

Brazilian biofuel program: An overview

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Brazilian National Bio-Fuel Program comprises ProAlcool and Biodiesel; the former was initiated in 1975 to substitute gasoline for sugarcane alcohol in automobile use. ProAlcool passed through intensive changes due to fluctuant social-economics situation and public policies, which are fundamental to definitely install the use of biomass and make it competitive to face traditional fossil fuels. The production of flex fuel cars is bringing great promise for ProAlcool, not only for Brazilian market but also for rest of the world. In parallel, program of vegetable oils – OVEG, conceived in 1983, gave significant contribution to the automotive applications of vegetable oils (biodiesel) in vehicles. The fleet tested ran more than one million km at that time. The results demonstrated the technical feasibility of using vegetable oils in diesel engines.

Keywords: Biodiesel, Ethanol production, Sugarcane

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The Brazilian National Alcohol Program - ProAlcool

Brazil is the seventh most important agricultural country in the world. Among coffee, soybeans, cassava and fruits, sugarcane has been one of the main products in the last decades. In 1970, 50 million tons of sugarcane was produced yielding approx 5 million tons of sugar. After 26 years, the production reached 273 million tons yielding 13.5 million tons of sugar and 13.9 billion liters of alcohol (ethanol). In 2003, the perspective of sugarcane production was around 333 million tons with 22.4 million tons of sugar and 13.92 billion liters of alcohol. During January-April 2005, record export valued at US\$ 12,244 billion, which was over 14.6 percent of the exports of the same period of 2004. For sugar and alcohol, it represents an increase of 68.3 percent of Brazilian exportations. The sugarcane production reached 378.51 million tons with alcohol production almost reaching 15 billion liters. This favourable situation of the alcohol sector indicates the effort made by the government to restart the Brazilian National Program of ProAlcool.

ProAlcool, started in the mid-1970's, was described as the answer to the first oil crisis as well as a solution to the problem of the fluctuation of sugar prices in the

international market¹. The government intensified the use of a mixture of ethanol (24%) and gasoline (76%) to fuel common cars. Since then, the automobile industry has produced alcohol-fuelled cars reaching, in the middle 1980s, the apex of the alcohol era². After its glorious phase, the alcohol production began to find some problems such as the significant oil prices drop.

The paper presents a brief historical presentation of evolution of the ProAlcool and its perspectives for the next years.

Brief history of ProAlcool's Social-Economical Evolution

Since the early part of the last century, Brazil started to use ethanol as fuel, although it was not until the 1930s that ethanol-gasoline blending took place on a significant scale³. The oil crisis and the low prices of the sugar in the 1970s push Brazil to the beginning of a new strategy to by-pass this situation. The ProAlcool was set up in 1975 when energy supply became a main priority. The objective was to slow down the energy consumption, so as to maintain economic growth, by producing ethanol from biomass (sugarcane, cassava and sorghum) to substitute gasoline. Sugarcane was the chosen substrate for ethanol production due to its great adaptation to the Brazilian soil and weather conditions. In this phase, the anhydrous alcohol (up to 20%) was mixed to

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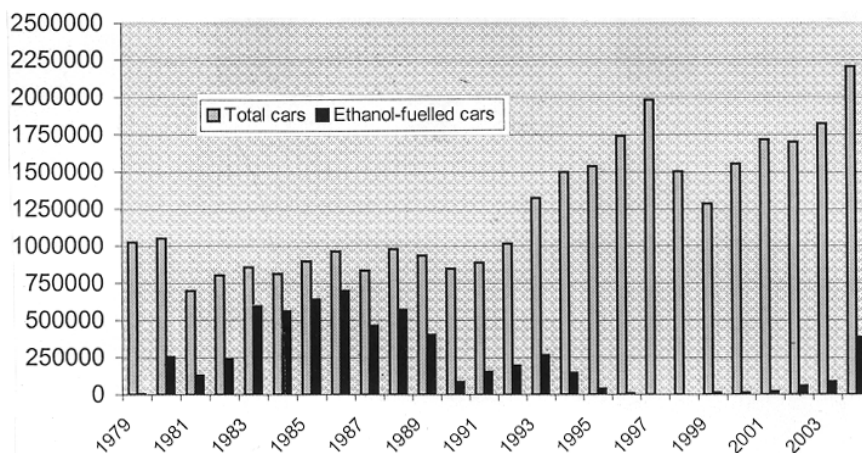


Fig. 1—Brazilian production of car¹²⁻¹⁴

gasoline. However, to attain this condition, the alcohol production would have to increase from 600,000 l/y to 3 billion l/y. Another fact was that there was no rigid commitment to supply alcohol intensively, since the proportion of alcohol in the mixture, which could vary without affecting car efficiency and alcohol production, was still low. If the sugar prices fell, alcohol could be produced instead and vice-versa.

In phase two, from 1980, the Brazilian government kept subsidizing the vast expansion of sugarcane capacity and industrial investment in mills and distilleries. Automobile factories started to produce only-alcohol-fuelled cars whose technology was developed in the universities and research centers². This phase was marked by the plants, only processing autonomous alcohol and built using government subsidies to achieve the agricultural output necessary to fulfil future demand for alcohol. These plants could not produce sugar as an alternative of end product.

In both phases, government interventions were very important to increase alcohol production and consumption. The rapid growth in hydrated ethanol production resulted in large surplus of gasoline which had to be exported, forcing Petrobras to make costly changes to oil refining structure.

Later, in 1984, passenger cars (94%) were fuelled by ethanol (Fig. 1). ProAlcool's credibility began to fall due to rapid increase in ethanol-fuelled passenger cars and stagnation of ethanol production, which was caused by low prices of ethanol paid by sugarcane growers, political uncertainty toward the programme, negative attitude of Petrobras, lower costs of imported ethanol and methanol, increased domestic oil

production, lower costs of oil in the international market, international political changes after the collapse of the USSR, and other factors³. Five years later, only 51 percent cars were ethanol-fuelled.

In 1989, the Brazilian alcohol production reached 11.7 billions liters. More than 4.5 million cars were fuelled by alcohol only and the other 9.5 billion by a mixture of alcohol-gasoline². The period 1990-1994 was marked by a political uncertainty. Vehicles were mainly using gasoline blended with ethanol, and not neat ethanol-powered cars, despite impressive technical advances with the ethanol engine. In 1996, sugarcane production reached 273 million tons, which represented 13.5 billion tons of sugar and 13.9 billion liters of ethanol. The beginning of 2005 was not good for the sugar-alcohol sector, which showed an increase in the production of sugarcane and derivatives not followed by the increase in the demand. The break of sugarcane production, caused by the weather, forced the use of remaining production of alcohol (2 billion l) of 2003. Brazilian exportation is increasing significantly and the appearance of the flex-fuel cars could guarantee a favourable situation for the sector⁴. New perspectives are coming for the Brazilian National Alcohol Program.

Process Ethanol Production in Brazil

In Brazil, the batch fermentation process, known by Melle-Boinot process, was traditionally used for ethanol production. This method was modified by a fed-batch process with cell recycle which is called the modified Melle-Boinot process⁵. The alcoholic fermentation consists of saccharification, where saccharose is hydrolysed into glucose and fructose by

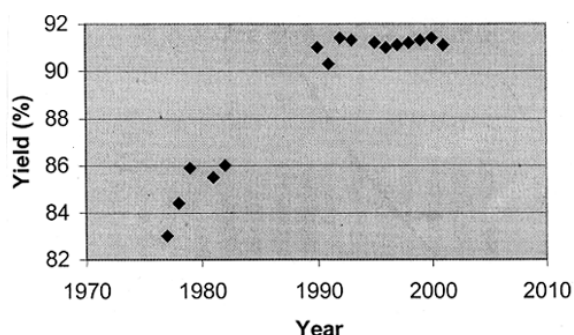


Fig. 2—Relation between the theoretic and stochiometric yield of fermentation

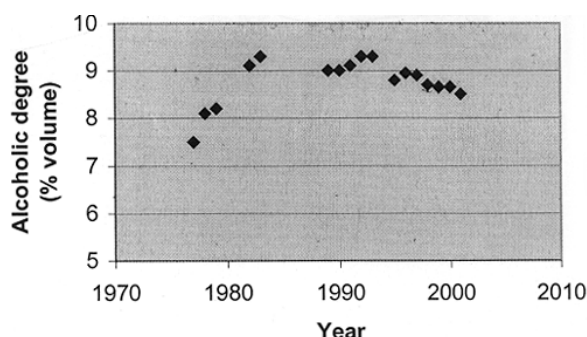
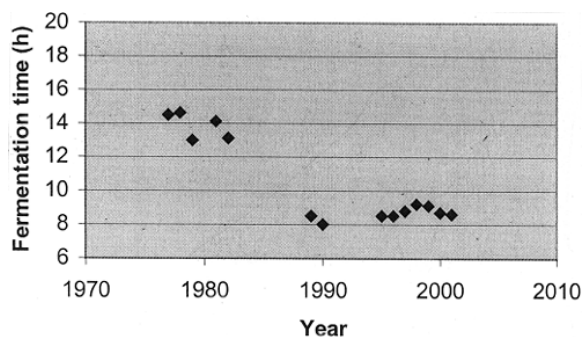
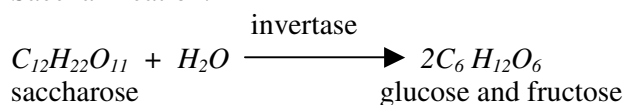


Fig. 3—Evolution of the alcoholic degree



the action of an invertase. This is followed by enzymatic fermentation catalysed by zymase, produced by *Saccharomyces cerevisiae*⁶. The sugarcane juice is fermented for ethanol production. Before fermentation, sugar concentration is adjusted to desired level with the aid of molasses and the juice from the evaporators.

Saccharification:



Alcoholic Fermentation:



The 70s and 80s were very significant⁷ for Brazilian distilleries (Figs 2-4) showing a gain in productivity (200%), in alcoholic degree (20%) of the wine and the total yield (10%). From 90s, there are some technological barriers such as sugar concentration of the used raw material and the availability of optimized yeast strains with good adaptation ability to the competitive environment of an alcoholic fermentation⁸. Optimized yeasts with better tolerance to alcohol are being developed. Traditional yeast strains are incapable of competing with selvage strains which contaminate the industrial processes⁹.

In Brazil, new installations are being projected with an optimized technology of employing continuous fermentation systems¹⁰, which possess numerous advantages as follows: i) Uniformity of the obtained product; ii) Significant reduction of non-productive time in the industrial plant; iii) Reduction of the amount of nutrients added to the medium; and iv) Facilities to introduce automatic control of the process with the guarantee of the final quality of the product. There are industrial unities (25%) employing the continuous process⁷ named “the Copersucar Continuous Process”, which uses a multistage system where the first stage is responsible for 90 percent of sugar conversion. The other stages conclude de-fermentation process. These modern unities of continuous fermentation have the same flexibility of the conventional ones and need lower investments⁵. After fermentation the yeast-free wine is sent to the distillation unity where it will be purified and concentrated.

In Brazil, in the Center-South, the yield⁸ in the distillation stage is very high (99.6 %). There is a possibility of enhancing this results which is related to the use of membranes or molecular sieves reducing the process's vapour consumption in the operation. Despite the existence of new possibilities to the optimization of process of ethanol production, there are no expectations of a significant amelioration in the sector. However, in the past (1980-2005) the cost of ethanol production was reduced three times^{7,11}.

Ethanol as Fuel

The different ethanol fuels produced are used in a variety of ways (Table 1). Ethanol has a higher octane

Table 1—Fuel-ethanol producers and common motor fuel formulations⁹

Country	Crop	Product	Fuel ethanol production 10 ⁹ litres	Fuel	Ethanol content % v/v
Brazil	Sugarcane (juice and molasses)	Hydrous	10.5 (in 1999)	Hydrous ethanol	95.5
		Anhydrous	6.5 (in 1999)	Gasoline	24
USA	Maize (95%) plus some wheat and barley	Anhydrous	5.3 (in 1998)	E85	85
				E10	10
				Oxygenated fuel	7.6
				Reformulated gasoline	5.7
Canada	Maize plus 15% wheat	Anhydrous	0.24 (in 1998)	—	—

Table 2—Brazilian production of sugar and alcohol

Year	Sugarcane tons	Sugar tons	Anhydrous alcohol m ³	Hydrated alcohol m ³	Total alcohol m ³
94/95	240.867.791	11.700.464	2.873.470	9.892.440	12.765.970
95/96	249.876.575	12.651.084	3.057.557	9.659.202	12.716.759
96/97	289.520.522	13.631.888	4.629.340	9.801.109	14.430.449
97/98	302.198.516	14.847.044	5.699.719	9.722.534	15.422.253
98/99	315.640.797	17.960.587	5.679.998	8.246.821	13.926.819
99/00	310.122.784	19.380.197	6.140.769	6.936.996	13.077.765
00/01	254.921.721	16.020.340	5.584.730	4.932.805	10.517.535
01/02	292.329.141	18.994.363	6.479.187	4.988.608	11.467.795
02/03	316.121.750	22.381.336	7.009.063	5.476.363	12.485.426
03/04	357.110.883	24.944.434	8.767.898	5.872.025	14.639.923
04/05	381.136.577	26.327.355	8.183.393	6.975.570	15.158.963

Source: Ministério da Agricultura, Pecuária e Abastecimento, 2005 a,b

rating than petrol, enabling combustion engines to run at higher compression ratio and thus giving a net performance gain (approx 15% w/w), even though a litre of pure ethanol contains only about two-thirds of the calorific value of a litre of conventional gasoline⁸. Ethanol's flammability in air is lower than that of gasoline, which reduces the number and severity of vehicle fires. The lower (21.2) and higher (23.4 MJ/l) heating values of anhydrous ethanol are less as compared to lower (30.1 MJ/l) and higher (34.9 MJ/l) heating values of gasoline¹. In Brazil, ethanol is used as octane enhancer in gasoline in the form of anhydrous ethanol at a mixture called gasohol [anhydrous ethanol at 99.6 Gay-Lussac (GL) and 0.4% water]. The hydrated ethanol is used in the neat-ethanol engines at 95.5 GL.

The great ethanol's properties have led to heavy research investments and, consequently, to the development of modified engines for the ethanol-gasoline mixture. Up to 1980, the Centro de

Tecnologia Aeronáutica (CTA), in the state of São Paulo, was the first to conduct tests with engines running with ethanol-gasoline blend and straight ethanol. Until 1988, manufactures (GM, Ford, Volkswagen, Fiat) developed carburettor-based systems. Later electronic fuel injection systems were available for all engines¹. In 2003, a new technology has arrived in the car industry. The developed flex-fuel car can use only ethanol, gasoline or both representing a new advantage for the consumer and could create new perspectives for the sugar-alcohol sector.

Panorama of Sugar-Alcohol and Vehicles Sector

The production¹²⁻¹⁴ of sugar and alcohol has increased during 1994-2002 (Table 2). However, ethanol-fuelled cars market (Fig. 1) had a significant fall in 1994 when cars were using mainly gasoline blended with alcohol. At this time, ProAlcool was suffering with the Brazilian political uncertainties.

From 2002, ethanol-fuelled cars reappeared in market bringing a new perspective for the sector. Since March 2003, the vehicle's industry has been producing flex-fuel cars representing a new revolution for the Brazilian industry of ethanol. In January 2004, 14.4 percent of the commercialised cars were flex-fuelled. In 2004, the market¹⁵ for flex-fuelled car technology (23%) was higher than for straight ethanol cars (3%). Actually, the production of alcohol is increasing significantly (> 15 billion l) and with this favourable situation there is also an increasing interest on flex-fuelled cars. In 2005, the Brazilian market for flex-fuelled cars has increased significantly (39%) as compared to straight-ethanol cars (3%). It certainly creates great promises for the ProAlcool¹⁶.

Brazilian Biodiesel Program

The Program of vegetable oils (OVEG), conceived in 1983¹⁷, gave a significant contribution to the automotive applications of vegetable oils in vehicles. The fleet tested ran more than one million km at that time. The first biodiesel researches reported in Brazil began in 1970, when the Federal University of Ceara (UFCE), started to develop a new fuel (PRODIESEL) originated from vegetable oils and with properties similar to those of conventional diesel¹⁸. A succedaneum of vegetable kerosene for jet planes was also developed at UFCE by the end of 1982. After exhaustive bench and turbine tests, the new fuel called PROSENE was approved and homologated by Brazilian Airspace Technological Center (CTA). Parente¹⁹ authored first Brazilian patent on biodiesel and vegetable aviation kerosene in 1980. Because of several reasons, including the reduction in petroleum prices, the production of PRODIESEL was discontinued.

Many research groups began to study biodiesel and many tests with biofuels were performed since 1980 in Brazil. One carried through in Curitiba, from January to March 1998 was distinguished²⁰. The biofuel (20% soybean-based biodiesel, 80% diesel) showed reduction in air pollution during the tests. American Soybean Association donated biodiesel was used in 20 buses during three consecutive months and results demonstrated a reduction in smoke emissions (35%).

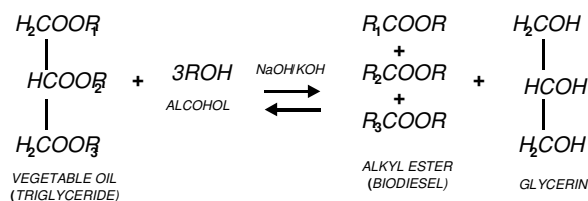
Design of Present Brazilian Biodiesel Program

The turbulence in the international petroleum market in the 90s, allied to pressures of environmental agencies on the automotive sector and the

introduction of Sustainable Development Concept, raised the interest on biodiesel again. Aiming the promotion of the scientific and technological development of ethyl esters of pure vegetal oils and/or residual oils, the Ministry of Science and Technology (MCT), created the Brazilian Program of Technological Development of Biodiesel (PROBIODIESEL) in 2002²¹. The main objective of PROBIODIESEL was to provide technical and institutional support for the widespread use of biodiesel in Brazil, as well as to develop production technologies. The main executor²² of PROBIODIESEL is the Brazilian Reference Center for Biofuels (CERBIO), located at Parana Institute of Technology (TECPAR), in Curitiba. CERBIO focus its actuation on the quality assessment of biofuels, the technological development of new routes for biodiesel production using different raw materials and the application of biodiesel in engines, by executing and monitoring bench and fleet tests. In July 2003, an Inter-ministerial Work Group²³ was created for biodiesel actions in Brazil. As a result, Federal Government Law N 11097 from January 13, 2005 authorized addition of biodiesel (5%) in petro diesel all over the country. According to government sources²⁴, about 740 million liters of biodiesel will be necessary to prepare the mixture.

How will biodiesel be produced in Brazil?

Brazilian government supports adoption of most known and wide-scale used process for the production of biodiesel, transesterification, which uses an alcohol (ethanol or methanol), plus a catalyst, to convert fatty acids of vegetable oils into methyl or ethyl esters, the biodiesel²⁵. Because of the abundance of ethanol, a renewable and ecological product, ethylic route is preferred. From the chemical point of view, to transesterify means to take a molecule from a triglyceride or a complex fatty acid, to neutralize the free fatty acids, to remove glycerin and to create an ester as follows:



The glycerin can be used by cosmetics industries for soap production and biodiesel is burned directly in

Table 3—Comparison among some properties of soybean and sunflower biodiesel with conventional diesel²²

Characteristic	Conventional diesel	Soybean oil biodiesel	Sunflower oil biodiesel
Density, kg/m ³	851.0	878.0	952.6
Kynematic viscosity at 40°C, mm ² /s	3.1	4.5	8.5
Flash point, °C	41.5	183.7	192.3
Cold filter plugging point, °C	6	7	-6
Total sulphur, %	0.15	< 0.05	< 0.05

Table 4—Requirements for biodiesel B100 according to National Petroleum Agency Resolution 42

Parameters	Limits
Aspect	Clean and without impurities
Flash point	Minimum 100°C
Water and sediment	Maximum 0.05 vol. %
Dynamic viscosity at 40°C	Take note
Sulfated ash	Maximum 0.02 mass %
Total sulfur	Take note
Total contamination	Take note
Ester content	Take note
Distillation, 90% of recovered volume	Maximum 360°C
Carbon residue	Maximum 0.10 mass %
Specific gravity at 20°C	Take note
Sodium + potassium	Maximum 10 mg/kg

diesel cycle engines. One matter of great concern and controversy is that related to the excessive offer of glycerin resulting from large-scale production of biodiesel.

Some Properties of Biodiesel

Biodiesel has properties similar to those of conventional diesel (Table 3). It is virtually free of sulphur and aromatic hydrocarbons and has a high cetane number. Viscosity and flash points of biodiesel are more than those of diesel. Market for biodiesel is quite specific and directly associated to agricultural activities. Biodiesel from residual oils has a great environmental appeal. Finally, the price is relatively superior to commercial diesel²⁶, possibly the only disadvantage.

Raw Materials for Biodiesel Production in Brazil

Main raw materials include vegetable oils (Table 4), animal fats and residual oils. Oil content of some main oilseeds of Brazil for biodiesel are as follows: soybean, 17; sunflower, 38-48; peanut, 40-43; cotton, 15; castorbean, 50-55; babassu, 66; rapeseed, 40-48; palm, 20; and coconut, 55-60 %. Animal fats for the production of biodiesel include

bovine tallow, fish oil and pig fat. In the case of residual oils, the potential sources of frying oil would be restaurants, snack bars and industrial catering services. Besides, mud from sewage treatment systems and residual water from food industries can be useful as raw materials for biodiesel production, as such residues are rich in fatty acids²⁷.

Use of Biodiesel in Brazil

Market Aspects

Market aspects of biodiesel in Brazil are highly influenced by its production costs. The major obstacle in trading biodiesel in the country is raw material costs, which make sale prices very high²⁷. Some preliminary diagnosis on the economic viability of biodiesel²⁸, show that for soybean oil derived biodiesel, the production cost would be around US\$ 0.40/l. The economical feasibility currently passes through tributary, fiscal and market evaluations. International biodiesel programs having tributary mechanisms that made them viable are taken as references²⁵. Government considers that, beyond the estimations detached above, wide-scale industrial production of biodiesel plus the additional values aggregated to by-products resulted from the productive chain of biodiesel can contribute to lower the sale price of biodiesel or at least, make it similar to diesel.

Social Aspects

The implementation of an energy program, involving exploitation of vegetable oils and other materials from biomass, opens chances for great social benefits resulting from the high index of job creation, culminating in the valorization of country land and promotion of agricultural workers. In a recent estimate²⁹, a US\$ 228.3 million investment can generate about 1,350,000 new jobs. There are thousands of families settled in north and northeast regions and involved in agrarian reform projects. They have infrastructure, habitation, electric energy,

water and especially organization. However, the majority of the settlements does not have sustainability and depends on the government assistance in case of draught²⁷. A consortium of castor beans and French beans, could contribute for the sustainability of these settlements.

The same premises apply to other parts of the country, where regions need development, even in the most progressive states. Familiar agriculture can equally be privileged in South region as to stimulate the production of raw materials such as sunflower and radish seed. In Paraná State, one of largest producer of agricultural products of the country, the government has as priority, the execution of a program directed to the production of biodiesel, which is considered a decisive factor in the development of agricultural energy. As results, familiar agriculture will be supported and men will be held at their lands with adequate conditions of subsistence. Besides, the incentive of using biodiesel in small communities will contribute to reduce fossil diesel consumption and to lower the cost of food production. This agriculture of energy will allow the raw material producers to still sale the grains for posterior processing or, to produce their own biodiesel. The by-products come from biodiesel production process could be used in animal feeding or other forms to be studied³⁰.

Environmental Aspects

The use of biodiesel in road and urban transport offers great advantages to environment, in view that emission of pollutants is minor than that of diesel and taking in account their re-absorption by the plants. Moreover, smoke emissions are reduced (90%) and the emissions of SO₂ are practically eliminated^{26,30-32}. R & D, during decade of 1980 in Brazil using transesterified vegetable oils, had demonstrated good results in environmental terms when biofuel was used in trucks and tractors engines, both pure and in B30 mixtures³³. About 80 thousand liters of biodiesel had been tested in a B20 mixture, providing satisfactory results concerning pollutants emissions³³⁻³⁵.

Quality of Biodiesel

In order to guarantee the good performance of the engines and their fuel injection systems, all biodiesel manufactured in Brazil will have to rigorously conform to ANP specifications, independently from the raw material or technological route used (Table 4). The specifications will certainly have adjustments as

Brazilian Biodiesel Program proceeds. The main concern refers to parameters that are relevant to the adequate functioning of fuel injection systems and diesel engines.

Future Perspectives

There is a national consensus on the importance of stimulating production of biodiesel in Brazil, with emphasis on ethyl route, because of the social benefits, as well as the environmental gains from the mixture of biodiesel to petroleum diesel. The introduction of biodiesel into the market will represent a new dynamics for the agro-industry, with its consequent multiplying effect in other segments of economy involving vegetable oils, alcohol, diesel and more incomes and by-products of the production of ethyl esters³⁶. However, viability of biodiesel requires implementation of an organized structure for production and distribution with competitiveness to the potential consuming markets. Therefore, introduction of biodiesel demands investments along its productive chain as to guarantee the offer of the product with quality. The production of vegetable oils, alcohol and sugar from sugarcane is more than an energy alternative; it constitutes the basis for a model of technological and industrial development which is self-supported and based on a concrete national reality and on the integration of man with an economic reality in harmony with the environment.

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