# CHAPTER 2
# HISTORIC BACKGROUND OF BIOFUELS IN BRAZIL

## 2.1. INTRODUCTION

When the Portuguese reached the Brazilian coast, probably the only source of energy they found was biomass. The country was named after a tree, the Brazil wood ("pau-brasil"), used to die clothes.

Sugarcane was officially introduced by Martim Afonso de Souza in 1532 and planted in São Paulo state coast (São Vicente) and other states in the Northeast region. Sugarcane was probably brought from Madeira Islands or Cabo Verde. Few years later, the production of sugar was successfully initiated by Duarte Coelho Pereira, in Pernambuco state.

About one or two centuries after introduction, sugarcane was mainly cultivated and developed in the Northeast region. Until 1580, the Dutch had direct involvement on sugar business produced in Brazil. They helped to finance the business as they also had an important role in the refining and commercialization of sugar in Europe.

Sugar was produced using the gur[1] or jaggery[2] method brought from India. At that time also "cachaça", the liquor from sugarcane, started to be produced. Cachaça, most likely, originated from the utilization of "cachaza[3]", the filter cake, as it is known today. Then, the cachaza was discarded by the engenho´s owner and then used by the first settlers. This filter cake is easily fermented and then distilled using an "alambique",[4]

1 https://en.wikipedia.org/wiki/Gur
2 https://en.wikipedia.org/wiki/Jaggery
3 https://publons.com/publon/3186206/
4 https://pt.wikipedia.org/wiki/Alambique

a still pot brought from Arabian countries to the Americas by the Portuguese and Spaniards.

The gur/jaggery sugar was produced first by extracting the juice (garapa[5]) and then boiling it up to crystallization point when "rapadura"[6] (a kind of gur/jaggery) was made. The boiling was made using metal open pans. This process was improved in a sequence of open pots in which the sugar juice was concentrated until the crystallization was completed (figure below).

**Figure 2.1** The concentration of sugarcane juice prior to crystallization. Source: Leandro Vilar.[7]

After the juice was concentrated and ready to crystalize, the massecuite was poured on conic molds made of clay or wood, with a hole in the middle. After the crystallization was completed, the liquid molasses could be drained from the bottom and the sugar loaf could be unmolded. A curious observation is that the Portuguese noted the similar shape between the sugar loaf and the mountain located right in the entrance of Rio Bay naming the mountain after that (Pão de açúcar = Sugarloaf).

(a) (b)

**Figure 2.2** (a) sugar loaf obtained from sugar crystallization; (b) The Sugarloaf Mountain in Rio.

5 https://pt.wikipedia.org/wiki/Garapa

6 https://pt.wikipedia.org/wiki/Rapadura#:~:text=Rapadura%20%C3%A9%20um%20doce%20de,pequenas%20quantidades%20para%20uso%20individual.

7 https://seguindopassoshistoria.blogspot.com/2013/12/o-engenho-e-o-fabrico-do-acucar-no.html?m=0

With the increasing production of sugarcane in the Caribbean in the 16 and 17th centuries, and the development of beet sugar in Europe, the Brazilian sugar production declined.

## 2.2. THE ETHANOL FUEL UTILIZATION IN BRAZIL

### 2.2.1. THE EARLY STAGES OF FUEL ETHANOL IN BRAZIL

During the second Brazilian Empire, D Pedro II created the Agronomic Institute of Campinas (IAC) in 1887 after his visit to USA (1st century of independence). D Pedro II was impressed with the agronomic research centres in the USA and wanted to do the same in Brazil. In the same year Franz Wilheim Dafert, the first IAC Director, presented 42 sugarcane varieties. The IAC research on sugarcane was initiated in 1892 which evolved, years later, into a more complete sugarcane variety program (SZMRECSÁNYI, 1979).

In early 20th century started a modernization process in the sugar industry with the objective to increase sugarcane yield and transform the old "engenhos" into modern mills. In the modernization process, "central mills" were created to gather sugarcane from the vicinities and centralize the processing. This fact created the preconditions to a more consistent development of the sugar sector in São Paulo state rather than in the Northeast states.

In 1903, the Brazilian President Rodrigues Alves inaugurated the *Exposição Internacional de Aparelhos a Álcool* in Rio de Janeiro, and the *Primeiro Congresso Nacional de Aplicação Industrial do Álcool*. In 1908, Henry Ford built the Ford T Model in the USA using ethanol and gasoline as its fuels.

Another parallel event that gave great impulse to the sugar industry, particularly in São Paulo state, was the Italian immigration. The Italians brought knowledge on how to make equipment and forged a strong industrial base with companies such as ZANINI and DEDINI.

During the 1920s several tests were carried out on the use of ethanol[8] as automotive fuel in Brazil. In 1925 a car successfully completed the journey between São Paulo to Rio using 100% ethanol as fuel (LEAL, 2022).

The Brazilian motor vehicle fleet developed rapidly reaching 220,000 in 1929, and consequently the consumption of imported gasoline.[9] With the urgent need to help

8 ethanol was first named "álcool", then "ethanol", and later "bioethanol". The reason for this change can be attributed to marketing since the molecule ($C_2H_5OH$) is the same.

9 The first oil refinery in Brazil, Landulpho Alves Refinery in Rio de Janeiro, was installed only in 1950 motivated by oil discovery in Bahia.

sugar producers together with the need to substitute, at least partially, imported gasoline, President Vargas signed the *Decree-Law n. 19.717*[10] in 1931. The main objective was to make compulsory= sugarcane ethanol to be added to the Brazilian gasoline. The blend was limited to 5% and varied according to the availability of ethanol.

During the WW II, when imported gasoline was lacking in Brazil, ethanol blends reached up to 50%. In 1942, President Vargas signed the *Decree-Law n. 4.722*[11] declaring the alcohol industry of national interest, establishing minimum prices for the product.

President Vargas also created in 1932 the Estação Experimental de Combustíveis e Minérios which became the Instituto Nacional de Tecnologia – INT, where Eduardo Sabino de Oliveira and Lauro de Barros Siciliano provided continuity to the studies initiated at the Escola Politécnica (Poli) at the University of São Paulo (OLIVEIRA, 1937; INT, 1979).

Also, in 1933, President Vargas created the Instituto do Açúcar e do Álcool (IAA) motivated by the crisis faced by the sugar sector. The main idea was for the IAA to act to establish *quotas* and arbitrate whenever necessary, both in the sugar and alcohol markets.

After the WW II, petroleum gained importance and in 1953 PETROBRAS was set up by *Law n. 2.004* during President Vargas second mandate. PETROBRAS was created as a state company to explore, refine oil, and with the mission to make Brazil oil self-sufficient. Later in the decade, President Juscelino Kubitschek gave great impulse to the automobile industry.

It is estimated that the average use of bioethanol between 1945-75 was around 7% (BNDES and CGEE, 2008), as seen in Figure 2.3.

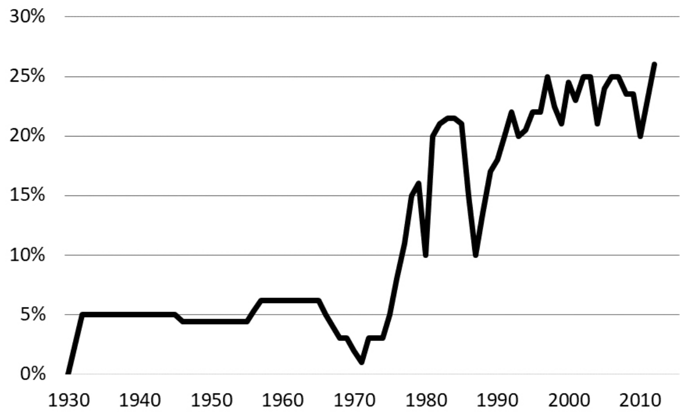


**Figure 2.3** Ethanol content in Brazilian gasoline between 1930 to 2010. Source: MME (2008) in BNDES and CGEE (2008).

10 https://www2.camara.leg.br/legin/fed/decret/1930-1939/decreto-19717-20-fevereiro-1931-518991-norma-pe.html

11 https://www2.camara.leg.br/legin/fed/declei/1940-1949/decreto-lei-4722-22-setembro-1942--414753-publicacaooriginal-1-pe.html

The sugar sector was highly competitive during the 1960s since there was the Cuban revolution and the target to achieve 10 million tons of sugar by 1970 in Cuba. The result of the Cuban policy was a considerable increase in world sugar production and a corresponding decline in the price of sugar, predisposing the sector to another crisis.

At the end of 1960s the private sector created the COPERSUCAR Technology Centre (CTC) in Piracicaba. COPERSUCAR is a cooperative, which at that time, had more than 100 members. The CTC objective was to work on two key areas: an independent program to develop new sugarcane varieties, and a group of highly skilled agronomic engineers to assist the cooperative members and associates.

Also, in 1971 the Brazilian Federal Government created the National Program for Sugarcane Genetic Improvement (PLANALSUCAR). At the beginning of 1970s, the sector already had three major sugarcane improvement programs: the IAC, the CTC, and PLANALSUCAR.

## 2.2.2. THE 1973 OIL CRISIS AND THE CREATION OF PROALCOOL

The year of 1973 witnessed the first oil crisis with significant increase in oil prices, from US$ 1.9/barrel to US$ 11.2/barrel (see figure below). This fact deeply affected the Brazilian economy and politics. At that moment, oil imports represented nearly 80% of total oil consumption corresponding to nearly 50% of total imports. The situation was so critical that something had to be done urgently to help the economy and prevent the country coming to a halt.

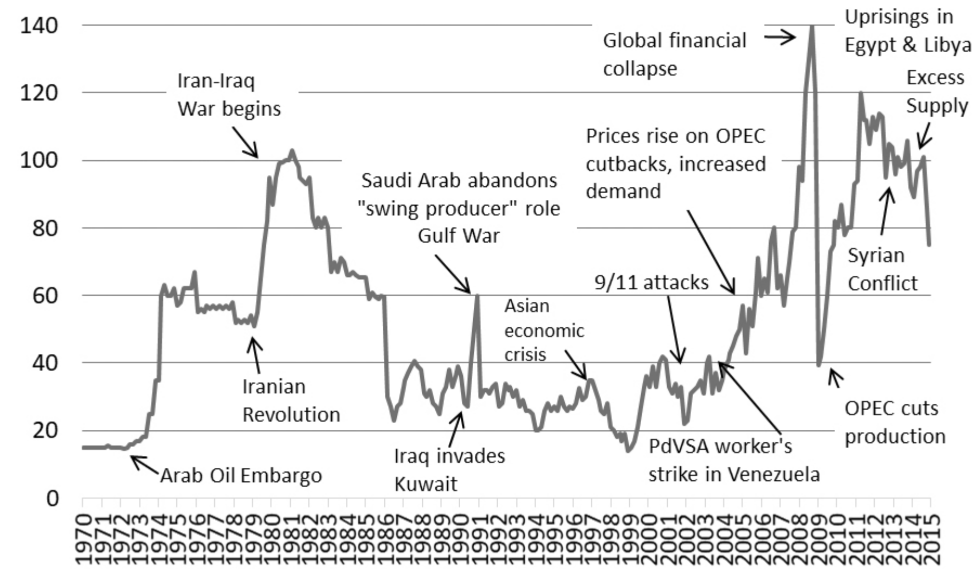


**Figure 2.4** Oil prices and main events, from 1970-2014. Source: US DOE .[12]

12 https://theconversation.com/oil-price-shocks-have-a-long-history-but-todays-situation-may-be-the--most-complex-ever-178861

At that time, Brazil was experimenting a rapid economic growth, the so-called "economic miracle" under President Garrastazu Medici. General Ernesto Geisel, President of PETROBRAS, succeeded Medici and implemented a series of projects, promoting Brazilian energy independence. Among these projects were for example, the construction of several large hydroelectric plants, a nuclear energy program, and PROALCOOL, the National Alcohol Program.

PROALCOOL was created on 14 November 1975 by the *Decree n. 76.593* (MENEZES, 1980). It is difficult to indicate a single name as the PROALCOOL creator, and hence it may be fairer to mention few important names who helped to conceive and implement the program. Among them were: José Walter Bautista Vidal (engineer, physicist, and university professor), Lamartine Navarro Júnior (engineer, entrepreneur, and ULTRAGAS manager), Luiz Gonzaga Bertelli (consultant, lawyer, professor), Tobias J. Barreto de Menezes (university professor), Cícero Junqueira Franco (sugar mill owner), Expedito José de Sá Parente (engineer, chemist, creator of biodiesel), Ozires Silva (ex-president of EMBRAER, PETROBRAS, and minister of Infrastructure, Severo Fagundes Gomes (minister of Industry and Commerce), João Camilo Penna (also minister of Industry and Commerce), and Antonio Dias Leite Júnior (minister of Mines and Energy). See Cortez (2016).

Brazil was the first country to create a national biofuels program (PROALCOOL) and to produce large amounts of modern biofuels for fossil fuel substitution (ROTHMAN et al., 1983). At that moment the existing sugar mills were relatively small and the productivity, both agricultural and industrial, were low and something had to be done to improve it.


(a) (b)

**Figure 2.5** (a) Minister Shigeaki Ueki fuelling ethanol in a car in Brazil; (b) President Ernesto Geisel (first on right) receiving entrepreneurs to discuss the PROALCOOL. Source: CORTEZ (2016).

In its origin, PROALCOOL tried to promote non-traditional energy crops such as cassava and sorghum without success. Probably the main reason why sugarcane succeed was the existence of a well-established sugarcane sector, particularly in São Paulo State. This sugarcane sector knew how to develop the new large-scale fuel ethanol industry, which was implemented in two steps:

The PROALCOOL first phase (1975-1979) had the objective to produce anhydrous ethanol to be blended with gasoline. According to ANP (2010), initially, 4.5% of ethanol was blended in the gasoline.[13] For this, annexed distilleries were installed in existing sugar mills. The production of ethanol increased from 600 million litres/year in 1975-76 to 3.4 billion litres/year in 1979-80. All investment was financed by the Brazilian government with subsided loans, both to expand sugarcane plantations and to install the annex distilleries. A great impulse of also given to increase the number of sugarcane varieties. At the beginning of the program North Argentina (NA) varieties were still predominant but they were gradually substituted by IAC SP and PLANTALSUCAR/RIDESA RB varieties as shown in the figure below.

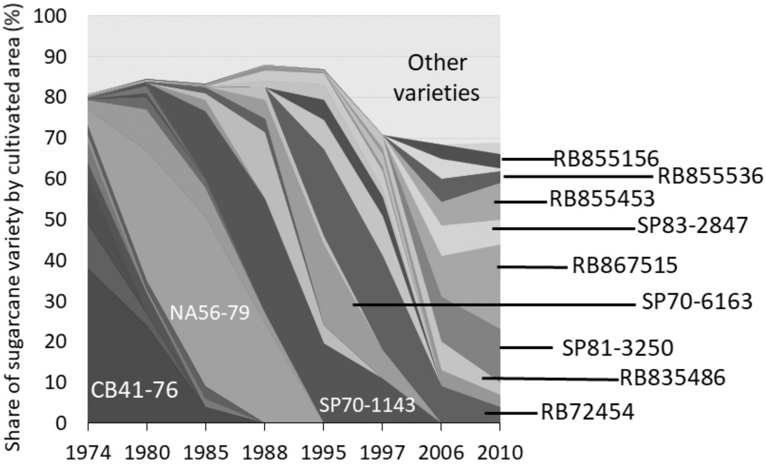


**Figure 2.6** Evolution of commercial sugarcane varieties from 1974-2010 in Brazil.
Source: CORTEZ (2016).

This decision to create and implement the PROALCOOL was not that simple. The idea was to improve the country´s national energy security. Therefore, directly, PROALCOOL didn´t have anything to do with greenhouse gases nor climatic change. The only objective was to alleviate the burden of imported oil and to support national sugarcane producers. The assistance to sugar producers was necessary due to serious problems such as low sugarcane productivity and an almost collapse of the sugar prices in the international market.

Initially, PROALCOOL intended to use not only sugarcane but also cassava and sorghum, as feedstocks. Sugarcane is a traditional large-scale crop in Brazil, primarily used for sugar production. Its main producing areas were the Southeast (São Paulo mainly) and the Northeast. However, in general terms, the sugarcane sector in São Paulo was at that point more dynamic and prepared to make good use of subsidies and other incentives than the Northeast, except for few mills in Alagoas.

13 https://www.researchgate.net/figure/Figura1-Evolucao-no-uso-dos-biocombustiveis-no-Brasil-Fonte-ANP-2010-Em-dezembro-de_fig13_320596282

On the other hand, cassava, although a traditional and indigenous Brazilian crop, despite good characteristics such as the easiness to store, did not take off. There were various problems e.g., cassava did not have a bagasse and hence the energy balance was negative. But probably the main reasons why cassava[14] failed as feedstock for ethanol in Brazil was the lack of agricultural experience with large scale plantations and inexistence of entrepreneurs interested to develop this crop, together with influence of the sugarcane lobby. There were also some serious problems in the industrial side such as difficulties with enzymes, infections, higher costs, etc. On the other hand, sugarcane was a better feedstock because it was a well-established, high productivity, and its bagasse could use as a by-product, (the fibrous by-product traditionally used to supply all factory energy needs in the mills). Cassava was a traditional crop, produced by many small holders, with low productivity while sugarcane growers, "*usineiros*", were a well-organized important group of rural entrepreneurs. The *usineiros* controlled several important cooperatives, associations and even had a well-organized R&D research centre(s) producing their own cane varieties besides exerting a considerable political and economic power.

Another crop that was not also successful was sweet sorghum, probably because of the same reasons as cassava.[15] A positive side effect of the PROALCOOL, or at least the intention, was to improve regional development, particularly with the introduction of other crops such as cassava and sorghum which turned out to have been unrealistic. It was believed, at that time, that with cassava and sorghum, the sugarcane monopoly could be avoided and regional development, particularly in the Northeast, could be achieved with the PROALCOOL.

The second phase of PROALCOOL (1979 to 1985) was a policy decision prompted by the second oil shock which forced the Brazilian government to speed up oil import substitution and put is faith into the new national fuel creating PROALCOOL II. This new phase was somehow more aggressive. According to ANP (2010) the percentage of ethanol blended in the gasoline went up to 15%.[16] Many completely new independent ethanol plants/distilleries were installed to produce only hydrous ethanol.[17] The new plants were conceived as autonomous distilleries and became the cornerstone because only ethanol was produced. The resulting hydrous ethanol was to be used in 100% ethanol vehicles (E100). This new phase was very successful, although there was an important subsidy associated, the so-called "ethanol account" which was compensated by the Brazilian government.

This situation could not continue after the democratic transition which took place in 1985, when the military government was replaced by a civilian one. This political transition set up the conditions for necessary changes in the economy which also impacted the recently created ethanol sector.

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14 Thailand and Colombia verified to be more successful with cassava as feedstock for ethanol production.

15 There is considerable experience with the production of ethanol from cassava in Thailand. https://www.isaaa.org/kc/cropbiotechupdate/article/default.asp?ID=2348

16 https://www.researchgate.net/figure/Figura1-Evolucao-no-uso-dos-biocombustiveis-no-Brasil-Fonte-ANP-2010-Em-dezembro-de_fig13_320596282

17 According to the Brazilian National Petroleum Agency (ANP) the ethanol content of hydrous ethanol is between 95.1 and 96 º GL or % by volume or between 92.5 and 93.8% by weight.

An important contribution was given by Ernesto Stumpf, from the Institute of Aeronautic Technology Institute) (ITA/CTA) who, with colleagues, investigated and developed the ethanol engine.

During that period, mainly 1975-1980, there were many engineering and non-engineering approaches to adapt the existing engines for ethanol blending. These blends were popularly known as "cocktails". Often, adaptations were made in garages without technical supervision.

However, the manufacturing industry was concerned with this issue, accepting that ethanol was becoming a reality in Brazil, and was to stay. Several adaptations were required to Otto cycle engines. A summary of these engine adaptations, performed by the automobile industry for ethanol blending in gasoline is given in the table below.

**Table 2.1** Engine adaptations for ethanol blending in gasoline. Source: ANFAVEA[18]

| Engine part Blending ratio | carburetor | Fuel injection | Fuel pump | Fuel pressure device | Fuel filter | Ignition system | Evaporative system | Fuel tank | Catalytic converter | Basic engine | Motor oil | Intake manifold | Exhaust system | Cold start system |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| <5% | | | | | | | | | | | | | | |
| 5 – 10% | | | | | | | | | | | | | | |
| 10-25% | | | | | | | | | | | | | | |
| 25-85% | | | | | | | | | | | | | | |

The Brazilian government wanted to stop paying royalties to manufactures (multinational automobile manufactures) who imported engines that were designed abroad. However, after the second oil crisis in 1979 the Brazilian government refused to accept their conditions and during an important meeting with ANFAVEA, made available a modified ethanol engine using E100, developed at the CTA. Mário Garnero, President of ANFAVEA, played an important role in this process too. The first 100% ethanol car was presented in 1979 by FIAT.[19]

Another important contribution was provided by an article published in Science under the title "Energy Balance for Ethyl Alcohol Production from Crops". The authors of this paper were José Gomes Silva et al (1978) This article stablished the basis for the negotiations involving sugarcane ethanol life cycle analysis (LCA).

Figure 2.7 below shows the main phases of the PROALCOOL including production volumes of ethanol and oil prices, 1972/1973 to 2014/2015.

18 Henry Joseph Jr. worked at Volkswagen and ANFAVEA playing an important role in these engine developments

19 https://www.automotivebusiness.com.br/pt/posts/noticias/fiat-comemora-40-anos-do-primeiro--carro-a-alcool/

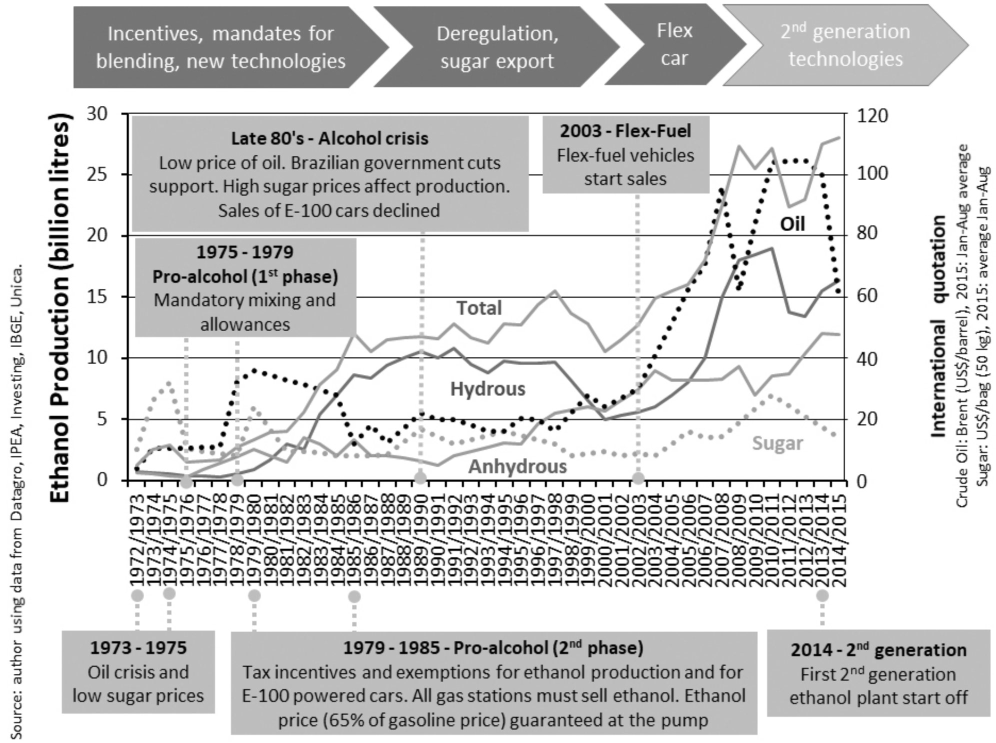



**Figure 2.7** Main phases of PROALCOOL 1972-2015. Source: CORTEZ (2016).

## 2.2.3. THE NEW PERIOD (1985-2000): END OF SUBSIDIES TO ETHANOL AND INCREASING SUGAR EXPORTS

After 1985, the sugar-ethanol sector in Brazil went through an important transformation. The democratic government did not want to guarantee the alcohol account, so subsidies where lifted. The Institute of Sugar and Alcohol (IAA) responsible for regulating the market (quotas and other issues) was closed down as well as all incentives associated with ethanol production. Therefore, investment on new distilleries dropped fast.

The period 1985-2000 was also marked by low oil prices. This was a period of great financial difficulties for ethanol producers due to the removal of subsidies and lower gasoline prices. Even so, ethanol producers and PETROBRAS maintained the policy to blend ethanol in gasoline and continued to support E100 sales in gas/petrol stations all over the country. According to ANP (2010) the percentage of ethanol in gasoline reached 22% in 2015.[20]

The production of E100 light vehicles continued to raise despite the fact that no additional investments were made available to the sugarcane/ethanol production. This situation was aggravated to the new crisis in 1989 when there was a shortage of

20 https://www.researchgate.net/figure/Figura1-Evolucao-no-uso-dos-biocombustiveis-no-Brasil-Fonte-ANP-2010-Em-dezembro-de_fig13_320596282

anhydrous ethanol in the pump stations. The Brazilian government had to import fuel methanol to satisfy the demand. Methanol is considered more dangerous fuel to be handled than ethanol which also helped to irritate consumers. As a result, the 1989 crisis created a certain mistrust in the consumers and the E100 vehicles sales declined to almost zero.

In 1991 the IAA was closed down. This was not a minor change since years back the IAA was the organism responsible for quotas and regulation in the sugarcane sector. The closing down of IAA could be understood as an important move towards the deregulation in the sugar & ethanol sector in Brazil.

On the other hand, due to the ethanol crisis, more sucrose was used for sugar production which received a major boost. By the middle of 1990s Brazil was already responsible for almost half of all sugar traded in the world. The period 1990-2000 was marked by the sector deregulation and a significant increase on sugar exports; Brazil become the first sugar exporter in the world.

Surprisingly, despite the inconvenient of low oil prices in the 1990s, according to ANP (2010), ethanol blending with gasoline continued, varying from 20 to 25%.[21]

### 2.2.4. THE END OF SUGARCANE BURNING AND THE FLEX-FUEL ENGINE

The early years of 2000 was marked, from the very beginning, by an increasing concern on the environment. Sugarcane burning prior to harvesting was considered an important issue since it was happening exactly in the driest period of the year (May to October) provoking air pollution and increasing respiratory diseases. This was a serious concern as many sugar plantations were close to urban areas. José Goldemberg, then Secretary of Environment in São Paulo state, promulgated the *State Law n. 11.241/02* to abolish sugarcane burning. The period afterward was marked by a rapid technological transformation because, in practical terms, meant the end of manual cutting of sugarcane. This important event resulted in the full mechanization of sugarcane fields with the introduction of heavy machinery and logistics for harvesting operations. (See figure below).

21 https://www.researchgate.net/figure/Figura1-Evolucao-no-uso-dos-biocombustiveis-no-Brasil-Fonte-ANP-2010-Em-dezembro-de_fig13_320596282

**Figure 2.8** Green sugarcane mechanized harvesting in Brazil. Source: Arthur Saraiva, site EMBRAPA.[22]

The beginning of XXI century was marked by the introduction of the flex-fuel vehicles in the domestic market, resulting in a rapid increase in ethanol demand. The sugar & ethanol sector had enjoyed its most prosperous years between 2002 and 2009 when it was growing at almost 10% annually.

Also, the sugar-alcohol sector paid much greater attention to improve energy efficiency in the mills. For example, the 2002 energy crisis forced more investments to improve cogeneration systems and created a third revenue from electricity sales for the mills, particularly in São Paulo state where several mills were connected to the national grid.

Since the implementation of the ethanol program, Brazil has created a sophisticated fuel ethanol regulation system comprising three phases:

- the first part was associated with sugar-ethanol distilleries. Most of sugar-ethanol distilleries in Brazil have the flexibility to produce either more sugar or ethanol as needed, depending on the circumstances e.g., the price of sugar or ethanol.
- Then, there is second part of the regulation system controlled by the Brazilian National Oil Agency (ANP). The ANP authorized the percentage of ethanol to be blended with gasoline as needed. So, when sugar prices are high, ANP authorizes less ethanol blending with gasoline and vice-versa.
- And thirdly the regulation system was a response by the consumer himself at the gas station. Depending on the price, the consumer will use hydrous ethanol (E100), or gasoline blended with anhydrous ethanol (today E27.5) depending on the price and his own car experience on mileage. On average, an ordinary car in Brazil will consume around 30% more of hydrous ethanol than if running on gasoline E27.5. Of course, the advent of flex-fuel engine and difficulties associated with increasing energy efficiency, somehow represent a limitation for the development of bioethanol in Brazil.

22 https://www.embrapa.br/busca-de-imagens/-/midia/4594001/colheita-de-cana-de-acucar-na-rmc

For further details on these three-level regulation system see Cortez et al. (2014) and on historical aspects of the PROALCOOL, Cortez (2016).

## 2.2.5. IMPORTANT TECHNICAL AND SCIENTIFICAL CONTRIBUTIONS OF THE SUGARCANE ETHANOL SECTOR

Several important contributions were made by the sugarcane ethanol sector since the implementation of PROALCOOL. The most important achievements in agriculture and industry are summarized in Table 2.2.

**Table 2.2** Incremental technological advances by the sugarcane ethanol in Brazil.

| Sector | Parameter | Previous status | Present status | Source |
|---|---|---|---|---|
| Agriculture | Sugarcane productivity | 45 tons/ha in 1975 | 75-80 tons of cane stalks/ha today | sugarcane variety programs: IAC, PLANALSUCAR/RIDESA, CTC |
| | Sugarcane mechanization | only soil preparation was mechanized | Practically all field operations are mechanized | By the authors |
| | Green cane harvesting | All sugarcane was burned and hand cut | Practically all sugarcane is green harvested | |
| Industry | Juice extraction | 93 | 97/98% | DEDINI |
| | Fermentation time | 18 hours | 6 hours | |
| | Fermentation yield | 80% | 92% | |
| | Wine ethanol content | 6.5° GL | Up to 16° GL | |
| | Industrial yield | 66 litres of ethanol/tc | 87 litres of ethanol/tc | |
| | Steam consumption | 620 kg of steam/tc | 300 kg of steam/tc | |
| | Excess Bagasse | up to 8% | Up to 78% | |
| | Vinasse production | 13 litres of vinasse/litre of ethanol | 5 to 0.8 litres of vinasse/litre of ethanol | |
| | Water use | 262.5 litres/litre of ethanol | – 3.7 litres/litre of ethanol[23] | |
| | Agri-industrial productivity | 3,000 litres/ha/yr | 7,000 litres/ha/yr | |
| | Harvest season duration | 6 months | 8 to 11 months with sugarcane & corn | |

23 This figure comes to be negative because part of water used in the process comes from the sugarcane itself.

Besides, there were several other contributions and improvements:

Agriculture:

- Increasing innovation in sugarcane planting
- Sugarcane diseases and pests' control
- Modern practices for sugarcane field management
- Implementation of highly competitive sugarcane logistics.

Industry:

- The size of sugar & ethanol mills grew up considerably ranging from 1 to 10 million tons of sugarcane/season (5 to 50,000 tons of cane/day) (crushed)
- Sugarcane dry cleaning, instead of water cleaning
- Increase in boilers efficiencies and cogeneration
- Maximizing electricity exports. For a 12,000 tons of cane/day plant, with 50% of bagasse/100% of trash excess, 84/112 MW of electricity.

Environment:

- GHG emissions reduction of sugarcane ethanol
- Important improvement of air quality in rural areas after the implementation of law stopping burning sugarcane
- Important improvement on air quality in Brazilian large cities

It is also important to mention the effort made by the productive sector to improve sustainability indicators of sugarcane ethanol in Brazil. An indication of this is given by the DEDINI concepts of optimization zeroing the amount of residues, odours, and water taken from water bodies. Also, great efforts have been made on mitigating GHG emissions comprising the whole production process.

Lastly, it is important to recognize that these efforts were compensated by declining costs (see the Ethanol Learning Curve below).

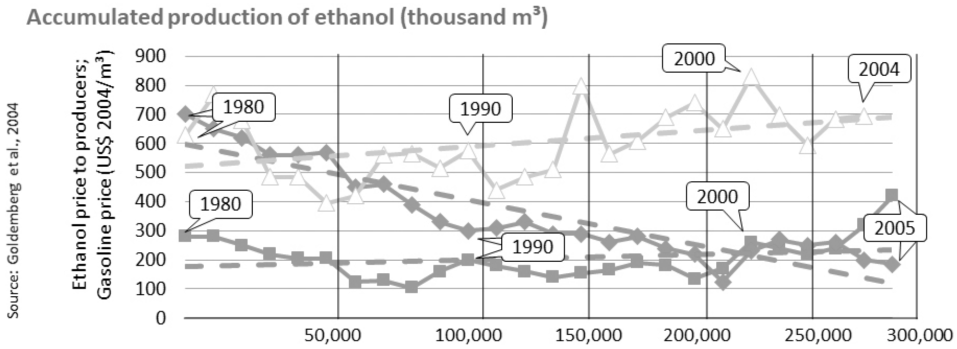



**Figure 2.9** Sugarcane ethanol learning curve, price of ethanol according to the accumulated ethanol production volume. Obs: green-ethanol BR, yellow-gasoline BR, orange-gasoline Rotterdam. Source: Goldemberg et al (2004).

In addition, these gains were only possible thanks to an efficient partnership between the private sector, universities and research centres, together with government policies and incentives. Several of these contributions were made possible by institutions dedicated to science and technology in Brazil. To name a few: CENBIO, CTBE, EMBRAPA, INT, IPT and Universities e.g., UFRJ, UNESP, UNICAMP, USP.

### 2.2.6. THE PARIS AGREEMENT AND THE NEW ROLE OF ETHANOL IN BRAZIL

In 2015 the Paris Agreement, Brazil signed a commitment to reduce GHG emissions and consequently fuel ethanol regains its importance. In 2017 the federal government launches the RENOVABIO program with the objective of ensure the predictability in the fuel market, inducing energy efficiency gains and reducing GHG emissions on production, commercialization, and final use of fuels.

Overall, ethanol use in Brazil can be considered a success story with good prospects for continuity, particularly if higher engine efficiency could be achieved. Also, ethanol received considerable support from PETROBRAS. As stated by Nastari (2017) *"without ethanol PETROBRAS would not be able to commercialize its low-octane gasoline, and without PETROBRAS ethanol would not have been developed and distributed, so successfully"*. So, in general terms, there was until now a certain complementary effect of fossil-renewable biofuel in Brazil.

In general terms, it can be said that PETROBRAS benefited from ethanol in Brazil. Besides this issue presented by Nastari (2017), PETROBRAS could sell anhydrous ethanol at the same price of gasoline. In addition, as will be discussed later, PETROBRAS is still in a unique position to become a green-oil company, taking advantage of ethanol and other sustainable biofuels produced in Brazil

## 2.3. BIODIESEL AND THE PROBIODIESEL PROGRAM

The idea of producing biodiesel in Brazil is not new. At the end of 1970s, Expedito Parente from the University of Ceará, Brazil, worked on methods to obtain biodiesel and its utilization in engines for partial diesel substitution. The first patent was submitted to INPI in 1980 and accepted in 1983 (CORTEZ, 2016).

Melo and Fonseca (1981) refer to the difficulties associated with lack of an equivalent crop to sugarcane among the vegetable oils. While sugarcane overall yields are around 7,000 litres of ethanol/ha/yr, soybeans oil yield are circa 600 litres. Better yields can be found with palm oil with around 5,000 litres of oil/ha/yr in Indonesia or Malaysia.

Biodiesel production in Brazil was encouraged in the early years of this century and a program called PROBIODIESEL was set up by the *Law n. 11.097/2005* (TOKARSKI; ARANDA, 2019).

The initial objective of PROBIODIESEL was to produce biodiesel to be blended with conventional diesel oil. The main idea was to promote family production of non-traditional crops such as castor (Ricinus communis L.) and sunflower particularly in Northeast Brazil. However, despite all experimental trials and government incentives, castor oil could not be produced in large enough scale and high productivity, and hence the original ideal did not prosper.

The main initial questions regarding the biodiesel program were the feedstock, the dilemma faced by the right wing government interested to launch their own program without the so-called negative effect of PROALCOOL. On the industrial side, the vegetable oil was somehow an almost ready-to-use fuel with only need to eliminate the fat acids though transesterification process. Various projects attempted to overcome this problem e.g., at the State University of Campinas (UNICAMP), Schuchardt et al (1998) developed a transesterification process to allow the separation of fat acids in biodiesel production.

Geographically, the distribution of biodiesel plants coincides with soybeans production regions (mostly in Central-West and South) since it is the most important feedstock for biodiesel in Brazil, with c.70%, tallow 13%, and other feedstocks from vegetable or animal origin.

In 2021 Brazil produced 6.4 billion litres of biodiesel in 49 biodiesel plants, according to the Brazilian federal government,[24] but according to Torkarski and Aranda (2019) there were 51 biodiesel plants. The biodiesel program received important official financial support, particularly to install the industrial facilities which were relatively much less capital intensive when compared with ethanol distilleries from sugarcane. For many years the installed industrial capacity exceeded demand. As the years progressed, new mandates were introduced: B5 (2010), B6 and B7 (2014), B10 (2018), and B11 in 2021. Today the target is to reach B20 in 2030 with RENOVABIO (see Table 2.3).

**Table 2.3** Evolution of biodiesel blends in Brazil. Source: UBRABIO based on 33.

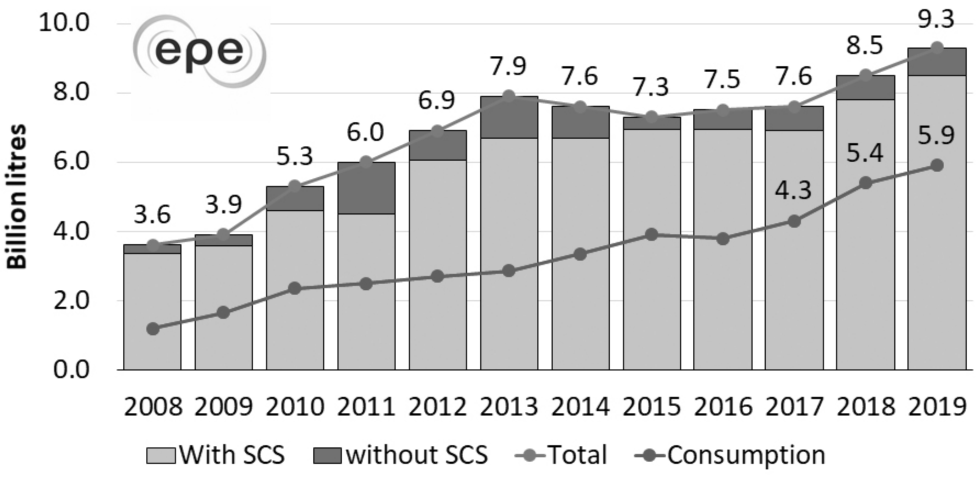
| Year | Biodiesel Blend (%) |
|---|---|
| 2017 | 8 |
| 2018 | 9 |
| 2019 | 10 |
| 2020 | 11 |
| 2021 | 12 |
| 2022 | 14 |

24 https://www.gov.br/pt-br/noticias/energia-minerais-e-combustiveis/2021/07/brasil-avanca-no-setor--de-biocombustiveis

| Year | Biodiesel Blend (%) |
|---|---|
| 2023 | 16* |
| 2024 | 18 |
| 2025 | 20 (51% of INDC target) |
| 2026 | 22 |
| 2027 | 24 |
| 2028 | 26 |
| 2029 | 28 |
| 2030 | 30 (80% of INDC target) |

*Obs: In 2023 the blend is actually still 10% of biodiesel.

Biodiesel does not have a good output/input energy ratio as ethanol. In Brazil, according to Macedo and Nogueira (2004) the ratio ranges from 2-3 for biodiesel and 8.3 for sugarcane ethanol. However, for palm oil and macaúba, Martins and Teixeira (1985) expect the ratio to be 5.63 and 4.20, respectively. These crops present a higher output/input energy ratio. However, the difficulties with both dendê palm (*Elaeis guineensis*) and macaúba (*Acrocomia aculeata*), is that they are not traditional large-scale crops in Brazil, therefore, there is not sufficient reliable agronomic experience for large scale cultivation. Figure 2.10 shows the evolution of plant capacity and consumption, from 2008 to 2019.




Source: EPE from (EPE, 2020a) and (ANP, 2020c).
Note: The Social Fuel Seal (SCS) is a distinction given to companies that produce biodiesel that use products from Family farms in their production chain. The objective is to guarantee income and stimulate the social inclusion of producing families. Biodiesel producers and SCS holders benefit from access to better financing conditions from financial institutions.

**Figure 2.10** Authorized nominal capacity and biodiesel consumption in 2019. Source: EPE (2020).

Greater increments on blending are expected in the near future, as it will be discussed on the next chapter.

## 2.4. LESSONS OF BIOFUELS FROM THE PAST 50 YEARS IN BRAZIL

The cumulative contribution of ethanol and biodiesel to Brazil (Figure 2.11) can be considered very important. Its contribution is not only important from an energy and macroeconomic perspective, but also from a social and environment points of view. Although institutions such as the EPA from USA has recognized sugarcane ethanol produced in Brazil as an advanced fuel, its global contribution has not yet been fully recognized.

Besides the macroeconomic benefits derived from hard currency savings, a significant number of direct and indirect jobs were created by ethanol and biodiesel industries in Brazil. Up to 2000s, a large number of jobs were on sugarcane harvesting. However, after the non-burning law has been approved, the sector gradually started to use mechanized harvesting substituting manual labour. At the beginning there was a concern, particularly by the rural unions, because manual harvesting attracted a large number of workers from different regions of the country. However, as the sector expanded, requiring more workers, these workers were absorbed in other sugarcane and ethanol activities. Today, the biofuels industry is one of the most important contributors to economic prosperity in rural Brazil. For example, it has been estimated that there are nearly one million workers, direct and indirect. Just the sugarcane sector alone employs more than 600,000 workers (AZANHA, 2010).

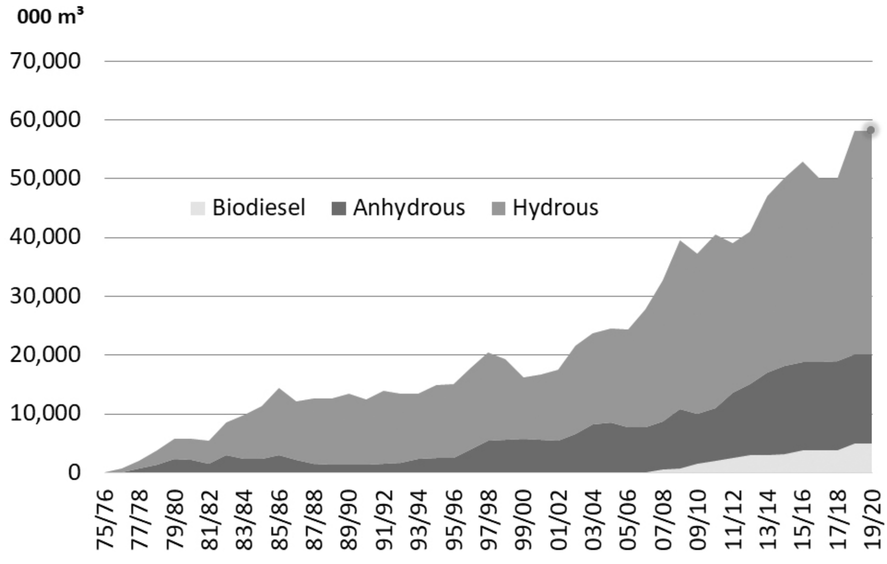



**Figure 2.11** Evolution of ethanol (anhydrous and hydrous) and biodiesel in Brazil. Source: DATAGRO and ANP, from Leal (2022).

Although the use of modern biofuels started almost 100 years ago, it can be said that the most intensive use happened in the last 50 or so years (since 1975), particularly with ethanol from sugarcane. From that, several lessons can be derived:

- **The successful use of biofuels depends on three things: feedstock production, feedstock conversion process, and biofuels final use (engines)**. So, the three must be efficient, not just one or two. Feedstock efficient production needs also to be competitive and environmentally sustainable. Feedstock conversion process needs to be energy efficient and sustainable with corresponding use of all by-products. And lastly, biofuels final use should also be efficient. Overall, it is an equation in which all the three components (feedstock, process, and engine) must be efficient and competitive.
- **Biofuel economics are heavily dependent on the feedstock**. For ethanol this represents around 70%, and for biodiesel c.80%. So, if the economics of feedstock is not well established, there is little that can be done.
- **Biofuel economics also depend on the valorisation/utilization of by-products**. This happens with sugarcane ethanol, in which sugar (for food) acts as the main coproduct, and ethanol for fuel and bagasse (for electricity) as second. The same phenomena occur with corn ethanol in which DDG,[25] the main coproduct from corn ethanol, is used as cattle feed. This point will be discussed in more detail below.
- **If biofuels are conceived to reduce GHG emissions, special attention should be given to its life cycle analysis**. For example, ethanol from sugarcane or corn ethanol, can be produced in different ways, hence achieving different life cycle results.
- **If biofuels are conceived to promote social benefits, its premisses should be analysed**. Ethanol or biodiesel, or any other biofuel, needs to be produced at competitive cost to be able to compete with fossil fuels. Markets are not willing to pay premium costs to any biofuel, unless forced by legislation. Of course, there is the problem posed by heavy subsidies given to fossil fuels, and in this case, oil. These subsidies to fossil fuels should be eliminated to increase the competitiveness of biofuels and other renewables to have a fairer playing field
- **Indirect land use change (iLUC) is a controversial concept** (to be further discussed on Chapter 4). It is not proven that a modern biofuel such as sugarcane ethanol produced any iLUC, at least in Brazil, **nor any negative impact of ethanol, nor biodiesel to food production**. On the contrary, sugarcane ethanol benefited sugar, and modernized other agricultural activities; soya biodiesel production benefited poultry or swine production in Brazil, as corn ethanol benefited cattle production in the USA.
- **All residues need to be recycled**

25 DDG-dry distillers' grains.

## FINAL REMARKS

This chapter has highlighted how biofuels have evolved in Brazil through its various historical phases. A special attention was given to fuel ethanol. It has identified the most salient features such as policy changes, technological achievements, regulations, major actors in the development of biofuels, agriculture, social, and environmental issues, as well as lessons learned.

It has been a long road since environmental sustainability was taken seriously. In the old school of thought, economic development was at the core of policymaking in Brazil, and biofuels development reflects this reality.

This chapter provides a realistic overview of this historical process for a spectrum of readers.

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