963,985
2002		14,201,202	2,353,114	16,554,316
2003	48,142	14,972,939	1,990,045	17,011,126
2004	331,762	15,560,064	1,698,340	17,590,166
2005	1,182,052	15,807,570	1,389,977	18,379,599
2006	2,596,846	15,534,130	1,122,169	19,253,145
2007	4,568,256	15,106,423	899,183	20,573,862
2008	6,843,750	14,554,392	711,428	22,109,570

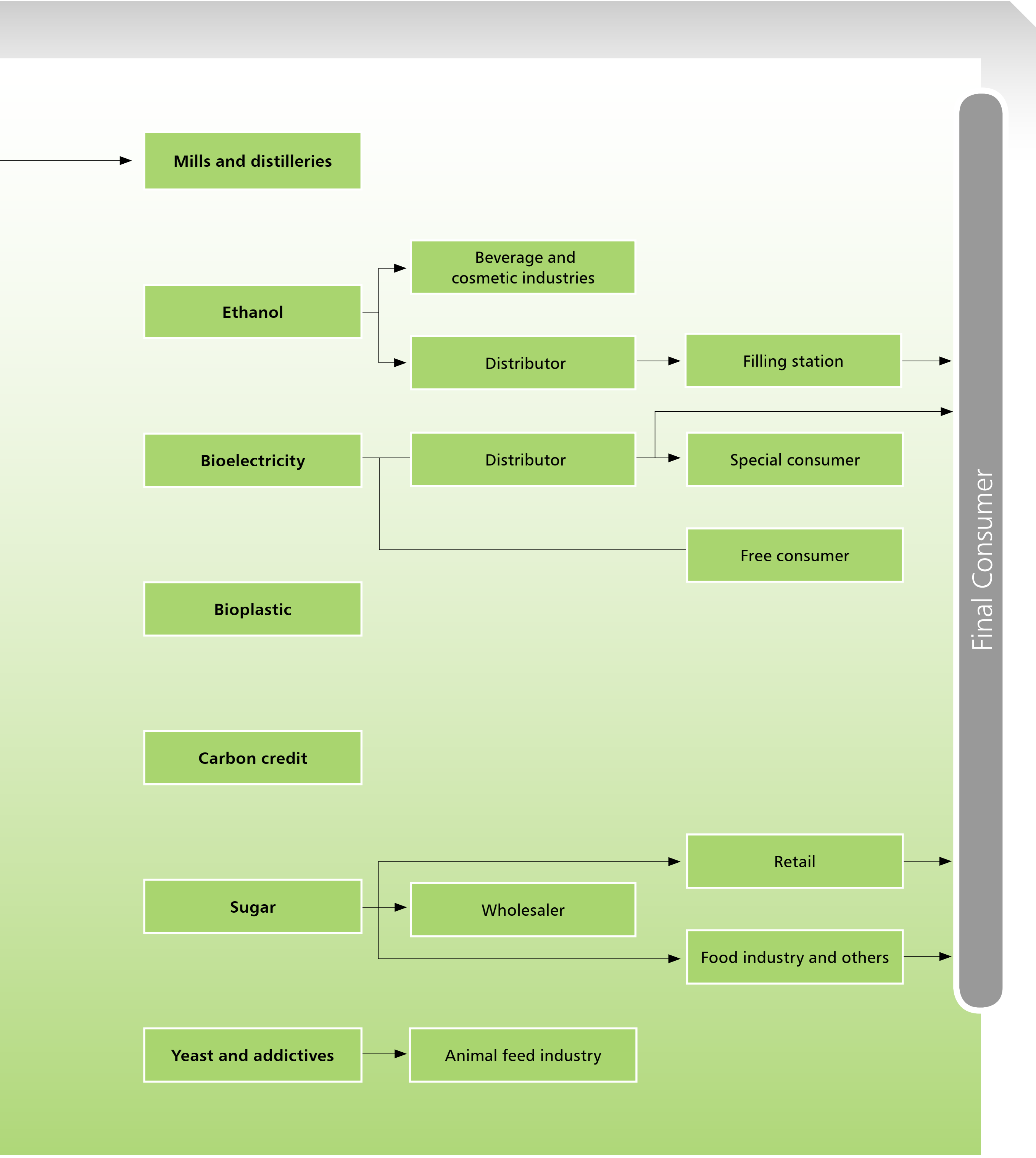
Source: Anfavea/UNICA.

Figure 1

Agri-industrial Sugarcane System



Source: Prepared by Neves, Trombin, Consoli, 2009.


Mills and distilleries
Ethanol
Beverage and cosmetic industries
Distributor
Filling station
Bioelectricity
Distributor
Special consumer
Free consumer
Bioplastic
Carbon credit
Sugar
Retail
Wholesaler
Food industry and others
Yeast and addictives
Animal feed industry
Final Consumer

to produce sugar and ethanol. There are therefore operational constraints to the productive process that require combined mill-distilleries to produce both sugar and ethanol, with the margin of substitution of these products varying from 5% to 10% (Zanão, 2009). The production of a typical Brazilian mill-distillery is shown in **Figure 2**.

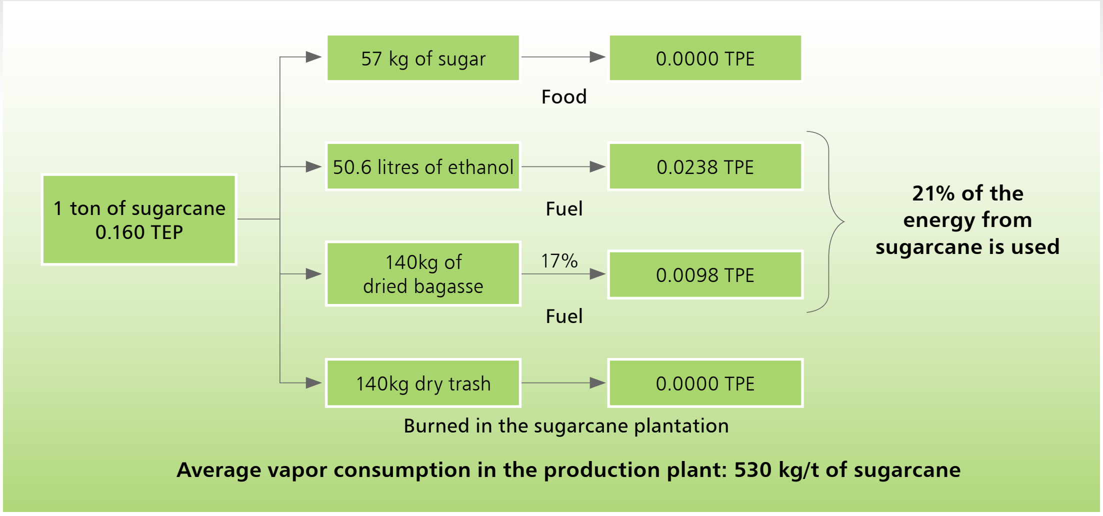
Another factor that influences the production decision of mill-distilleries is the cost of stocking ethanol, which due to the specific characteristics of the product is extremely high. Investments in storage assets are specific to the production volume of ethanol and could represent an economic limitation for switching between sugar and ethanol to respond to changes in the relative price.

Xavier (2008) classifies ethanol storage infrastructure in Brazil in two major categories: the first comprising fuel tanks that belong to the distilleries; and the second comprising tanks operated by distributors, Transpetro terminals, ethanol collection centers and, to a lesser extent, port terminals. The same author estimates that a typical distillery has sufficient tankage to store 50% of its total production for one harvest.

With respect to the static capacity for ethanol storage in Brazil, Zanão (2009) reports that distilleries can store approximately 11.6 billion liters. Within this total tankage, 5.3 billion liters or 45% is for anhydrous ethanol, while 6.3 billion liters or 55% is for hydrous ethanol. Distilleries in the state of São Paulo accounted for 56.2% of total national storage capacity during the 2007/2008 harvest.

Figure 2 **Production of a typical Brazilian combined sugar mill and ethanol distillery**

1.3 million tonnes of sugarcane/year, in 2008[i]



Source: : Center of Sugarcane Technology, from Simtec 2008 (International Symposium and Technology Show for Sugar and Ethanol Agribusiness)

2.2 Relationship between gasoline and hydrous ethanol

Brazil's Proálcool (national ethanol promotion program) was created in the 1970s as a response to the two oil crises that pushed up international prices. The program created a basis for fuel ethanol to return the national energy matrix, including the introduction of ethanol used by itself as a fuel. Even with the high oil prices of the period, hydrous ethanol depended on subsidies to be competitive with gasoline. Petrobras played an important role in creating and developing the fuel ethanol market, given that it made possible the distribution of ethanol through the same retail channels as gasoline and diesel distribution.

The development of the Brazilian ethanol fuel market also reveals how sensitive technological development can be to changes in the market of the substituted product in the short and medium term. After the initial boost given by Proálcool, technological development lost momentum due to declining oil prices and hydrous ethanol's "loss of reputation" as a gasoline substitute. At this time, fuel substitution effectively occurred at the moment when the vehicle was purchased or converted. In other words, the consumer migrated totally from the market, ceasing to consume Type C gasoline any more. Hydrous ethanol's loss of competitiveness and its lack of availability at filling stations left consumers with no other option, and this affected the reputation of the Proálcool program. The result was that the hydrous ethanol fleet virtually ceased to exist.

The advent of flex-fuel vehicles in 2003 transformed the fuels market in Brazil. The possibility of filling up with ethanol, Type C gasoline or any proportion of the two types of fuel prompted the return of hydrous ethanol as a potential competitor for Type C gasoline. In that year, 48,000 flex-fuel vehicles were sold. Sales reached 2.3 million in 2008, demonstrating not only the favorable conditions but also the strong participation of the auto industry[ii].

Today, ethanol is competitive with petroleum derivatives within a certain price range, dictated by the relative energy efficiency of the fuels. Graph 2 compares the history of the average index price for a barrel of petroleum (WTI) negotiated on the New York Mercantile Exchange (NYMEX) with the index price for Brazilian Type A gasoline (zero ethanol content) and the index consumer price for Type C gasoline. The graph shows the gap between the indexes, highlighting the stability of Type A and Type C gasoline prices.

2.3 Relationship between anhydrous and hydrous ethanol

Vehicles in Brazil use two different types of fuel ethanol, hydrous and anhydrous, where the latter is blended with Type A gasoline by distributors to produce the Type C gasoline available at filling stations. Currently, the amount of anhydrous ethanol added to Type A gasoline to make Type C gasoline varies between 20% to 25% in volume (fixed by the Ministry of Agriculture via Decree No. 3.966/2001, issued under Law no. 10.696/2003).

Since anhydrous ethanol is derived from hydrous ethanol[iii], its production costs are higher that those for the hydrous version. **Graph 3** compares anhydrous and hydrous ethanol prices received by producers in the state of São Paulo, excluding shipping and taxes. The vertical arrows on the graph indicate the effective starting dates for Ministry of Agriculture decrees adjusting the percentage blend of anhydrous ethanol with Type A gasoline, to make Type C gasoline. The respective details are in **Table 2**.

Since the 1999/2000 harvest, production of anhydrous ethanol has surpassed that of hydrous ethanol only in the period between the 2000/2001 and 2004/2005 harvests. From the 2003/2004 harvest through the 2008/2009 harvest, hydrous ethanol production grew at an average rate of 21% per year. **Graph 4** shows the growth trend for ethanol production, reflecting the reduction in the ethanol-powered vehicle fleet at the start of the millennium and the advent of flex-fuel vehicles as of 2003.

3 The ethanol supply chain

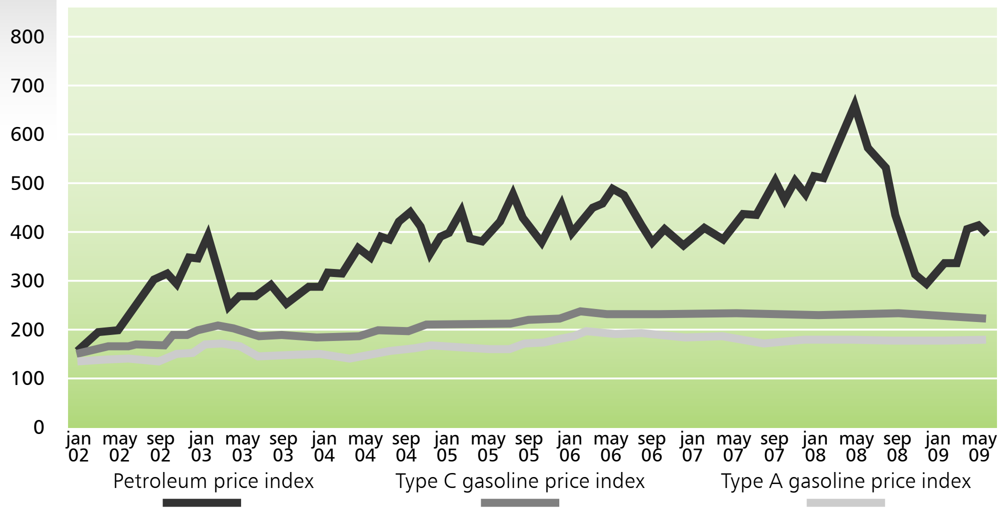
This section analyzes the relationship between the markets for ethanol, sugar and petroleum derivatives, and the impact of the productive structure on the dynamics of the sector.

3.1 The competitive environment

The role of public policy and the design of market intervention mechanisms depend crucially on the competitive process observed in each segment of the supply chain, and their vertical relationships. Within this general perspective, the present section examines the structure and competition pattern in the ethanol supply chain,

Graph 2

Comparison of price trends for petroleum, Type A gasoline, and Type C gasoline



Source: ANP, Bloomberg. Prepared by the authors.

paying particular attention to price-formation mechanisms. The main focus is on the sugar and ethanol production segment, and downstream segments – liquid fuel distributors and retailers.

There were 423 sugar and ethanol plants registered with the Ministry of Agriculture (MAPA) in Brazil as of August 2009. Of these 248 were mixed units (producing both sugar and ethanol), 159 were distilleries (producing just ethanol) and 16 produced just sugar[iv].

An important factor in the competitive environment of Brazilian mills is the heterogeneity of sizes. In the Center-South region 58% of the companies crushed less than two million tonnes of cane in the 2009/2008 harvest, representing only 31% of cane crushing in the region.

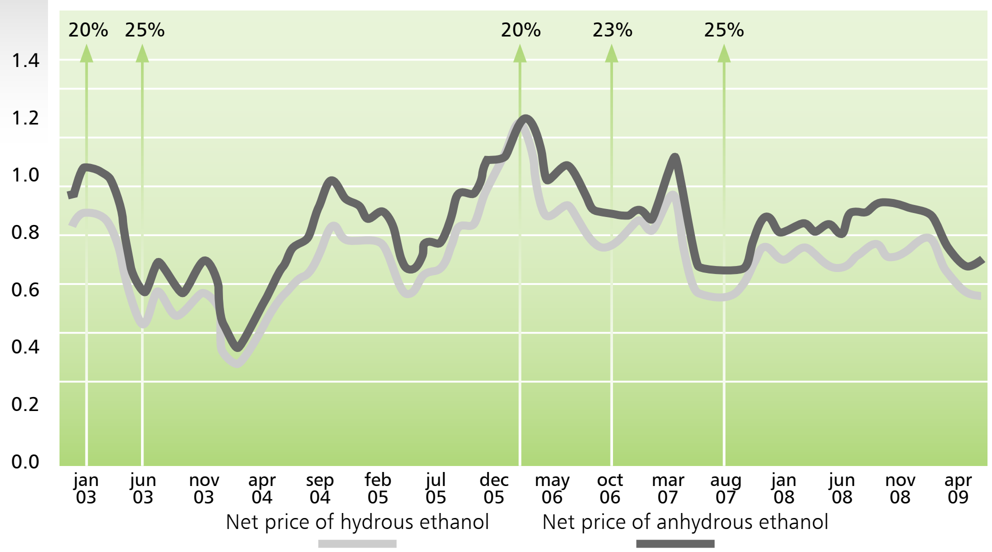
Table 2 **Changes to the anhydrous ethanol blend in gasoline**

From January 2003 to June 2009

MAPA Instruction Nº	Date published	Percentage fixed	Operational date
17	22/01/03	20%	01/02/03
554	27/05/03	25%	01/06/03
51	22/02/06	20%	01/03/06
278	10/11/06	23%	20/11/06
143	27/06/07	25%	01/07/07

Source: Ministry of Agriculture; prepared by the authors.

Graph 3 **Price trend of anhydrous and hydrous ethanol[v]**



Source: UNICA, prepared by the authors.

With respect to ethanol, 60% of distilleries produced less than 100 million liters of ethanol each and together accounted for 31% of total production, while just 8% of mills produced 25% of all the ethanol in the Center-South region.

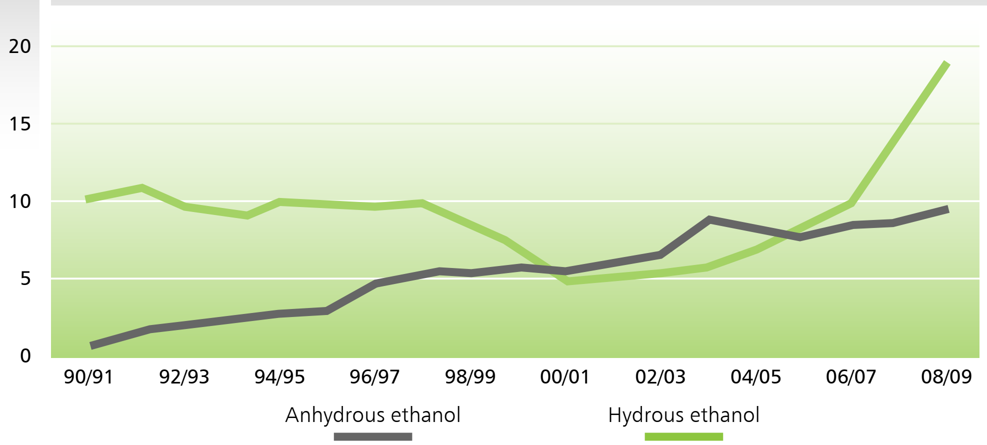
According to the Syndicate of the Ethanol Production Industry in the State of Minas Gerais (Siamig)[vi], 13 of the 15 largest production plants in the country are in São Paulo, with the other two located one in Mato Grosso and one in Minas Gerais. The difference between the first and the last in this ranking was approximately three million tonnes in the 2007/2008 harvest, revealing the difference in scale of the leading companies. Of these 15 companies, two exceed six million tonnes.

Also according to the Siamig report, concentration is a recent phenomenon in the Brazilian sugar and ethanol sector. There have been more than 60 mergers and acquisitions since 2004, producing the large groups in the sector. However, concentration is still low. No producer accounts for more than 10% of domestic production in terms of crushed sugarcane.

Sugarcane processing involves moving large volumes of low-value cargo. For this reason, mills and distilleries are located close to sugarcane plantations and freight usually involves road trains of special sugar-cane trailers, known in Brazil as "treminhões" (Xavier, 2008).

In the ethanol-production segment, "distribution" includes responsibility for the acquisition, storage, transport, marketing and quality control of the fuel (Xavier, 2008). According to the ANP, Brazil has 508 fuel distribution depots, 36,730 filling stations and 459 companies authorized to transport and effect retail sale of fuel (such companies are known in Brazil as Carrier Dealer Retailers (TRR in the Portuguese acronym)[vii]. The flowchart in **Figure 3** summarizes the fuel distribution chain.

Graph 4 **Growth of Brazilian ethanol production** *In billions of litres*[viii]



Source: UNICA, ANP. Prepared by the authors.

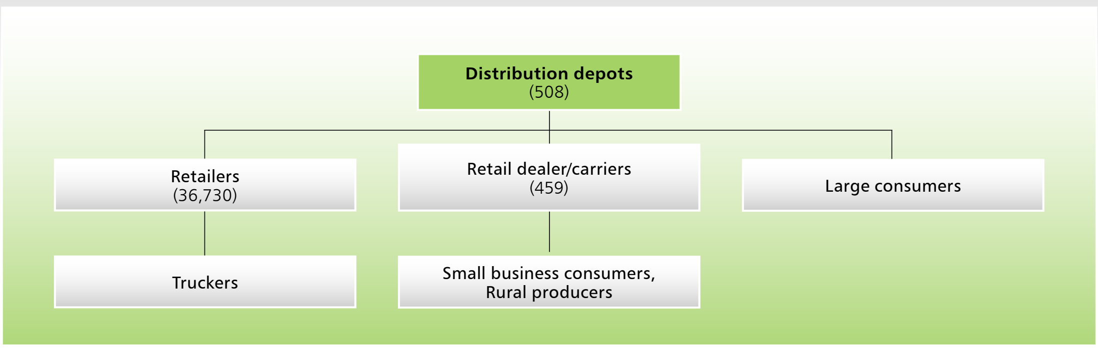
Fuel distribution depots are mainly located in regions close to ports and consumer markets. Products are transferred and stored in distribution depots, where tanker trucks fill up and the products are shipped to the final clients of the company – filling stations, large consumers and wholesalers (Rodrigues and Saliby, 1998).

Deregulation of the sector favored the entry into the market of new distributors and encouraged the use of logistics as a competitive differential in the Brazilian fuels market (Maligo, 2005). Distributors, who emerged on the scene after deregulation, became known in the sector as "newcomers" (emergentes in Portuguese). As discussed below, the newcomers are located principally in São Paulo, according to the ANP, and have become very important in the distribution of hydrous ethanol.

Of the 36,730 filling stations existing in the country, 43% are independent, not tied to a specific brand – see **Graph 5**. These independent stations can be supplied by any distributor, while tied filling stations can be supplied only by a distributor of their own brand.

Currently, the pump price for hydrous ethanol can be divided into four components. First is the cost of producing hydrous ethanol, which represents the price at which it is sold by producers to fuel distributors, net of taxes and shipping. The second refers to taxes. There are two taxes on ethanol: ICMS, a state tax; and PIS/Cofins, a federal tax. Both are paid by producers and distributors. In the state of São Paulo, ICMS was 25% on top of the sale price for producers and distributors in 2003, then since January 2004 it has been 12%. PIS/Cofins on hydrous ethanol was 3.65% for producers and 8.2% for distributors between January 2003 and September 2008, then since October 2008 mills have paid R$48 per thousand liters, while distributors pay R$78[ix]. The third component of the hydrous ethanol pump price is logistics, comprising freight from the distillery to the distribution depot, and subsequent delivery to the filling station. The fourth and last item relates to the margins of distributors and filling stations[x].

Fuel distribution chain, 2009 Figure 3



Source: ANP. Prepared by the authors.

Graph 6 illustrates the change in the composition of hydrous ethanol pump prices in the state of São Paulo, showing the compression of producers' margins – a situation that has worsened since 2007. However, data for 2009 includes just the period from January to September, when production is greater and prices are lower. It is therefore possible that the price paid to the producer is underestimated.

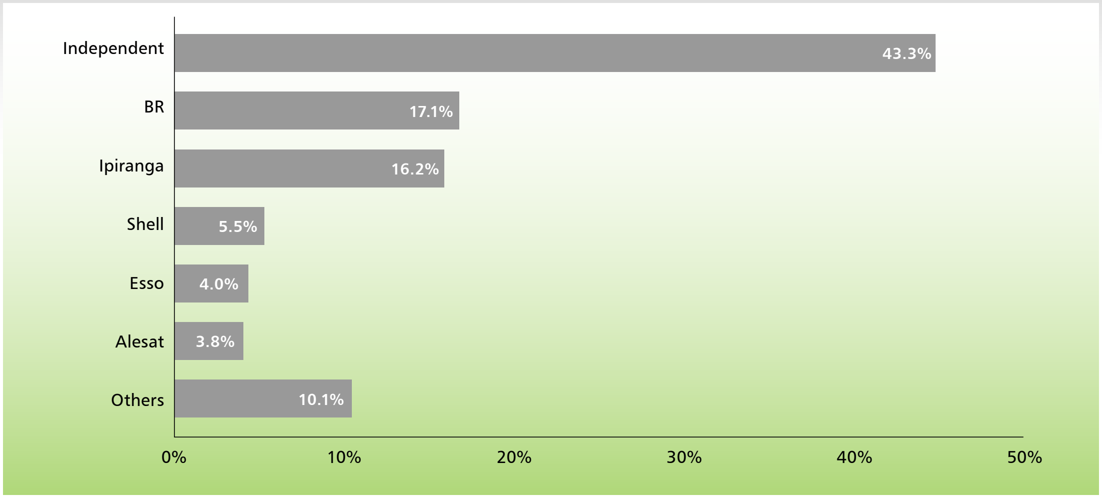
While all values have been normalized so that the pump price is equal to one, in some years the column in the graph exceeds one. In 2003 and 2004 this was due to a negative margin for distributors, and in 2008 and 2009 to a negative margin for producers. Thus, if we add together all the values that make up the price, including the negative margins, the price at the pump will be equal to one[xi].

3.2 Concentration in the supply chain

The behavior of ethanol supply is also influenced by the structure of the market, to the extent that this reflects the relative price bargaining conditions between ethanol producers and purchasers (distributors).

Concentration is a basic characteristic of market structure and can be measured by tools such as the Herfindahl-Hirschman Index (HHI) and the Concentration Ratio (CR_K). The studies that most contributed to this topic were Rocha et al (2007), Mori and Moraes (2007) and Mattoso (2008). This literature permits the conclusion that the ethanol production sector was, until recently, characterized by low concentration, but in recent years there has been a strong trend towards mergers and acquisitions.

Graph 5 **Distribution depots in Brazil, by brand**[xii] *In percentage, situation at 31/12/2008*



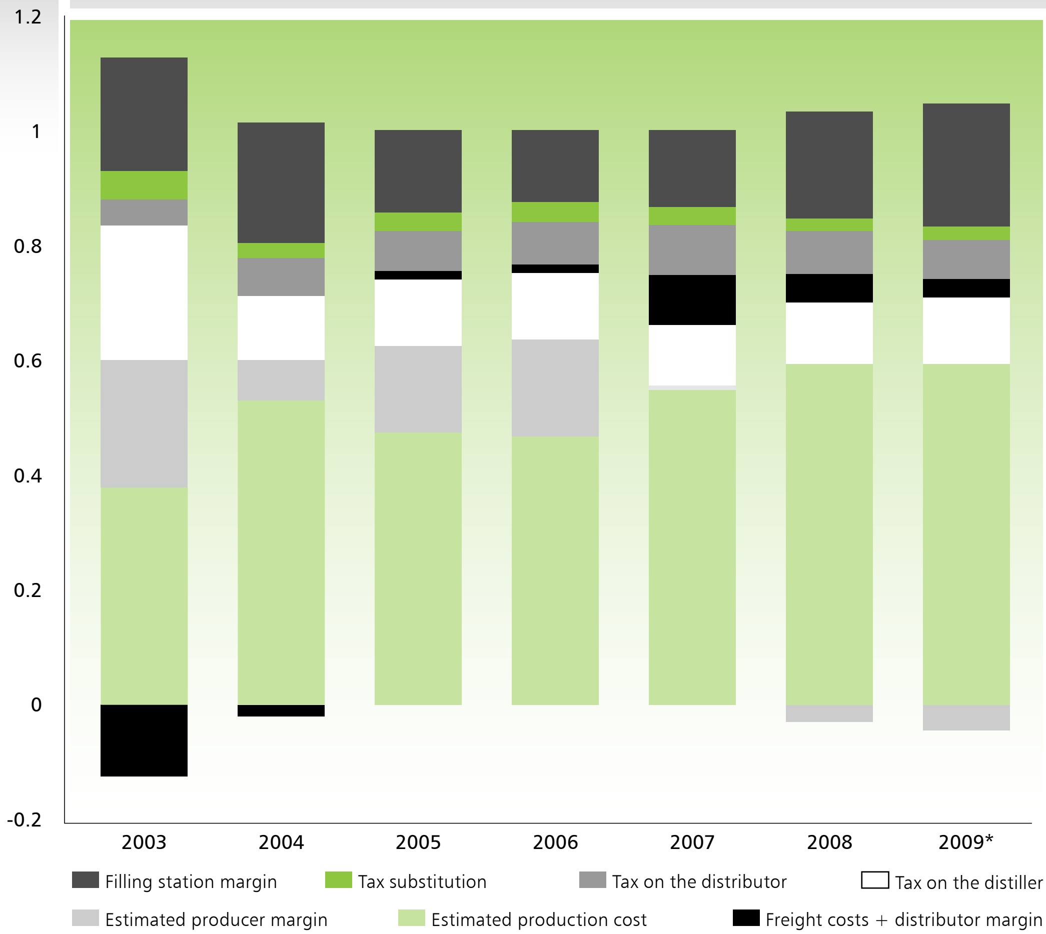
Source: ANP.

Table 3 shows the results of three concentration indexes – HHI[xiii], Equivalent Number and CR5 – for fuel distributors in Brazil for 2008, taking Brazil as the reference market.

Despite the substantial participation in the market of the five largest, the HHI is below 1,800 for distribution of hydrous ethanol and Type C gasoline, indicating low concentration. The markets for fuel oil, aviation gasoline and aviation kerosene are extremely concentrated.

Graph 6

Breakdown of the hydrous ethanol pump price, in São Paulo



* The data for 2009 refers to the period January-September. While the values were normalized to make the pump price one, in some cases the value on the graph exceeds one due to the negative margin received by the distributors or the producers, so "compensating" for the value above one at the pump. • *Source:* Agroconsult, Cepea/UNICA, ANP. Prepared by the authors.

As we know, HHI varies with the participation of each company in the market and also with the disparity between them. The Equivalent Number corresponds to the number of companies of equal size that would generate the same HHI. This number is relatively high for both ethanol and Type C gasoline. A dozen companies of equal size competing in the market could generate strong competition via the purchase of raw materials or sales to filling stations.

It is worth noting that these indexes can be skewed by excessive aggregation of data. Given that this data is not available disaggregated; we opted to calculate the HHI by state, using data from Sindicom and the ANP for hydrous ethanol and Type C gasoline.

When calculated by state, HHI continued to show a low degree of concentration in 2008 in the states of São Paulo, Minas Gerais, Rio de Janeiro, Santa Catarina, Paraná and Mato Grosso (HHI<1,800). In the case of São Paulo we found HHI below 1,000, which indicates a fragmented market on both the purchase and sales sides. For other states we obtained HHI greater than 1,800.

However, interviews with distillery executives in São Paulo revealed that some mills do not sell to the majority of "newcomer" distributors, in particular those that are not members of Sindicom (the National Syndicate of Fuel and Lubricant Distributors) for reasons associated with tax evasion and non-payment. This means that buyers would be restricted to the five liquid fuel distributors that are members of Sindicom. To evaluate this question, we calculated concentration taking into account just that part of the market where only the so-called Sindicom distributors operate. Only then did HHI exceed 1,800 in all states. This means that distillers selling only to Sindicom distributors effectively face higher concentration on the demand side.

When only the distributors within Sindicom are considered in every state, the HHI for ethanol sales was relatively stable in the period 2003-2008. There was a slight increase in 2008, given the acts of concentration that occurred that year. The distribution arm of the Ipiranga Group was acquired by Ultrapar and Petrobras.

Table 3 **HHI, number equivalent to CR5 of fuel distributors in 2008**[xiv]

Fuel	HHI	Equivalent Number	CR5 (%)
Hydrous ethanol	951	11	55
Type C gasoline	1,395	7	66
Diesel oil	2,050	5	71
Fuel oil	5,946	2	99
Aviation gasoline	4,036	2	100
Aviation kerosene	4,377	2	100

Source: ANP. Prepared by the authors.

The former got the filling stations and fuel and lubricant distribution in the South and Southeast regions[xv], while the latter got the same operations in the North, Northeast and Midwest regions[xvi]. Ultrapar (Ipiranga) subsequently bought Texaco's fuel distribution operations[xvii].

The HHI for Type C gasoline is slightly higher than that for ethanol. Once again, the index is below 1,800 in the state of São Paulo, as it is in Mato Grosso, Minas Gerais and Bahia. Considering only Sindicom distributors, the index is higher and above 1,800 in every state.

In the distilleries sector, we calculated the HHI, equivalent number and CR5 for the production of distilleries in the state of São Paulo in the 2008/2009 harvest, examining not individual plants but the economic groups to which they belong (economic concentration). The calculation is restricted to the state of São Paulo because of the availability of information. However, given the major share of this state within the national ethanol market, the index is relevant for this analysis. Of the 317 distilleries located in the Center-South region, 182 are in the state of São Paulo. Ethanol production in São Paulo state and the Center-South region represent respectively 60.8% and 91.3% of the national total[xviii].

The results shown in **Table 4** indicate a fragmented sector, with 108 economic groups controlling 182 distilleries. Despite approximately 60 mergers and acquisitions since 2004[xix], the sector still cannot be described as concentrated. The equivalent number of companies shows that this same HHI value corresponds to a market with low concentration, with a relatively high number of companies. Moreover, the combined market share of the five largest distilling groups also points to low concentration.

Tabela 5 shows HHI, equivalent number and CR5 data for distilleries by unit of production (technical concentration), in the period between the 2004/2005 and 2008/2009 harvest. Calculations were based on the production ranking of mills in the state of São Paulo, as provided by UNICA.

Table 4

Pulverized sector

HHI, equivalent number and CR5 for distillery production in São Paulo by economic groups, 2008/2009 harvest

Product	HHI	Equivalent number	CR5 (%)
Sugarcane	311	32	27
Sugar	428	23	32
Anhydrous ethanol	429	23	36
Hydrous ethanol	246	41	24
Total ethanol	270	37	25

Source: UNICA. Prepared by the authors.

Tabela 5 reveals a sector with very low concentration, as indicated by the low values for HHI and CR5, and the high equivalent number. There is also a slight trend to dispersal, if we consider total ethanol production, reflecting the growth of the relative volume of hydrous ethanol and the entry of new mills.

HHI, the equivalent number and CR5 were also calculated by individual distillery for the 2008/2009 harvest in the Center-South region. Results are in **Table 6**. As can be seen, the HHI results were approximately 40% lower than those found in the state of São Paulo during the same period, pointing to even greater dispersal of the sector when looking at the Center-South region. The increase in the equivalent number of companies and reduction of CR5 also confirm the lower concentration of the Center-South region when compared to the state of São Paulo.

We therefore have an upstream segment with low economic concentration, where HHI is below 430 when looking at economic groups and below 116 when considering individual mills. The upstream segment is legally required to sell its production via distributors, a segment where concentration is higher, but nevertheless below levels considered worrisome in the main consumer states.

As is well known, concentration by itself does not determine the level of competition and market power, although it is an important element. Other factors such as rivalry, market entry and countervailing power must be taken into account. Furthermore, low concentration hampers but does not eliminate the possible formation of cartels, while in the fuel retail segment the Brazilian Competition Policy System (BCPS) has identified and condemned several groups of filling station for price-fixing. Condemnations have been achieved in the cities of Florianópolis (SC), Goiânia (GO), Lages (SC), Belo Horizonte (MG) and Recife (PE).

Allegations of filling station cartels are so frequent that the Secretariat of Economic Law of the Ministry of Justice (SDE) has, as part of its functions with respect to competition law, published a booklet dealing exclusively with gasoline retailing. Of the 298 cartel investigations under way at the SDE, 152 are related to fuel retailing.

Table 5

Sector with low concentration

Trend of HHI, equivalent number (n) and CR5 (%) of distilleries in São Paulo, from 2004/2005 to 2008/2009 harvest years

	2004/2005			2005/2006			2006/2007			2007/2008			2008/2009		
Product	HHI	n	CR5	HHI	n	CR5	HHI	n	CR5	HHI	n	CR5	HHI	n	CR5
Sugarcane	112	89	12,1	109	92	12,0	104	96	11,3	94	106	10,1	87	115	9,8
Sugar	126	79	13,0	124	81	12,4	113	88	11,5	112	89	11,2	109	92	11,3
Anhydrous ethanol	145	69	14.8	149	67	15,1	153	65	14,8	169	59	17,5	159	63	16,5
Hydrous ethanol	147	68	13,0	140	71	14,5	119	84	12,6	97	103	10,2	94	106	9,9
Total ethanol	118	85	12,7	114	88	12,1	108	93	11,8	93	108	10,1	87	115	9,6

Source: UNICA. Prepared by the authors.

Market power is limited by the behavior of demand. The more sensitive demand is to price variations, less will be the ability of a company to increase prices to boost profit. The following item is dedicated to the study of ethanol demand.

▶ 4 Analysis of domestic demand for hydrous ethanol and Type C gasoline

The main characteristic of the Brazilian consumer market for fuel is the competition at the pump between hydrous ethanol and Type C gasoline for flex-fuel vehicles. Competition between the two fuels is related to their sensitivity of demand given variations in the relative price.

The fact that ethanol has increased its participation and importance in the Brazilian energy matrix has prompted several studies focusing on the sector[xx]. Examples include: Bentzen (1994), Eltony and Al-Mutairi (1995), De Negri (1998), Alves and Bueno (2003), Roppa (2005) and Nappo (2007).

The literature suggests that gasoline demand is not sensitive to variations in income or fuel price (Marjotta-Maistro, 2002; Iootty and Roppa, 2006; Nappo, 2007). For ethanol, the price elasticity is positive for supply, while the price elasticity for demand shows divergent results in the studies of Oliveira et al (2008) and Silvério (2007). Moreover, both studies indicate that the demand for Type C gasoline became more elastic beginning in 2003, when flex-fuel vehicles were introduced into the Brazilian market. This shows that hydrous ethanol has become a less-imperfect substitute for Type C gasoline. The evidence also shows that the price of gasoline is not influenced by the price of ethanol, while the inverse is true.

Pursuing another line of investigation, Lucilio (202) looked at price transmission between the main products in the sugar and ethanol sector between 1998 and 2002. The results show that the price of anhydrous ethanol does not explain the price of industrial and exported crystal sugar. The article by Lamounier et al (2006) studies the trade-off between sugar and ethanol production in the mills, indicating that sugar and ethanol prices affected the production ratio only in some states and certain harvests. In addition, Alves and Bacchi (2004) estimate the export supply of Brazilian sugar. The authors' results indicate that increases in export prices and exchange rate depreciation significantly increase Brazilian exports.

Table 6

Lower concentration in the Center-South region

HHI, equivalent number and CR5 for individual distilleries the Center-South, 2008/2009 harvest

Product	HHI	n	CR5 (%)
Sugarcane	53	187	6,7
Sugar	75	133	7,1
Anhydrous ethanol	105	95	8,9
Hydrous ethanol	54	185	5,5
Total ethanol	52	192	6,7

Source: UNICA. Prepared by the authors.

In summary, these studies do not provide evidence of demand sensitivity for gasoline faced with changes in the ethanol price; neither do more complete analyses of the relationship between ethanol demand and fuel prices. It must be noted that these studies do not include recent periods when hydrous ethanol has been gaining strength as a direct competitor for gasoline. One of the main questions debated in the above-mentioned studies is the inclusion of information about sugar and petroleum markets and other macroeconomic information in the supply model for ethanol. According to the literature, these variables are relevant in the decisions taken by mills.

The following items analyze the demand for hydrous ethanol and Type C gasoline. They take as a starting point the hypothesis that hydrous ethanol can be characterized as a normal good: one with negative price elasticity (demand sensibility to prices) and that responds significantly to variations in Type C gasoline prices, given that this is its main competitor.

4.1 Domestic demand of hydrous ethanol

The analysis of the relations of demand for hydrous ethanol makes possible the calculation of the price elasticity of demand and the identification of the effects of the principal factors that influenced domestic demand, such as: the prices of substitutes, income, length of loans for financing vehicles, and real interest rates, among others. The database that was used for this analysis is in the form of a time series, from July 2001 to August 2009. The data was organized based on information from ANP, UNICA, IBGE, BCB and Bloomberg as described in Annex 1.

The method used for the estimates of demand equations is based on cointegration analysis. The aim of this modeling is to verify the existence of short-term and long-term relationships between liquid fuel prices in Brazil and sales of the product.

The demand equation for ethanol to be tested for the data for Brazil and São Paulo can be written as follows:

$$\Delta Q_t^D = \alpha_0(Q_{t-1}^D + \beta_1 p_{t-1} + \beta_2 pg_{t-1}) + \sum_{i-1}^{L}\alpha_1(i)\Delta Q_{t-i}^D + \sum_{i=1}^{L}\alpha_2(i)\Delta p_{t-1} + \sum_{i=1}^{L}\alpha_3(i)\Delta pg_{t-1} + \lambda.D_t + \varepsilon_t$$

where:

- Q_t^D is the volume of hydrous ethanol demanded per vehicle (total fleet) in period t, Brazil and the state of São Paulo;
- p_t is the price of hydrous ethanol during period t;
- pg_t is the price of Type C gasoline during period t;
- D_t is a vector of variables that influence the demand for hydrous ethanol during the period t (average real income of workers and unemployment rate, among others) and temporal dummy variables (annual and monthly);
- ε_t is the erro term of the equation;

α_0 is the short term adjustment coefficient;
β_1, β_2 are the parameters of the cointegration vector, which indicate the long-term relationship between variables;
$\alpha'_1, \alpha'_2, \lambda'$ are parameter vectors to be estimated.

According to Enders (1985), the definition of cointegration is related to three important points: the same order of integration of all cointegrated variables; stationary linear combination of non-stationary variables; and the number of existing cointegration vectors is equal to the quantity of variables of the model minus one.

The results of the unit root tests for the relevant variables of the model indicate that the variables of interest are non-stationary in the first order[xxi]. The next stage consisted of cointegration testing among variables, using the Johansen Procedure (1988), with the final results for the estimated coefficients by the VEC summarized below[xxii]:

Results for the whole sample (Brazil):

$$\Delta Q_t^D = \underset{[-6,0]}{-0,78}(Q_{t-1}^D + \underset{[0,4]}{0,70} + \underset{[8,24]}{1,23}p_{t-1} - \underset{[-4,38]}{1,45}pg_{t-1}) + \hat{\lambda}.D_t + \hat{\varepsilon}_t$$

Results for the state of São Paulo:

$$\Delta Q_t^D = \underset{[-5,7]}{-0,75}(Q_{t-1}^D + \underset{[1,1]}{1,92} + \underset{[7,48]}{1,33}p_{t-1} - \underset{[-3,94]}{1,54}pg_{t-1}) + \hat{\lambda}.D_t + \hat{\varepsilon}_t$$

The results obtained demonstrate the high relative sensitivity of ethanol demand to the prices of ethanol and gasoline. In other words, the long-term elasticities found by the cointegration method are superior, in module, to the unit, and have the correct signs (negative for ethanol and positive for gasoline)[xxiii]. Note that elasticities for São Paulo were significantly higher than those for Brazil, which indicates that consumers in São Paulo are more sensitive to price than the average Brazilian consumers of fuel. This sensitivity reflects the composition of the fleet, which contains an increasing percentage of flex-fuel vehicles.

Adjustment coefficients are expected to exhibit signs opposite to the signs of the components of the cointegration vector to conclude that an adjustment to equilibrium happens in the short term. The adjustment coefficient was significant and negative for both equations. Taking as an example the model for Brazil, and starting from a point where the variables are in a long-term relation, then an increase in gasoline price turns the error term negative. Given the negative adjustment coefficient, the change of this variable is positive, so that there is an increase in the demand for ethanol in the following month, ***t***, towards the restoration of the long-term relation. The speed with which this adjustment occurs is -0.78 in the model for Brazil and -0.75 for São Paulo. Therefore, if there is an unexpected increase (positive shock) of 1% in the demand for ethanol in ***t-1***, then there will be a reduction in demand of 0.75% (0.78%). In other words, approximately 75% (78%) of the shock is transmitted to the following period[xxiv].

In summary, it is believed that the results obtained in this study appear to be more price-sensitive, when compared to the reviewed literature, due to period of analysis, which includes the years where ethanol gained importance by virtue of the success of flex-fuel vehicles in the market.

4.2 Domestic demand for Type C gasoline

The analysis of the relations of gasoline demand makes it possible to calculate the price elasticity of demand. The estimates of these measurements of consumer sensitivity to acquire gasoline are important to compare with the measurements found for hydrous ethanol. The assumption to be verified in this empirical analysis is that "the demand for ethanol is more sensitive to gasoline prices than the demand for gasoline is sensitive to ethanol prices." The database used for this analysis is also in a time series format, from July 2001 to August 2009, with the sources of data the same as those used in the previous subsection.

The method used to estimate the equations for gasoline demand was also based on cointegration analysis. The gasoline demand equation to be tested for Brazil data can be written as follows:

$$\Delta q_t^D = \alpha'_0 (q_{t-1}^D + \beta'_1 p_{t-1} + \beta'_2 pg_{t-1}) + \sum_{i-1}^{L} \alpha'_1(i)\Delta q_{t-i}^D + \sum_{i=1}^{L} \alpha'_2(i)\Delta p_{t-1} + \sum_{i=1}^{L} \alpha'_3(i)\Delta pg_{t-1} + \lambda'.D_t + \varepsilon'_t$$

where:

- q_t^D is the volume of Type C gasoline demanded per vehicle (total fleet) in period t, in Brazil;
- p_t is the price of hydrous ethanol during period t;
- pg_t is the price of Type C gasoline during period t;
- D_t is a vector of variables that influence the demand for hydrous ethanol in the period t (average real income of workers and unemployment rate, among others) and temporal dummy variables (annual and monthly);
- ε'_t is the error term of the equation;
- α'_0 is the short-term coefficient adjustment;
- β'_1, β'_2 are the parameters of the cointegration vector, which indicate a long-term relation between the variables;
- $\alpha'_1, \alpha'_2, \lambda'$ are parameter vectors to be estimated.

The results for the coefficients estimated by VEC are summarized below, with the t statistics reported in brackets:

$$\Delta q_t^D = -1{,}57(q_{t-1}^D + 1{,}55 - 0{,}28 p_{t-1} + 0{,}63 pg_{t-1}) + \sum_{i-1}^{6} \hat{\alpha}'_1(i)\Delta q_{t-i}^D + \sum_{i=1}^{6} \hat{\alpha}'_2(i)\Delta p_{t-1} + \sum_{i=1}^{6} \hat{\alpha}'_3(i)\Delta pg_{t-1} + \hat{\lambda}'.D_t + \hat{\varepsilon}'_t$$

$$[-5{,}55] \quad [*] \quad [-3{,}6] \quad [3{,}88]$$

* *Significant/Not reported.*

The results indicate that the relative demand for Type C gasoline exhibits sensitivity to ethanol prices and to the price of gasoline itself. However, unlike the findings for ethanol demand, the price of ethanol has only a small influence in the long-term demand for Type C gasoline. Note that the signs found were in accordance with the theory (positive for ethanol and negative for gasoline)[xxv].

The estimated adjustment coefficient exhibits the opposite sign to that of the main component of the cointegration vector. It can therefore be concluded that there is a short-term adjustment to reach equilibrium. The adjustment coefficient was significant, negative and greater than one in module, indicating rapid adjustment to long-term equilibrium. Therefore, for an increase in the price of Type C gasoline, which would make the error term positive, the change of this variable will be negative (given the negative adjustment coefficient), so that there is a strong reduction in the demand for Type C gasoline in the following month, t, towards restoration of equilibrium.

4.3 Considerations on the market reactions for ethanol and Type C gasoline

Estimates suggest that consumers are sensitive to price, both in Brazil as a whole and in São Paulo, and that ethanol demand responds more to price variation than does the demand for Type C gasoline.

This analysis for hydrous ethanol and Type C gasoline is complemented below with considerations on anhydrous ethanol.

▶ 5 Considerations on anhydrous ethanol

The focus of this section is the role of anhydrous ethanol in determining the price of Type C gasoline. Moreover, in order to improve the effectiveness of public policies in the sector – in particular the change in the mandatory blend of anhydrous ethanol in Type A gasoline – item 5.2 examines by how much ethanol production would need to fall to endanger the supply of anhydrous ethanol.

Consumer sensitivity to price variations

Ethanol Market		
Price-elasticity of ethanol	-1.23 (BR) -1/33 (SP)	An increase of 1% in the price of ethanol negatively affects Brazilian demand for ethanol by 1.23%
Price-elasticity of Type C gasoline	-1.45 (BR) -1.54 (SP)	An increase of 1% in the price of gasoline positively affects Brazilian demand for ethanol by 1.45%
Type C gasoline market		
Price-elasticity of ethanol	0.28 (BR)	An increase of 1% in the price of ethanol positively affects the demand for gasoline by 0.28%
Price-elasticity of Type C gasoline	-0.63 (BR)	An increase of 1% in the price of gasoline negatively affects the demand for gasoline by 0.63%

5.1 The role of anhydrous ethanol in establishing the gasoline price

In the fuels sector, 2002 marked the beginning of freely established prices for consumers (Marjotta-Maistro, 2002). Given the structure of fuel price formation, the aim of this section is to analyze how the institutional environment and the changes in the price of one fuel can affect the price of others. In particular, the model seeks to assess the impact on Type C gasoline price variation of the anhydrous ethanol price and ordinances of the Ministry of Agriculture relating to fuel blend. The model thus consists of estimating the "consumer price of Type C gasoline" variable in the first difference. To explain price variations, the control variables are mainly those that shift the supply and demand curves of the product as well as other variables exogenous to prices that do not have a direct impact on supply and demand. Technically, the use of variables in first difference allows for correction of the problem of non-stationarity of these variables, which could lead the model to spurious correlations.

The estimated equation can be described as follows:

$$\Delta \ln \mathrm{PgasolinaC}_t = \alpha_0 + X\beta + \mathrm{DummiesPortariasMAPA}_t\theta + \ln \mathrm{Petanolanidro}_t\pi + \varepsilon_t$$

for t=1,...,T

- α_0 Parameter that measures model intercept;
- X Matriz of k control variables (T x k);
- β Vector of parameters (k x 1) to be estimated;
- π Parameter that measures the effect of the anhydrous ethanol price on the variation in gasoline price;
- θ Vector of parameters (p x 1) to be estimated, on the p ordinances relating to fuel blend during period t.

Data covers the period from January 2003 to July 2009, and the model was estimated using Least Ordinary Squares with correction of the variance-covariance matrix using White's method (White, 1980)[xxvi]. Stationarity tests of the variables used in the model do not indicate a non-stationary standard[xxvii]. The results of the estimates can be seen in **Annex 2**[xxviii].

The results of the model indicate that the fuel blend of anhydrous ethanol in gasoline reduced, on average, the volatility of Type C gasoline consumer prices (estimated coefficient for the dummies) in 2% to 3%, which is a statistically significant impact[xxix].

The influence of the anhydrous ethanol price on the volatility of Type C gasoline price was captured by the variable of the logarithm of these prices for producers, with the dummies that measure the determination of each blend percentage during the period in question. The estimated coefficients were statistically significant only for the duration of Ministry of Agriculture decrees numbers 17, 51 and 278. During the period in which the blends determined by those decrees were in force, increases in anhydrous ethanol prices for producers had a positive average effect on the variation of Type C gasoline prices for consumers. This relationship reflects the countercyclical behavior of the blend policies, which act in an environment of rising anhydrous ethanol prices. The periods following the blend reductions are also periods when the price of ethanol is more volatile.

5.2 Risk simulation for anhydrous ethanol supply

This section develops simulations for the risk of harvest failure threatening the supply of anhydrous and hydrous ethanol in the Brazilian market. In other words, by how much would the harvest need to fall to create a credible risk of shortage of anhydrous ethanol in the market? This analysis is relevant to inform the discussion about supply risks in relation to policies for the blend of anhydrous ethanol with Type A gasoline. Fuel blend policy should be used as an instrument to regulate quantity rather than price, so giving the market greater predictability for consumer supply and for fuel producers to take decisions.

The following steps illustrate the stages involved in performing a simulation of supply risk.

I Calculation of current domestic production of anhydrous and hydrous ethanol, net of exports;
II Calculation of current domestic consumption of hydrous ethanol and Type C gasoline, with consumption of anhydrous ethanol assumed to be 25% of Type C gasoline consumption;
III Estimate of the Brazilian vehicle fleet by type of fuel;
IV Construction of fuel-use scenarios that could lead to an ethanol shortage in the market;
V Estimate of harvest decrease for each scenario based on information from items **I**, **II** and **III**.

Data is for the period 2004 – 2008[xxx].

Four scenarios[xxxi] were evaluated, namely:

Base-information referring to 2004 – 2008:
Scenario 1: 100% use of Type C gasoline by light flex-fuel vehicles;
Scenario 2: 50% use of hydrous ethanol by light flex-fuel vehicles;
Scenario 3: 70% use of hydrous ethanol by light flex-fuel vehicles;
Scenario 4: 90% use of hydrous ethanol by light flex-fuel vehicles.

Scenario 1: Assuming the use of Type C gasoline by all gasoline and flex-fuel vehicles in the fleet, and looking at ethanol production net of exports, we can say that the percentage production reduction required to create a shortage of ethanol in the market would be[xxxii]:

2004	2005	2006	2007	2008
4.5%	18.49%	21.82%	36.39%	42.13%

These results indicate that in 2008, with everything else remaining constant in the market, there would have had to be a 42.13% harvest failure to create a crisis in ethanol supply.

Scenarios 2 to 4: These scenarios assume that hydrous ethanol is consumed by, respectively, 50%, 70% and 90% of all the flex-fuel vehicle fleet, with Type C gasoline consumption restricted to 50%, 30% and 10% of gasoline-powered vehicles.

In this context, considering ethanol production net of exports in each of these years, the percentage harvest failures required to create a shortage of ethanol in the market are shown in **Table 7**.

The risk of ethanol shortage increases significantly in 2008 as individuals with flex-fuel vehicles switch in mass to consuming ethanol. The worrying level of harvest failure is reduced from 24% to 9.4% as consumption grows from 50% to 90% of vehicles in 2008, with all else remaining constant in the market.

We should stress that changes to the blend are justified only by harvest failures large enough to put at risk the supply of anhydrous ethanol to make Type C gasoline. This policy should not be used to address seasonal variations, because unjustified changes increase risk to the business and to the sustainability of ethanol production.

To better identify critical moments for shortage of anhydrous fuel ethanol it would, for example, to possible to encourage the federal government's Energy Research Company (EPE) to construct models for the ethanol sector to identify the relationship between supply and demand for the fuel, similar to what is done for the electricity market. In that way, decisions about changes to the mandatory blend tend to become less politicized, more technical and more transparent.

Using information about production and consumption for 2004 – 2008, we simulated ranges for the size of production decrease in the period that would justify changing the mandatory blend, indicating that the risk of ethanol shortage increases as the percentage of flex-fuel vehicles consuming hydrous ethanol increases. In the most extreme scenario for 2008, in which 90% of all flex-fuel vehicles in Brazil are fueled with hydrous ethanol, there would be an ethanol shortage if ethanol production in this year were 10% lower than was effectively observed (or 4.9% greater than ethanol production in the previous year).

Table 7 **Harvest failure for risk of ethanol shortage**

	Scenario 2 (50% ethanol)	Scenario 3 (70% ethanol)	Scenario 4 (90% ethanol)
2004	10.0%	9.3%	8.7%
2005	14.3%	12.1%	10.0%
2006	11.4%	7.3%	3.1%
2007	22.3%	16.6%	11.0%
2008	24.0%	16.7%	9.4%

▶ 6 Final considerations: outlines for public policy

The institutional environment comprises a group of formal and informal rules. It shapes business conduct and is largely responsible for performance of the markets. The institutional environment provides a set of incentives and controls that in one way or another guide the expectations of the various actors directly involved, including sugarcane, sugar and ethanol producers, automakers and consumers, influencing the operational strategy of each of these players.

The orientation and shape of public policies are, therefore, essential tools for directing production. In the case of ethanol, this becomes even more relevant given the strategic importance of the fuel's availability to ensure the supply of the domestic market. This can be clearly illustrated by the crisis that European countries went through recently when Russia cut gas supplies, or by the breach of international agreements, or the renegotiation of prices, as occurred in Latin America with the political changes in Bolívia and Venezuela. No less important have been the effects of oil price volatility on modern economies.

The results of this study allow us to identify which problems in the ethanol supply chain should be a target for public policy, given the goal of increasing ethanol participation in the Brazilian energy matrix. Based on the main results of these tests and empirical evidence, their relationships and implications, we can highlight priority actions to improve the functioning of the market, so benefiting both producers and consumers. These priority actions are: (a) establishing technical criteria to monitor the market in order to identify harvest failures that would prompt changes in the mandatory blend of anhydrous ethanol in Type A gasoline, based on technical and transparent criteria; (b) the participation of a greater number of players, so increasing market liquidity; and (c) the greater use of warrantage contracts (inventory credit system).

These specific actions do not necessarily depend on legal changes. We have focused on creating conditions for ethanol production to expand via market mechanisms, which are capable of providing adequate remuneration for growth of businesses while encouraging efficiency gains that, in a competitive environment, are shared with consumers through lower prices. In the absence of market failures, as identified in this study, improving market functioning with the minimum of intervention is the most efficient way to give proper incentives for the sustainable expansion of production.

Anexo 1 **Names of variables in the model, with description and source**

Variable	Description	Source
lnveh	Logarithm of hydrous ethanol sales by distributors, in liters	ANP
lnpeh	Logarithm of the average consumer price of hydrous ethanol, reais per liter	ANP
lnpdi	Logarithm of the average consumer price of diesel, reais per liter	ANP
lnpgc	Logarithm of the average consumer price of Type C gasoline, reais per liter	ANP
lnpgnv	Logarithm of the average consumer price of vehicular natural gas, reais per liter	ANP
ptax	Exchange rate at the end of the period, reais/dollar	Sisbacen PTAX8
lnp_acucarBRL	Logarithm of the international price of sugar (future contract NYBOT) in reais	Broadcast
lnpib	Logarithm of state GDP	IBGE
prazo_medio_ veiculos	Average financing period for vehicle acquisitions by individuals with pre-fixed interest rate, in days	Sisbacen PESP3
ln_vflex	Registration of flex-fuel cars, per state	FENABRAVE
ln_vgasolina	Registration of gasoline cars, per state	FENABRAVE
juros_real	Real interest rate – Selic rate, deflated by the IPCA inflation index	BCB e IBGE
inadimplencia_pf	Percentage default rate, individuals	BCB
inadimplencia_total	Complete default, in percentage	BCB
Ufs	Dummies for states (and the federal district)	
Anos	Dummies for years	

Annex 2 **Results of the estimates: price model for Type C gasoline**

Least Ordinary Squares with robust matrix for variance

Model Information

Observations: 77 — R2 = 0,770

F(26,50) = 28,23 — R2 Ajust = 0,651

P–value F: 0.00

Dependent variable: dif_ln_pgas_c

Controls	Coefficient
lnpreco_alcool_hidr	–0.03331
dif_in_pdiesel	0.43095 **
dif_in_ppetroleo	–0.01120
ln_prod_veic_flex_alcool	0.01346 **
taxa_desemprego_30d	0.00496 *
lei 554_25p	–0.02745 **
lei 51_20p	–0.03135 **
lei 278_23p	–0.02939 **
lei 43_25p	–0.02977 **
lnpanidro_lei 17_20p	0.15632 **
lnpanidro_lei 554_25p	0.02342
lnpanidro_lei 51_20p	0.12576 **
lnpanidro_lei 278_23p	0.03721 *
lnpanidro_lei 43_25p	0.02279
ln_cambio	0.03036 **
m1	–0.00420
m2	–0.00806
m3	–0.01208 *
m4	–0.01487 **
m5	–0.01612 **
m6	–0.01111 *
m7	–0.01395 **
m8	–0.00836
m9	–0.00139
m10	–0.00427
m11	–0.01097 **
Constant	–0.28408 **

* Indicates statistical significance at 10% • ** Indicates statistical significance at 15%

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Explanatory Notes

[i] A tonne equivalent of petroleum (TPE) is a unit of energy defined as the heat released by combustion of one tonne of crude oil.
[ii] Figures provided by Anfavea (National Association of Automobile Manufacturers).
[iii] For the production of anhydrous ethanol it is necessary to use cyclohexane as a dehydrating agent. Site: http://www.etanol.ufscar.br/palestras-do-dia-02-de-setembro/o-processo-produtivo-do-etanol. Accessed in August 2009.
[iv] Available at: http://www.agricultura.gov.br/pls/portal/docs/PAGE/MAPA/SERVICOS/USINAS_DESTILARIAS/USINAS_CADASTRADAS/UPS_04-08-2009_0_1.PDF. Accessed on 06/08/2009.
[v] Anhydrous ethanol was first added to gasoline in Brazil in the 1930s. The restriction on the period of the graph is due to the lack of a longer price series. It is important to note that the first change in the blend of anhydrous ethanol with gasoline shown in the chart corresponds to the Ministry of Agriculture decree No. 17 which set the percentage at 20%, following a period in which the percentage was 25%, according to Ministry of Agriculture decree No. 266, 21/06/2002.
[vi] Economic Report, Union of the Ethanol Production Industry of Minas Gerais, Belo Horizonte, v. 6, 2009.
[vii] Direct sales to rural consumers, small business consumers, motorists and truckers.
[viii] Data for the 08/09 harvest were not finalized in the North-East when we obtained the information, and refer to the position of production 16 May 2009.
[ix] These rates refer to the period for which we had access to data, from January 2003 to August 2009.
[x] Economic Report, Union of the Ethanol Production Industry of Minas Gerais, Belo Horizonte, v. 11, March 2009.
[xi] One possible explanation for the presence of negative margins is the fact that the industry suffers significant tax evasion, which squeezes the margins of law-abiding agents.
[xii] The category "Other" includes 106 brands.
[xiii] HHI = $\Sigma\, si^2$, which itself is the participation of firm i in the relevant market. The index ranges between 0 and 10,000. The CRK = $\Sigma\, s_5/S$, where s_5 is the production of the five largest and S the production value of any relevant market. The equivalent number N = 1/HHI.
[xiv] Aviation gasoline for piston engines; aviation kerosene for turbo-jets.
[xv] Concentration Act No. 08012.002816/2007-25.
[xvi] Concentration Act No. 08012.002820/2007-93.
[xvii] The purchase of Texaco's fuel distribution operations by Ipiranga was submitted to CADE under AC No. 08012.009025/2008-15, and at the time of writing was in the phase of instruction.
[xviii] 2008/2009 harvest, UNICA.
[xix] KPMG, in: Economic Report, Union of the Ethanol Production Industry in Minas Gerais, Belo Horizonte, v. 11, March 2009.
[xx] Many of the scholarly articles of demand and supply estimation make use of cointegration methods to estimate the price and income elasticities of supply and demand, given the non-stationary characteristics of the time series used for the estimates.
[xxi] We used the following unit root tests: Augmented Dickey-Fuller (ADF), Phillips-Perron (PP) and Kwiatkoviski, Phillips, Schmidt and SAIWA (KPSS). All these tests assume the hypothesis of a unit root at the expense of stationarity of the series, taking into account the presence of deterministic terms in the model specification.
[xxii] The t-statistics are reported in brackets.
[xxiii] To obtain the equation for the long-term relationship between ethanol demand and prices, simply equate the equation in brackets to zero, thereby generating elasticities in the correct direction for both products. Example: $Q_{t-1}^{D} = -0{,}70 - 1{,}23 p_{t-1} + 1{,}45 pg_{t-1}$
[xxiv] The analysis of the waste, making sure that they have approximately normal distribution, is made by conducting the Jarque-Bera test, whose null hypothesis is tested on the normal distribution (symmetry close to zero and kurtosis close to three). The test indicates non-rejection at 5% of the normality of residuals of the equations.
[xxv] To obtain the equation for long-term relationship between ethanol demand and prices, simply match the equation in brackets to zero, thereby generating elasticities in the correct direction for both products. Example: $q_{t-1}^{D} = -1{,}55 + 0{,}28 p_{t-1} - 0{,}63 pg_{t-1}$
[xxvi] White (1980).
[xxvii] Augmented Dickey-Fuller (ADF) test and Phillips-Perron (PP) test.
[xxviii] Besides the independent variables reported in the Annex, we tested the inclusion of other variables in the model, such as: dummies for year, average real income, amount of Type A gasoline refined, quantity of petroleum imported, among others. None of the above-mentioned variables showed satisfactory joint significance (for significance levels of 5% and 10%), and were thus removed from the estimated equation.
[xxix] This result appears to converge with the current aim of policy for fuel blend, which would be to contain the volatility of prices of both gasoline and anhydrous ethanol. See article in the Folha de S.Paulo newspaper 09 November 2009 http://www1.folha.uol.com.br/folha/dinheiro/ult91u649684.shtml.
[xxx] 2008 was the latest year with complete information available in this study.
[xxxi] It was assumed that one liter of hydrous ethanol is equivalent to one liter of anhydrous ethanol and the fuel blend is constant in the order of 25%.
[xxxii] The production drop is considered in relation to that produced in the period, and not the previous period.

09

Ethanol and Bioelectricity Sugarcane in the Future of the Energy Matrix

Ethanol in the Brazilian Energy Matrix

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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

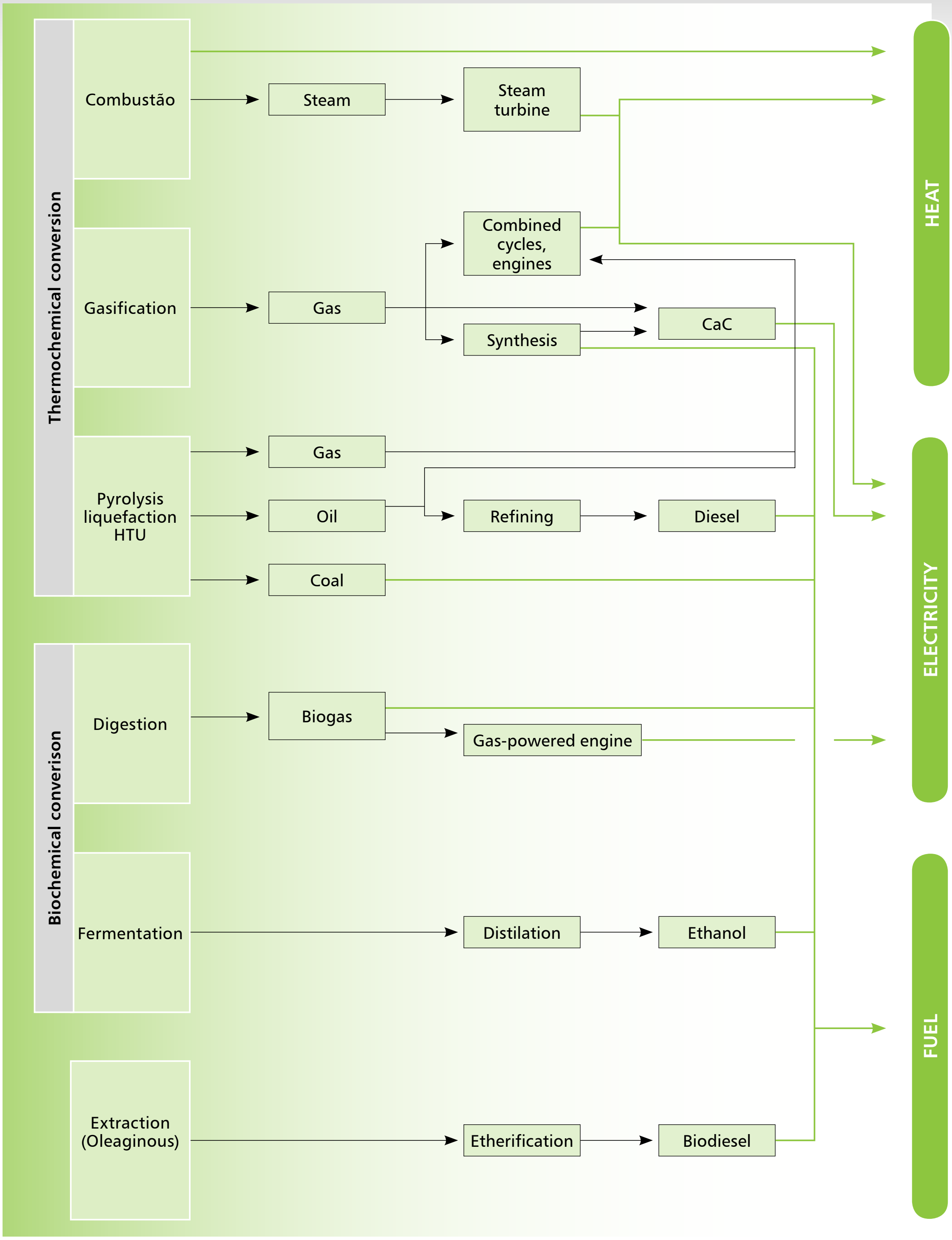
The ethanol supply chain in Brazil is almost always integrated with sugar production. It starts with sugarcane cultivation, with productivity in the Center-South region reaching about 80 tonnes per hectare in the best plantations (Nogueira, 2009). Recent decades have seen remarkable progress in the agricultural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

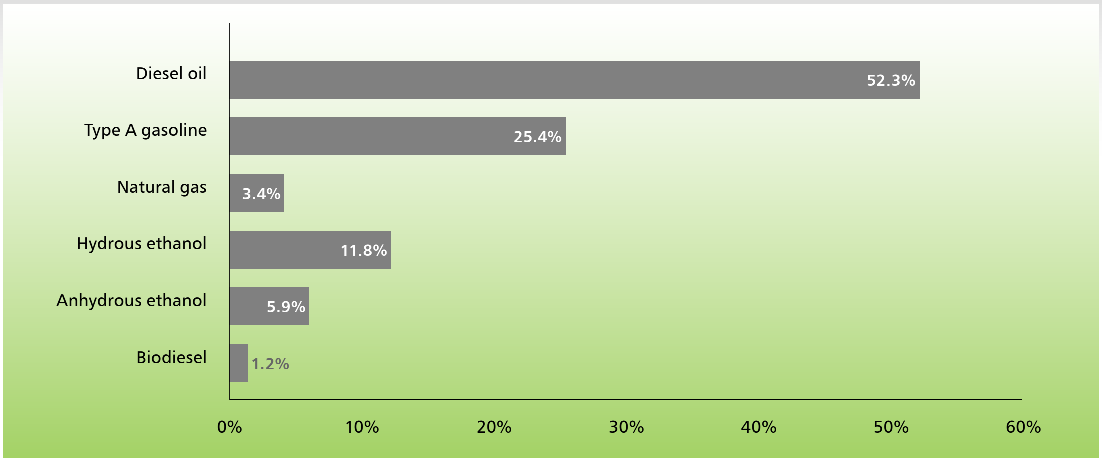
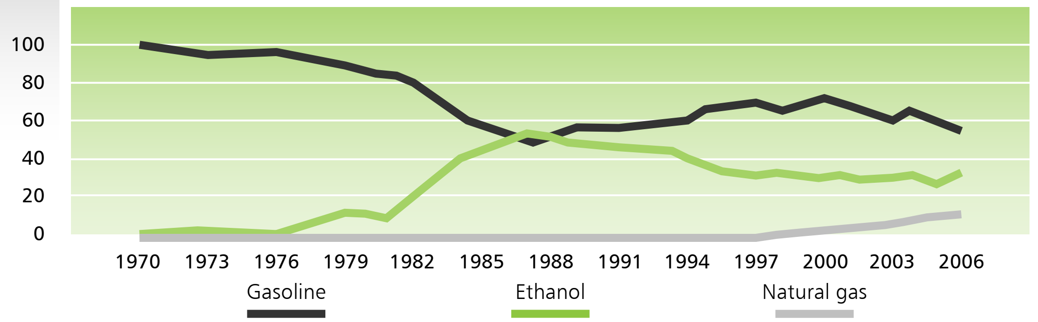


Figure 3 **Breakdown of fuel consumption for Otto Cycle engines** *Share (% TPE)*



Source: MME

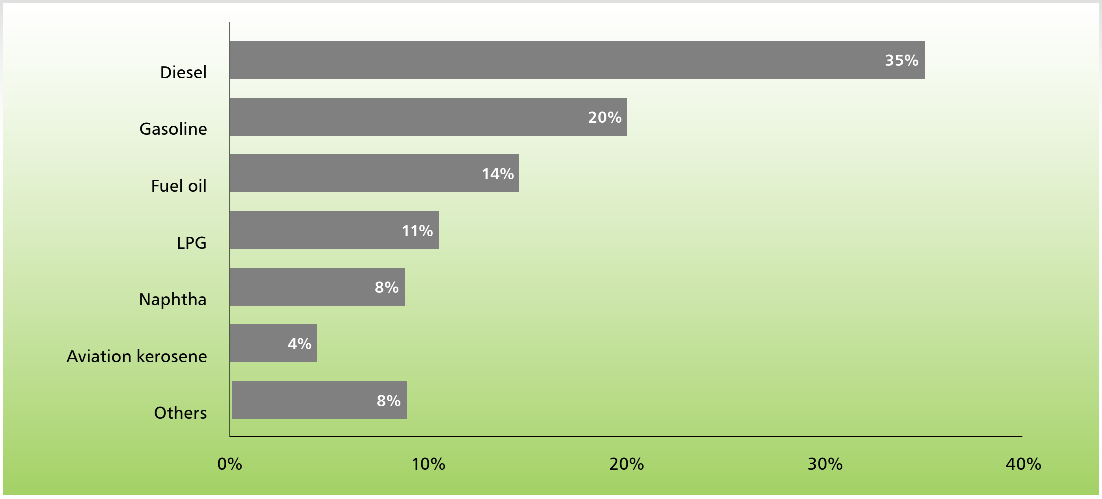
The country has been a net exporter since 2006. In 2008, it exported 432,000 BOPD at an average price of US$87/b and imported 404,000 BOPD at an average of US$111/b[iv]. Given that the average value of imported derivatives was well above the price achieved by domestic oil, the oil trade balance was negative 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 Table 8

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

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 m^3)		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.

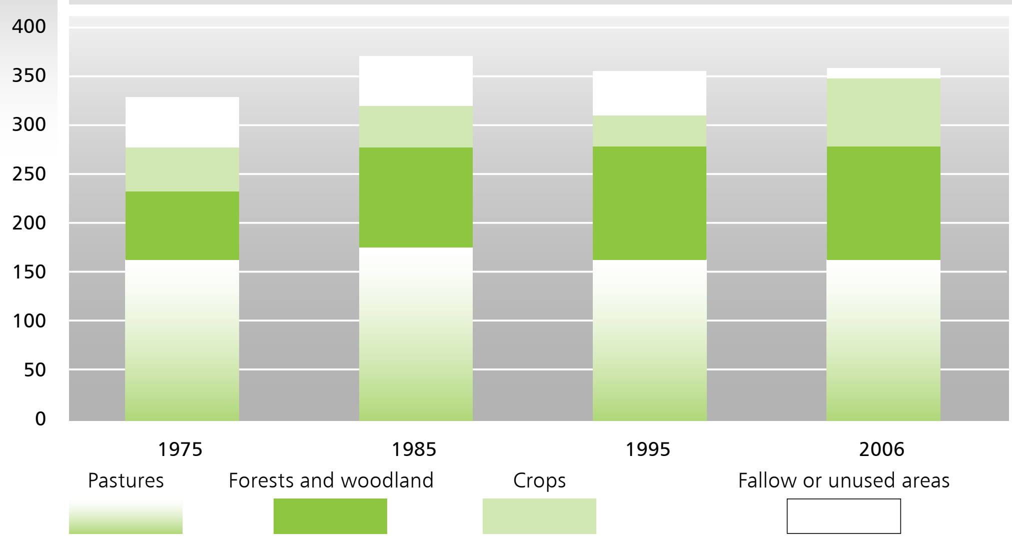
Brazil has a surface area of 851.4 million hectares, much of it covered by tropical forests. Based on the results of the 2006 Agricultural Census, the total area of rural properties was 354.8 million hectares representing 42% of national territory excluding protected areas, unsuitable areas, lakes and 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.

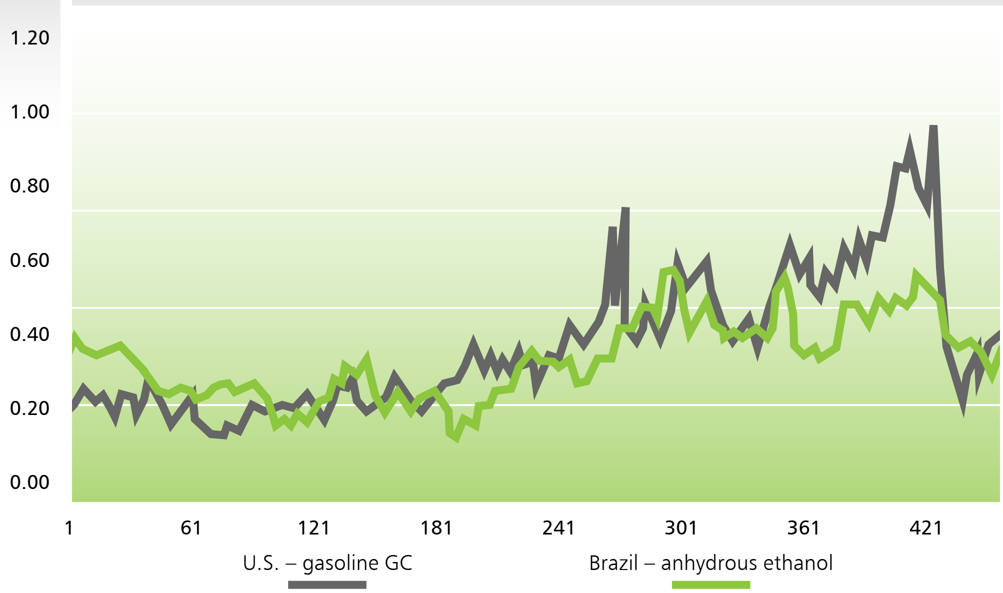
The feasibility of using ethanol instead of gasoline can be confirmed by comparing prices at the distilleries, without freight or taxes, as shown in Figure 6. The values refer to the average price of anhydrous ethanol in the state of São Paulo, as reported by the Center for Advanced Studies in Applied 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.

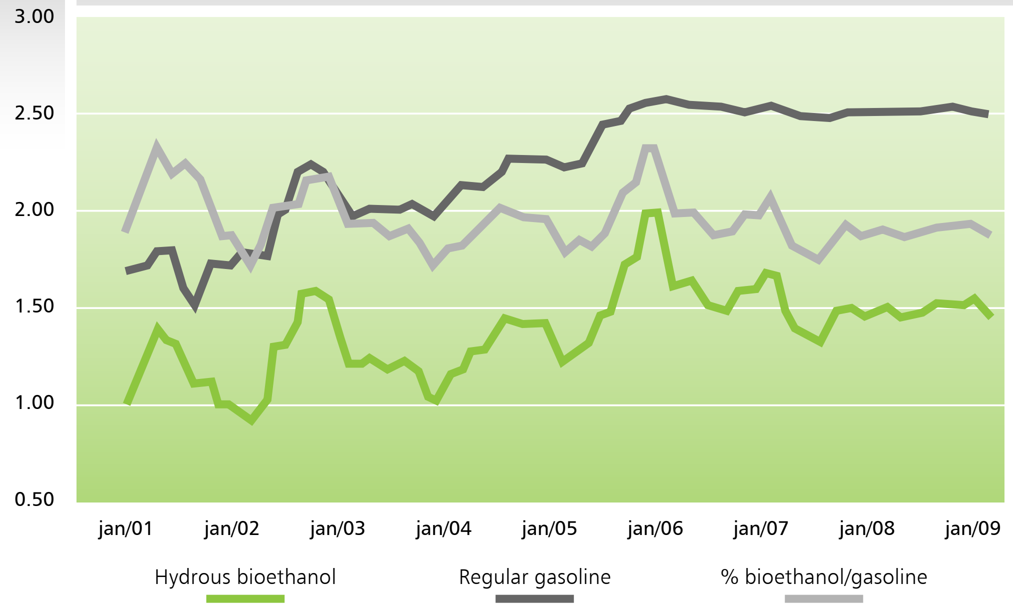
Conab, the agency responsible for monitoring the activities of Brazilian agriculture, recognizes that these factors have brought the sugar-ethanol sector to an "a major economic crisis, certainly the most persistent and long-lasting since the sector was deregulated," requiring important adjustments to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

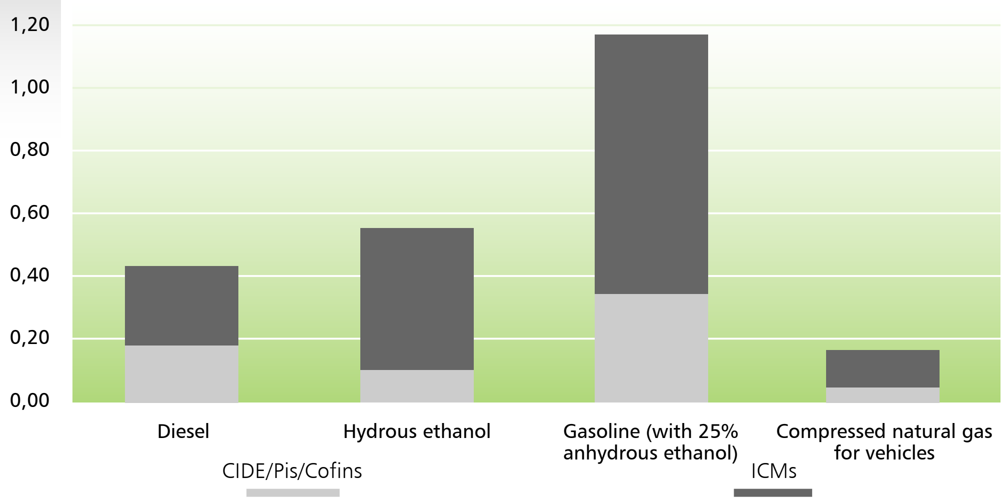


Source: ANP (2009).

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).

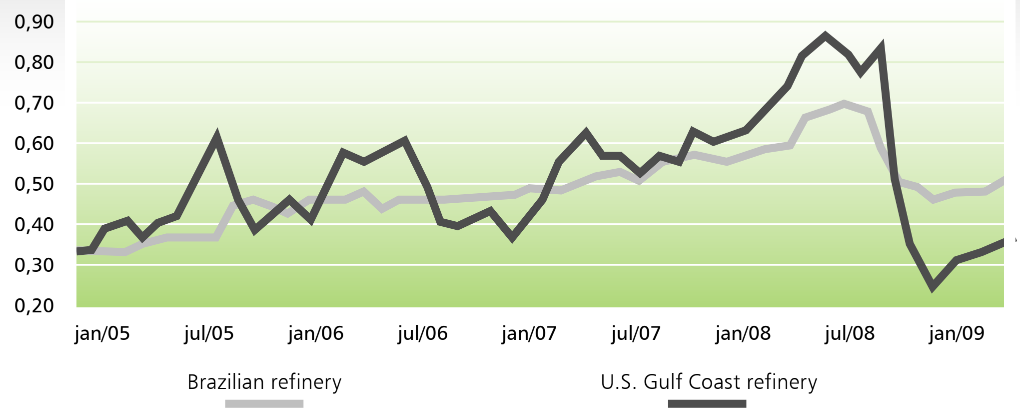
This procedure gives consumers incorrect signals about the value of energy sources, increases market uncertainties and leads to a significant loss of tax revenue. Considering the difference between domestic and international prices, the losses for Petrobras in the period 2005-2008 would be around US$2.8 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.

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AGORA PROJECT

The **Agora Project – Agro-energy and the Environment** is designed to develop a broad and integrated communication and marketing effort to promote the benefits of the production and use of clean, renewable and sustainable agricultural energy sources such as ethanol, bioelectricity, bioplastics and hydrocarbons, among others.

The project has five main objectives:

- Clarify and promote questions related to climate change and the environment, highlighting the contribution of ethanol and bioelectricity;
- Inform and promote the sugar-ethanol supply chain, emphasizing its impacts and benefits for the Brazilian economy;
- Increase the consumption of ethanol in motor vehicles, encourage new uses and the growth of bioelectricity;
- Promote consumption and market integration of new products from the sugarcane supply chain;
- Clarify myths about the sugar-energy sector.

The following companies and organizations in the sugarcane supply chain are part of the Agora Project:

- **Itaú**
- **Monsanto**
- **Amyris**
- **Basf**
- **BP**
- **FMC**
- **Sew Eurodrive**
- **ALCOPAR** – Association of Bioenergy Producers in the State of Paraná
- **BioSul** – Association of Bioenergy Producers in Mato Grosso do Sul
- **Orplana** – Organization of Sugarcane Growers of the Center-South Region of Brazil
- **SIAMIG** – Syndicate of Ethanol Manufacturing Industry in the State of Minas Gerais
- **Sifaeg** – Syndicate of the Ethanol Manufacturing Industry in the State of Minas Gerais
- **Sindalcool/MT** – Syndicate of Sugar and Ethanol Manufacturing Companies in the State of Mato Grosso
- **UNICA** – Brazilian Sugarcane Industry Association

BRAZILIAN SUGARCANE INDUSTRY ASSOCIATION

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