The Alternative Energy Program in Brazil*

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INTRODUCTION

According to predictions of petroleum consumptions obtained by a national oil company in Brazil (PETROBRAS), the country would have to spend between US$157 x 10^9 and US$229 x 10^9 from 1980-1987 to buy on the international market the difference between its demand and its internal production. Actually, petroleum prices will probably reach values higher than those used in the calculations above, and expenses will in consequence be higher than these values. They will be even higher if internal production of petroleum turns out to be smaller than is currently estimated. With this in mind, serious steps have been taken in Brazil to save energy and to find substitutes for petroleum derivatives. Ethanol production from vegetable sources is the most important among these substitutes.

ETHANOL AND VEGETABLE OILS

Figure 1 illustrates why ethanol is considered a permanent solution, and why large and continued energy plantations will not cause oil exhaustion, at least theoretically. The plant (tree, sugar cane, manioc, or any other plant) absorbs from the atmosphere CO_2 which, together with H_2O, are transformed by photosynthesis into carbohydrates (base molecules CH_2O), liberating O_2 to the atmosphere. At the same time, the plant absorbs nutrients from the soil (N, P, K, Ca, Mg, etc) being then transformed into ethanol and into vinasse through some appropriate industrial process. Ethanol molecules (C_2 H_2 OH) contain only C, H, and O, which are taken from the air and from water (grouped in the carbohydrates), while vinasse contains the nutrients taken from the soil.

When ethanol is burned in engines in the presence of 0_2, it liberates CO_2 and H_2O molecules which, in turn, will feed other plants for their photosynthetic process. Since nutrients removed from the soil are localized in the vinasse, this product can be put back into the soil as a fertilizer. This method is being employed in Sao Paulo, which now has an increasing sugar cane productivity. The important point is that the ethanol cycle is closed and that consequently there will always be the possibility of its production once there is availability of land, water and sun, as there is in Brazil and in many other developing countries.

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Figure 2 shows that ethanol is an excellent substitute for gasoline; the figure compares values of the octane and centane indexes and the calorific power of gasoline, Diesel oil, vegetable oils and ethanol. For Otto cycle engines, the lower calorific power of ethanol (6,400 kcal/kg) as compared to gasoline (10,500 kcal/kg) is largely compensated by its larger octane index, since this allows the engine's compression rate to increase, resulting in a consumption approximately equal for both fuels but with higher power for the alcohol engine (as will be shown later). For a Diesel

* Extracted from a report of the Servico Publico Federal, Brazilian Ministry of Industry and Commerce, July 1980.

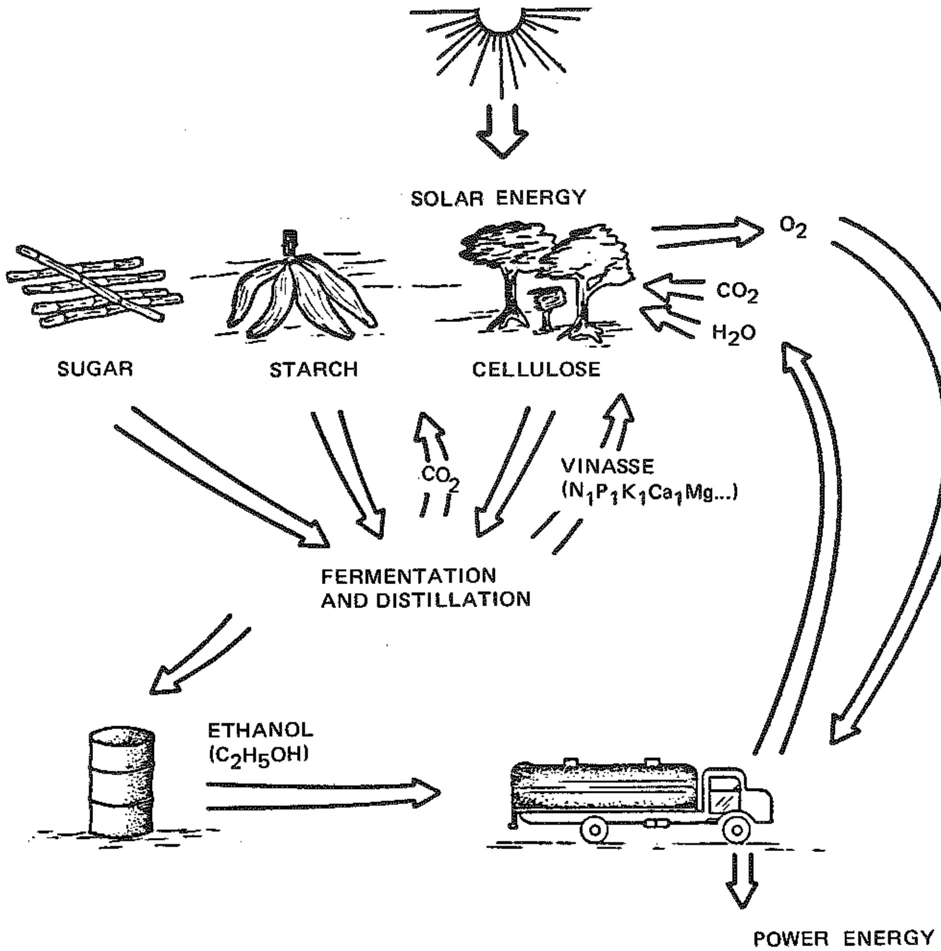
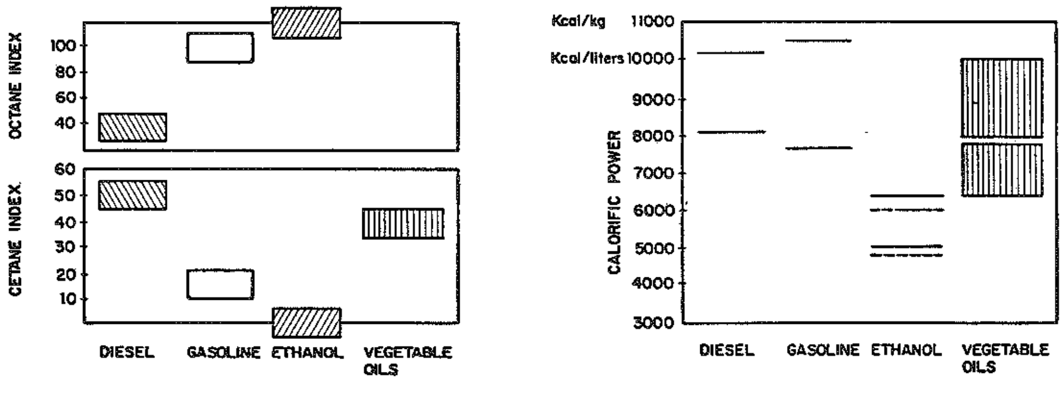


Fig. 1: The ethanol cycle



Note: Calorific power is indicated in kcal/kg (top line) and kcal/liter (below line) for each fuel. The continous line for ethanol refers to anhydrous and the dashed line to hydrated alcohols.

Fig. 2: Values of octane index, cetane index, and the calorific power of fuels.

engine, however, which already has a high compression rate, what is important for its fuel is a high cetane index and a high calorific power. Alcohol does not have these properties: to use it as Diesel fuel requires the addition of an explosive substance in a proportion varying from 5% to 20%. Besides, alcohol consumption increases by more than 65% relative to Diesel oil. For these reasons, ethanol is still considered inconvenient as a substitute for Diesel oil.

On the other hand, vegetable oils have, in general, cetane indexes and calorific power values very similar to those of Diesel oil; consequently they are possible candidates to replace it as a fuel.

GASOLINE SUBSTITUTION

The Secretariat of Industrial Technology of the Ministry of Industry and Commerce (STI/MIC) established a research program developed by the Air Space Technical Center (CTA) to look into the necessary modifications in Otto engines to optimize the use of straight ethanol and the use of this fuel mixed with gasoline. This program also studies the modifications in Diesel engines necessary to use vegetable oils or other renewable fuels for total or partial subsitution of Diesel oil. Some conclusions of the program are worth noting.

Figure 3 shows the specific consumption of an engine in relation to alcohol and gasoline blendings. Curve "A" corresponds to an engine without any modification. It shows that under these conditions blendings with less than 20% of alcohol result in a lower consumption than when using straight gasoline, and that for blendings with more than 20% of ethanol consumption grows to high values. It is necessary, then, to make changes in the engines in order to appropriately use more than 20% of alcohol blended with gasoline. Curve "B" shows the consumption behavior for engines modified to use 30% ethanol and 70% gasoline. The necessary modifications to optimize consumption for percentages higher than 20% will have about the same costs, whatever the percentage – even up to 100% alcohol.

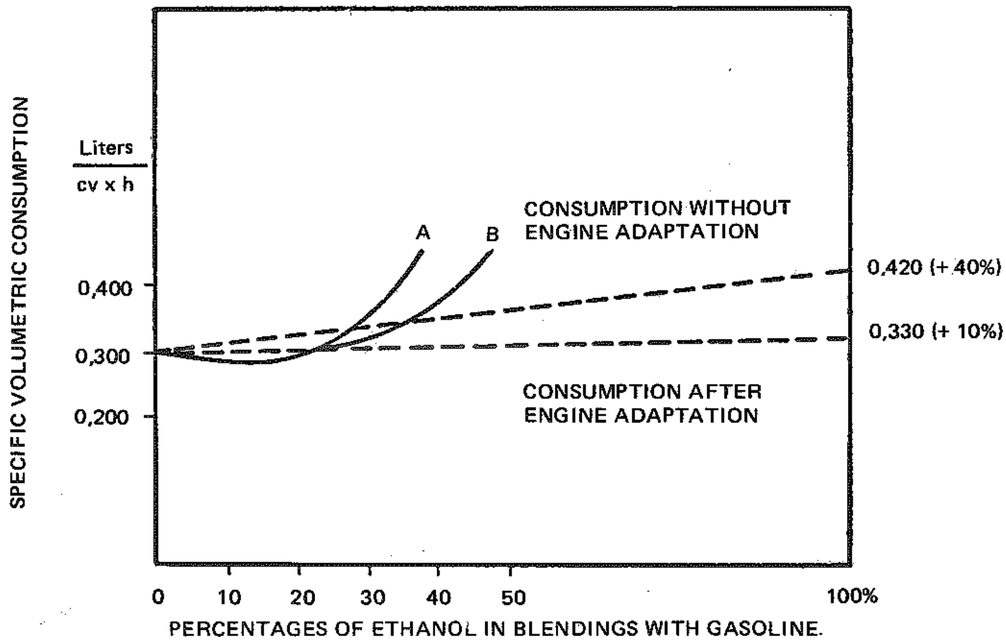


Fig. 3: Specific consumption of an engine as a function of alcohol and gasoline blendings.

Based on these experiments, the Brazilian Government took the logical decision to authorize 20% blending of alcohol into gasoline for the entire country, and to start a research program for the conversion of all types of Otto engines to the use of straight alcohol. Some of the results are shown in Figures 4, 5 and 6. Figure 4 shows that the compression rate should be about 12:1 for an engine using straight hydrated alcohol with an octane index of about 125.

Figures 5 and 6 show the behavior, in terms of power and consumption, of Otto engines using either gasoline or ethanol in relation to the compression rate and the fuel/air mixture percentages. For example, for the gasoline engine used in one of the experiments, which had a compression rate value of 6 and was regulated for a 0.08 fuel/air ratio, the resulting power was 9.5 hp and the correspondent consumption was about 200 g/hp hour. If ethanol is used in this same unmodified engine, i.e. with the same compression rate of 6, the power can be increased, say, to 11 hp (for instance), with a value 0.14 for the fuel/air ratio. However, the consumption, in this case, would double to a value of the order of 400 g/hp hour. On the other hand, by changing the compression rate to 10 and by using the chemically correct value 0.11 for the fuel/air ratio (indicated by line B), the power will increase to 12 hp and the specific consumption will remain about the same as for gasoline, i.e., 200 g/hp hour. Experiments of this kind have to be made for each type of engine, in order to optimize their power and fuel consumption.

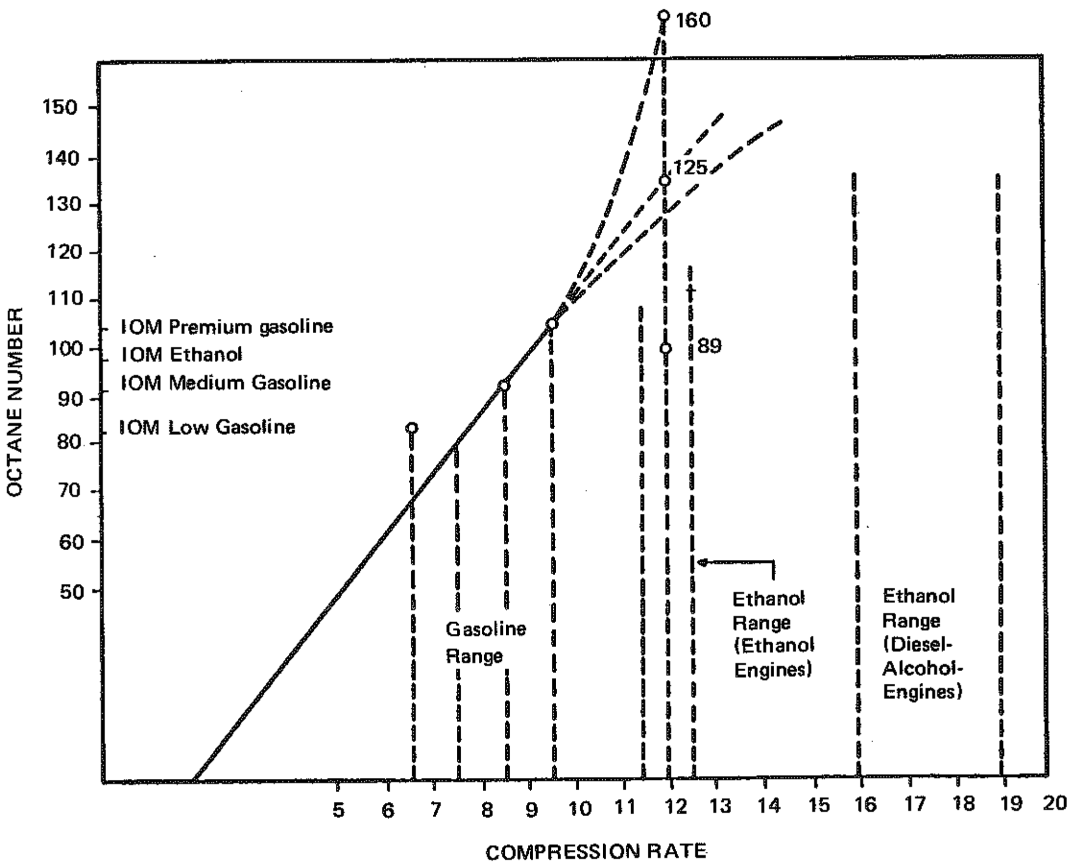
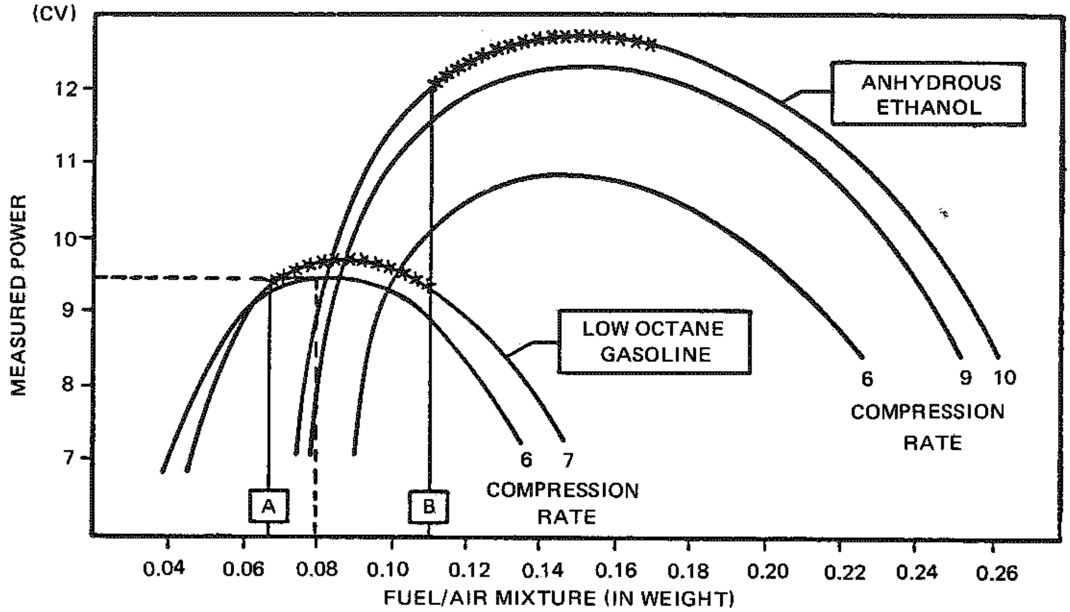


Fig. 4: Position of ethanol in the relationship of octane number with admissible compression rate without detonation.



A – CHEMICALLY CORRECT MIXTURE FOR GASOLINE
B – CHEMICALLY CORRECT MIXTURE FOR ETHANOL

Fig. 5: Power of Otto engines using either gasoline or ethanol as a function of the compression rate and of fuel/air mixture percentages.

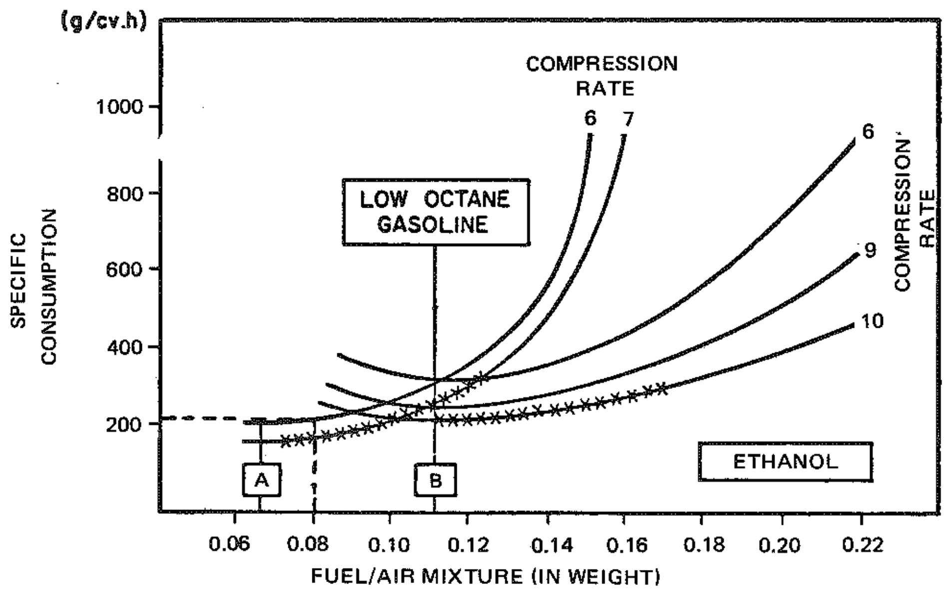


Fig. 6: Specific consumption of Otto engines using either gasoline or ethanol as a function of the compression rate and of fuel/air mixture percentages.

Experiments have shown that in general the global efficiency for Otto engines using ethanol is about 38%, which means that 38% of the ethanol energy content is transformed into useful energy, while for gasoline the corresponding efficiency is only about 28%. Actually better results can be obtained if the engine is specially conceived for the use of ethanol.

To convince the public about the technical feasibility of hydrated ethanol as a fuel in modified Otto engines, a long trip was organized for three different types of cars running over 8,000 kms on different kinds of roads in Brazil. Several journalists accompanied this expendition, and one stationary wagon transported the alcohol fuel. No technical problems were encountered and the trip was a success.

The technology for conversion of the most used engines in Brazil was then transferred to a private company. In a short time, some hundreds of cars were converted for ten urban service company fleets in seven cities. These fleets were kept under rigorous technical control, and during the 100 million km experiments on roads, monthly meetings were held to discuss and to point out solutions for the technical problems, resulting in one of the most extensive controlled technological experiments in the world.

The STI has recently decided to transfer the results of this experiment to Brazilian enterprises, having created for this purpose 13 technological centers in several regions in the country, through which the companies receive information and technical assistance needed for the best possible conversion of engines. More than 200 companies applied to use this conversion technology; they are now acquiring equipment and training their technicians in accordance with STI instructions, and about 110 of them have already been authorized to convert used cars. At the moment, there are 60,000 cars in Brazil running exclusively on ethanol. By the end of the year this number will increase to 200,000, and in 1982 will be over a million.

DIESEL OIL SUBSTITUTION

1. *Vegetable Oils*

As was already pointed out in connection with Figure 2, the best substitutes for Diesel oil are vegetable oils, whose chemical properties and behavior in Diesel engines have been investigated for a long time in Brazil. The National Institute of Technology (INT/STI), for instance, published an interesting paper on this subject as far back as 1942. The research program has recently been reactivated by STI, and now several technical institutes are working on this subject – EMBRAPA, INT, CTA, IME, CEPED, ITAL, and others.

Practically all vegetable oils produced in Brazil were tested in Diesel engines, with encouraging results. Without modifications, they work well with blendings of up to 30% of vegetable oil and 70% of Diesel oil. With minor modifications, Diesel engines also work with straight vegetable oil, although some small problems related to carbon deposits in the combustion chamber still have to be solved. From the technical point of view vegetable oils can thus partially or totally replace Diesel oil in Diesel engines, and some of them with advantage over fossil fuel. However, there are some economic and agricultural difficulties, since existing vegetable oil production is already committed to food, exports and siderurgy. Also, agricultural productivity is still very low, except for dende (palm oil), avocado macauba, and a few other products.

Before deciding to use vegetable oils as one of the possible substitutes for Diesel oil, STI, together with EMBRAPA and other agencies, is compiling farming data, notably on suitable areas, specimens, productivities, etc, as well as economic data on industrial and agricultural processes, internal and international markets, etc.

2. *Other Solutions*

Other solutions have been tested to replace Diesel oil: a) ethanol with additives; b) the double feeding system with two tanks, one with ethanol and the other with Diesel oil; c) other partial solutions.

a) *Ethanol with an additive* is one of the solutions tested by the industry. The main advantage is that minimal modifications are necessary in the engine. Due to its low cetane index value, ethanol does not explode when injected after the air is compressed in the combustion chamber, and consequently it is necessary to add some explosive substance to it. Several additives have already been tested by some industries, notably tri-etil-amine, exil-nitrate and 2 etoxinitrate. In general, the amount of additive to be blended to Diesel oil varies from 5% to 20%. In laboratory tests, the consumption of this fuel is increased by a factor larger than 1.6, and on roads larger than 1.75. This higher consumption, the high cost of additives (and of ethanol as compared to Diesel oil) as well as the still unknown polluting effects produced by the additives, are the main factors delaying the decision to use ethanol as a substitute for Diesel oil.

b) *The double storage and feeding system* is another solution which has already been tested, and consists in introducing one or more fuel injectors connected to an ethanol tank. Ethanol is injected into the combustion chamber immediately after the Diesel oil has exploded. One alternative to this solution, which seems to work better, consists in introducing one carburetor where Diesel and ethanol are mixed together before going to the combustion chamber. The changes in engines are simple and allow the use of up to 50% of ethanol and 50% of Diesel oil. This solution can immediately be put into practice, depending on the production costs of ethanol as compared to Diesel oil.

c) *Other partial solutions* – As has already been pointed out, vegetable oils can totally or partially replace Diesel oil in Diesel engines, but some economic and agricultural uncertainties have still to be defined. Consequently, other partial solutions were also sought and different mixtures involving ethanol, gasoline, Diesel oil, and vegetable oils (with and without additives), were tested; the overall results show that these mixtures can replace up to 10% Diesel oil without any modifications in the engine. Some of the results are indicated in Table 1. From the technical point of view, these solutions can be adopted immediately, but they will not substantially change the petroleum consumption picture.

Table 1: Results of tests with mixtures used to replace Diesel oils

MIXTURE	PROPORTIONS	Variation in relation to Diesel Oil		OBSERVATIONS
		Power	Consumption	
Anhydrous Ethanol and Diesel Oil	7% Ethanol + 93% Diesel	– 4.4%	– 2.4%	Between 0^{o} C and 4^{o} C, the mixture is not homogeneous (2.5% of ethanol separates)
	3.5% Ethanol + 96.5% Diesel	– 0.7%	– 0.8%	Homogeneous mixture at temperatures over 0^{o} C.
Anhydrous Ethanol Gasoline (and Diesel Oil)	4.5% Ethanol 4.5% Gasoline 91% Diesel	– 2.6%	– 0.4%	The maximum of mixture allowed without alteration in the motor is 10% (5% ethanol + 5% gasoline). The mixture has to be in the same proportions.

Table 1 (Cont.)

MIXTURE	PROPORTIONS	Variation in relation to Diesel Oil		OBSERVATIONS
		Power	Consumption	
Anhydrous Ethanol Vegetable Oil and Diesel Oil	33% Ethanol + 33% Castor Oil + 33% Diesel	–35%	+59%	Chemically homogeneous mixture.
	80% Ethanol + 20% Castor oil	–20%	+38%	2 stroke Diesel motor from Detroit Diesel Allison of Brazil.
Diesel Oil and Vegetable Oils	Intol 220 (Diesel + Soybeans oil)	+ 1.5%	+ 1.0%	Other vegetable oils are being studied. The utilization of vegetable oil requires the realization of economic, agricultural, social and ecological studies.
	Intol 420 (Diesel + Babacu oil)	+ 1.6%	+ 3.4%	
Diesel Oil, Ethanol and Additives	7% Ethanol + 1.25% iso-amilic alcohol + 91,75% Diesel	– 2.6%	– 0.4%	Other additives are under research by industry.
	10% Ethanol + 2 octilic alcohol 88% Diesel	– 5.7%	+ 3.4%	Research is under way.

Finally, according to the evolution of petroleum prices and the development of technologies for alternative solutions, as well as the evolution of ethanol and vegetable oil production, a more drastic solution could be envisaged for the future, namely the substitution of Diesel engines by Otto engines adapted to use straight alcohol.

BRAZIL'S "PROALCOOL" TARGETS

The main target of Brazil's National Alcohol Program – PROALCOOL – is to replace the increase in gasoline consumption by ethanol in such a way that the level of gasoline consumption in 1985 will remain the same as in 1973. Another consists in gradually increasing the use of ethylene from ethanol until its consumption reaches a minimum of 1.5 billion liters in 1985. To accomplish these targets, ethanol production should reach a minimum of 10.7 billion liters in 1985, requiring 316 new distilleries (with 150,000 liters/day capacity each). The necessary investments will be of the order of 4 to 5 billion dollars. An estimated production of 14.5 billion liters is expected in 1987.

The above mentioned distilling capacity was considered only for economic calculations. Actually, smaller distilleries with a capacity of 10,000 liters/day are under consideration because many more private companies could afford to build and operate them. With such distilleries income will be better distributed and many more people can be settled in villages and in small cities.

The partial substitution of all petroleum derivatives, involves some important economic considerations. For example, 10.7×10^9 liters of ethanol, in 1985, will reduce consumption of gasoline and petrochemical products to about 45%. If 33% of Diesel oil could be replaced by vegetable oils and/or alcohol, there would only remain to be replaced a correspondent amount of fuel oil. This could be reached by a combination of all other energy sources, such as mineral and vegetable coals, wood, bagasse, hydro-electricity, etc. We could thus have savings of about 33% in the consumption of all petroleum derivatives, meaning a reduction of about 41% in petroleum imports. This would save more than US$ 60 billion in imports.

Plans of action have already been approved to replace fuel oil by mineral and vegetable coals in the cement, cellulose, paper, siderurgy and ceramic industries. The government also authorized the production of 900 thousand new cars to use straight hydrated ethanol until 1982, and conversion to the use of ethanol of 270 thousand used cars, i.e., totaling 1,170 million cars using only ethanol as fuel in the year 1982, besides continuing blending 20% of ethanol to gasoline for all other Otto engine powered cars.

Measures are being taken to reach the approved PROALCOOL targets with a minimum of investments. One of them is to increase industrial productivity, and mainly to increase agricultural productivity of sugar cane, manioc, and other vegetable raw materials. Others aim at diversifying raw material production, to use regional potentialities, such as agricultural and forestry wastes, bagasse, pineapple, babacu, etc. For that purpose a large research program is necessary in order to enable design of industrial projects for plants that can operate economically whatever their capacities, large or small, and whatever the raw materials used.

Technological processes have been developed for the fermentation of several raw materials, providing the basic engineering projects for ethanol plants using manioc, babacu and cellulose. In addition, technology was developed for engine adaptation to the use of ethanol in an experiment with 5,000 vehicles with 100 million kilometer on roads, under total technical control. That program also turned into reality the economic use of vinasse as fertilizer, avoiding its polluting effects. Tests have also been carried out not only to study the different potentialities but also to develop industrial technologies that could be transferred to the country's productive sectors.

Data obtained through a project financed by STI prove that there is a potential to produce 80 liters of ethanol per ton of sugar cane, and an average of 60 tons of sugar cane per hectare/year, (i.e., a production of 4,800 liters per hectare/year); this means a 37% increase over the average Brazilian 3,500 liter/ton productivity, from 70 liters/ton and 50 ton/ha. It is estimated that in the year 2000 it will be possible to produce 7,000 liters/ha yr of enthanol. This could be obtained through more productive sugar cane varieties (75 ton/ha yr or more), higher sugar contents (18% of total weight), and by improving the industrial process to obtain close to 100 liters of ethanol per ton of sugar cane.

Bagasse could also be utilized through the acid hydrolysed method to add about 1,000 liters of ethanol per hectare/yr, besides its use as an energy source to operate the distillery. Bagasse is available at the distilleries, with no transportation costs. On the other hand, all fermentation and distillation facilities can be used to process it. Within these perspectives, the economic use of residues (mainly vinasse and bagasse) is of high priority to solve pollution problems and to lower production costs of ethanol.