40 Years of the Brazilian Ethanol Program (Proálcool): Relevant Public Policies and Events Throughout Its Trajectory and Future Perspectives

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Abstract

Facing the First Oil Crisis of 1970s, in 1975 Brazilian Government decided to reduce the national dependence on imported oil and implemented the Proálcool Program, promoting in the following 40 years relevant positive impacts on transportation sector and national economy. The Proálcool was officially implemented on November 14th 1975 and the first phase (1975-1979) was characterized by blending mandate and subsidies, involving the entire ethanol production chain and consumption. At that moment, the ethanol production was totally based on molasses (sugar industry). In the second phase (1979-1985), E100 vehicles were launched and the production of hydrous ethanol had a rapid growth (production based on juice and/or molasses). In 1986, the sales of E100 vehicles already represented 92% of the Brazilian light vehicle market. In 1992, the ethanol production reached over 12.7 billion liters, against 0.6 billion liters produced in 1975. However, since 1975, the sugarcane ethanol in Brazil has been facing ups and downs, strongly influenced by national public policies and economic events. Considering this long history of success and opportunity this work aims to present and discuss the main forces that acted in the Brazilian ethanol market, as well as to present the future perspectives and opportunities facing the new scenario for modern bioenergy in whole world. Taking into account the recent efforts on ethanol production and use in Latin America and Caribbean we strongly believe that this discussion is a rich opportunity to understand the positive and negative actions that conducted a large scale biofuels program in America.

Keywords: biofuel national program, sugarcane, blending mandate, economy impacts.

1. Introduction

The Brazilian economy and the sugarcane agroindustry developed relevant links during a long time, crucial to the implementation the Proálcool Program in 1975. The Sugar Cycle in colonial period (1540-1640) based on sugarcane was the first one. The success of the sugar enterprise in that time resulted from the Portugal's know-how on sugarcane agricultural practices, and sugar equipment manufacturing, associated with the good Brazilian's climate and soil conditions. Furthermore, the easy

access to the African slave trade supplying the necessary manpower to the sugar production, and the Portugal's commercial skills became possible a rapid penetration of Brazilian sugar in the European market, assuring to the Portuguese the sugar monopoly up to 1640's. In this time, the international sugar price declined as a result of Caribbean sugar boom, making the sugar production in Brazil an unattractive business and reducing the interest in the Brazilian product.

In the late seventeenth century large volumes of gold and other precious minerals were found in the Minas Gerais State, starting the Gold Cycle which occurred until the end of following century, replacing the Sugar Cycle. Although very important, pushing the development in the Centre-South region, in economic terms, this cycle was less important than the Sugar Cycle. In the early nineteenth century, Portugal royal family moved to Brazil forced by Napoleonic Wars in Europe. In that moment, there were started many reforms which developed the educational, cultural and economic sectors in Brazil. With the end of war, the King of Portugal returned to Lisbon, but his son Pedro remained in Brazil as governor of the newly created Kingdom of Brazil (1815- 1822). On September 7, 1822, it was declared the Brazilian Independence. The early years were extremely difficult, and the economy was reduced to the subsistence stage (self-consumption activities).

A new scenario just started in the early nineteenth century with another agricultural commodity as protagonist. Coffee plantation was introduced initially only to attend the domestic market but after 1840 observed a remarkable expansion, sharing the Brazilian exports with other commodities (sugar, cotton, tobacco, cocoa, and rubber). However, with the high coffee international prices in the late 1920s and early 1930s (Fig. 1), the coffee became the major Brazilian exported item, with an expressive impact in the national economy, comparable to Sugar and Gold Cycles. In the early 1930s, the coffee economy declined, influenced by the Great Depression and the coffee overproduction. It was the end of Coffee cycle.

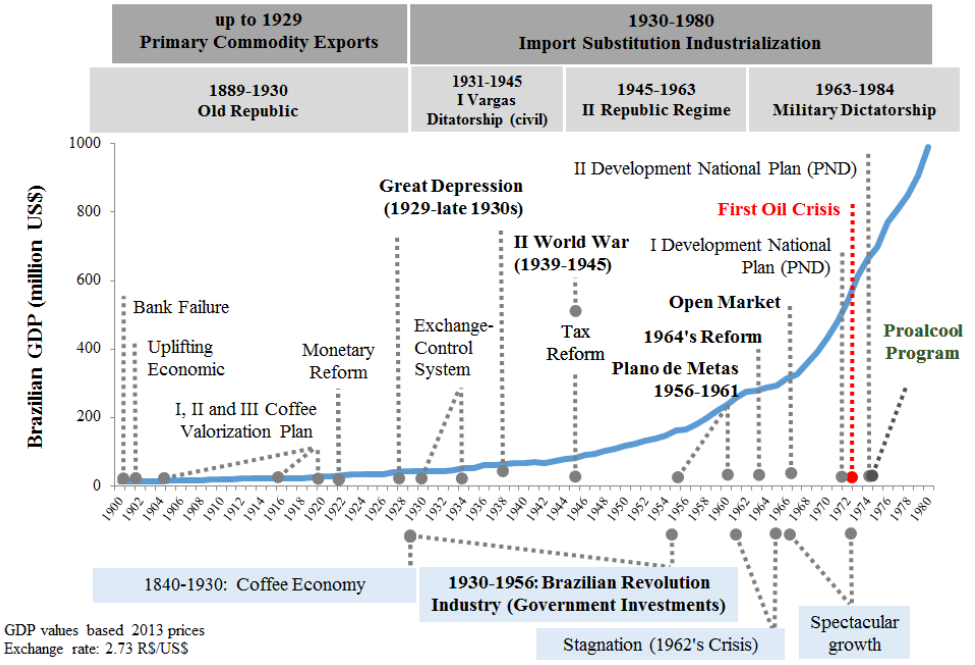

Fig. 1. Economic history of Brazil (1901-1980) [1]

The 1930s was a period of strong political and economic changes. With the end of coffee exports, and with a large foreign debt, the government was pushed to suspend part of the debt payments and implement a severe exchange-control. In this context, a mandatory minimum 5% ethanol blend in all imported gasoline sold in the Brazilian gas stations was implemented. In that moment, facing that the country could no longer rely solely on exports of primary goods and the restrictions imposed by World War II, the government decided to change its action plan, primarily working in response to the demands of the export sector. The change paved the way to the new Brazilian economy period, the Import Substitution Industrialization (1945-1980).

In 1945, with the end of war and the reintroduction the liberalism (II Republic Regime), the government implemented a strong tax reform. In the second half of 1950s, the government launched a serious of program to guide the industrialization process, focusing on the segments considered basic to growth, such as automotive, cement, steel, aluminium, cellulose, heavy machinery, and chemicals. As a result, between 1950 and 1961 the Brazilian economy observed rapid growth and notable diversification. However, the industrial growth resulted in a large influx of foreign capital (foreign debt) due to the substantial increase in imports, and to an inadequate foreign-exchange policy (export restriction). The crisis was intensified with the reform introduced by the military regime in 1964. To overcome the crisis and transform Brazil into a modern capitalist economy, it was implemented a severe reform, with actions to attract foreign capital, expand public investments (infrastructure improvements), and develop state-owned basic industries. As a result, the period between 1968 and 1973 was fruitful. The exports increased expressively (mainly manufactured goods and commodities), and the industrial sector observed a considerable modernization. In general, the rapid growth was a result of substantial public investment, and investments by state-controlled companies.

In 1973, the oil shock caused a drastic effect on the Brazilian trade, and led to a sharply higher import bill. Aiming to continue the high-growth policy, the government was pushed to develop a plan to increase the self-sufficiency in many sectors. The efforts included actions to promote import substitution of basic industrials inputs, expand the investments in the expansion of the economic infrastructure, and promote exports. In that moment, Brazil was strongly dependent on imported oil. In 1973, the Brazilian oil deficit was 77.3% (586,000 boe/day), and reached to 84.8% in 1979 (964,000 boe/day) [2]. This scenario paved the way to the implementation of a national plan to reduce the dependence on imported oil. In November 14th 1975, it was implemented the Proalcool Program, a large national program to substitute the use of gasoline in light vehicles by bioethanol [3].

2. The Brazilian Ethanol Program (Proalcool Program)

The program created by The Decree 76.593 aimed to stimulate the bioethanol production to supply the national and international demand of automobile fuels. According to the Decree, the ethanol could be produced from sugarcane, cassava, or other feedstocks, and the production should encourage to increase the feedstock supply, with special focus on agricultural improvements, and modernization, upgrade and new implantations of distilleries (autonomous or annexed) and storage units. According to Gordinho [4]: *Proálcool was a public-private policy that evolved from being a matter of purely government interest into an agreement with mill owners and the construction of independent distilleries with the obligatory involvement of Petrobras. Later Proálcool won the support of the automotive industry and incorporated*

financing, pricing, agriculture, logistics, equipment and the development of ethanol-powered internal combustion engines.

Initially, the adoption of sugarcane as the feedstock resulted from the downward trend of the international sugar price in next years, and the Brazilian experience and structure in sugarcane and sugar production. In 1974/1975 harvest, the sugarcane plantations occupied 1.9 million ha, and the sugar and ethanol production were around 6.7 million tonnes and 555 million liters, respectively [5].

Over last 40 years, the sugarcane ethanol in Brazil faced ups and downs, strongly influenced by national public policies and economic events (Fig. 2). In the next topics, we present the main forces that acted on the Brazilian ethanol market, as well as the future perspectives and opportunities facing the new scenario for modern bioenergy in Brazil and worldwide.

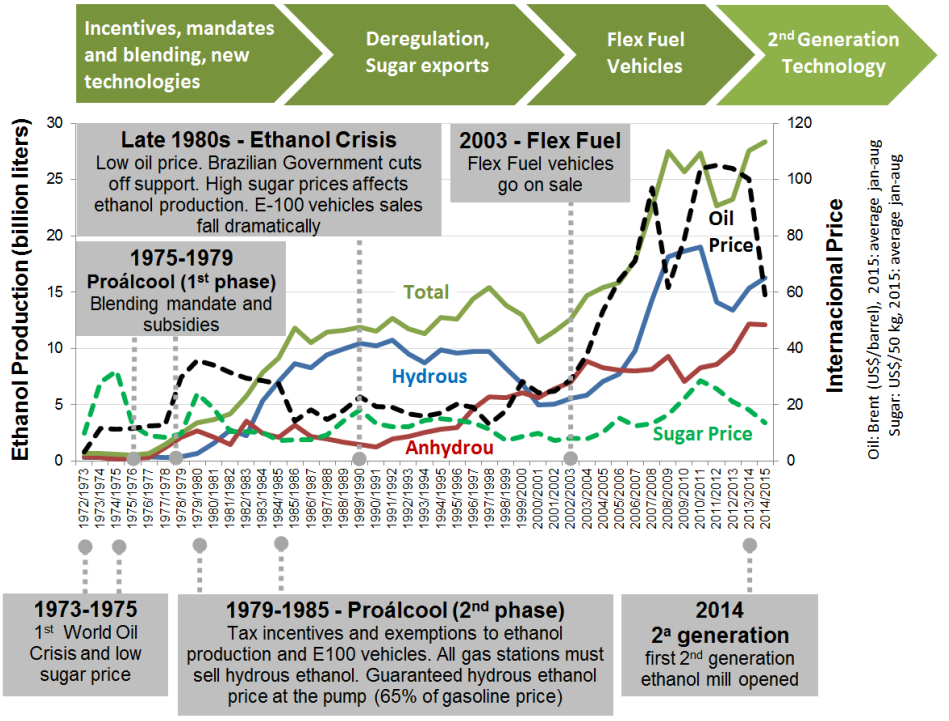

Fig. 2. Main events throughout forty years of sugarcane ethanol in Brazil. Figure: adapted from [6]. Ethanol data: [2,7]. Petroleum and Sugar prices: [1]

3. Proálcool phases

In the last 40 years, the Brazilian ethanol market has been basically guided by three main actors: the national policies, the international oil price, and the international sugar price. The government political changes and the fluctuations of the international prices were responsible for generating five different phases over the Brazilian's ethanol history.

Although the Brazilian ethanol program has just started officially in 1975, there were in Brazil several efforts and experiences in progress that were essential to the consolidation and development of the

program in the coming years, among which are highlighted:

- 1887: Instituto Agronômico (IAC), a state agronomic research institution based on US agronomics research institutions, that would be in coming years a key player in the bioethanol history;
- 1920s: Dedini, the most important Brazilian sugar technological manufacturing company. Today, Dedini is recognized worldwide;
- 1931: Decree 19.717, a federal decree that established the mandatory purchase of ethanol by gasoline importers to be added at 5% (E5) rate to the imported gasoline, in order to expand the use of the ethanol engines;
- 1933: Instituto Nacional de Tecnologia (INT), an important research center that hosted research for automotive use of ethanol;
- 1933: Instituto Nacional do Açúcar e Álcool (IAA), a federal agency responsible to guide and regulate the sugar and ethanol expansion and production;
- 1935: IAA published the first volume of "Brazil Açucareiro" and "Anuário Açucareiro", two important technical and data publications about the Brazilian sugarcane and sugar industry;
- 1942: Decree 4.722, a federal decree that declared the alcohol industry of national interest, and established minimum prices for the product;
- 1953: Petrobras, in October 3rd 1953 was born the national oil company;
- 1963: Sociedade de Técnicos Açucareiros Alcooleiros do Brasil (STAB), a technical association created by an initiative of 83 sugarcane companies in order to exchange information about agricultural and industrial innovation, and procedures among sugarcane producing regions, in Brazil and abroad;
- 1969: Centro de Tecnologia Copersucar (CTC), an initiative of sugarcane industry created to support the sugarcane development. It became a center for sugarcane progress, and a world reference in sugarcane research, production technology and industrial processing. Later, in 2004, CTC was renamed Centro de Tecnologia Canavieira;
- 1971: Plano Nacional de Melhoramento da Cana-de-Açúcar (PLANALSUCAR), a federal agency linked to IAA created to develop new sugarcane varieties, and make harvest prediction. The PLANALSUCAR was the Proálcool antecessor, with the goal of developing in three years new sugarcane plantation regions and sugarcane varieties.

3.1. Phase I (1975-1979): Initial phase

The first phase was characterized by blending mandate and subsidies, involving the entire ethanol production chain and consumption. At that moment, the ethanol production was totally based on molasses (anhydrous ethanol) from sugar industry, and fully dedicated to gasoline substitution. The ethanol production model used was denominated "annexed distillery", and basically consisted of a new building connected to sugar production line.

Among the main definitions implemented by the Decree 75.593 were: definition of the regulators and financing agents, financing conditions (interest rate, grace period for payment, etc), and ethanol price policy.

The government subsidies basically comprised of loans with low interest rates for the implantation of sugarcane plantations and new mills.

During this period it was observed a relevant increase of anhydrous ethanol production. The annual production increased from 216 million liter to 2,715 million liters [2].

3.1.1. Relevant events and initiatives

- The development of new sugarcane varieties was crucial to the success of sugarcane in Brazil. Up to 1975, the sugarcane production (Center-South region) depended mostly on one variety of cane

(NA567916[*]). During 1970s, The PLANALSUCAR, CTC and IAC conducted robust genetic breeding programs. In that moment, new research groups on soil, herbicides, and biologic control of pests and diseases were created.

- 1976-1978: Instituto de Pesquisas Tecnológicas do Estado de São Paulo (IPT), an important state research institute linked to São Paulo State University (USP). The IPT Energy Program conducted various relevant researches involving ethanol and its use (chemistry, mechanical, metallurgy, engines, among other);

- 1977: publication of two important scientific papers about ethanol in Brazil entitled "Energetics, Economics and Prospects of Fuel Alcohols in Brazil" in II International Symposium on Alcohol Fuels (ISAF) by Centro de Tecnologia Promon, and "Energy balance for ethyl alcohol production from crops" in Science Journal by Professor José Goldemberg. According to Goldemberg, the ethanol is "liquid solar energy";

- 1970s: Professor Urbano Ernesto Stumpf and his team carried out the first researches on ethanol engines in the Brazil's Aerospace Technical Center (CTA). He was a pioneer in ethanol engines in Brazil. The Centro de Tecnologia Promon conducted pioneering studies on ethanol production that some are still in use today;

- 1979: scientific researches and tests on hydrolysis and biodiesel (transesterification of vegetal oils) started in the State University of Campinas (UNICAMP);

3.2. Phase II (1979-1985): Affirmation

In 1979-1980, the international oil price tripled, it was the second oil shock. In 1979, the Brazilian deficit on oil reached 84.9%, the higher in Brazilian history [2]. The high oil dependence and price impacted significantly the Brazilian trade balance, and the spending on oil represented almost half of Brazilian imports.

Facing this context, the Brazilian Government decided to improve the efforts on the ethanol expansion. The autonomous distilleries began operating, and it was started the increase in production of hydrous ethanol.

In that moment, the expansion of ethanol production (sugarcane plantations and new mills) was mainly financed by Brazilian Government, but it was also observed support from foreign institutions, such as The World Bank.

In this period the ethanol production jumped from 3,396 million liters to 11,829 million liters annually. However, during this period the hydrous ethanol was the protagonist and represented around 73% of the Brazilian ethanol production in 1985, against 20% observed in 1979 [2]. This new scenario demanded that all Brazilians gas stations had two types of fuel pumps, one for gasoline vehicles and another for ethanol vehicles (E100).

3.2.1. Government actions

- to support and guide the program, the government created two important agencies, Conselho Nacional do Álcool (CNAL) and Comissão Executiva Nacional do Álcool (CENAL) The agencies implemented relevant actions in coming years;

- The National Science and Technology Development Council (CNPq) and the Research and Projects Financer (FINEP), both federal institutions, played a key role supporting the scientific research

[*] NA sugarcane variety: North Argentina

on sugarcane and ethanol.

- The Ministry of Industry and Commerce (MIC), through the Secretary of Industrial Technology (STI), gave to ethanol a leading position in the National Energy Plan.

3.2.2. Initiatives, scientific researches and technological relevant innovations

- 1978-1980: after tests in government fleets, using various prototypes developed by the local subsidiaries of Volkswagen, General Motors, Ford and Fiat, the production of the new alcohol powered vehicles (E100) began in the 1980s;
- 1979: The Associação Brasileira de Reforma Agrária (ABRA) started the discussion about the impacts and the feasibility of ethanol expansion. This movement paved the way to further studies and public policies to strengthen the sustainability of sugarcane bioenergy in Brazil;
- 1979: It was born Fermentec, a company specialized in developing technology for the fermentation process. The company was one of the main responsible for the increase in fermentation yields achieved over the years;
- Consolidation of national sugarcane processing equipment suppliers and manufacturers companies, such as Dedini, Zanini, and metallurgical industries;
- 1979-1987: IPT improved the researches on ethanol;
- Late 1970s: early studies of the use of vinasse for sugarcane irrigation (ferti-irrigation). Later, the CTC promoted advances in vinasse ferti-irrigation and today the process is widely applied;
- 1984: CENAL and STI realized the first seminar in Campinas city (São Paulo state) to discuss the state of the art in sugar and ethanol production;
- 1985: The directors of the autonomous distilleries founded the União dos Produtores de Bioenergia (UDOP), an association to foster the exchange of information and to train professionals;

3.3. Phase III (1986-1995): Stagnation

The mid 1980s were marked by the end of the Military Government and the implementation of the New Republic Regime. Totally supported by the Military Government, the Proálcool Program institutionally no longer exist (ceased the government efforts to promote the sugarcane and ethanol expansion). However, facing the increasing of ethanol demand by E100 vehicles sales the ethanol production was maintained stable in coming years. With the increase of E100 vehicles sales, the ethanol production could not meet the demand, and in 1989 there was a shortage of ethanol in the whole country.

Facing this context, aligned with the decreasing of oil price, the low domestic price of ethanol, the high international sugar price, the importation of gasoline vehicles, the low government resources to implement new investments in the sector, the crisis strongly affected the ethanol credibility, resulting in a drastically reduction the E100 vehicles sales (Fig. 3), but the total ethanol demand was maintained due to increase in anhydrous ethanol blended with gasoline.

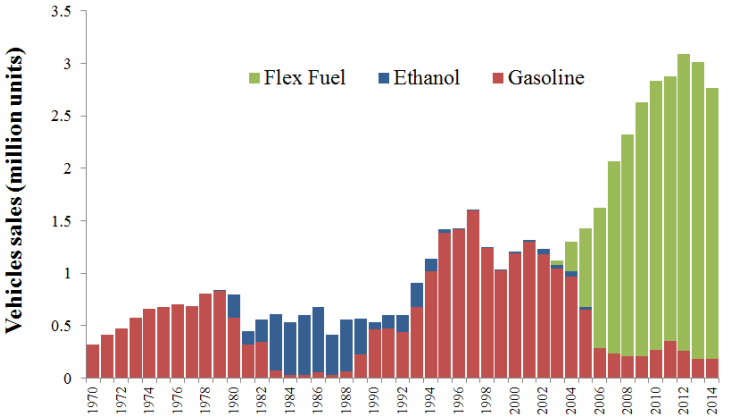

Fig. 3. Brazilian vehicles sales (1970-2014) [8].

3.3.1. Relevant aspects

- 1990: the creation of the International Consortium for Sugarcane Biotechnology (ICSB) allowed the genetic mapping of sugarcane, and consequently the development of new sugarcane varieties;
- 1992: extinctions of IAA and PLANALSUCAR. It was born Rede Interuniversitária para o Desenvolvimento do Setor Sucroalcooleiro (RIDESA), a federal university network composed by seven federal universities that was responsible for the development of new varieties of sugarcane. Today, the Ridesa's varieties (RB) are used in around 70% of the Brazilian sugarcane harvested area;
- 1992: the companies Dedini and Zanini joined efforts and created the company DZ, Engenharia, Equipamentos e Sistemas, the world's largest manufacturer of equipment for sugar and alcohol production. A mandate for blending between 20% and 25% of anhydrous ethanol in gasoline nationwide allowed the sugar-ethanol sector to catch its breath and regroup institutionally.

3.4. Phase IV (1995-2000): Redefinition

Between 1995 and 2000, the annual hydrous ethanol production reduced drastically from 10 billion liter to 5 billion liters [2], and the sugarcane surplus production was used to produce sugar and anhydrous ethanol. The anhydrous ethanol consumption kept growing thanks to the blending mandate and the increased sales of gasoline vehicles.

As result, the Brazilian sugar exportation increased from 0.8 million tonnes in 1990 to 7.48 million tonnes in 2000, and the international sugar price decreased from 316.7 US$/t to 192.1 US$/t [5].

In this period the price of ethanol was no longer controlled by the government and was defined by supply and demand in a free market.

Aiming to restructure the sector and get more autonomy in their business, the various associations, sugarcane producers and sugarcane mills joined efforts to defend the interests of the sector and build a free and transparent marketplace. In 1997 it was born the União da Indústria de Cana-de-Açúcar (UNICA), the largest representative organization for the sugar and ethanol sector with the mission of establishing the Brazilian sugar-energy sector as a modern agro-industry that can compete globally and sustainably in the production of ethanol, sugar and bioelectricity.

According to Gordinho [4], as a result, *the leading sugar groups have invested in the direct marketing of their own products, building relationships with traders and trading companies – an innovation that led to the formation of specialized departments within companies.*

However, the major advancement on the business front was the establishment of a model of self-management in the sugar-energy sector introduced in 1998-1999, which defined a system of payment for sugarcane based on the of sucrose content in the cane. The new model was coordinated by the Conselho dos Produtores de Cana-de-Açúcar, Açúcar e Álcool de São Paulo (CONSECANA-SP), a council stablished in 1983 formed by sugarcane, ethanol and sugar producers, and others associations. At that moment, the price per tonne to be paid for sugarcane would be based on TRS (total recoverable sugars) and the prices of sugar and ethanol sold in domestic and foreign markets.

The Brazilian government introduced two important actions during this period: the increase on ethanol blending mandate in 1998 to 22% (minimum), up to 24% (maximum); and The Plano Real (1994), an efficient economic stabilization plan that aimed to halt inflation, increase the purchasing power of the population and reshape sectors of the Brazilian economy.

At this moment, the Federal Government started a strong restructure of the national energy sector, and introduced new laws and programs to develop and regulate the electricity and the fuels sectors in Brazil. The Brazilian National Electric Energy Agency (ANEEL) and the National Agency of Petroleum and Natural Gas (ANP) were key players at this process. To stimulate the research and innovation, the Federal Government created a Financial Fund (CTEnerg) to stimulate and finance studies on energy, including on bioenergy.

According to Gordinho [4], *in 1998, facing the increase of the oil price (gasoline), Brazilian creativity led to the popularization of what was generally known as the "rabo de galo", an unofficial high blend of ethanol with gasoline to reduce fuel costs. The media always praised the benefits of the biofuel*.

All this actions paved the way to the rebirth of Brazilian ethanol in next century.

3.5. Phase V (2000-today): Flex Fuel and 2nd Generation

In 2000, Brazil was beginning to live the results of the economic reform, and the oil price was notably high. Aiming to stimulate the economy, the São Paulo government reduced the state tax, and provided a great stimulus for ethanol production and export. At that moment, the Federal government also demonstrated interest in ethanol and its potential for the future.

In view of the positive scenery, the sugar-ethanol sector resumed investments in new plants, mainly in the South-Central Region, and the sugarcane industry returned to growth. In this phase, the introduction of the flex fuel cars was crucial to the fast growth of ethanol consumption and expansion. The first flex fuel vehicle was developed in the United States by General Motors in 1992, however in Brazil the technology was improved and found a positive scenario to be commercially implemented in large scale [4]. In Brazil, faced the blending ethanol-gasoline background and the complexity of its technology, it was developed a new system to substitute the gasoline-ethanol mixture sensor controls, reducing costs. Another important Brazilian background was the ethanol fuel-injected engines launched in 1993. Some scientific researches conducted by IPT (after 1997) and technological developments started by Magneti Marelli and Bosch paved the way to the production and introduction the flex fuels vehicles in Brazil.

In 2003, in celebrations of 50th anniversary Volkswagen launched the Gol Total Flex, the first Brazilian commercial flex fuel vehicle. Facing the potential savings, the versatility, and the quality, consumers were quick to accept flex-fuel vehicles. The Proalcool was essential to the success of the flex fuel vehicles. Thanks to the program, which mandated national distribution of the product at all gas stations countrywide, the consumers should have the options to choose between ethanol and gasoline, based on fuel costs, and that this choice could be made without harming the vehicle. During this period, the light vehicles sales increased 150% pushed by the economic growth, and today nine in out ten cars sold are flex fuel (Fig. 3). In last years, the vehicles sales were also positively affected by the subsidies (tax-free) implemented by the Federal Government.

During this period the ethanol consumption increased 170% and today around 29 billion liter is

produced in 362 sugar-ethanol mills [2,9].

In 2015, Brazil had 383 ethanol mills installed (362 in operation and 21 with operating permission), and the total capacity of ethanol production (hydrous and anhydrous) was approximately 38 billion liters per year[†] . Currently, about 10 million ha are cultivated with sugarcane [7], which represent 1.2% of Brazilian total area, and 15.4% of the area identified for sugarcane expansion (65 Mha) [10]. Approximately, half of the sugarcane harvested is dedicated to ethanol production and the other half to sugar production.

Although Brazil started the commercial production of advanced biofuels in 2014 (cellulosic ethanol from sugarcane trash and bagasse), it is marginally economically feasible to produce on a large scale due to the high cost of the technology, the cost of the enzymes, among others.

Regarding domestic consumption of ethanol, the Brazilian fleet in 2015 is estimated at 35.8 million units and pure hydrous ethanol and flex fuel vehicles together represent approximately 68 percent (24.2 million units) of the total fleet. The motorcycle fleet is estimated at 15.3 million units including 4 million flex-fuel units [8].

3.5.1. Government actions

- 1994: Programa Cana IAC, a São Paulo state program linked to IAC created for sugarcane varieties development. The research program works in partnership with more than 180 institutions, such as universities and research centers;

- Mid 1990s: the São Paulo Research Foundation (FAPESP), a São Paulo state foundation for support and funding of scientific research, launched the Genomic Program to expand the studies on genetic sequencing of sugarcane. This initiative was essential in the formation and consolidation of a research network in genomics in Brazil. Today, Brazil is in the top of indexed international publications on sugarcane;

- 1999: trough FINEP and CNPq, the Federal Government funded the implementation of laboratories for ethanol quality monitoring (and other fuels) in several Brazilian universities.

- 2002: Law 11.241/02, an important São Paulo state law that implemented the gradual elimination of sugarcane field burning before harvesting;

- 2002: based on ethanol background, the Brazilian government launched the Biodiesel Program (Probiodiesel). The initial mandate introduced a B2 blending, and today B7 blending is in progress;

- 2003: Canasat, a consortium of federal and São Paulo state institutions created a system to monitor the sugarcane planting and harvesting using satellite monitoring in Brazil;

- 2006: Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA) launched the Plano Nacional de Agroenergia 2006-2011, a strategic national plan to promote sustainable development and agribusiness competitiveness to benefit Brazilian society. At that moment, MAPA created the EMBRAPA Bioenergia, a bioenergy research center of the Brazilian Agricultural Research Organization (EMBRAPA);

- 2008: creation of the Brazilian Bioethanol Science and Technology Laboratory (CTBE), a high level federal research center on bioenergy, sugarcane and ethanol production. In the same year, FAPESP launched The BIOEN Program, a research program in bioenergy to guide the scientific research efforts in São Paulo state. The São Paulo Government launched the Sugarcane Agroecological Zoning, defining the potential suitable areas for sugarcane expansion in São Paulo state;

- 2009: FAPESP created the SPBIOENRC, a bioenergy research center composed by the three São Paulo state universities in order to join efforts on bioenergy research and education (University of São

[†] Installed capacity of production: 205.9 m^3/day; average crushing days: 185 days/year

Paulo – USP, State University of Campinas – UNICAMP, and São Paulo State University – UNESP). The Federal Government launched the Sugarcane Agroecological Zoning, defining the potential suitable areas for sugarcane expansion in Brazil

- 2011: the Brazilian Development Bank (BNDES) in partnership with FINEP launched the PAISS Program, a support plan for industrial technological innovation of the sugar-based energy and chemical sectors;

3.5.2. Initiatives, scientific researches and technological relevant innovations

- Relevant studies, new concepts and knowledge advances: sustainability of ethanol production, potential recovery and use of sugarcane trash for electricity generation, energy efficiency on ethanol production, fuel ethanol use and its impacts on human health in big cities; sugarcane pests and disease control; Brazilian Ethanol Learning Curve, consolidation of the Ethanol-Sugar Brazilian Model (flexible production system), Technological Roadmapping for Sugarcane Bioethanol;
- Industry researches contribution: sugarcane bagasse hydrolysis (organosolv process from Dedini), anaerobic digestion of sugarcane vinasse (BIOSTIL project from Alfa-Laval), bagasse compaction (BAGATEX) and reduction of vinasse volume production (from Fermentec)
- 2005: Embraer launched Ipanema, the world's first series-produced airplane to leave the factory designed and equipped to fly 100% on hydrous ethanol. The Ipanema airplane is used mainly for agricultural activities;
- 2010: Petrobras started the researches on cellulosic ethanol at the CENPES (Centro de Pesquisas e Desenvolvimento Leopoldo Américo Miguez de Mello), a research and development center on basic engineering and energy. Foundation of Petrobras Biofuels company, a subsidiary of Petrobras;
- 2013: the company Logum Logistica, a joint venture of Petrobras, Cosan, COPERSUCAR, Odebrecht, Camargo Corrêa and Uniduto, started the investments in a multimodal logistics system for the transportation and storage of ethanol. The system covers pipelines, waterways, highways and cabotage, and will cross 45 cities, linking the main ethanol producing regions in the states of São Paulo, Minas Gerais, Goiás and Mato Grosso do Sul to the Paulinia Refinery in São Paulo.
- 2014: Granbio and Raízen inaugurated the first commercial plants for advanced biofuels (cellulosic ethanol from sugarcane trash and bagasse). The total capacity of production of the two plants is around 124 million liters of cellulosic ethanol per year;

4. Main benefits of sugarcane ethanol to Brazil

- Energy Security: today, sugarcane accounts for 18% of primary energy production, ethanol represents 34% of energy consumption in transportation sector (light duty vehicles), and sugarcane bioelectricity contributes with 5.5% of Brazilian electricity generation [2];
- Good agricultural practices, synergy with food production, innovation and forests protection: the sugarcane sector has influenced and has generated benefits for the entire agricultural sector in Brazil. The high levels demands for equipment, process, management, services and constant improvements have stimulated the efforts on scientific research and innovation throughout Brazilian agriculture. The expansion of agricultural crops demanded greater planning and management of Brazilian land use and consequently the protection of native forests;
- GHG emissions reductions and air quality improvements in big cities: compared to gasoline the sugarcane bioethanol makes possible to reduce the carbon dioxide emission in around 2.2 kg CO_2/liter[11]. Taking account that 530 billion liter of sugarcane ethanol were produced in last 40 years in Brazil [2], emissions around 1,166 billion kg CO_2 could have been avoided;
- Income and improvements in the quality of life in rural areas: the sugarcane cultivation

registered the highest number of formal jobs in agriculture in 2014, representing around 9.9% of the 2.7 million agriculture jobs, and the average salary was the third highest in agriculture, behind only of cotton and soybean crops (Fig. 4) [12]. The recent decrease in jobs in sugarcane cultivation and the increase of the average salary reflect the positive effect of the modernization of planting and harvesting process (mechanization). The prohibition of pre-harvest sugarcane field burning and the introduction of mechanized harvesting allowed reductions in number of accidents (mainly in manual harvesting activity) and improved the working conditions.

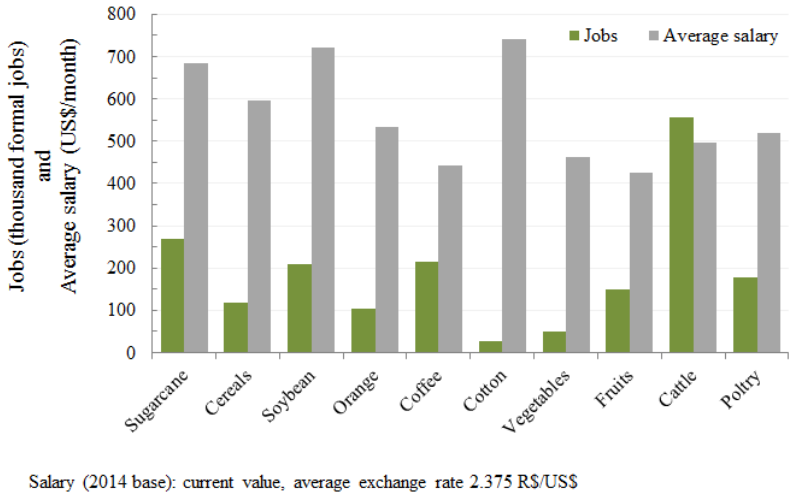

Fig. 4. Brazilian Agriculture and Livestock: number of jobs and average salary (2014) [12].

- New markets: the Brazilian sugarcane ethanol has a high export potential due to the competitive price, sustainable production, growing demand for modern energy worldwide, among other. The recent advances in sugarcane and ethanol production have permitted to meet the main international principles and criteria, such as Roundtable on Sustainable Biomaterials (RSB), Bonsucro, and the International Sustainability and Carbon Certification System (ISCC) [13]. Today, several initiatives and partnerships are in progress involving Brazilian and foreign research institutions and companies. The Dedini S/A, a 96 years old Brazilian company and world leader in sugar and ethanol equipment manufacturer, has customers in more than 40 countries worldwide.

5. Conclusions

The main reasons for the success of Brazilian sugarcane ethanol are not only the use of a high level energy crop and soil and climate conditions in the Brazilian Center-South, but mainly due to perseverance of entrepreneurs, government, and in large measure, researchers who believed in building a sustainable society in the future.

It was clear that the Government actions, as a regulatory, planning and financing actor, should be an efficient element in developing the bioenergy market.

In Brazil, as observed in few other tropical countries such as Colombia, Guatemala and Paraguay, sugarcane is a relevant solar energy collector and the main vector of sustainable development, and generating energy, as well as income and welfare.

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References

[1] IPEA. Ipeadata 2015. http://www.ipeadata.gov.br/ (accessed January 10, 2016).
[2] EPE. Brazilian Energy Balance 2015: year 2014. Rio de Janeiro: 2015.
[3] BRAZIL. Decreto 76.593/1975. Brazil: 1975.
[4] Gordinho MC. Do álcool ao etanol: trajetória única = From alcohol to etahnol: a winning trajectory. São Paulo: Editora Terceiro Mundo; 2010.
[5] MAPA. Anuário Estatístico da Agroenergia 2010. Brasilia: 2011.
[6] Zechin MR. Internacionalização do etanol: Oportunidades e desafios ao Brasil 2009.
[7] UNICA. UNICAData 2015. http://wwhttp//www.unicadata.com.br/index.php?idioma=2 (accessed January 10, 2016).
[8] ANFAVEA. Brazilian Automotive Industry Yearbook 2015. São Paulo: 2015.
[9] ANP. Boletim do Etanol N. 05/2015. Brasilia, Brazil: ANP; 2015.
[10] EMBRAPA. Zoneamento Agroecológico da Cana-de Açúcar: Expandir a produção , preservar a vida , garantir o futuro. Rio de Janeiro, Brazil: Embrapa; 2009.
[11] Macedo IC, Seabra JEA, Silva JEAR. Green house gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020. Biomass and Bioenergy 2008;32:582–95. doi:10.1016/j.biombioe.2007.12.006.
[12] MTE. Programa de Geração de Emprego e Renda - PROGER: Base de Gestão. 2013. http://acesso.mte.gov.br/portal-pdet/ (accessed January 1, 2016).
[13] Souza GM, Victoria RL, Joly CA, Verdade LM. Bioenergy & Sustainability: bridging the gaps. Paris: Scientific Committee on Problems of the Environment (SCOPE); 2015.