論文

# Flex fuel vehicles and the ethanol production from sugar cane
## ―A success case from Brazil―

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**Abstract.**

This text, developed from a bibliographical revision, intends to show the program of alcohol fuel (ethanol) from sugarcane and the development of flex fuel vehicles for the Brazilian market, in an objective way and with recent data. From these data (qualitatively and quantitatively), the conclusion is that this case, entirely developed in Brazil, for the Brazilian market, is a success: economically and environmentally promising.

**Keywords**: automotive, environment, ethanol, flex-fuel, sugarcane

**Introduction.**

Bioenergy is one special form of chemical energy. It includes any kind of chemical energy accumulated through recent photosynthetic processes. Examples of sources of bioenergy include wood and sawmill waste, charcoal, biogas resulting from the anaerobic decomposition of organic waste and other farming waste, as well as liquid biofuels, such as bioethanol and biodiesel, and bioelectricity, generated from the burning of fuels such as bagasse and wood. (BNDES, 2008)

In the broad context of bioenergy, the production of liquid biofuels arose specifically to meet the needs of transport. Liquid biofuels can be used very efficiently in internal combustion engines. These engines are basically classified into two types, depending on how the combustion is started: spark ignition Otto-cycle engines, for which the preferred biofuel is bioethanol; and Diesel-cycle engines, in which ignition is achieved by compression and good performance is attained with biodiesel. Biofuels can be used in both types of engines, either alone or blended with conventional petroleum-derived fuels. (BNDES, 2008)

Bioenergy can be an economically viable and environmentally sustainable alternative to partially replace fossil fuels in transport, and particularly, in automotive land transport. In the case of Brazil, ethanol obtained from sugarcane is the most currently used and promising alternative to the future (economically and environmentally).

Brazil produces two types of ethanol: hydrous, which contains about 5.6% water content by volume; and anhydrous, which is virtually water-free. Hydrous ethanol is used to power vehicles equipped with pure ethanol or Flex-Fuel engines, while anhydrous ethanol is mixed with gasoline before it reaches pumps. Several countries are now blending anhydrous ethanol with gasoline to reduce petroleum consumption, boost the octane rating and provide motorists with a less-polluting fuel (UNICA, 2009b).

Brazil has some comparative advantages to be one of the worldwide leaders in agriculture for energy. At first, there are new areas available for incorporation that doesn't compete with food agriculture, as it occurs in the case of maize in the United States, for example. There is also a great availability of land with degraded pastures, where the insertion of sugarcane and some crops, such as soybean and peanuts (those needed for the rotation), helps to increase the production of ethanol, sugar and vegetable proteins. At last it's important to note that due to the tropical climate, there is the possibility of multiple crops in the agricultural year (Goldemberg, Nigro and Coelho, 2008).

The use of alcohol in a large scale substituting gasoline in Brazil has begun in 1975, when the National Alcohol Program was created. In 1983 it was already mixed 20% of alcohol in vehicular gasoline. It is important to note that, since then, the ethanol production from sugarcane has increased 3% per year in productivity (liters per hectare).

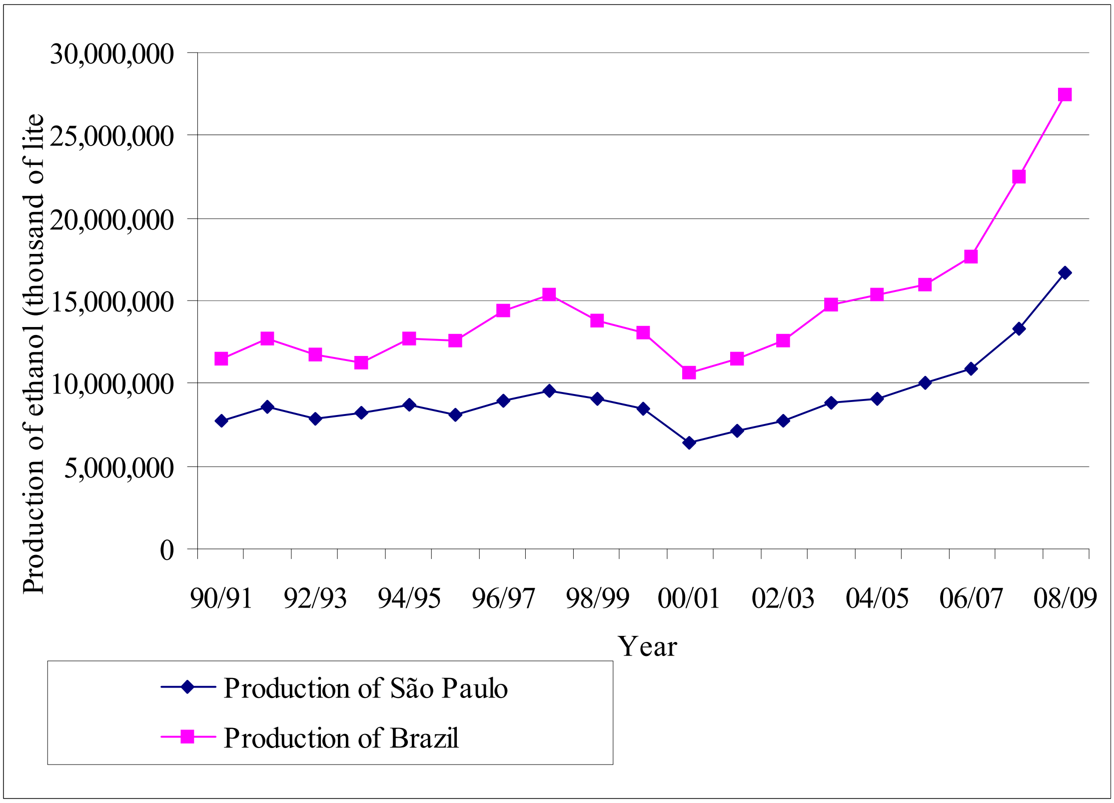


Figure 1. Production of ethanol over the years (UNICA - Statistics, 2009a)

Brazilian sugarcane cultivation today occupies 7.8 million hectares, or 2.3% of the country's total arable land. Sugarcane is grown mainly in South-Central and North-eastern Brazil, with two different harvest periods: from April to December in South-Central Brazil, and from September to March in the Northeast. The South-Central area accounts for over 85% of total production. Sao Paulo alone produces more than 60% of all Brazil's sugarcane, as can be seen on figure 1 (UNICA, 2009b).

**Ethanol and its Environmental Sustainability**

The current need for using renewable energy encourages researches about this subject. Since Sao Paulo State from Brazil is responsible for 62% of the ethanol production of the country (stemmed from sugarcane plantations), there is a rigorous study about its sustainability.

One of the criteria to measure the advantages of sugarcane ethanol is to evaluate its merits of replacing gasoline. The most notable benefit is that ethanol from sugarcane is a renewable fuel while gasoline derived from petroleum is not. The reason for this is that $CO_2$ from the burning of ethanol releases are reabsorbed by photosynthesis during the growth of sugarcane. The production of ethanol from corn and other crops requires considerable imports of fossil fuels into the producing plants, resulting in energy balances that vary from almost zero to only slightly higher than one as can be observed on figure 2 (Goldemberg, Coelho and Guardabassi, 2008).

All the energy needed for sugarcane ethanol production (heat and electricity) come from the bagasse (byproduct of sugarcane crushing) and excess bagasse is used to generate additional electricity to be fed into the grid. Studies show that for every Joule of fossil energy consumed in the production process, including planting and industrial processing, 9.3 Joules are obtained in the form of renewable energy. Besides, the International Energy Agency estimates that the production and use of ethanol in Brazil allows for a reduction of more than 80% in the greenhouse gases that would have been released into the atmosphere by using gasoline (UNICA, 2009c).

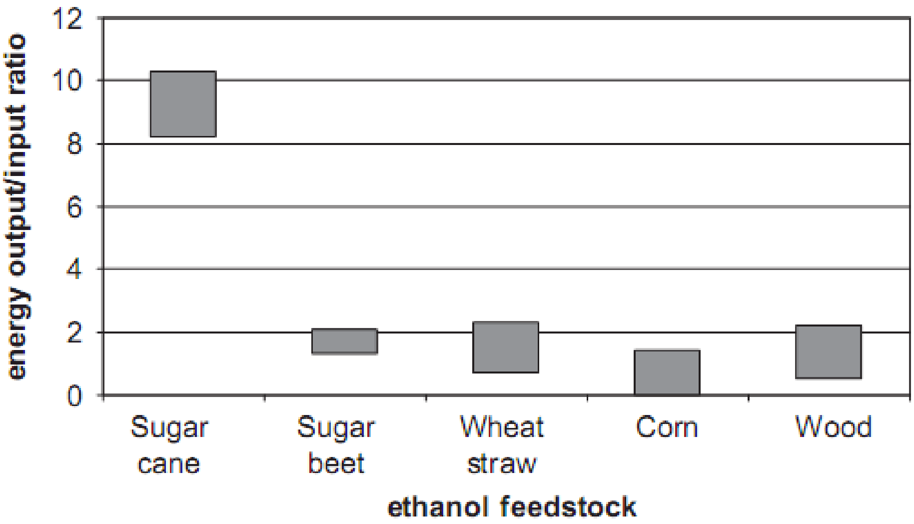


Figure 2. Energy balance of ethanol production (Goldemberg, Coelho and Guardabassi, 2008).

The sustainability is also measured by the environmental aspects, including factors such as air, water, land use (soil) and biodiversity.

As well as the combustion of gasoline, diesel, natural gas and liquified petroleum gas, ethanol combustion generates considerable quantities of aldehydes. However ethanol utilization (straight, or blended with gasoline) has led to important improvements in air quality in urban areas, through the elimination of lead compounds in gasoline and sulphur, and the reduction of CO emissions and the reactivity and toxicity of organic compound emissions (Szwarc, 2005).

The use of E10 decreased hydrocarbon emissions by 12%, noxious emissions of 1–3 butadiene by 19%, benzene by 27%, toluene by 30% and xylene by 27%. The decreased carcinogenic risk was by 24%. CO emissions were reduced by 32% (Apace Research Ltd., 1998 apud Goldemberg, Coelho and Guardabassi, 2008).

Furthermore, air emissions (CO, $CH_4$, non-methane organic compounds and PM) due to sugarcane burning (practice used to facilitate the manual harvest of the stalks and also repel poisonous animals) are decreasing thanks to the growing use of mechanical harvesting of green cane. Besides air emissions, sugarcane burning is responsible for damage the cell tissue of the cane stem, and thus increase the risk of diseases in the cane, destroy organic matter, damage the soil structure due to increased drying, increase the risks of soil erosion and the risks to electrical systems, railways, highways and forest reserves in addition to increase the troposphere ozone concentration in sugarcane producer areas (Goldemberg, Coelho and Guardabassi, 2008). That is why harvesting burning practices are being phased out in the State of Sao Paulo (State Law 11,241/2002[1]).

Galdos, Cerri and Cerri (2009) showed that an area with a period of 8 years of unburned management, had higher contents of total carbon (30% higher), microbial biomass carbon (by a factor of 2.5), and particulate organic matter carbon (by a factor of 3.8) than the area where the residues were burned. The total carbon stocks were also higher in the unburned treatment.

The Agri-Environmental Protocol, signed between the State of Sao Paulo and the Brazilian Sugarcane Industry Association (UNICA) in 2007 brought forward from 2021 (Law 11,241/2002) to 2014 the eradication date for areas where mechanized harvesting is currently possible, and from 2031 to 2017 the deadline for other areas, for example steep slopes. Table 1 shows the schedule for the elimination of burning in the State of Sao Paulo.

The impacts of the sugar cane culture on the water supply today (volumes and quality) are small under the conditions found in Sao Paulo. The main reasons for this are non-utilization of irrigation; an important reduction of water withdraw for industrial purposes that has been attained over the past few years thanks to internal reuse in the processes; and the practice of returning water to the crops in the ferti-irrigation systems. The levels of water withdraw and release for industrial use have substantially decreased over the past few years, from around 5 $m^3$/ton of cane collected in 1990 and 1997 to 1.83 $m^3$/ton of cane in 2004 (sampling in São Paulo). The water reuse level is high (the total use was 21 $m^3$/ton in 1997), and the efficiency of the treatment for release was in excess of 98 percent. It seems possible to reach rates near 1 $m^3$/ton (collection) and zero (release) by optimizing both the reuse and use of waste water in Fertilization-irrigation (Macedo, 2005).

Pesticide consumption in sugar cane crops is lower than in citric, corn, coffee and soybean crops; the use of insecticides is low, and that of fungicides is virtually null. Among the main sugar cane pests, the sugar cane beetle (the most important pest) and spittlebug are currently biologically controlled. The sugar cane beetle is the subject of the country's largest biological control program. Ants, beetles and termites are chemically controlled, and it has been possible to substantially reduce the use of pesticides through selective application. Sugar cane crops still use more herbicides than coffee and corn crops, less herbicides than citric crops, and the same amounts as soybean crops. (Macedo, 2005).

1 Available at <http://www.sigam.ambiente.sp.gov.br/>

Table 1: Schedule for the elimination of sugarcane burning in the State of São Paulo, according to the Agri-Environmental Protocol[2]

| Mechanical harvested area – slope less than 12% | |
|---|---|
| Year | Percentage of elimination |
| 2010 | 70% of burning must be eliminated |
| 2014 | Total elimination of burning |
| Non-mechanical harvested area - slope exceeding 12% | |
| Year | Percentage of elimination |
| 2010 | 30% of burning must be eliminated |
| 2017 | Total elimination of burning |

One of the arguments most commonly used against the Brazilian ethanol is the expansion of sugarcane plantations, which is considered a threat because it may cause irreversible conversion of virgin ecosystems (decreasing the biodiversity), the reduction of food crops and soil degradation. However, efficient attitudes can be taken so that these problems are avoided. The use of mechanical harvesting of green cane and the genetic modifications are reducing the soil degradation because they avoid the use of burning harvesting and the use of pesticides. The rotation system used for the sugarcane crops (during every harvesting season 20% of the sugarcane crop is removed and replaced with other crops like beans, corn, peanuts and others) also reduces the soil degradation and increases food crops. Besides, the expanding of sugarcane occurs over the pasturelands, which are far from biomes like Amazon Rain Forest, Savannah, Atlantic Forest and Wetland what evidences that sugarcane plantation isn't such a threat to the biodiversity and food crops. (Goldemberg, Coelho and Guardabassi, 2008)

Notice that the sugarcane fits itself easily on land with medium fertility and high porosity (sandy soils), and the most critical element is the rainfall in the region, requiring a minimum of 1.200 mm of rainfall concentrated in the seasons of spring and summer. Areas that need financial resources for irrigation are not the most appropriate because of the initial investment and the energy used to enable artificial irrigation (Goldemberg, Nigro and Coelho, 2008).

Sugarcane ethanol also represents a social promotion to Brazil, since for every 300 million tons of sugarcane produced, approximately 700,000 jobs are created (Macedo, 2005). Besides, the working conditions and the opportunities are getting better for those who work at sugarcane plantation. In Sao Paulo State, the same legislation that

[2] Available at <http://www.ambiente.sp.gov.br/cana/protocolo.pdf>

established the mandatory mechanized harvesting of green cane includes a program of professional re-qualification for those rural workers who used to harvest sugarcane and were replaced by mechanical harvesting (Goldemberg, Coelho and Guardabassi, 2008).

**Flex Fuel Technology**

Brazil is a pioneer in using ethanol as a motor vehicle fuel. Table 2 shows the principal properties of ethanol compared with gasoline. The country began using ethanol in automobiles as early as the 1920s. In 2003, with the launch of the first Flex-Fuel vehicles (FFVs), the "Volkswagen Gol Total Flex", a new era begun.

Table 2. Fuel properties (Araujo, et. al, 2009)

| | Ethanol E100 | Gasoline E0 |
|---|---|---|
| Stoichiometric air/fuel ratio (Kg/kg) | 9 | 14.7 |
| Specific calorific value (Kcal/kg) | 7,090 | 12,300 |
| Vaporizing latent heat (KJ/kg) | 904 | 350-450 |
| Ignition temperature (°C) | 392 | 280-430 |
| Burning rate (cm/ms) | 44 | 33/47 |
| Evaporation curve (°C) | 78 | 35-200 |
| Octane number (RON) | 108 | 91 |

The FFVs vehicles can run on ethanol, straight gasoline or any mixture of the two. This characteristic offers the consumer the advantage to choose the cheapest fuel available on the pump, or even the fuel more appropriate to his or her driving characteristic. As the consumption differs (Table 3), its use is more if its price is less than 70% than gasoline's one in Brazil.

Table 3. Performance characteristics (%) of the same car with different fuels

| | Gasohol E-22 | Ethanol 100% |
|---|---|---|
| Power | 100 | 103 |
| Torque | 100 | 102 |
| Consumption | 100 | 130 |

Customer's preference on the FFV should bring an end to the production of the car that runs only with ethanol. After that they achieved low levels in the market (aprox. 0,1% in 1997 and 1998), those have registered a little progress, but now they are facing competition with FFV and its great triumph of flexibility. Since 2005 vehicles equipped with flex-fuel engines have represented the majority of the new car sales in Brazil (Table 4).

Currently there are over 60 different engine models produced by ten U.S., European and Japanese manufacturers operating in Brazil. It should be emphasized that the Brazilian approach to flex-fuel vehicles gives the driver complete discretion to choose the fuel to be used from 100% hydrated ethanol to gasoline-ethanol blends containing 20% to 25% ethanol. In the United States, Canada and Sweden, vehicles with flexible engines are also sold, but under a different context: they use gasoline-ethanol blends ranging from pure gasoline (without ethanol) to a blend of 85% anhydrous ethanol and 15% gasoline, a product known as E85, with limited, but growing availability (BNDES, 2008).

Table 4. Registration (Brazil) of new light vehicles (cars and light commercials) by fuel type (ANFAVEA, 2009)

| Year | Diesel | Gasoline | Alcohol | Flex Fuel | Total | Flex fuel (%) |
|---|---|---|---|---|---|---|
| 2002 | 64,341 | 1,283,963 | 55,961 | 0 | 1,404,265 | 0 |
| 2003 | 54,729 | 1,152,463 | 36,380 | 48,178 | 1,291,750 | 3.7 |
| 2004 | 66.247 | 1.077.945 | 50.950 | 328.379 | 1.523.521 | 21.6 |
| 2005 | 77,453 | 697,033 | 32,357 | 812,104 | 1,618,947 | 50.2 |
| 2006 | 82,954 | 316,561 | 1,863 | 1,430,334 | 1,831,712 | 78.1 |
| 2007 | 92,175 | 245,660 | 107 | 2,003,090 | 2,341,032 | 85.7 |
| 2008 | 124,639 | 217,021 | 84 | 2,329,247 | 2,670,991 | 87.2 |

To manage an efficient operation, FFV has an electronic control unit (ECU). It processes instructions, such as the ignition timing, quantity of fuel injected, idle rotation and also maps the car's behavior. There are several sensors in the whole car, giving information about temperatures, pressures, amount of fuel in the tank (and their proportion), quality of the burn and the exhaust products, among others. Ethanol is more corrosive than gasoline due to the presence of sulfuric acid ($H_2SO_4$) and water (in case of hydrated ethanol). As a result, all parts in contact with fuel may be corroded. Some critical parts that are prone to corrosion are: fuel tank, fuel piping and hoses, manifolds, injectors and valves.

FFVs have received improvements ever since they were introduced. Several models already have larger fuel tanks, increasing autonomy by about 10% and reducing the number of refueling stops. There have also been noticeable gains in efficiency. While the first generation of flex vehicles consumed 30% to 35% more ethanol than gasoline to cover the same distance, the current generation shows a drop in that difference, to a 25% to 30% range. This is happening partly because of a change in outlook by some automakers that have realized there is a clear consumer preference for ethanol and have begun to optimize their engines for the renewable fuel. Whereas the first FFV generation was developed from gasoline powertrains that could also run on ethanol or mixtures of the two fuels, the current generation has increasingly more vehicles developed for preferential use with ethanol. Evidently, optimizing an engine for two fuels with physical and chemical differences involves costs, so that some compromises in engine design occurs, limiting a greater optimization for ethanol (Szwarc,2009).

Bosch launched, in 2009, a new cold-start system that eliminates the need of a gasoline tank to start engines in cold days in FFV cars. That reduces the pollution and gives more comfort to the customer, as he doesn't need to feed this gasoline reservoir any more (Araujo, et al. 2009). This system has to be adapted for its use in colder countries.

In March of 2009, flex fuel technology was also incorporated into two-wheeled vehicles. Honda introduced the world's first commercial version of a flex motorcycle at its industrial plant in Manaus, Brazil. The CG Titan Mix is equipped with a 150 cc engine plus several innovations compared to the previous, gasoline-powered model. These include electronic fuel injection and a catalytic converter, which result in reduced consumption and significantly lower emissions compared with emission levels adopted in 2009 in the European Union. Albeit on the market for only a short period, the flex version is already a success (Szwarc, 2009).

**Conclusion**

The alcohol program in Brazil (ethanol obtained from sugarcane), the world's largest program of tapping a renewable energy source, has proved to be resilient and successful. Continuous technical improvements, which constitute an essential component of the program, have been lowering the cost of production of ethanol and increasing its production in volume in a sustainable way.

The FFV technology, using ethanol and a blended fuel (gasoline with ethanol), is reaching the maturity for the Brazilian market. Customers nowadays believe on the synergy between the ethanol program and the continuous FFV technical improvements.

Ethanol from sugarcane, as fuel for cars, together with the flexibility of the FFV is the current successful response of Brazil for the use of a renewable energy for the individual land transport.

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