Ethanol and Bioelectricity Sugarcane in the Future of the Energy Matrix

Ethanol as a Fuel

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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.

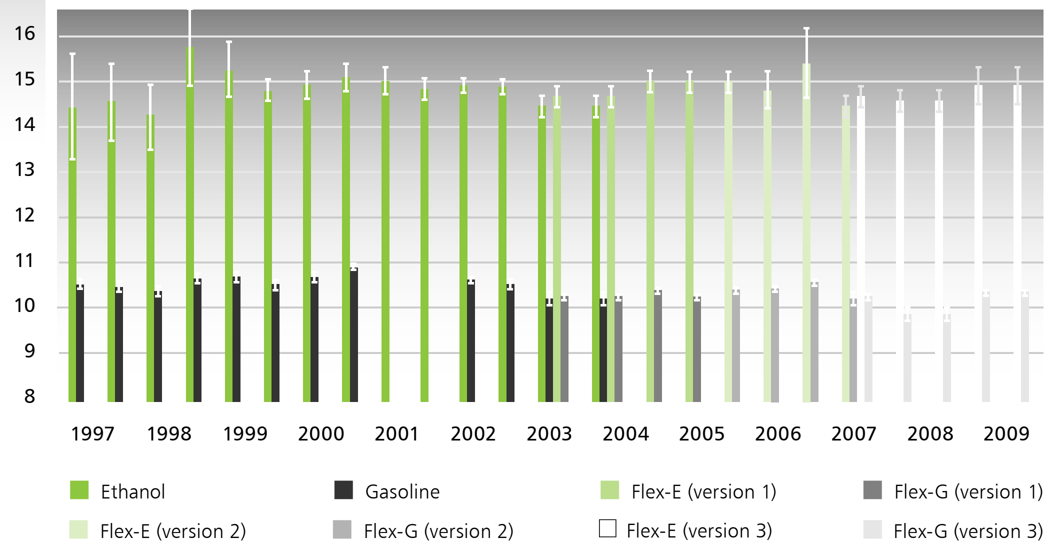
Table 3 **Average factors of flex-fuel vehicle emissions compared to limit values**

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*

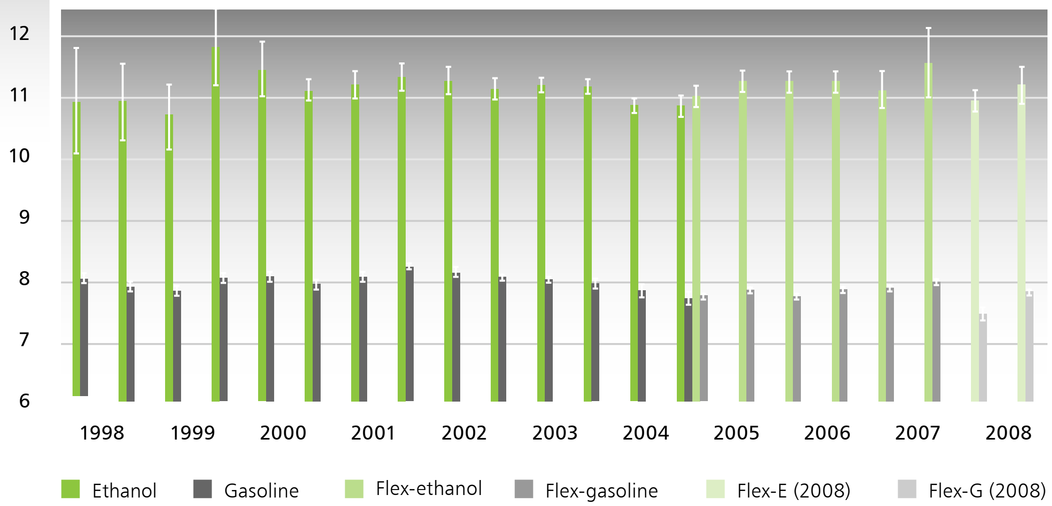


hicles, with compression ratios similar to gasoline engines, the energy advantage of ethanol was reduced by 0.6±0.8%, because of the increase in ethanol consumption. Despite reduced ethanol consumption in the more recent generation where the engine compression ratios are similar to vehicles dedicated 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 Urban cycle Ethanol (km/l)	Km/L Urban cycle Gasoline (km/l)	Km/L Highway cycle Ethanol (km/l)	Km/L Highway cycle Gasoline (km/l)	2009 Classification	Inmetro Classification Area (m²)
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.
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[iii] STI/MIC, Fuel Economy Program for Light Vehicles with Otto Cycle Engines, Brasilia, 1983.
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[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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[xvi] Results of the 14th Biodiesel Auction (05/29/2009) - ANP.
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