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Environment and perspectives of alternative fuels in urban transport in Brazil

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Abstract

In this paper the perspectives for the use of alternative fuels in urban transport are evaluated, as responses to environmental pressures in the country, within a time period up to the year 2010. Reacting, initially, to specific legislation to control emissions of pollutants, new technologies and energy saving materials, the reorientation of planning activities and new energy sources, which are environmentally more sustainable than the traditional ones, are emerging in Brazil and elsewhere. The environmental question, the security of energy supply and the interests of the automobile and oil industries are seen as factors pushing forward the development of alternative fuels, while the likely evolution of oil and oil product prices and the cost trends of the alternative fuels are identified as restricting factors. The main alternative fuels for motor vehicles used in urban transport evaluated in this paper comprise oxygenated gasoline and reformulated gasoline and Diesel oil, synthetic fuels obtained from fossil resources, compressed natural gas-CNG-, liquefied natural gas-LNG-, liquefied petroleum gas -LPG-, electricity, hydrogen and fuels from renewable sources.

1 Introduction

Road transport, with the motor vehicles, become and indispensable part of modern living, having an important role in the social and economic structures of most of the countries worldwide. There are no signs of change in his picture up to the year 2010. However, objective actions on some existing restrictions to the expansion of the motor vehicle fleets should be undertaken, namely traffic and vehicles security, traffic congestions in medium and large towns, energy consumption, full dependence of oil and environmental impacts of pollutants.

Periods of supply constrains for the oil products produced significant substitution efforts of gasoline and Diesel oil. The two oil price crisis in the seventies pushed forward research and development projects on alternative fuels, but it was after this period, with a greater consciousness about the environmental impacts of burning fossil fuels, that this question won a broader scope. It is of general agreement that, in the medium and long terms, part of the energy demand generated by road transport will be met by alternative fuels environmentally more sustainable than the traditional ones.

2 Factors working for or against alternative fuels

2.1 Oil and oil products prices

In the medium and long terms, and exclusively from the economic point of view, the feasibility of substituting alternative fuels for gasoline and Diesel oil will depend, essentially, on the future evolution of the oil prices, and consequently, the prices of its products. There is a lot of speculation as to what will happen to oil prices up to the year 2010. Only a large rupture of the current market structure and the strategic stock controls could produce a drastic evolution of the oil prices. The main risk lies in an unstable situation political and military in the Middle East, where 57 per cent of the world's oil reserves (Owen & Coley, 1990). The environmental impacts of burning oil products have not produced, so far, reductions in the sales either of oil or its of products.

Countries usually adopt particular price policies for the oil products consumed in their transport sector, not following, necessarily, a direct correlation with the evolution of oil prices. Figure 1 shows the evolution, during the period 1979-94, of the prices, to the Brazilian consumer, of the equivalent barrels of gasoline and Diesel oil, compared to the prices of a barrel of imported oil. It can be observed in figure 1 that no significant correlation can be found among these prices, since, in Brazil, the prices of gasoline and Diesel oil have been manipulated in short term economic policies.

2.2 Costs of the alternative fuels

For the ordinary consumer, that makes his decisions based on strict profitability criteria, the competitiveness of the costs of the alternative fuels vis-à-vis the costs of the traditional options is essential. The basic problem in the definition of the real costs of using the several energy options has to do with the difficulty of forecasting them, since the development of the majority of the alternative fuels is still in an early stage.

A study carried out by the International Energy Agency-IEA (1990) evaluated the comparative costs of alternative fuels. Table 1 show estimated cost ranges for them, based on technologies available in 1990. It shows that methanol and synthetic gasoline made from natural gas may be close to competitivity, provided optimistic assumptions about gas prices are assumed, and methanol and ethanol from biomass have a cost at least double that of gasoline. CNG and VHO products, at the lower end of their estimated cost ranges, may be economically competitive with conventional gasoline. In the specific case of producing ethanol from biomass, the production costs in Brazil, using sugar-cane as the raw material, lie in the range from 38 to 42 US$/barrel equivalent of gasoline.

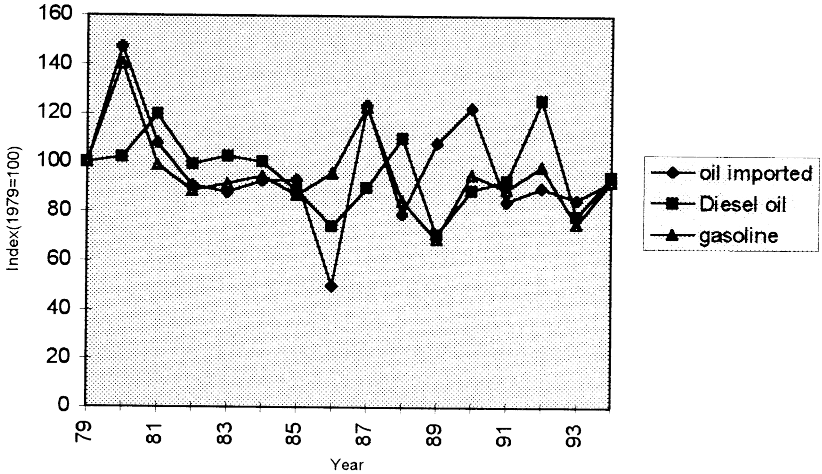

Figure 1 Evolution of the prices of oil, gasoline and Diesel oil in Brazil
Source: MME, (1995)

Table 1 Comparative costs of alternative fuels

Fuels	Costs(in 1987 US$ /barrel equivalent of gasoline)
Crude oil (assumed price)	18.00
Conventional gasoline (assumed price)	27.00
CNG	20 to 46
VHO products	21 to 34
Methanol from natural gas	30 to 67
Diesel oil from natural gas	69
Gasoline from natural gas	43 to 61
Methanol from coal	63 to 109
Methanol from biomass	64 to 126
Ethanol from biomass	66 to 101

Source: IEA/OECD, 1990

A conversion to alternative fuels would require significant investments in new production and distribution equipment. There could be significant problems associated with applying unfamiliar technologies on a large scale in an uncertain market environment. However, reductions of up to 10 per cent in the production costs of methanol from natural gas are expected in the short term, while figures such as 30 per cent or even 50 per cent can be achieved in the long term. Production cost reductions are also expected in the production of gasoline and Diesel oil from natural gas and CNG. In the cases of VHOs, however, no significant alterations on productions costs and total costs are foreseen.

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2.3 The interests of the oil and the automobile industries

The substitution oil products in the transport sector does not go necessarily against the interests of the oil and the automobile industries. As road vehicles will keep still for many years their prominent role in the world economy, it is reasonable to suppose that both industries will have interest to perpetuate their activities, searching alternatives, forced by environmental or strategic constraints. The resistance showed by both industries aims to postpone the market penetration of alternative fuels, since not all possible benefits - for them - have been extracted from oil, as a primary energy source, yet. In effect, several automobile and oil companies are already, directly or indirectly, engaged in research and development of alternative fuels, proving their interest in keeping their market. The current efforts to make feasible the use of methanol and ethanol in heavy vehicles and the development of electric vehicles able to meet the environmental legislation of the State of California, USA, are a good examples that energy substitution can also be a stimulating factor to competition (Sinício & Bajay, 1996). The Brazilian experience, substituting, partially, ethanol for gasoline, showed the initial resistance of these economic groups and their later engagement in the process, after, obviously, a long negotiation, mediated by the government.

2.4 Security of supply

One of the key questions in the search for alternative fuels in transport systems is the vulnerability of many nations, as far as energy supply is concerned, particularly oil supply, even in periods of regular international trade, and even taking optimistic forecasts for the future rates of new oil discoveries and for the depletion rates of the current reserves. In this context, the security of supply question stimulates research and development efforts that can lead to a greater energy supply self-sufficiency of large energy consumption countries.

2.5 The environmental question

As the amount of vehicles and their use have increased in recent decades, the concentration of motor vehicle combustion gases increased to the point that the need for emission controls has been recognised and corrective action has been taken. Motor vehicles burn hydrocarbons and emit a variety of combustion products, including carbon dioxide -CO_2 -, carbon monoxide - CO -, oxides of sulphur - SOx -, oxides of nitrogen - NOx - and other gases. The usual forms to minimize this problem consist in reducing the specific consumption of the various types of motor vehicles, and in incorporating technology to the vehicle subsystems in order to improve the efficiency of the combustion process and/or to reduce the emission of noxious gases of the atmosphere. In some countries social pressures have led to the definition of ever stricter emission patterns, impossible to be met just with the use of the traditional fuels, whatever the combustion and/or fuel gas cleaning technology employed.

3 The main alternative fuels

3.1 Oxygenated gasoline

The use of oxygenated gasoline expanded considerably in the 1970s as a result of the rapid increase in oil prices. Ethers also can be used in oxygenated gasoline. The most important oxygen sources for gasoline are methanol, ethanol, methyl tertiary butyl ether -MTBE- and ethyl tertiary butyl ether - ETBE. The main problem is the corrosive properties of gasoline containing alcohol or ethers, but additives are generally effective for protection against corrosion. In terms of the emissions of pollutants, the use of oxygenated gasoline reduce the emissions of CO and HC's, with no significant changes in the emission of NOx. According to Owen & Coley (1990), in motor vehicles equipped with a catalyst the use of oxygenated gasoline reduces the emissions of CO and HC's and increases slightly the emissions of NOx. Aldehydes are increased in the exhaust gases when oxygenates are present in the gasoline, mainly because of the leaning effect; the increase is proportional to the oxygen content of the fuel.

3.2 Reformulated fuels

The interest in the concept of "reformulated" gasoline and Diesel oil to reduce pollution has grown rapidly, particularly in the USA, pushed ahead by a joint efforts of the oil and automobile industries.There is a significant correlation between the chemical composition of the fuel and its emission of unburned hydrocarbons. The concentration of these hydrocarbons - benzene, butadiene, formaldehyde, acetaldehyde and polynuclear aromatics - in the exhaust gas is also correlated to the fuel composition. The most complete set of results on gasoline reformulated combustion behavior published by the American-Oil program, shows that the use of such type of gasoline decreases the emissions of the ozone, benzene, butadiene, formaldehyde and acetaldehyde (Douad, 1995).

Reformulation of Diesel oil can contribute to reduce the emissions of CO_2, NOx and particulates. Under standard operating conditions, deeply reformulated Diesel oil reduces particulates by 30 per cent. If the engine is designed to achieve low NOx emissions, then the benefit of reformulated Diesel oil is much greater. Advanced combustion systems and reformulated Diesel oil can combine their benefits to reduce NOx by 50 per cent and particulates by 60 per cent. The european oil and automobile industries have greatly interesting reformulated Diesel. There are tax incentives -US$ 100/m^3- for the producing of reformulated Diesel oil in Northern Europe.

3.3 Synthetic fuels derived from fossil resources

The synthetic fuels are substances similar to gasoline and Diesel oil, produced from fossil primary energy sources such as coal and shale oil. Although the stage of technological development is still incipient, priority was given to this option up to the mid eighties, because of the abundance of those primary energy sources and the fact that there is no need for changes in the supply and end use structures. It is a conservative alternative, that do not go against, in the short term, to the interests of the oil and automobile industries, but do not meet the environmental constraints. The use of synthetic fuels means, at least, the same levels of pollutant emissions verified in motor vehicles burning the traditional fuels, and even potentially greater impacts because of the high concentration of cancerous and toxic components. As it is a capital-intensive option, the feasibility of synthetic fuels depends fundamentally on the regulating role of governments, and, likely, on their financial support. The likely future role of synthetic fuels, particularly because of the environmental problems, should be, at most, limited. The main processes for synthesizing synthetic fuels are the Fischer-Tropsch process, used to produce SASOL in South Africa and the Mobil process, used to produce gasoline from methanol in New Zealand.

3.4 Gaseous fuels

3.4.1 Natural gas: LNG and CNG
Compressed natural gas -CNG- and liquefied natural gas-LNG- are the cheapest gaseous fuels available today to be considered in transport activities. The world natural gas reserves are as large as and better distributed than the oil ones.

The use of LNG in transport systems is still in an early stage of development. The advantage vis-à-vis the use of CNG is the lower volume of the storage tank, that is offset by the greater complexity of the system and by its higher cost. The use of CNG requires large cylinders to store the high pressure gas -200 bar- (Douad, 1995). As the fuel density is reduced, for equal volume tanks the autonomy of a vehicle using CNG is limited to one third to one sixth of the autonomy with a conventional fuel. The Otto cycle engines running with CNG are basically adaptations of the original engines. At the end of the eighties, there were many vehicles converted to CNG in Italy, New Zealand, USA, Canada; Argentina, Indonesia, Paquistan and Thailand (Blevis & Walzer, 1990). The use of CNG in Diesel cycle engines is currently less developed than its use in Otto cycle engines; the known fleets are limited to some buses and trucks in Australia and tests units in Canada, Italy, New Zealand and Sweden. Tests have already been carried out in some large Brazilian towns with buses converted or specially manufactured to run fueled by natural gas. The feasibility of natural gas is a fuel for widespread use in transport activities depends upon an integrated substitution program, with heavy investments in the building up of a distribution infrastructure and in the development of specific engines. It is necessary that the governments act as catalysts and coordinators of the process, with the public opinion support; this implies that the consumers should be convinced that, with natural gas, the environmental problems can be minimized, with a side benefit as far as the security of supply is concerned.

3.4.2 Liquefied petroleum gas: LPG
According to Douad (1995), LPG is a clean fuel that has been use of in the Far East for taxi fleets. The recent development of an engine build by Renault to

burn LPG showed a reduction of 50 per cent in the emission of pollutants during cycle test and a reduction of more than 75 per cent at low temperatures.

3.5 Fuels derived from renewable energy sources

3.5.1 Fuels from biomass

Fuels from biomass can be produced by processing agricultural crops, as for instance, wood for methanol, sugar-cane or corn for ethanol and rapeseed, sunflower, coconuts or soya for vegetable oils. However, fuels from biomass for transport activities are not produced commercially today, with the exception of ethanol from corn and sugar-cane, primarily due to noncompetitive costs. In the case of ethanol from cane and corn, subsidies have supported commercial production. In the final use, the environmental impacts of alcohols and vegetable oils are considered less serious than the impacts of the traditional fuels. Particularly, as far as the greenhouse effect is concerned, the contribution is positive, since practically exists a CO_2 cycle between production and consumption. In the production stage, however, the impacts on the environment can be considerable. In the short and medium terms, biomass can be a feasible alternative just for substituting partially gasoline and Diesel oil.

3.5.1.1 Methanol

In the USA methanol has been produced from natural gas and naphtha. Mixed with gasoline, it has been used as an automotive fuel, with still a small distribution network. With present prices, it appears that wood-derived methanol is not an economically competitive fuel (Larson, 1993). Methanol can not be considered either a permanent option or an advantageous one regarding gasoline, but is can contribute to improve the environmental conditions in large towns, particularly as far as the concentrations of CO and NOx, and alterations of the ozone layer, are concerned (Bajay et al, 1991). The contribution of methanol substituting Diesel oil can be more significant. In heavy vehicles, methanol do not produce particulate matter and sulphur oxides and produce very little CO, hydrocarbons and formaldheyds.

3.5.1.2 Ethanol

Ethanol from sugar-cane has a high octane quality and is used neat or in blends with gasoline in some countries, notable Brazil - by far the largest ethanol producer in the world - , where gasoline subsidies the alcohol in order to reduce dependency on crude oil imports. For environmental reasons, there is a law in Brazil that obliges a mixture of 22 per cent anhydrous alcohol and 78 per cent gasoline. Ethanol is less toxic and less corrosive than methanol and emission levels are similar. Alcohol production in Brazil increased rapidly from 1975 up to the level of 13 billion litres/year by the end of the eighties, but, since then, production and productivity have been stagnant. Today, it is necessary to restructure the National Alcohol Programme - PROÁLCOOL, because since the drastic fall of the oil prices in the mid eighties, alcohol production costs have been far higher than gasoline ones. Furthermore, the share of alcohol fuelled motor vehicles in the total sales of news vehicles droped from more than 70 per cent in the middle of the last decade to less than 4 per cent in 1995 (ANFAVEA, 1996). The average cost of ethanol production in Brazil, of 0.258 US$/litter - it ranges from 10.2 to 11.1 US$/GJ (Walter, 1994) -, does not appear to be competitive on a strict cost basis with gasoline unless oil prices are above US$ 30 per barrel. The USA is the world's major producer of ethanol from corn; it is consumed there as a fuel in a 10 per cent blend with gasoline.This corresponds to about 8 per cent of total gasoline use in the USA. With no cost for the corn, ethanol would be competitive as a gasoline octane booster with oil at US$ 25/bbl, while for the corn costing US$ 100/dry tonne, the oil price would need to exceed US$ 45/bbl (Larson, 1993).

3.5.1.3 Vegetable oils

Vegetable oils have been promoted as possible Diesel substitutes due to their good ignition quality. However, their high viscosity, resulting in poor fuel atomisation, fuel injector blockage and contamination of the lubrificating oil, means that they are best blended with Diesel oil. Particulate matter, CO and hydrocarbon emissions are all higher than those of Diesel oil and, in addition, vegetable oils are associated with unpleasant odours and aldehyde emissions.

3.6 Electricity

The electrical vehicle is one of the best options to preserve in the large term the car within the current transport structure, provided that solutions can be found to the current problems related to performance - low autonomy, slow acceleration and low maximum speed -, rapid recharges should become feasible, and cheaper and lighter batteries should be developed. A decrease of the emissions in roads and streets and an increase in the power station sites may happen; the magnitude of the net effect obviously will depend on the technologies employed to generate electricity. As to the greenhouse effect, an improvement can be achieved with the use of hydropower more than with the use of natural gas, or the opposite using coal. Electric vehicles will find a niche market as inner town or commuting vehicles. The hybrid vehicle may also be of interest, particularly in the short term. The anti-pollution legislation of the California, that defines growing market shares of absolutely "clean" vehicles, created favourable conditions for continuous R&D investments in the electrical vehicle (Quandt, 1995). There are already several models of electric vehicles able to be commercialized. In California, where electric cars are classified as Zero Emission Vehicles, legislation has been passed requiring that, from 1998, 2 per cent of vehicle sales must be ZEVs, rising to 10 per cent by the year 2003.

3.7 Hydrogen

Hydrogen is the less polluting fuel that can be burnt in internal combustion engines. It is usually produced by electrolysis; the costs and environmental impacts depend basically on the electricity generation source used. Potential sources include hydropower, natural gas, coal and biomass. Hydrogen produced from biomass follows a processing route similar to methanol. Putting aside the

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environmental problems eventually associated to the production of electricity, the sole possible restriction to the use of hydrogen in vehicles is the emission of nitrogen compounds, although it is possible to keep them at acceptable levels, even without the use of catalytic converters. The main technical difficulty is storage - an expensive and heavy tank in the vehicle is necessary to contain hydrogen in a compressed gas or liquid form. The hydrogen alternative is still very expensive because all the stages of the production - end use chain are costly. The prospects for hydrogen as an automotive fuel are therefore poor in the short term.

4 Perspectives of alternative fuels in urban transport in Brazil

Gasoline an Diesel oil should continue to be the major automotive fuels in Brazil in the medium and long terms. Energy forms other than gasoline and Diesel oil, however, should have larger roles, particularly in urban transport, in the next fifteen years. Beside the increasing problems associated to the circulation of the motor vehicles in large towns, environmental restrictions and the economic difficulties in the country for increasing the supply of oil products should enlarge the market shares of alternative energy sources, such as fuels derived from biomass, natural gas and electricity. The supply structure available today - a refining capacity of 1,5 millions barrels of oil per day and 44 millions liters of alcohol per day - will be unable to meet the foreseen demands. Even with the most pessimist assumption about the future evolution of the motor vehicles fuel consumption, supply problems with the current refining capacity are expected for the year 2000 (Bajay et al. 1991).

The ethanol produced from sugar-cane should go on being used for cars, mixed with gasoline and as hydrated alcohol. A higher security of the national energy supply and the alcohol more favorable environmental impacts, compared to gasoline, are the reasons to keep it as a supply alternative. In this sense, it is interesting to point out that ethanol already plays a role in Brazil that is defended, by many analysts, for methanol in the USA. The deeper and more efficient the restructuring of PROÁLCOOL and the more competitive can alcohol be vis-à-vis gasoline, broader will be role of alcohol in the energy supply structure. A well succeeded restructuring of PROÁLCOOL and an effective competitivety of ethanol may create conditions for the penetration of vegetable oils in the Brazilian energy market. The gasoline and Diesel oil "reformulation" paths do not seen to be efficient alternatives. Gaseous fuels, specially natural gas, already start to find some room in urban transport in Brazil with the first experiences with urban buses and taxis, in large towns. This still market should be enlarged with the increase of gas supply and a large demand resulting from the likely deterioration of the environmental conditions.

In the first years of the next century, provided the initial experiences in California and elsewhere are well succeeded, the first electrical vehicles should be running in Brazil. Two market niches should be occupied by this vehicle category: small cars for urban use and light commercial vehicles for relatively short distance deliveries.

5 Conclusions

There is no doubt that, in the next fifteen years, there will be a process of partial substitution of gasoline and Diesel oil in the transport sector, particularly in urban transport. The choice of the alternative fuels will be determined by their availability and price, financial and technological resources of each country, and by their energy supply and environmental problems. In Brazil, it is likely that the substitution process will be slower than in some other countries, because no major energy supply difficulties are expected; among the several national problems, the environmental one should not get a high priority, and the country is not in the scientific and technologic forefront in this area. There are, however some alternative energy forms for which the country is in a favorable condition, due to its technological capacity already available and due to the availability or facility of access to the associated primary energy resources. In this context, it is likely the occurrence of endogenous and practically autonomous programs concerning fuels from biomass and, perhaps, from natural gas.

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