# Bioethanol Program in Brazil: Production and Utilization of Trade-offs for $CO_2$ Abatement

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*Abstract*—**Brazil has established a bioethanol program with a target for replacing conventional gasoline. This paper assesses the impacts of achieving the target on greenhouse gases (GHG) emissions with carbon dioxide ($CO_2$) abatement. Carbon dioxide is the most important of the GHG whose emissions increase by human action. The transport sector has been at the centre of discussions about policies aiming at reducing $CO_2$ emissions. Road traffic is by far the largest source of gas pollution in urban areas, not only for $CO_2$, but also for carbon monoxide, nitrogen and sulphur oxides, and volatile organic compounds. Furthermore, vehicles fleets go on growing. The substitution of bioethanol for gasoline, consumed pure or blended with gasoline, in urban transport vehicles has favourable air pollution impacts. The evaluation of the contribution of vehicles exhaust pollution to the greenhouse effect cannot be restricted to fuels consumed by vehicles, but it is necessary to assess the whole fuel cycle emissions including sugarcane production, the transport to the processing plant, the conversion of sugarcane to bioethanol, the distribution to the filling stations and, finally, the bioethanol consumption by vehicles. This paper shows to what extent the bioethanol burnt in vehicles' engines in Brazil can contribute to improve the GHG effect**.

*Index Terms*—**Bioethanol production and utilization, bioethanoluse, pollution control, sugarcane culture, transport sector.**

## I. Introduction

Pollution control is changing into a priority for development policies. There is an increasing perception that environmental degradation is harmful to health, reduces productivity and decreases the "*quality of life*". Among the damaging pollution consequences, the greenhouse effect can be emphasised. Transport activities have contributed the most for environmental degradation through a large scale emission of pollutants, mainly in large urban centres. Oil products consumed in the transport sector have an expressive participation in the atmospheric pollution. Their main emissions are of carbon dioxide ($CO_2$), carbon monoxide (CO), nitrogen oxides ($NO_X$), sulphur dioxide ($SO_2$), and particulate matter.

In respect to greenhouse effect, its consequences are not known in details, but there is a growing awareness that is necessary to act in order to mitigate the emissions of the so-called greenhouse gases, particularly $CO_2$. Carbon tax is a good example of suchaction that, unfortunately, has not won a widespread support yet, with the Americans and Japanese, for instance, to warrant its application in a world-wide scale, in a short term [1], [2].

Approximately 23% of overall $CO_2$ emissions from fossil fuel combustion emitted in the world result from transport activities [3]. The sector accounts for approximately 15% of overall GHG emissions in 2009 [3].The consumption of oil products in the transport sector represents almost 60% of the total world energy demand and approximately 50% is demanded by on-road vehicles. In Brazil, the transport sector is responsible for almost 80% of the oil products consumed in the country, with 73% used in road transport [4]. Diesel oil and gasoline are the main oil products consumed in the Brazilian transport sector.

## II. Bioethanol Program in Brazil

Bioethanol or ethyl alcohol is a primary alcohol containing two carbon groups ($CH_3CH_2OH$) which may be produced in a petrochemical process from ethylene or biochemically by fermentation of various sugars from carbohydrates found in agricultural crops and cellulosic residues from crops or wood. Brazil is the most important fuel bioethanol producer in the world, the largest exporter of bioethanol and has the most comprehensive domestic consumption program. Brazil has used bioethanol as a transportation fuel since the 1920's. Brazil's current program was started in 1975 driven by a combination of mitigation of the first oil shock of 1973 and a desire to stabilize revenues to its large sugar industry. All Brazilian bioethanol is produced either directly from sugarcane or indirectly from molasses, a byproduct of the sugar industry.

In the first phase, bioethanol, followed the oil shocks of the early 1970's, Brazil Government adopted an aggressive plan to guarantee the country's energy independence. In 1975, a Federal Decree 76,593/1975 created the National Alcohol Program (Proalcool) to reduce dependence on oil imports by promoting the production of anhydrous bioethanol as an additive to gasoline.

The second phase, Proalcool, started at the beginning of the 1980's and it was driven by the second oil crisis. The National Bioethanol Commission (Cenal) and Ministry of Industry and Commerce set new goals for the program based on the Federal Decree 83,700/1979, which included the expansion of sugarcane fields and the industrial capacity to produce hydrated bioethanol (E100) as fuel, bioethanol as a substitute and not as an additive to gasoline. The automobile manufacturers had to adjust their engines to the new E100. By the mid-1990's the program was nearly abandoned as bioethanol shortages and low gasoline prices led to

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widespread popular rejection of bioethanol-powered cars. Despite the collapse of the program in the early 1990's, bioethanol has remained an integral part of the Brazilian fuels matrix [5].

The third phase, resurgence of bioethanol,was due toprivate sector commitment to take advantage of bioethanol's availability. Flex-fuel cars were developed and put into production so that consumers would be able to freely choose between gasoline and hydrated bioethanol (E100). Unlike most countries, Brazilian gas stations offer both gasoline - actually a mixture of 75% gasoline and 25%bioethanol -, and bioethanol - 100% percent - as a legacy of Proalcoolto promote bioethanol use. Following the launch of *flex* cars in March 2003, *s*ales increased to more than ninety percent of new car sales by the end of 2009.

For consumers, flex-fuel cars mean flexibility at the pump and increased re-sale value. While the market forces to drive current demand growth for bioethanol, governmental policy does have a significant influence on market dynamics. Policy supports for bioethanol consumption include both bioethanol use mandate and significant tax credits.

Updated information and statistics on bioethanol in Brazil have been published in August 2012 by USDA shows Brazil as the world's second biggest producer of fuel bioethanol - 6921 million gallons in 2010 from sugarcane -, and the world's biggest exporter offuel bioethanol. Bioethanol blends are mandatory in Brazil (E20 to E25) and hydrous bioethanol (E100) is also available in thousands of filling stations. There are 6 million flex-fuel vehicles in Brazil and 3 million able to run on E100. Bioethanol accounts for 48% volume of light transport fuels in Brazil [5].

The Brazilian government is aware of the need to develop instruments that promote production deconcentration when considering sugarcane plantations expansion to new areas. Fig. 1 shows data for the evolution of new bioethanol and sugar plants as of marketing years 2005/06 as reported by UNICA [6]. UNICA estimates only two new plants for 2012/13, due to low investments on greenfield projects. The total number of sugar-bioethanol mills in 2012 is estimated at 440 units, whereas total operating units for 2013 are projected at 442.

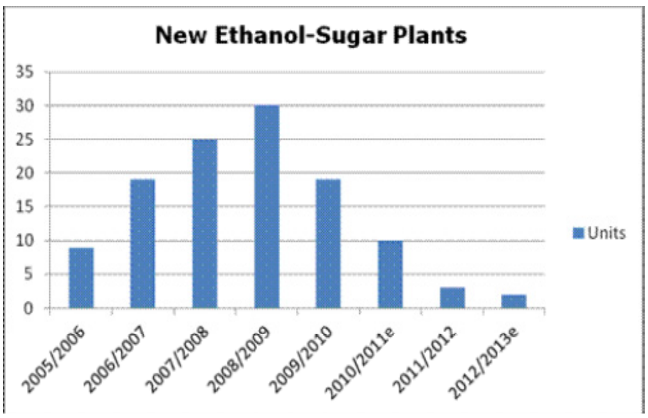


Fig. 1. Evolution of new bioethanol sugar plants [5], [6]

There was strong expansion in sugarcane production between 1975/1976 and 2009/2010, from 89 million to 696 million metric tons. In the same period, sugar production increased by 369%, from 6,72 million to 31,51 million tons. The total bioethanol production including both anhydrous and hydrated increased from 0,60 billion liters in 1975/1976, to 25,56 billion liters in 2009/2010 as shown in Fig. 2).

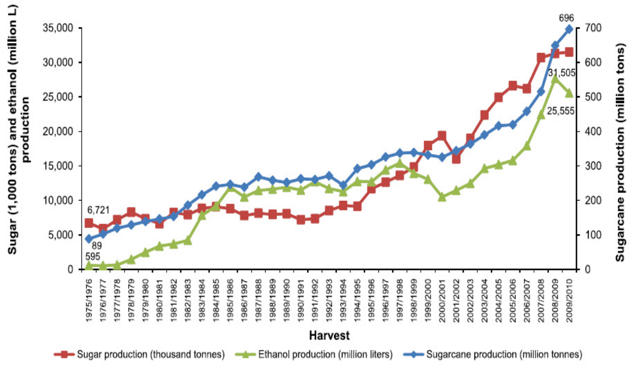


Fig. 2. Evolution of sugarcane, bioethanol and sugar production in Brazil from 1975/1976 to 2009/2010 [7].

## III. Bioethanol Consumption and $CO_2$ Emissions

The evaluation of the vehicles running with hydrated or anhydrous bioethanol contributing to the greenhouse effect cannot be restricted to the fuel consumed by the vehicle. It is necessary to assess the whole fuel cycle emissions, including: (i) the production of sugarcane and bioethanol, (ii) its transport to the processing plant, (iii) the conversion of sugarcane to bioethanol, (iv) the distribution ofbioethanol to the filling stations and (v) the bioethanol consumption by the vehicles.

### *A. Production of Sugarcane and Bioethanol*

The $CO_2$ absorbed by sugarcane is completely recycled, liberated to the atmosphere by the green cane burning. Sugarcane burning leads to environmental problems, like most agricultural burning. The development of energy markets for the sugarcane residues and the diffusion of mechanical harvesting techniques are leading to an efficient harvesting of green cane and residue collection, avoiding its burning in the fields.

The sugarcane agro-industry consumes fossil fuels and electricity for its agricultural operations, for the transport of sugarcane to the mills and for bioethanol production, as shown in Table I.

TABLE I: Energy in Sugarcane and Bioethanol, in MJ/ton Cane

| Activities | Sugarcane | Bioethanol |
|---|---|---|
| Agricultural operations | 30,10 | - |
| Transport of sugarcane to mills | 34,92 | - |
| Fertilizers | 66,96 | - |
| Lime, herbicides, etc. | 19,06 | - |
| Seeds | 5,76 | - |
| Equipment | 33,07 | 27,96 |
| Buildings | - | 10,78 |
| Chemical and lubricants | - | 7,34 |
| TOTAL | 189,87 | 46,08 |

Source: [8]

93% or 219.4 MJ/ton of sugarcane, of the total energy consumption in Table II is made up of fossil fuels, like Diesel oil. Considering the rate of $CO_2$ released from Diesel oil combustion of 20 x $10^{-6}$ tons of $CO_2$/MJ [9], the carbon released as $CO_2$ due to fossil fuel consumption in the production of sugarcane and bioethanol in the season 2009/2010 as seen in Fig. 2–696 million tons sugarcane production- was therefore $3,05 \times 10^6$ tons.

TABLE II: 195 MILLION TONS BAGASSEPRODUCTION BESIDES CONSUMPTION, FUEL OIL REPLACED AND THE AVOIDED RELEASE OF $CO_2$, ALL IN $10^6$ TONS IN THE SEASON 2009/2010IN BRAZIL.

| | Uses | Fuel oil replaced | Avoided release of $CO_2$ |
|---|---|---|---|
| bioethanol production | 94 | 16,5 | 14,2 |
| food and beverages industries | 73 | 12,8 | 11,0 |
| pulp and paper/chemical plants | 20 | 3,5 | 3,0 |
| other uses | 8 | 1,4 | 1,2 |

In the mills, bagasse, a sugarcane residue, substitutes fuel oil as the energy source of the mills' cogeneration plants. In the season 2009/2010, $195 \times 10^6$ tons of bagasse, with a 50% moisture content, were produced. Bagasse is also consumed as a fuel in other industrial branches, such as chemical and pulp and paper plants. The energy consumption figures in Table I do not take into account bagasse consumption in the mills' cogeneration plants, since their electricity production is already accounted for.

There are benefits in terms of $CO_2$ emissions, however, in burning bagasse instead of fuel oil in such plants. These benefits are quantified in Table II that also considers $CO_2$ emission benefits in other industrial branches that consume bagasse. The energy output from agriculture as well as sugarcane industry considered was 2,172 MJ/t of cane [8]. Then, the net $CO_2$ release in the production of sugarcane and bioethanol is therefore $27,2 \times 10^6$ tons - 30,2to3,05. In setting up Table III, lower heating values of 7,74 MJ/kg for wet bagasse and 44 MJ/kg for fuel oil, as well as an emission rate of 0,86 kg of $CO_2$/kg of fuel oil were assumed [4].

TABLE III: PRODUCTION OF BIOETHANOL, GASOLINE REPLACED AND AVOIDED RELEASE OF $CO_2$ DUE TO THE CONSUMPTION OF FUEL BIOETHANOL, ALL IN $10^6 M^3$, IN BRAZIL

| Bioethanol | Production | Gasoline replaced | Avoided release of $CO_2$ |
|---|---|---|---|
| Anhydrous | 7.1 | 7.6 | 5.8 |
| Hydrated | 18.5 | 14.8 | 11.2 |
| TOTAL | 25.6 | 22.4 | 17.0 |

### B. Distribution of Bioethanol to the Filling Stations

In this work, $CO_2$ emissions in the distribution of bioethanol to the filling stations in Brazil were estimated using data of methanol distribution from the product terminal to the service stations in the United Kingdom [10]. The British calculations assume a 31,560 litre capacity tanker as a reference, with Diesel oil consumption of 32,8 litre/100 kilometre and an average round trip distance of 450 kilometres. The energy consumed in this activity is therefore 10MJ/GJ of methanol and the corresponding emission is approximately 0,1kg of $CO_2$/litre of methanol. Adapting these data to the distribution of bioethanol (including both anhydrous and hydrated) in the season 2009/2010in Brazil, it yields a $CO_2$ emission in this activity of $2, 56 \times 10^6$ tons.

### C. Consumption of Bioethanol-Fuelled Vehicles

For the usual Otto cycle-vehicle engines employed in Brazil, one litre of hydrated bioethanol substitutes for 0.8 litre of gasoline - in neat bioethanol engines - and one litre of anhydrous bioethanol substitutes for 1.04 litre of gasoline - as a blend in engines running with "gasohol". The release rate of $CO_2$ from gasoline fuelled engines is 0.76 kg/litre [8]. Table III shows the avoided $CO_2$ emissions in the 2009/2010 season due to the consumption of fuel bioethanol in Brazil.

TABLE IV: FUEL BIOETHANOL IN BRAZIL - CONTRIBUTION TO $CO_2$ RELEASE IN $10^6$ TONS IN THE 2009/2010 SEASON

| Contribution | $CO_2$ release |
|---|---|
| Fossil fuel used in the sugarcane and ethanol production, net bagasse consumption | - 27.2 |
| Bagasse substitution for fuel oil in the food and beverage plants | - 11.0 |
| Bagasse substitution for fuel oil in the chemical/pulp and paper industrial sectors | - 3.0 |
| Other uses | -1.2 |
| Distribution of ethanol to the filling stations | + 2.5 |
| Ethanol substitution for gasoline in the vehicles' engines | - 17.0 |
| Net $CO_2$ emissions' contribution | - 56.9 |

## IV. CONCLUSION

A summary of the net contribution of the sugarcane agro-industry to greenhouse gases accumulation is shown in Table IV. Recycling of carbon in the bioethanol production and use is allowed for avoiding large $CO_2$ emissions. Bioethanol fuel has played a significant role in reducing pollution in large urban centres, especially in the São Paulo Metropolitan Area, where the air quality would otherwise be much worse. Furthermore, the PROÁLCOOL stimulates the use of sugarcane bagasse as a substitute of fuel oil in the mills'cogeneration plants, including power surplus sales to the grid, and helps to reduce acid rainfall.

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