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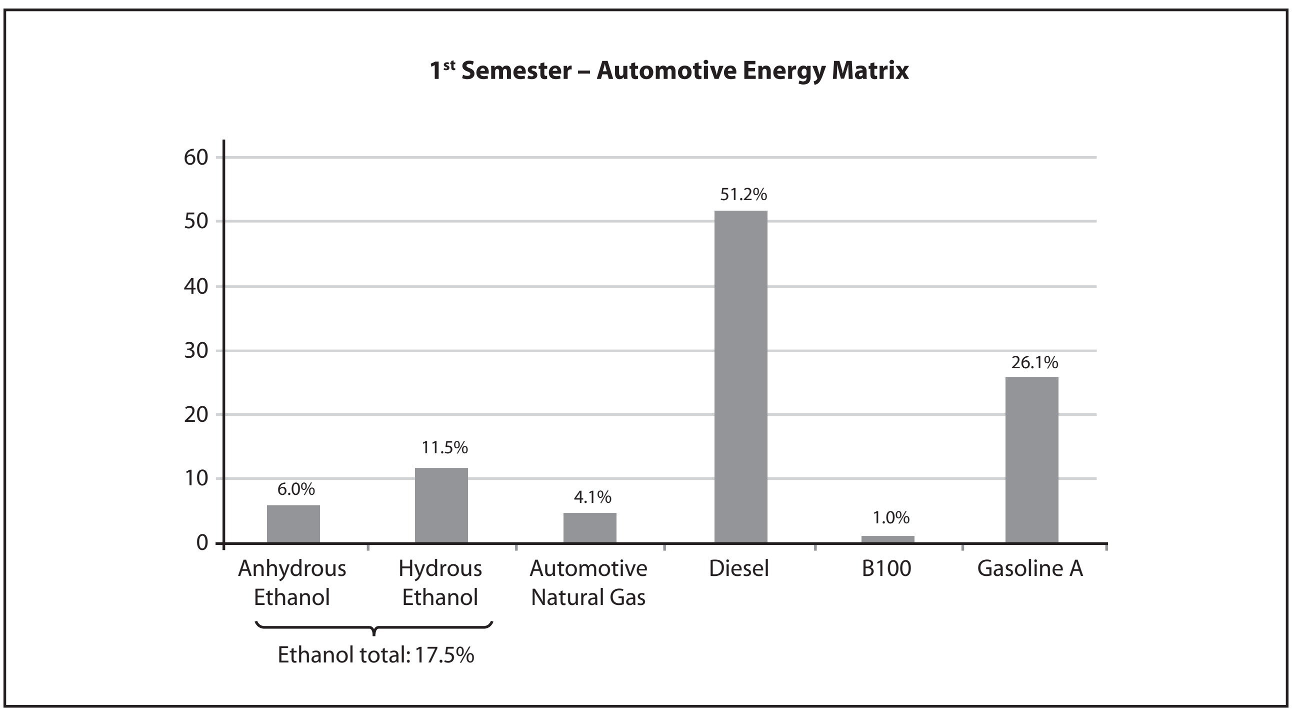
USE OF ETHANOL IN DIESEL – CYCLE ENGINES

Jose Roberto Moreira, Sílvia M. S. G. Velázquez and *Euler Hoffmann Melo*

INTRODUCTION

The global fuel option for urban public transport is diesel, a fossil source of energy which is produced from the fractional distillation of petroleum. The diesel fuel is the most important fuel in the Brazilian Automotive Energy Matrix, accounting for 51.2% of the total volume of fuel consumed in 2008, as shown in Figure 1.

Other type of fuels, such as gasoline or ethanol, have not been commonly used in the urban public transport. However, some initiatives have been taken in order to search for new technologies with lower environmental impact. One of the initiatives in order to diversify the automotive energy portfolio and partially replace the diesel is the production of biodiesel (B100). However, this option cannot meet the total diesel demand based in the available known technology. On the other hand, ethanol fuel from biomass, a renewable fuel with low emission of pollutants if compared to diesel or gasoline, has only been used in spark ignition engines (Otto



Source: ANP (2008).

FIGURE 1 Brazilian Automotive Energy Portfolio.

cycle), due to technical limitation prohibiting the use of ethanol in Diesel cycle engines. Beyond that, Brazil already has an infrastructure for large-scale production of ethanol that could supply a significant diesel demand in the shorter term.

Technological improvements have provided, in the last decade, a Diesel cycle engine which runs on ethanol blended with a clean additive, whose applicability is the same as conventional diesel engine and, therefore, the automotive energy portfolio can be diversified with ethanol, which is a renewable fuel and less polluting than the diesel.

The Diesel cycle engine adapted to operate with ethanol has been developed and it is already commercially available. In Brazil, this technology has been transferred through the BEST Project – BioEthanol for Sustainable Transport (BEST, 2006)[1]. The project is an initiative of the European Union, coordinated by the city of Stockholm, which aims to encourage the use of ethanol as a fuel for urban public transport and as a replacement for diesel in Brazil and in the world.

São Paulo, the pioneer city in the America, has demonstrated the technical and economical performance of buses which are fuelled with ethanol in order to seek an alternative for reduction in the consumption of fossil fuels and, therefore, a reduction in emission of pollutants from the transport sector.

This concern is due to the fact that the city of São Paulo, with 10.8 million[2] inhabitants, is the greatest urban center of São Paulo Metropolitan Region, which has more than 19.4 million inhabitants. São Paulo Metropolitan Region is the fourth greatest urban center of the world[3]. This center is responsible for 18% of the Brazilian GDP[4] (US$ 247 billions per year) and where roughly 3.2 million[5] people are transported every day through 13,726 urban buses[6], almost all of them fuelled by diesel oil. These Figures generate stakeholders concern regarding pollutants emissions due the use of diesel, which is harmful to the environment as well as to the health of the people who live in São Paulo.

HISTORICAL REVIEW

In the early 1980's, there was a Brazilian initiative to replace diesel with ethanol, which consisted in the adaptation of a Diesel cycle engine, originally designed to run on diesel oil, installed in buses and trucks for the transport of sugarcane.

Swedish Scania started researching Diesel cycle engines powered by ethanol blended to additives in 1985; finally, in 1989, the first Scania buses fuelled by ethanol additive were officially incorporated to the Stockholm's bus fleet as a replacement of the diesel buses which previously circulated in the urban center. The objective of the Swedish program was to reduce the pollution generated in the city center, where there was high concentration of pollutants. In 2007, about 500 buses circulated in eight cities in Sweden, 400 of those in Stockholm Municipality (MILJOBILAR. STOCKHOLM, 2007).

As a result of the operation of the ethanol buses in Stockholm, for the past fifteen years, about 140,000 tonnes of carbon dioxide (CO_2) are no longer released in the atmosphere (SCANIA, 2007). The equivalent emission reduction is compared to 5 thousand cars withdrawn from the roads.

Due to demands of the Swedish environmental legislation, Swedish Scania has developed the engine and Sekab (<www.sekab.com>) developed the additive. In Sweden ethanol imported from Brazil has been used and there are tax incentives

[1] See Report BioEthanol for Sustainable Transport – Results and Recommendations from the European BEST Project, January 2010 (www.best-europe.org)

[2] Source: São Paulo's City Hall Site. Data referred to 2005. Available in: <www9.prefeitura.sp.gov.br/sempla/md/mostra_tabela.php?cod_subtema=ger&nome_tab=geral1&partes=1>.

[3] Source: São Paulo's City Hall Site. Data referred to 2005. Available in: <www9.prefeitura.sp.gov.br/sempla/md/mostra_tabela.php?cod_subtema=ger&nome_tab=geral1&partes=1>. Access in: 2008.

[4] Source: Seade. Data referred to 2003. Available in: <http://www.seade.gov.br/negocios/snpct-v2.html>. Access in: January 2008.

[5] Source: São Paulo' s City Hall. Data referred to 2005. Available in: <www9.prefeitura.sp.gov.br/sempla/md/mostra_tabela.php?cod_subtema=tra&nome_tab=transportes6&partes=1>. Access in: January 2008.

[6] Source: São Paulo's City Hall. Data referred to 2003. Available in: <www9.prefeitura.sp.gov.br/sempla/md/mostra_tabela.php?cod_subtema=tra&nome_tab=transportes4&partes=1>. Accessed in: January 2008.

from the government which makes ethanol be sold at 40% of the price of diesel.

In 1997, the São Paulo Transporte S.A. – SPTrans, acting as Management Company of urban transport of São Paulo city and also the responsible for measures to minimize the levels of pollutants emissions, performed tests for 30 days in actual operating conditions for two buses fuelled by an ethanol additive manufactured by Swedish Scania. SPTrans performed that demonstration in partnership with *Santa Brígida, a* bus concessionaire and also with *Santa Madalena* another bus concessionaire (SPTRANS, 2007).

A comparative study was performed of ethanol-powered vehicles with a diesel and natural gas, in buses lanes operated in the same conditions. Considering only the fuel consumption by buses, the ethanol results were excellent from the environmental point of view, however more costly. This is hoped to be overcome with the new generation engine and also with a lower cost additive.

A more detailed research regarding the benefits of these buses is an important step for the implementation of this ethanol engine technology. That is the reason why Best Project has been initiated.

BEST PROJECT – BIOETHANOL FOR SUSTAINABLE TRANSPORT

In Brazil, the project is coordinated by Cenbio – Brazilian Reference Center on Biomass, IEE/USP – Institute for Electrotechnology and Energy of the University of São Paulo, and project partners are: Scania, Baff/Sekab, Marcopolo, Unica, Copersucar, Petrobras, EMTU and SPTrans. Through the Best project in the São Paulo Metropolitan Region there is one ethanol bus which circulates in the segregated bus lane managed by EMTU (Jabaquara/São Mateus), which passes through municipalities of São Bernardo do Campo, Santo André, Diadema and São Paulo. More recently, November 2009, a second bus with similar characteristics has been in operation through the city center. Beyond São Paulo, eight other cities in Europe and Asia also took part in the Best project, they are: Somerset County Council (United Kingdom), Dublin (Ireland), La Spezia (Italy), Rotterdam (Netherlands), Nanyang (China), Stockholm (Sweden), Madrid and the Basque Country (Spain).

After complete analysis of the results, the European Community and the project coordination will provide blue prints of public policies in order to encourage the use of ethanol in urban public transport.

The current engine powered by ethanol is a third-generation engine which complies the Euro 5 emission standard that will be validated in Europe in October 2009 and it is also certified as an EEV – Enhanced Environmentally Vehicle. EEV emission standard is even stricter than Euro emission standard and do not have any prevision to be validated in Europe. Therefore, this engine technology is advanced even for the current emission standard in Europe (SCANIA, 2007).

In accordance to the engine manufacturer, Swedish Scania, there are no significant differences between a conventional Diesel engine and an Ethanol Diesel engine. Among differences, the higher compression ratio can be mentioned, which achieves 28:1, against 17:1 in conventional Diesel engines, different injector nozzles in order to compensate the lower energy content of the ethanol in comparison to diesel, materials resistant to ethanol in order to avoid the corrosion of the parts such as gaskets, seals, coils and valves, and finally a different fuel pump with higher flow capacity. Other parts of the vehicles, such as breaks, transmission

Source: CENBIO (2008).

FIGURE 2 The ethanol bus in São Paulo City.

gear box, body and chassis, and exactly the same as used in conventional diesel vehicles.

The differences found in the engine are due to the fact that ethanol does not have the property of self-ignition, which is the operating principle of a diesel engine. Therefore, for the diesel engine running on ethanol, it is necessary the high compression ratio of 28:1, as well as the fuel must have a 5% additive by volume, with an additive in order to promote the fuel self-ignition. The fuel is commercially known as E95, in reference to the percentage of ethanol by volume, which is 95%. Sekab is the only company to offer E95 to the fleet of 600 ethanol buses in Stockholm and for the Best project, its fuel E95 is known commercially as Etamax D (BEST, 2006).

Companies Scania and Sekab, both Swedish, have developed their products together since 1985 and are technically ready for the supply of components and fuel ethanol – powered buses additive. Some characteristics of the engine are shown in Table 1.

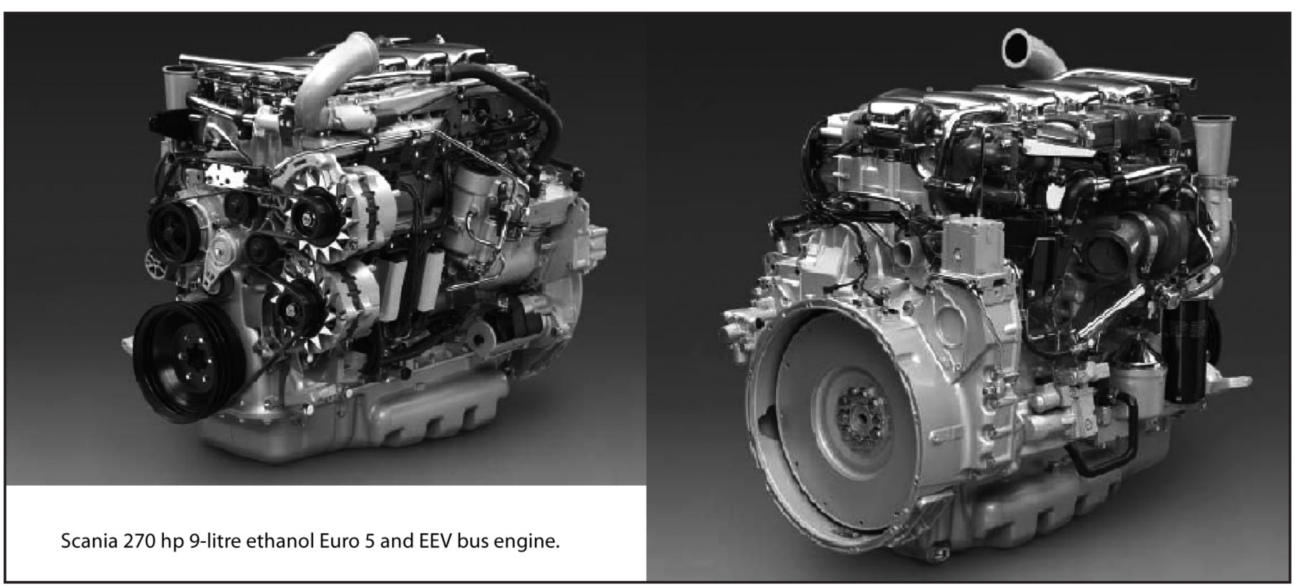
Due to the lower energy content of ethanol in comparison with diesel, the ethanol bus has higher fuel consumption than an equivalent diesel-powered vehicle. As energy contained in one liter of diesel is the same as that contained in 1.7 liters of ethanol, ethanol powered bus requires 70% greater volume of fuel to travel the same distance with the necessity of the vehicle to have a greater fuel tank capacity (400 liters of E95), while a conventional vehicle has a tank capacity of 300 liters of diesel (CENBIO, 2008).

The fuel has been developed and improved since the start of the tests in Sweden. Its composition is presented in Table 2.

TABLE 1 General Specification of the Diesel engine powered by ethanol.

Scania Engine DC9 E02
Compression Ratio – 28:1;
5 cylinders;
Maximum Power – 270 hp (198kW) @ 1,900 rpm;
Maximum torque: 1,200 Nm @ 1100 – 1,400 rpm;
Special Injector Nozzles – UI (Unit Injectors);
Electronic Fuel Injection;
Turbo compressor;
Intercooler: air-cooled;
EGR – Exhaust Gas Recirculation (NO_x emission controller).

Source: CENBIO (2008).



Scania 270 hp 9-litre ethanol Euro 5 and EEV bus engine.

Source: SCANIA (2008).

FIGURE 3 Diesel engine powered by E95.

TABLE 2 Etamax D composition.

Elements	Amount by volume
Hydrous ethanol	95%
Ignition improver	5%
Isobutanol **(denaturant)**	Small amount
Corrosion Inhibitors	Small amount
Identification pigment (red)	Small amount

Source: SEKAB (2008).

The fuel sold in Europe has in its composition methyl-tertiary butyl ether (MTBE). However, according to the manufacturer of the additive, MTBE can be replaced by ethanol or another ethanol derivative in order to adapt the fuel to the Brazilian legislation which does not allow the use of MTBE since September 1991. The additive supplied by Sekab for the Best project in Brazil is composed of derivatives of polyethylene glycol, which is the promoter of ignition, isobutanol, identification pigments, corrosion inhibitors and does not use MTBE.

The main advantage of use of ethanol as fuel in urban public transport is environmental gains regarding the reduction of emissions. São Paulo's captive bus fleet is around 15,000 buses, and almost all of these vehicles are diesel-powered[7]. According to José Roberto Moreira, coordinator of the BEST project in Brazil, if the bus fleet of 15,000 buses were replaced by an ethanol-powered fleet, it would, environmentally, be equivalent ,to operating only 3,000 diesel buses in the city.

Ethanol is a biodegradable fuel, renewable, which implies also in another significant contribution on reducing greenhouse gases responsible for the global warming. Furthermore, it has no sulfur content which, when burned in internal combustion engines, produces SOx responsible for acid rain.

The engine has been already approved in Brazil by *Companhia de Tecnologia de Saneamento Ambiental* – Cetesb. This engine is perfectly adaptable to the Brazilian legislation because its local emissions are well below the limits imposed by the *Controle de poluição do Ar por Veículos Automotores* – Proconve. Table 3 shows the local emissions of this ethanol engine and makes a comparison with the emission limits established by Proconve:

The results of the essay are compared to limits established in Proconve. It can be concluded that results on emission data collected from an ethanol engine are much lower than the limits imposed by phase P-5 and P-6 Proconve. The P-6 Proconve legislation is the strictest emission set, in Brazil, imposed to engine manufacturers, and was designed to be effective by January 2009. Unfortunately, due delays in the supply of low-sulfur diesel by Petrobras, enforcement of P-6 has been postponed by 2 years.

The Brazilian Ethanol bus powered by an engine assembled in Sweden went through one small technical adjustment in order to be adapted to operate in Brazilian climate conditions. Operating in the segregated bus lane of EMTU, the vehicle's engine used to make sudden stops at idle speed. This problem manifested itself most often on hot days and at the end of the long steep path. The original design of buses running on ethanol additive, which was developed in Sweden, provided fuel heating before it flows to the engine for better engine efficiency, through a heating device in the fuel supply line of the engine. Brazilian climatic conditions caused overheating of the fuel and its vaporization caused loss of line pressure and, consequently, sudden stops of the engine. The heating device was removed and no more sudden engine stops have been registered since the technical modification.

More than to encourage the use of ethanol in the urban public transport, the initiative launched by Cenbio, partners companies and the European Community forwarded the discussion of the economic model that Brazil is currently seeking. The present time is very favorable to the deployment of this technology in Brazil, because it is the largest producer of ethanol from sugarcane and has the lowest production cost. Brazil produced 24 billion

[7] On top of diesel powered buses the fleet is composed by a few hundred electric buses, and a few natural gas Otto cycle powered buses.

TABLE 3 Emission of the ethanol engine.

Emission values	CO (g/kWh)	HC (g/kWh)	NO_x (g/kWh)	PM (g/kWh)
Emission Essay*	0	0.05	1.7	0.01
Proconve P-5**	21	0.66	5	0.1
Proconve P-6***	1.5	0.46	3.5	0.02

* Essay performed in September 2007, in RDW laboratory in the Netherlands.
** Established in Conama Resolution 315/02, and in effect since 01.01.2006.
*** Conama Resolution n. 315/02, Art.15, Table 1, line 2, and to be effective by 01.01.2009.

Source: CENBIO (2008).

liters of ethanol in 2008 and there is the prospects to reach 38 billion liters in 2012 (UNICA, 2008).

Given the figures above, added to the competitive and environmental advantages, such as the reduction of emissions of greenhouse gases, the use of ethanol in Diesel engines offers a wide range of benefits and favorable points for Brazil. They are: diversification of energy sources in the transport sector and the proper use of the existing Brazilian infrastructure for production and distribution of ethanol. It is also compatible with the existing interests of various sectors of government which support the product.

However, a model of urban public transport powered by ethanol needs to receive incentives from the Government, since it is a sustainable alternative. Studies and operational data indicate that the bus consumes about 70% more ethanol to travel the same distance, notwithstanding that ethanol is 50% cheaper than Diesel. Thus, fuel expenses are higher and increases slightly more when adding the cost of the additive. Presently, the Swedish Sekab is the only company that produces the additive for the Diesel engine powered by ethanol. One of the challenges for the commercial use of ethanol in public transport in the country is the production of the additive in Brazil and its expected cost reduction.

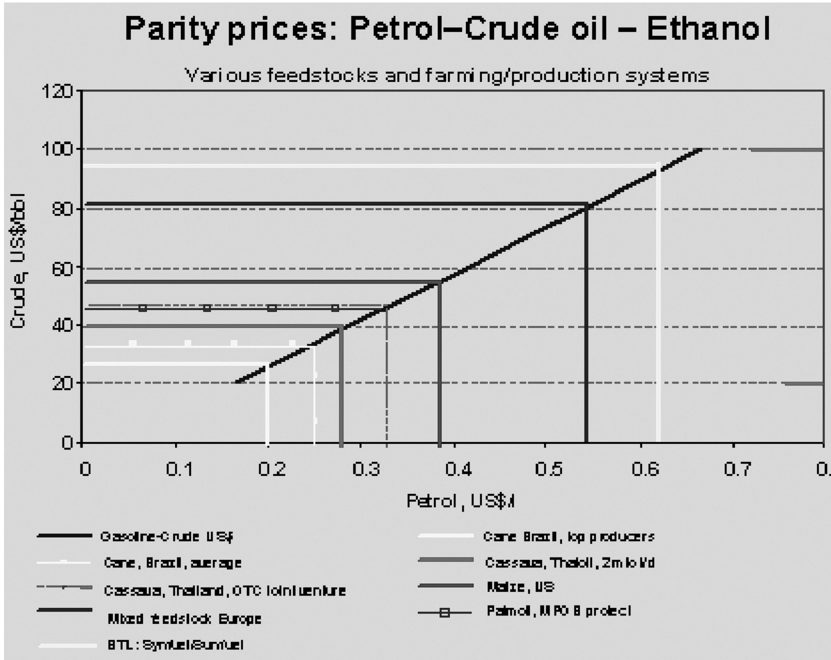
ECONOMIC EVALUATION

Considering that the technology has been sufficiently tested in Sweden by a process of implementation of about 600 ethanol buses, for over 15 years and that the operation of ethanol buses purchased by the Best Project during the years 2007 and 2008 in other countries, the technology has been successful (CENBIO, 2008), it can be concluded that there are no technological barriers for these vehicles.

In order to analyze the economic barriers, it is necessary to examine the particularity of each country; the economic feasibility depends on the price of diesel and ethanol added to the additive in each location.

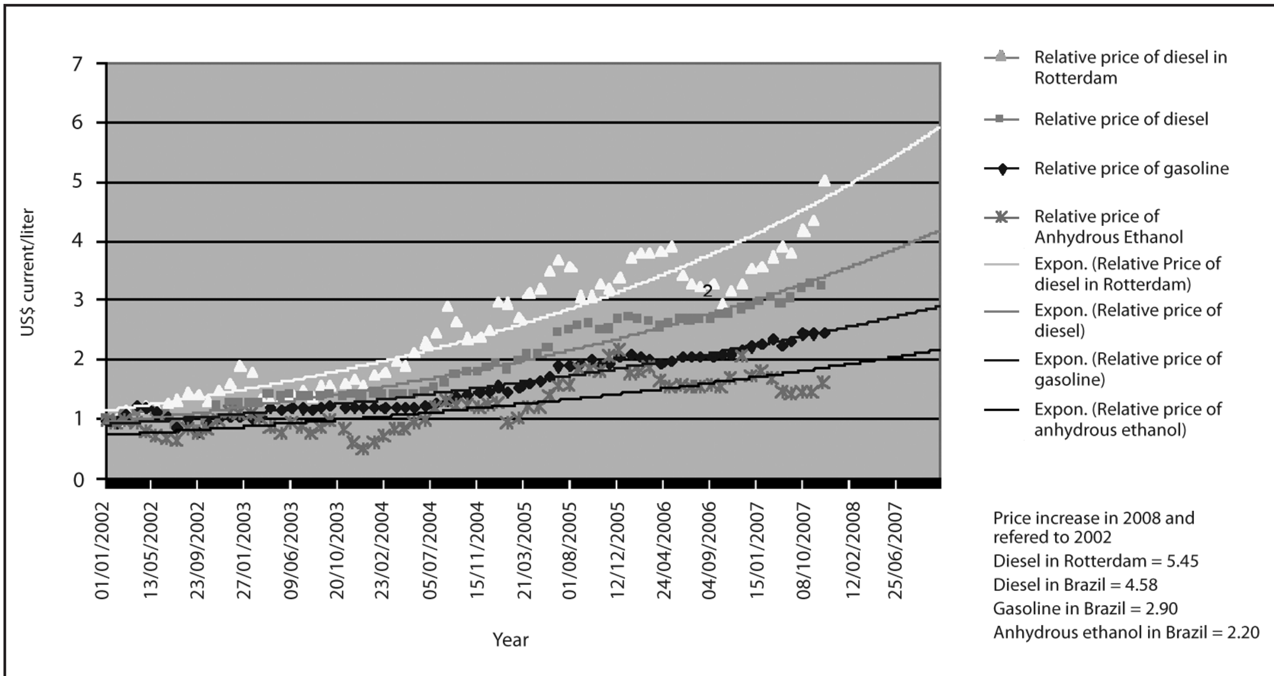
Figure 4 shows that the lowest cost production of ethanol occurs in Brazil, followed by Thailand. Prices are higher in the United States and the European Union. It is also important to analyze the price of diesel fuel. Figure 5 shows the variation of the price of ethanol, diesel and gasoline, in the domestic and international market (Rotterdam Port). It is noted that diesel is more expensive than gasoline as shown in Figure 5. It is seen that in January 2002 and December 2007 (thus ignoring the high prices of oil in 2008), diesel oil in Rotterdam shows a price increase roughly five times while in Brazil the increase was 3.3 times. Even more interesting is to compare the increasing price of gasoline in Brazil, which was 2.5 times.

Given these increases, in June 2008, the price of diesel at gas stations in Brazil were around R$ 2.20 while those of gasoline around R$ 2.50, which means that diesel now costs 88% of the price of gasoline, when at the begin of the century its cost was only 50%. It is also important to note that the price of diesel increased more in the Rotterdam market than in Brazil, 5, and 3.3 times, respectively, which shows that this fuel in Brazil receives special cost treatment and its price is



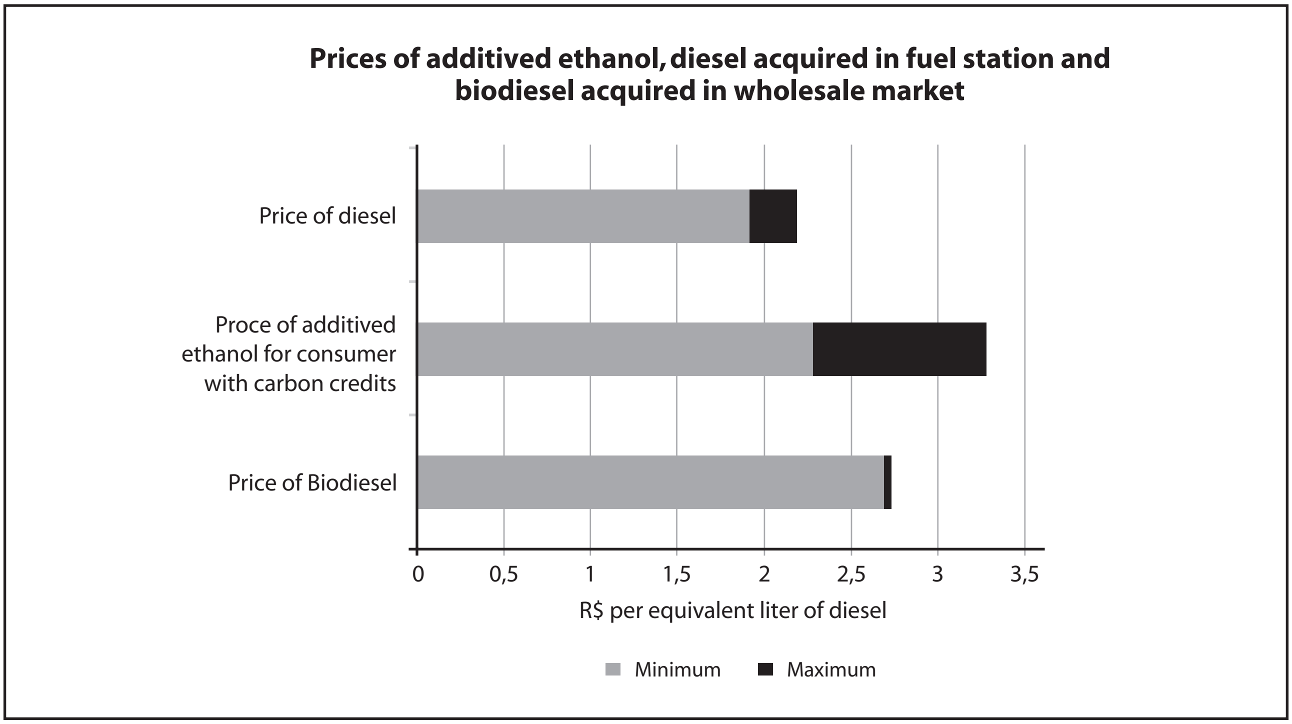
Source: SCHMIDHUBER (2005).

FIGURE 4 Ethanol Production Cost in several regions and countries.



Source: Built with data from EIA (2009) and from ANP (2008).

FIGURE 5 Time variation of the relative prices of diesel oil in Rotterdam and in Brazil, of the ethanol in Brazil and of gasoline in the 2002/2007 time period. For 2008 the values are projected based in econometric data by the authors.



Source: Authors referred to ANP data (2008).

FIGURE 6 Prices of the additived ethanol, diesel and biodiesel in wholesale market.

lower than its international market value. This is part of government's economic policy which claims that the transfer to the final price of diesel of all its true market value is harmful to the economy as its impact is greater than for gasoline. On the other hand, transfer to the gasoline consumers the price increases of petrol is also difficult in Brazil because of the competition with ethanol, a fuel that is well established due to the large-scale production and the large fleet of flex-fuel cars. This explains why Petrobras has not increased the price of gasoline to the extent necessary to compensate for oil prices increase, but tried to expand its revenue increasing diesel price, despite the limitations imposed by economic policy.

It is also important to mention that in addition to greater increase for diesel compared to gasoline, diesel in Brazil is still less costly than gasoline. This is against the trend of the international prices because in most of the countries' diesel oil is more expensive than gasoline. Moreover, that is logical because the energy content of diesel oil is greater in comparison to gasoline. This occurs because the diesel's density is roughly 0.84 kg/liter while gasoline's is 0.74 kg/liter, and there is more carbon in the same mass of diesel than in gasoline ($C_{12}H_{26}$ for diesel and C_8H_{18} for gasoline).

However, examining the situation in Brazil, there are two reasons to expect an increase in the price of diesel in the next few years, regardless of variation in the international price of oil. The first reason has economic origin and is shown in Figure 4, from where it has been observed that in recent years the increase in diesel price has always been higher than gasoline and it might remain so in the future. The second reason is the improvement in the quality of diesel produced in Brazil. According to standards of environmental legislation, the sulfur content in diesel was supposed to be reduced in Brazil to 50 ppm in January 2009. This did not happen due Petrobras inability to comply with this requirement of legislation, which became an uncomfortable issue for the company. Through agreements seeking a compensation for the damage to the environment, Brazil continues to use diesel with 500 ppm in cities and to 2,000 ppm in the less urbanized areas. However, Petrobras is still obliged to comply as soon as possible with the legislation, and produce diesel whose sulfur is 50 ppm. Petrobras will invest up to 2012 about R$ 4 billion in refineries[8] and will increase energy use by 35%[9] in the production of diesel, which eventually will raise its production cost. The expected cost increase mentioned is required to pay for the investments of new production processes and to minimize the environmental impact of oil refineries. Therefore, evidently, cleaner diesel production will demand an increase in the fuel price.

All the discussion above is intended to forecast future prices of diesel and ethanol, which could facilitate the competition of ethanol as an additive with petroleum diesel. This may help the market penetration of additive ethanol, but there is an urgent need, as will be shown below, that niche markets, where competition can occur nowadays, be immediately explored.

Figure 6 demonstrates the cost of the fuel for diesel engines; all figures are quoted in Brazilian currency (R$ per equivalent liter of diesel). The comparison must be on diesel equivalent basis because, as mentioned, ethanol and diesel have different energy content per unit of volume, which means that 1.7 liters of ethanol are necessary in order to substitute a liter of diesel to travel the same distance. Figure 6 reflects data of the average prices published by the Brazilian Oil Agency – ANP. Collected data below are referred to the initial months of 2008 (ANP, 2008):

- Ethanol
  - Minimum price → R$ 1.21
  - Maximum price → R$ 1.82
- Diesel
  - Minimum price → R$ 1.92
  - Maximum price → R$ 2.18

In addition, it is necessary to point out that ethanol blended with additive is composed of 95% of hydrous ethanol and 5% of ignition improver additive.

- Additive

Considering the importation cost of additive is $ 18.2 SEK per kilogram, which means, US$ 2.81/kg (1 US$ → R$ 1.80) and its density 1 kg/liter, the price composition of the minimum and maximum prices of the final fuel are:

Minimum price = [0.95 x (1,21) + 0.05 x (5,06)] x 1.70
Minimum price = R$ 2.38/liter
Maximum price = [0.95 x (1.82) + 0.05 x (506)] x 1..70
Maximum price = R$ 3.37

Considering Carbon Credits:

- Carbon credit – CER → US$ 20/tonne of CO_2

Diesel CO_2 emission = Density (kg/liter) * % mass of carbon in diesel * (CO_2 molecular weigh/ C molecular weigh)

CO_2 Emission of diesel = 0.85 x 0.86 x 44/12 =
CO_2 Emission/liter = 2.68 kg CO_2/liter diesel

Value of Certification Emission Reduction – CER = 2.68 x 20 x 1.80 x 10^{-3}

CER = R$ 0.10/liter

Therefore, considering the Carbon Credits:

Minimum price of the fuel = 2.38 – 0.10 = **R$ 2.28**
Maximum price of the fuel = 3.37 – 0.10 = **R$ 3.27**

These Figures demonstrate that in some regions of the state of São Paulo, where the price of ethanol fuel is the cheapest in Brazil, the price of additivated ethanol overcomes the maximum price of diesel (R$ 2.18) by only R$ 0.10, when considering the carbon credit from the reduction of diesel CO_2 emission. It is important to be observed that ethanol presents a seasonal variation on its price; during the season its price can be reduced by R$ 0.10 or R$ 0.15/liter compared with the value quoted above. The price reduction to R$ 1.11/liter (R$ 1.21 – R$ 0.10) makes possible to bring the price of an equivalent liter of diesel, as additivated ethanol, to R$ 2.12/ liter, as demonstrated in the sequence:

$M_{\text{inimum price of fuel in season}}$ = [0.95 x 1.11 + 0.05 x 5.06] x 1.70
$M_{\text{inimum price of fuel in season}}$ = 2.22 R$/l

Subtracting the carbon credit:

[8] Source: Jornal o Estado de São Paulo. Petrobras investe US$ 4 bi em diesel menos poluente. Accessed in January 2009. Available in: <http://www.estadao.com.br/noticias/economia,petrobras-investe-us-4-bi-em-diesel-menos-poluente, 306572,0.htm>.

[9] Personal Information collected from Supply Board of Petrobras.

$M_{\text{inimum price of fuel in season considering carbon credits}} = 2.22 – 0,10$
$M_{\text{inimum price of fuel in season considering carbon credits}} = 2.12$ R$/ equivalent liter

Therefore, additivated ethanol may have a price inferior to the maximum price of diesel of R$ 2.18. Beyond that, it is important to observe that fuel stations put over an average profit of R$ 0.15 per liter of diesel sold. Considering that the fuel station would sell 70% more fuel when selling additivated ethanol than diesel, thus, in order to maintain the same gain of R$ 0.15 per liter of diesel sold, it would be sufficient to earn R$ 0.15/1.70 → R$ 0.09 per liter which means a reduction from R$ 2.12/liter to R$ 2.06, which is significant less than the maximum price of the diesel (R$ 2.18/liter). Thus, we conclude that in some regions of the state of São Paulo there are already niches were additivated ethanol is already cost competitive with diesel, mainly if the fuel is acquired during the harvest season and stored for full year use.

Furthermore, other very favorable niche to the use of ethanol fuel as a replacement for diesel is the Brazilian ethanol production sector. The sugarcane mills own a great quantity of trucks to move the sugarcane production. A simple calculation considering that Brazilian ethanol production is around 600 million tones of cane and that:

- Each truck transports 30 tonnes per trip.
- The average travel time, including loading and unloading, takes 2 hours.
- Average distance travelled per trip is 30 km.
- Each truck operates 20 hours per day.
- Annual sugarcane season lasts 200 days.
- Utilization Coefficient of the vehicle is 90%.

Each truck may transport:

- 30 tonnes * 10 trips/day * 200 days * 90% = 54,000 tonnes/year.

Based in these figures sugarcane transportation demands more than 11,000 trucks.

These cost conditions are more interesting for the mills because there is not the presence of the fuel distributor in the production and use chain of ethanol, and there are also tax exemption such as the *imposto de circulação de mercadoria* – ICMS and others, since the ethanol built in additivated ethanol is not commercialized between different producers and users.

As for ICMS, whose rate varies between 12% to 25%, depending on the state of the Brazilian Federation, this may imply in a reduction of 1.21 * 0.12 to 1.21 * 0.25 and 1.82 * 0.12 to 1.82 * 0.25 for the minimum price and the maximum ethanol price listed above, which means minimum prices of the hydrous ethanol of R$ 1.06 to R$ 0.91 and maximum prices of R$ 1.60 to R$ 1.36. In these conditions the average price of the fuel would be:

$P_{\text{min ICMS free}} = [0.95 \text{ x } 0.91 + 0.05 \text{ x } 5.06] \text{ x } 1.70 =$ R$ 1.90
$P_{\text{max ICMS free}} = [0.95 \text{ x } 1.60 + 0.05 \text{ x } 5.06] \text{ x } 1.70 =$ R$ 3.01

Consequently, the additive ethanol would be competitive with diesel in several regions in Brazil, mainly in the state of São Paulo where more than 60% of the mills are located. Prices would be even lower because there would not be any ethanol commercialization outside the mills and other taxes would be also reduced.

Only in this market niche, ethanol would be able to replace diesel in the following amount:

(54,000 tonnes/per year/truck) x 30 km = 1.62 Million tonnes.km/truck/yr.

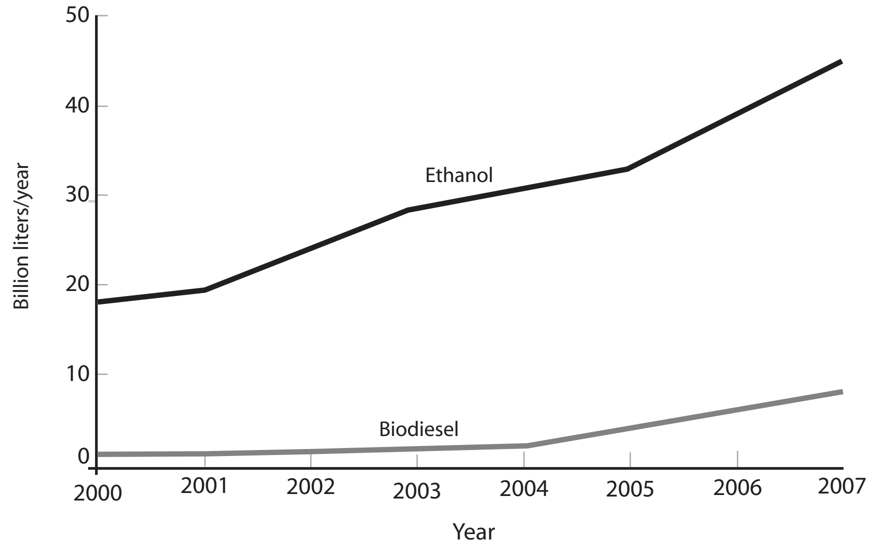
Considering the displacement of the trucks from the source to destiny is about 15 km:

1.62 Million tonnes/km/ 70 tonnes/km/liter[10] = 23,143 liters/truck/yr.

For 11,000 trucks, more than 255 million liters of diesel or 412 million liters of additive ethanol, approximately 1.5% of the ethanol amount produced in Brazil (28 billion liters of ethanol) would be necessary; the relative volume is modest but capable to create a new market of vehicles powered by ethanol blended with additive.

Another fuel developed to diversify the Automotive Energy Portfolio is Biodiesel. However, biodiesel is not able to replace the total demand of diesel in short term since the production of

[10] Average diesel consumption by trucks transporting sugarcane.



Source: MARTINOT (2007).

FIGURE 7 Biodiesel's and ethanol's production capacity.

biodiesel is still very small. On the other hand, ethanol presents advantages if compared to biodiesel because there is a great infrastructure for the production and the distribution of ethanol that may supply the market in the short term.

Besides, as it can be observed from Figure 7, the growing production capacity of ethanol is superior to the production capacity of biodiesel. The increase rate of ethanol production is larger than the increase rate of biodiesel between 2000 and 2007.

The feasibility of the production of biodiesel is related to the cost of the feed-stocks used for its production. There is some variation on costs for processing vegetable oil to biodiesel but the major contribution to the final cost of biodiesel is the cost of feedstock production, which also varies according with the type of vegetable oil.

The energy balance also demonstrates ethanol's competitiveness with biodiesel. For each unit of energy used in biodiesel's production from soybeans, for example, the energy ratio is only 2.5 energy units of the fossil energy used in its production. On the other hand, the energy used in ethanol's production, about 8.06 renewable energy units are obtained for each unit of fossil fuel invested in its production (MARTINOT, 2007).

The final price of the fuel is influenced by this energy efficiency. The average price of biodiesel in the 12th auction, in August 2008, achieved R$ 2.38/liter, which is superior to the maximum price of diesel oil (R$ 2.18/liter). Therefore, any blend proportion of biodiesel in diesel would make the final price of the latter fuel more expensive. This is a good evidence that additive ethanol, based in our previous discussion, has better cost advantage than biodiesel.

FINAL CONSIDERATIONS

The use of ethanol instead of diesel has been a goal pursued for many years. Efforts have been made in Brazil, since the early 1980's, and in Sweden since 1990's. The major difficulty found was economic while technical difficulties were easily overcome. The additive developed in Brazil, in order to increase the cetane number of ethanol fuel to make it feasible to use it in diesel engines, had some technical problems that could be solved in short time. However, the low price of oil in the early 80's discouraged its use. In Sweden, where the cost factor had not been of significant interest when compared with pollution issues and consequently the quality of life of the people, the additive has been successfully developed since 1990's and currently it is widely used in buses running in Stockholm and other nearby cities.

The increase on oil prices noticed over the past two years, the increasing appreciation on quality of life of the population in many countries, including Brazil, and the necessity to reduce the risk in obtaining energy, all make the use of ethanol as an additive more desirable.

The experiences during the buses operation and their good performance as noted by the users in the city of São Paulo have shown that it is technically and economically feasible to use this fuel, since its price is equal or very slightly higher than diesel (June 2008) but, below the price of biodiesel.

Currently, the Brazilian legislation establishes a mandatory addition of biodiesel to diesel up 3% proportion by volume. Due to the merits shown by the use of ethanol, there is no reason why not to develop a political effort in order to encourage the use of ethanol in diesel engines in a compulsory manner similar to biodiesel.

The only drawback is that in the contrary with occurs for biodiesel, ethanol additive cannot be blended in diesel and used in existing diesel engines. It requires that the vehicle's producer prepare an adapted diesel engine especially designed. Thus, the fuel should be used only on new vehicles or on vehicles that have their engines replaced by new engines.

On the positive side we should add that the gains to public health and global environment through mitigation of climate changes mean that the transport sector of heavy urbanized areas should be the first sector for the introduction of this technology.

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