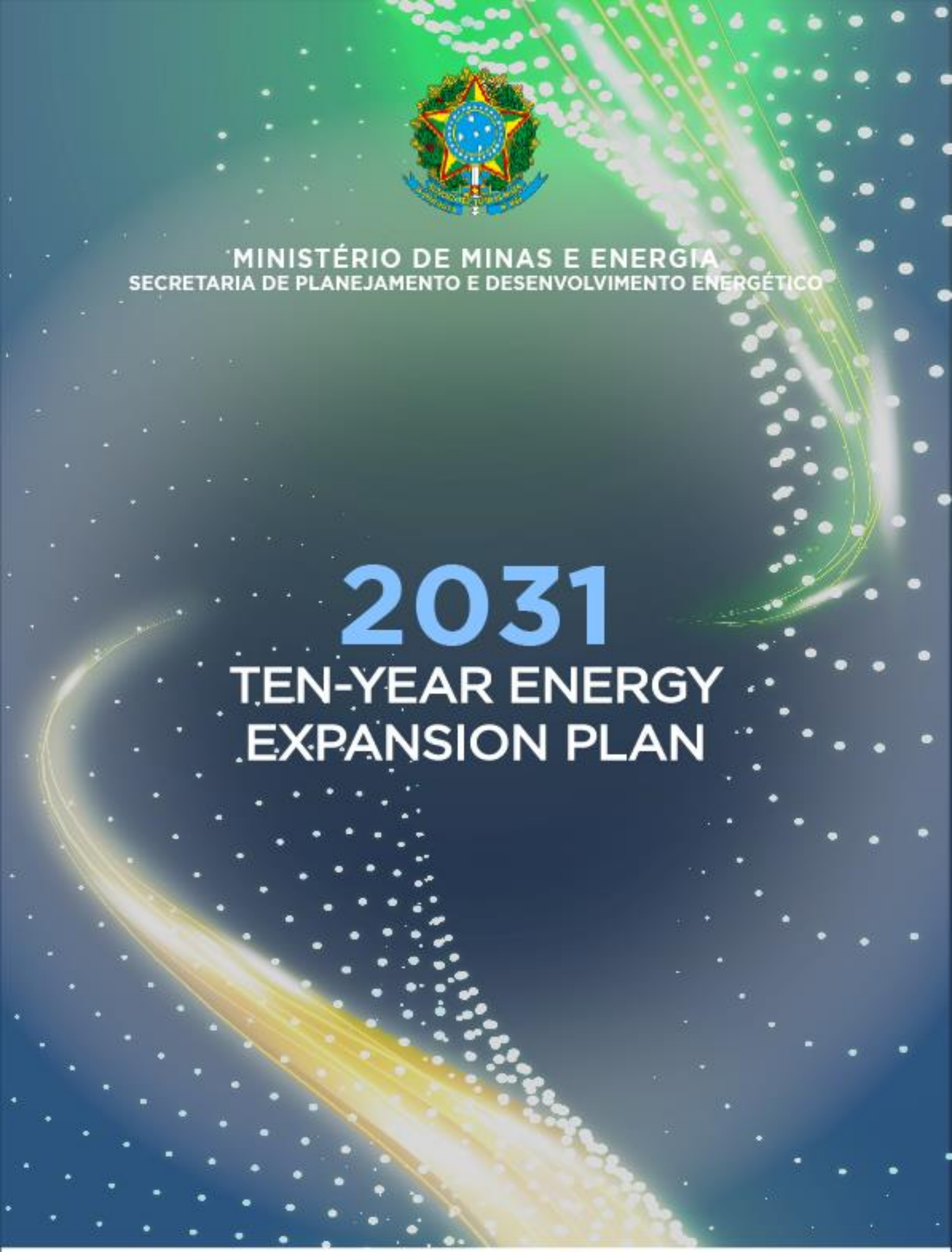

MINISTÉRIO DE MINAS E ENERGIA
SECRETARIA DE PLANEJAMENTO E DESENVOLVIMENTO ENERGÉTICO

2031
TEN-YEAR ENERGY EXPANSION PLAN

epe
Empresa de Pesquisa Energética

Ministério de
Minas e Energia

8. Biofuel Supply

This chapter presents the prospects of ethanol supply expansion to meet the domestic demand and the share of the international market supplied by Brazil, as well as forecasts for sugarcane biomass for electrical energy generation, biogas, and the supply of biofuels for the diesel cycle, biojet fuel, and the prospects for alternative fuels for maritime use and for the installation of biorefineries, on the PDE timeframe.

The estimates consider the positive signs arising from the establishment of the National Biofuels Policy (RenovaBio), as well as the results of the analysis by the Working Group on the insertion of biofuels for use in the Diesel cycle (CNPE, 2020) and the consequences of the “Fuel of the Future” federal program (CNPE, 2021b). It should be noted that the forecasts for the supply of biofuels prepared in this study cycle encompass the developments resulting from the COVID-19 pandemic, whose impacts should be noticed more intensively in the short term (EPE, 2020b).

8.1 Public Policies for Biofuels

Since the beginning of the 21st century, the Brazilian government has used public policies to stimulate the biofuels market, such as the introduction of vehicles with flex fuel technology, the mandatory blending of anhydrous ethanol in gasoline, the National Program of Production and Use of Biodiesel (PNPB) and, more recently, RenovaBio and the Fuel of the Future Program. Note that public policies to stimulate the market for renewable fuels in Brazil date back to the 1930s.

Additionally, the country has policies for tax differentiation between biofuels and their fossil analogues, in terms of PIS/Cofins[1] and Cide[2], such as those adopted for ethanol and biodiesel in relation to gasoline and diesel, respectively. The states have also been playing an important role, through differentiated ICMS rates[3] [1] [2]. Also noteworthy are the specific lines of financing administered by the National Bank for Economic and Social Development (BNDES).

Created through Law No. 11,097/2005 [3], PNPB has established the mandatory use of biodiesel in the mixture with fossil diesel. Initially, the addition of 2% biodiesel to fossil diesel was optional, becoming mandatory from 2008 on. The percentage reached 5% in 2010 and, since then, there has been a rapid evolution, reaching 13% in March 2021, with a schedule to advance to 15% in 2023.

RenovaBio, established by Law No. 13,576/2017 [4], is a State policy that recognizes the strategic role of biofuels in the national energy matrix, focusing on the security of fuel supply and the mitigation of greenhouse gas (GHG) emissions [5] [2]. The developments for the year 2020 will be presented in item 8.1.1.

Established through CNPE Resolution No. 7/2021 [6], the Fuel of the Future Program aims to increase the share of sustainable and low-carbon fuels, integrating various public policies, such as RenovaBio, PNPB, the National Vehicle Labeling Program and Route 2030. The Program will also study the use of aviation biojet fuel and sustainable alternatives in the maritime sector, measures to capture carbon in the production of biofuels and ways of using hydrogen as a fuel [7].

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[1] PIS/Pasep: Contribution to the Worker's Social Integration and Public Servant Asset Formation Program. Cofins: Social Contribution for the Financing of Social Security.

[2] Cide: Economic Domain Intervention Contribution.

[3] Tax on Operations Related to the Circulation of Goods and on Provision of Interstate and Intermunicipal Transport and Communication Services.

8.1.1 RENOVABIO

RenovaBio seeks to expand the competitive share of biofuels and its operation is based on three pillars: (1) the establishment of annual targets for reducing carbon intensity, in units of gram of CO_2 per mega Joule (gCO_2/MJ), from transport energy matrix to a minimum period of ten years; (2) the Biofuels Certification and (3) the Decarbonization Credit (CBIO). For more details, access the Analysis of Biofuels´ Current Outlook publication series [5] [2].

The Program officially begun in 2020, with the obligation to meet the decarbonization targets by fuel distributors. The certifications of the production facilities progressed from January, reaching a level of stability in July 2020, ending with 239 approvals. Considering the authorization for the commercialization of biofuels granted by ANP [8], until November 11, 2021, there were certified 267 ethanol plants (75% of the total authorized to operate), 30 biodiesel plants (58%) and three of the four biomethane plants, totaling 300 approvals.

8.2 Ethanol

8.2.1 ETHANOL SUPPLY IN BRAZIL

The domestic production of ethanol is directly related to soil and climate conditions, with the proper cultivation of sugarcane and with the international sugar market. Recently, ethanol production from corn has become more significant.

In particular, the Brazilian sugar-energy sector takes advantage of its flexibility in the production of sugar and ethanol, to adjust to market fluctuations and maximize its revenues or minimize losses [2].

An overview of the sector shows that the indebtedness of part of its companies has reduced investments in greenfields (new plants) of sugarcane, as well as those directed to brownfields (expansion and/or retrofit of existing plants). This situation can also have negative consequences for the conservation and improvement of the biological assets of some companies in the sector (renewal of sugarcane fields, development and insertion of new varieties, etc.), affecting their productivity and yield parameters. The level of indebtedness contributed to the drop of raised funds by the sugar-energy sector from the BNDES, which, in 2020, corresponded to about 20% of the total amount observed in 2013, the year with the highest disbursement [9].

This part of the sector has been seeking to balance its financial situation, with actions to improve production factors, which provide cost reduction and margin growth, increasing its economic sustainability, in order to get closer to companies with best practices.

On the other hand, there has been a series of investments focused on the production of ethanol from corn in recent years, already with results in the present and with great expectations for the future.

From the perspective of public policies, the federal government has been using regulatory instruments and has sought to signal and provide adequate economic incentives for the resumption of investments. The international gasoline price parity also contributes to improving business predictability.

The forecast of ethanol supply considers a series of assumptions, such as the sugarcane cycle (five cuts); expansion of productive capacity;

evolution of production factors (sugarcane yield, harvest area, TRS[4], etc.); sugar production; industrial transformation index; the technological stage of second-generation ethanol (lignocellulosic ethanol or E2G) and the production of corn ethanol. For more detail on the methodology used to forecast the ethanol supply, please consult PDE 2024 [10] and the publication Scenarios of Ethanol Supply and Demand for the Otto Cycle 2022 - 2035 [11].

The Ministry of Agriculture, Livestock and Supply [12] registered, in December 2020, 361 ethanol and sugar production facilities in Brazil, whose effective crushing capacity was 745 million tons of cane (Mtc) (90% of the nominal capacity). Considering the crushing carried out in 2020 (663 Mtc), the occupancy of the effective processing capacity was 89% [12] [2].

According to ANP [13], in July 2021, the facilities authorized to produce ethanol had anhydrous and hydrated production capacities of 130 thousand m³/day and 239 thousand m³/day, respectively. There was estimated an anhydrous and hydrated annual production capacity of 23 billion liters and 43 billion liters, respectively, (considering an average of 180 days of harvest). The year 2020 saw the stoppage of one facility and the resumption of activities at four plants. There are also facilities operating in a situation of judicial recovery.

The forecast of ethanol production capacity from sugarcane is analyzed in two different periods: from 2022 to 2026 and from 2027 to 2031.

In the first period, investments for capacity expansion refer to projects with construction authorization by ANP, in July 2021: a total of four, two of which have small production capacity (ethanol production capacity of 800 m^3/day). In the second period, among the assessed scenarios[5], the chosen one for this PDE considers an implementation of 5 facilities with an average specific grinding capacity of 3.7 million tc/year/plant (ethanol production capacity of 6,031 m^3/day[6]) totaling 9 facilities in the ten-year period

The nominal sugarcane processing capacity should be expanded by 1.1 Mtc[7] in the ten-year timeframe. Reactivations and stoppages will result in a positive balance of 4.8 Mtc (nominal) (ethanol production capacity of 400 m^3/day) between 2022 and 2025. **Chart 8 - 1** presents the flow of sugarcane producing facilities (historical, new facilities, reactivation and closure) and the change in installed capacity forecast for the period.

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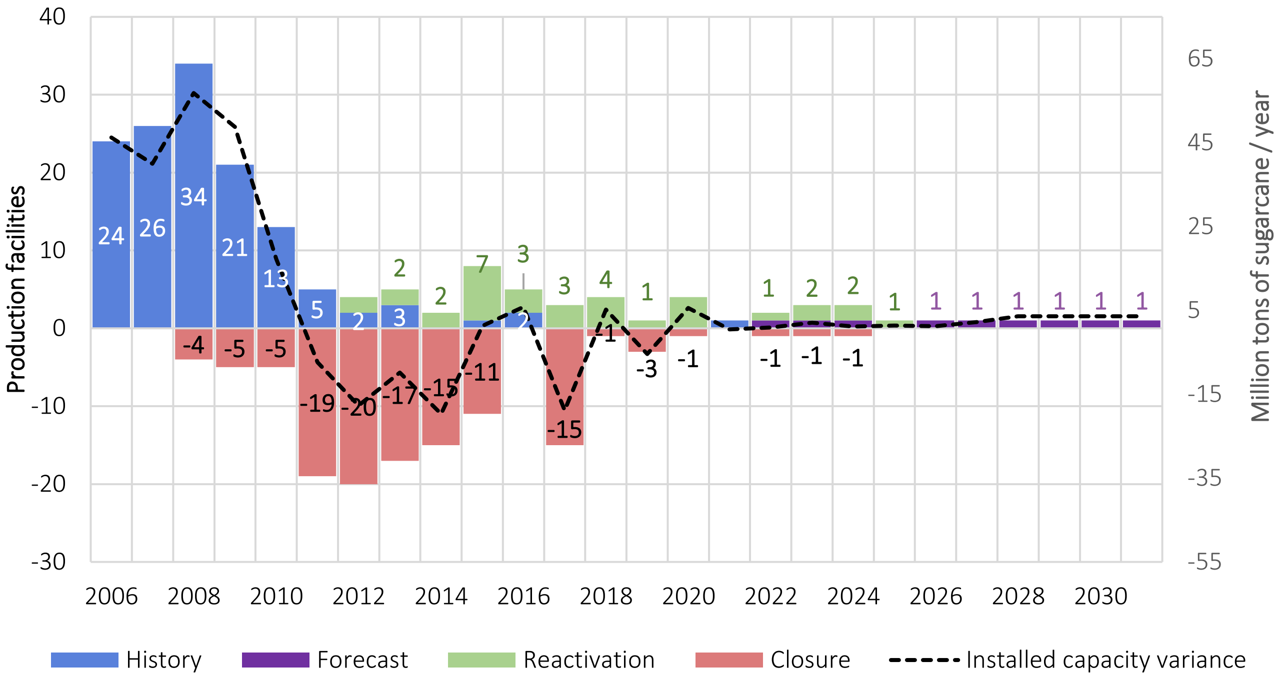
[4] Total recoverable sugar

[5] The publication Scenarios of Ethanol Supply and Demand for the Otto Cycle 2022 - 2035 (EPE, 2021c) presents the trajectories analyzed for the ten-year period, including the one adopted in this PDE.

[6] Value determined based on a mixed facility, with a nominal crushing capacity of 4 Mtc (CTBE, 2018).

[7] In June 2021, there were 50 facilities (sugarcane) authorized to expand their ethanol production capacity (totaling about 2 billion liters). However, there is no information on whether or not there will be an increase in the milling capacity of these facilities.

Chart 8 - 1: Sugarcane producing facility flow and installed capacity variation



Source: (MAPA, 2021) and (UNICA, 2014) (historic) and EPE (forecast).

In recent harvests, the average age of the sugarcane fields remained high (around 3.8 years). Weather conditions, renewal of sugarcane fields, improvements in planting and introduction of new varieties influenced productivity (76.0 tc/ha) and quality (144.1 kg ATR/tc) in the 2020/21 crop, whose values were the highest in recent years [14]. The yield improvement from late periods is also associated with the amount of total impurities (minerals and vegetables) present in the harvested sugarcane, which was 8.4% (7.4% lower than previous harvest).

The sector introduced mechanized harvesting mainly to achieve the goals imposed by environmental laws and agreements to reduce slash-and-burn fires [15] [16]. However, there was a mismatch between the mechanization of harvesting and planting, in addition to other operations related to sugarcane cultivation. Some producers have been using technologies and production systems capable of increasing yields and, since the 2018/19 harvest, there has been a reduction in mechanized planting, in order to recover productivity and reduce costs (seedling consumption and planting failures by machines), in addition to an increase in the use of the MEIOSI technique[8].

These themes are subject to continuous evaluation by specialists in research centers and by agricultural managers. Therefore, that part of the sector will seek the implementation of best practices, through varietal and agronomic management, in order to reduce its production costs, increasing economic sustainability.

In this cycle of studies, energy cane (EC) will represent, in 2031, around 100 thousand ha, corresponding to 1.1% of the total sugarcane area.

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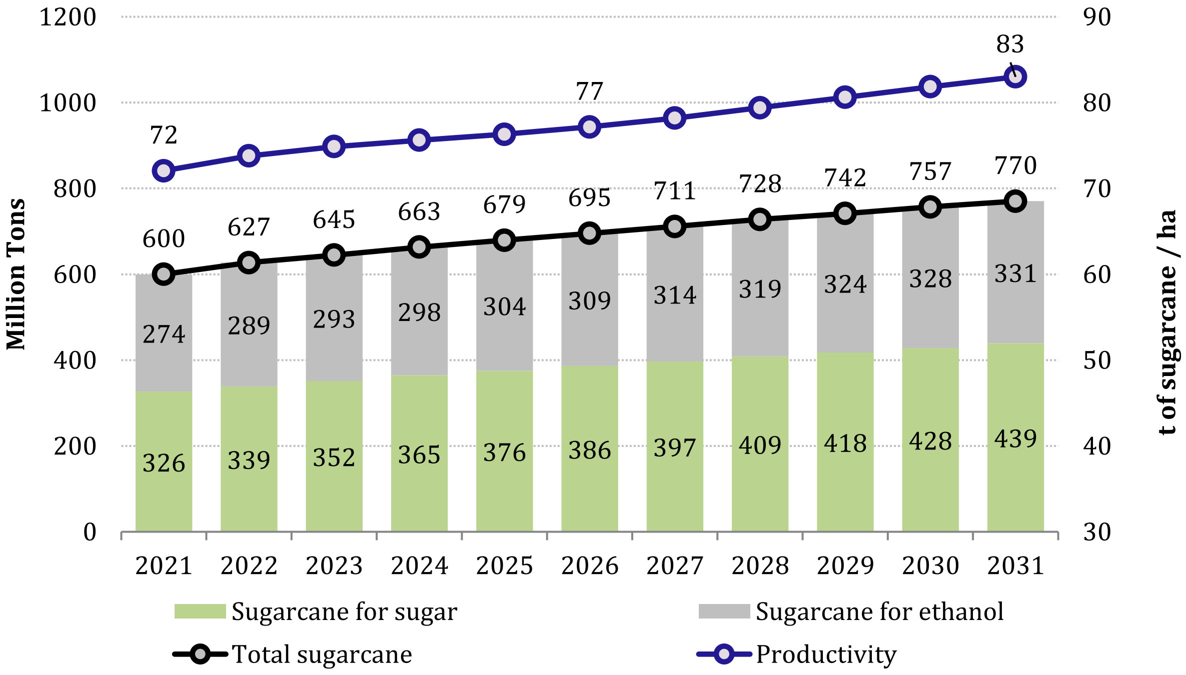
[8] MEIOSI – Simultaneously Occurring Interrotational Method.

In the ten-year timeframe, it is estimated that the total area of sugarcane harvest will increase from 8.3 million hectares in 2021 to 9.3 million in 2031. Productivity will grow 1.4% p.y., reaching 83.0 tc/ha in 2031, while yield will be at the level of 141.0 kg of ATR/tc.

Based on area and productivity, harvested sugarcane is expected to grow at a rate of 2.5% p.y., reaching 770.4 million tons in 2031, according to **Chart 8 - 2**, and the percentage of sugarcane destined for ethanol varies from 54%, in 2021, to 57%, in 2031, an increase that is due to the greater demand for biofuel.

For the ten-year timeframe, it is estimated that investments for the formation of the sugarcane field will be approximately 32 billion reais, considering the ratio between plant cane (new + renewed area) and total cane of 17%.

Chart 8 - 2: Productivity, harvested sugarcane and destination to ethanol and sugar



Note: Productivity in Crop Year
Source: prepared by EPE

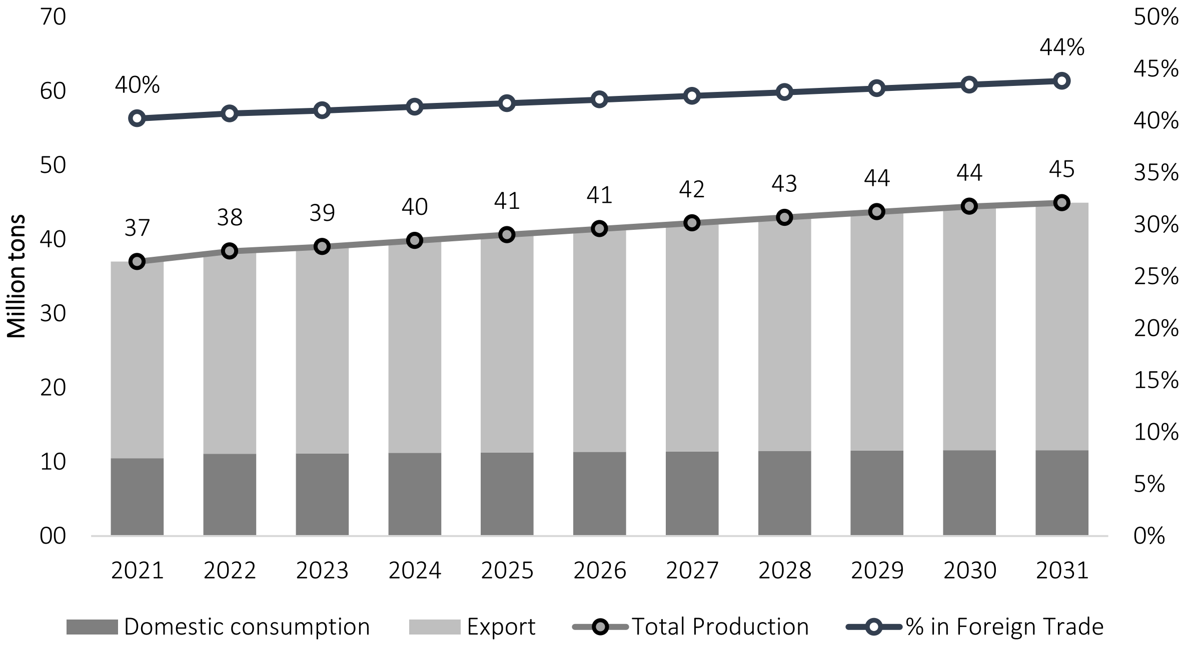
The industry divides the total sugarcane ATR between sugar and ethanol based on the greater profitability of the commodity sugar and the Brazil share in its world trade. Thus, the amount necessary to meet their respective demands is removed from the total ATR, resulting in the portion destined for ethanol.

The forecast of Brazilian sugar production is composed of two parts: domestic consumption and exports. Domestic consumption considers the evolution of Brazilian per capita consumption (kg/inhabitant/year) and is related to aspects of income, population aging and changes in eating habits [17] [18] [19].

In the portion dedicated to the foreign market, Brazil maintains its outstanding position in the decade, being responsible for more than 42% of the flow of international trade, based on the increase in supply to meet the growth in demand in importing countries in Africa and Asia [17] [18]. The production of important players, such as India, Thailand and the EU, influence Brazilian exports.

The forecast of sugar production, divided between domestic and foreign markets, is shown in **Chart 8 - 3** and reaches 44.9 million tons in 2031.

Chart 8 - 3: Productivity, harvested sugarcane and destination to ethanol and sugar



Source: prepared by EPE

Ethanol can also be produced through other feedstocks, such as bagasse and straws and tips (E2G) and corn.

Brazil has two commercial second-generation ethanol plants (Granbio and Raízen), with nameplate production capacity of 60 and 42 million liters per year, respectively [20] [21]. The commercial facilities faced technical problems, such as in the pre-treatment and lignin filtering stage, and they still operate below rated capacity. According to Raízen, the company was able to overcome these challenges, with the Costa Pinto facility producing 24 million liters in the fiscal year ended March 31, 2021 [22] Bioflex/Granbio had a production of 1.6 million liters in 2019 [23].

In June 2021, Raízen announced the construction of a new plant in the city of Guariba (SP), whose production capacity will be 82 million liters per year. The investment has a long-term contract for the commercialization of 91% of the production with a global energy player [24]. In addition, the company announced sales agreements for 460 million liters of E2G over nine years [25]. This company believes it has the possibility of having up to 20 E2G plants operational by 2031, due to its raw material control and proprietary technology, which it intends to license to other countries with high availability of biomass, such as India.

In other countries, E2G projects have not been able to reach commercial production and many plants have stopped their operations, with no prospect of resumption.

In the forecasts, the integration of lignocellulosic and conventional ethanol production was judged to be more economical and competitive. Plants that already have cogeneration and are interested in producing lignocellulosic ethanol should evaluate the availability and diversity of raw materials (collection of straw and tips and the possibility of energy cane), as well as the efficiency of the production process (change of boilers and turbines and equipment electrification).

The production of second-generation ethanol will use a small portion of the bagasse and straw produced and should reach more than 400 million liters in 2031 (conversion factor of 300 liters of ethanol per ton of dry bagasse).

The use of corn for the production of ethanol enables taking advantage of occasions when the price of the grain is low, since the logistical costs of shipping from the Central-West region affect the competitiveness of the product in the international market, which induces investments in new production facilities. In addition, corn oil, intended for human consumption, and DDGS (distiller's dried grains with solubles), for animal nutrition, are generated as co-products, adding two more assets to the mills' revenue pool [26] [27]. The annual aggregate capacity was 3.5 billion liters in 2020, with 2.4 billion liters being produced [28]. To date, there are 20 facilities in operation, nine of which are full type (only uses corn)[9] and 11 of the flex type (associated with sugarcane ethanol facilities).

In the ten-year timeframe, it is estimated the building of eight flex facilities and 23 of the full type (10 of which are authorized by the ANP, June 2021[10] position), with the installed capacity reaching 8.9 billion liters, according to **Table 8 - 1**. Thus, corn ethanol production is forecast to reach 8.1 billion liters in 2031.

As for ethanol imports, occasional purchases of anhydrous in the foreign market will be necessary for trade balance.

Because of domestic production and anhydrous imports, the total supply of ethanol will grow at a rate of 4.0% p.y., reaching 46.4 billion liters in 2031, as shown in **Chart 8-4**. For hydrous ethanol, this rate is 5.9% p.y., reaching 34.6 billion liters in 2031, while anhydrous (domestic and imported) is estimated to be 11.8 billion liters at the end of the period. A sensitivity analysis for another ethanol supply scenario, less favorable for the sugar-energy sector, is presented in Box 8-1.

Table 8 - 1: Installed capacity of ethanol and corn producing facilities

	2021		2031	
	No. of facilities	Ethanol production installed capacity (liters)	No. of facilities	Ethanol production installed capacity (liters)
Total	23	3.9 Bi	54	8.9 Bi
Flex	12	1.3	20	2.9
Full	11	2.6	34	6.0

Source: Prepared by EPE based on (MAPA, 2021).

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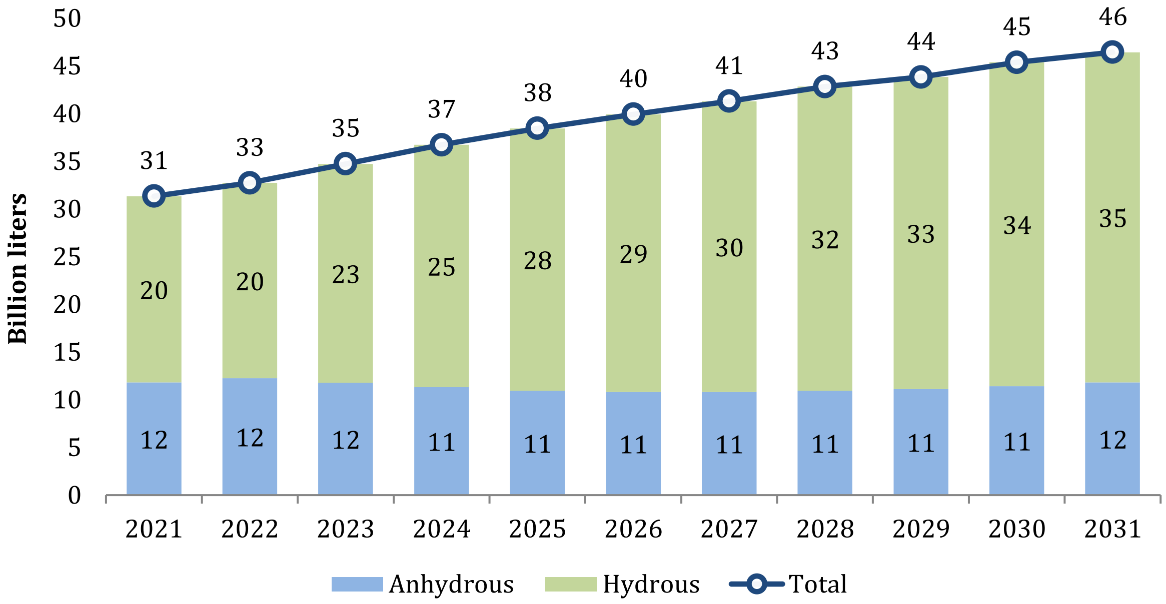
[9] There is a facility that came into operation in 2021, using soy as an input.

[10] The entry of a soybean facility and three cereal facilities is also considered, with construction authorized by the ANP.

Chart 8 - 4: Total ethanol supply forecast



Source: prepared by EPE

INVESTMENT - OUTPUT CAPACITY

To assess the investments needed in first-generation sugarcane facilities (greenfields), this study considered that these would be mixed ones (sugar and ethanol) or distilleries, with an optimized technological profile and an average size of 3.5 million tons of nominal sugarcane crushing capacity. It is estimated that the average investment is BRL 360/tc, according to **Table 8 - 2**. For the expansion of existing facilities, an average investment of BRL 256/tc was adopted.

Therefore, investments in industrial capacity should be around BRL 7.2 billion, related to the new proposed facilities, and BRL 0.5 billion, for the expansions raised, totaling BRL 7.7 billion in the ten-year period [29]. [28].

The estimate of investments in new lignocellulosic ethanol plants is based on the values of the commercial facilities in operation in Brazil, estimated at BRL 5.6/liter. The forecast amount reaches BRL 2.1 billion between 2022 and 2031, a value that may be lower due to the learning curve of the sector.

For corn ethanol, it is estimated that CAPEX for the implementation of a flex plant will be BRL 1.60/liter, while for a full plant, the value is BRL 1.80/liter [29] [26] [30]. Then, the estimated investment in the decade is around BRL 9.0 billion.

Thus, investments in ethanol and sugar production capacity reach BRL 18.8 billion.

Table 8 - 2: Average investment for building new facilities and expanding existing ones

CAPEX (Sugarcane)	BRL (Dec. 2017) / tc
Expansion of existing facilities (*Brownfield*)	**256.0**
New facilities (*Greenfield*)	**359.8**
Industrial (includes optimized co-generation)	287.6
Farming Machinery (includes trucks)	67.9
Leasing (Central-West Region)	4.3

Note: For conventional sugarcane plants, CAPEX was given per cane ton, once part of production can be destined for sugar (unlike what was presented for E2G and corn ethanol facilities).

Source: EPE, based on (CTBE, 2018) and (UNICA, 2021)

8.2.2 TOTAL ETHANOL DEMAND

Total ethanol demand is comprised of domestic demand (divided between the carburant and the non-energetic or other uses) and international demand or Brazilian ethanol exports.

DOMESTIC MARKET DEMAND

Fuel ethanol demand (anhydrous and hydrous) starts from 28.0 billion liters in 2021, grows 4.4% p.y. and reaches 43.0 billion liters in 2031. Impacts of the COVID-19 pandemic, specifically in the biofuel sector, must be observed with greater intensity in the short term, with the sector resuming growth along the ten-year period, as per [31]. The increase in demand for fuel ethanol is due to the greater competitiveness of hydrous compared to gasoline, partly because of the positive signs coming from RenovaBio and the improvement in production factors carried out by the sector. It is expected that non-fuel use (beverages, cosmetics, pharmaceuticals, oxygen compounds and alcohol chemicals) will reach 1.2 billion liters in 2031. In 2020, the consumption of 1.4 billion liters of ethanol was influenced by its use as antiseptic, one of the preventive measures to the spread of COVID-19.

INTERNATIONAL MARKET (EXPORTS)

The consequences of the COVID-19 pandemic affected the world energy market, including the global production and consumption of biofuels. In 2020, world ethanol production reached the value of 105 billion liters (8% less than 2019), with Brazil and the United States representing 84% of the volumes produced [32]. Support for policies to encourage energy efficiency and/or promotion of more advanced energy sources and a tendency towards modest volumes of commercialized renewables remains, compared to fossil fuels.

In 2020, Brazil showed an increase in exported volumes, reaching 2.7 billion liters, 0.7 billion more than in 2019 [33], even with the reduction in the total supply of ethanol. Part of this increase in Brazilian exports can be due to the retraction of the US market, which showed a drop in production volumes and net exports in 2020. There was a large demand for ethanol as an antiseptic in several countries, like in the domestic market.

Regarding ethanol imports, since January 2017, there have been significant volumes in the months of intense harvest[11]. In 2020, 1.0 billion liters were imported [33].

An outlook on the production and use of ethanol is presented below, with an emphasis on the USA, European Union and Asia, in order to support the evaluation of the Brazilian export potential of the product.

United States

The Energy Independence and Security Act of 2007 - EISA – conducts the US energy policy and, through the Renewable Fuel Standard (RFS), establishes an annual addition of biofuels to automotive fuel, in increasing volumes, beginning from 2007 and 2022. The volumes are distributed in two categories: conventional biofuel (ethanol from corn) and advanced (biofuels from other feedstocks, which also reduce GHG emissions by at least 50%, based on the life cycle analysis). The second category is divided into cellulosic biofuels, biomass diesel and other advanced biofuels, such as sugarcane ethanol [34].

Due to EISA, the country has presented consecutive records in the production of corn ethanol (53 billion liters in 2020), whose main destination is the domestic demand, which varies around 55 billion liters. This value is equivalent to 10% of the annual demand for gasoline, because of the addition of 10% of ethanol[12] to the fossil fuel (E10) [35]. The rest is exported to several countries, Brazil as its main destination.

The volumes of ethanol mixed with gasoline are sufficient to meet the portion of conventional biofuel (ethanol from corn) established by the RFS [34]. Difficulties in the commercial production of cellulosic ethanol were forcing the government to reduce the volumes related to advanced and cellulosic biofuels every year. However, in 2020, the Environment Protection Agency - EPA – didn't established changes in the volumes [36], remaining those previously established in December 2019 [37]. For the timeframe beyond 2022, the RFS will remain in effect, with volumes being established by the EPA, in conjunction with the US Secretaries of Energy and Agriculture.

European Union

Currently, the bloc maintains an action plan for GHG mitigation and energy security, with targets for 2020, 2030 and 2050. For 2020, the so-called "Triple 20" aimed to: a 20% reduction in GHG emissions, compared to 1990, a 20% share of renewable sources in energy consumption, with 10% share of renewables in automotive consumption[13], and a 20% increase in energy efficiency, compared to 1990 [38].

Regarding the objectives of 2020, according to the European Environment Agency, the bloc may have managed to meet the GHG mitigation and the share of renewables in the final consumption. In 2019, GHG emissions had already accounted for a 24% drop from 1990 levels, while the share of renewables in final consumption reached 19.4%[14] [39]. The impact of the COVID-19 pandemic caused a reduction in consumption of primary sources due to circulation restrictions. About the energy efficiency target, the European Union is far from achieving it. According to the agency, in 2018, primary and final energy consumption in the block were respectively 2.4% and 2.1% above projected values [39].

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[11] On August 29, 2017, Brazil' Government published CAMEX Resolution No. 72 to restrict growing ethanol imports, until the end of August 2019. This measure released a total volume of 1.2 billion liters from the import tax during the period in force, with a quarterly quota of 150 million liters (ME, 2017). On the end date of this Resolution, Ordinance No. 547 was published, extending the quota for another 12 months, and changing the volumes to 750 million liters in total, distributed in 187.5 million liters quarterly (ME, 2019).

[12] Blends with 15% ethanol (E15) are also allowed, depending on availability at service stations and consumer preference.

[13] In favor of second-generation biofuels, the bloc limited the participation of traditional ones (ethanol from sugarcane and corn, and biodiesel from oilseeds) to a maximum of 7% in energy demand until 2020, eliminating their participation in final demand until 2030 (BIOMASS MAGAZINE, 2018).

[14] In 2020, figures for electricity generation indicate that there was a greater share of renewable sources, accounting for 38% against 37% for traditional fossil sources and 25% for nuclear (REUTERS, 2021).

Through the 2018 Renewable Energy Directive, the European Parliament approved changes in the values of the climate and energy action targets for the European Union, for 2030: 40% reduction in emissions, 32% share of renewables in final consumption, 14% share of renewables in automotive consumption and 32.5% increase in energy efficiency [38].

Asia

China is the third largest ethanol producer in the world, having produced 4.0 billion liters of sugarcane ethanol in 2020 for domestic use [40]. The country has an E10 blending program in 10 provinces and had plans to roll it out to the entire country by the end of 2020. However, this action was suspended with no expected term extension, due to the limitations of increasing ethanol production capacity and low inventories, in view of the increase in gasoline consumption in recent years [41].

South Korea is one of the main destinations for ethanol exported from Brazil (954 million liters in 2020, 35% of the total exported) [33]. Although the country uses it exclusively in industry and in the food sector, the government is studying the use of fuel ethanol as a way to mitigate the problems of atmospheric pollution in large cities and to help in the search for energy security [42].

On July 3, 2018, Japan established its 5th Strategic Energy Plan as the basis for the country's energy policies until 2030. The plan reinforced the guidelines in favor of less dependence on fossil sources and on nuclear energy, promoting renewable sources, whose share in the total energy supply is expected to expand to 13% by 2030 [43]. The country imports a large part of the ethanol it consumes, both for industrial use and as fuel, which is not directly added to gasoline, but previously converted into ethyl-tert-butyl ether - ETBE. The country imported 0.9 billion liters of ethanol, 56 million of which from Brazil [USDA, 2021].

India is the fourth largest producer of ethanol in the world, with a production of 1.8 billion liters in 2020 [32], coming mainly from the conversion of molasses[15]. The Ethanol Blending Program, launched in 2003, allows the acquisition and conversion of the sugar industry by-product into biofuel, which is used in a non-mandatory blend of 5 to 10% throughout the territory [44]. The program also established an increase in the mix to 20% by 2030. By the end of 2020, the government announces a plan to bring the E20 forward to 2025 [45]. In addition, India plans to make mandatory to install flex fuel engines in the country-produced cars, following the standard of Euro VI regulations [46] [47].

Forecasts

For the forecast of the Brazilian ethanol exports, this study considered the Brazilian biofuel production and the domestic demand, in addition to analysis of the main destination markets for Brazilian exports, mainly the United States, the South Korea and the European Union. Therefore, the exports will increase by 25%, from 1.6 billion liters in 2021 to 2 billion in 2031.

TOTAL DEMAND

Chart 8 - 5 consolidates the demand for fuel ethanol and other uses (non-energy), which grows at a rate of 4.2% p.y., reaching 44.2 billion liters in 2031, with the big increase coming from the demand for hydrated fuel.

When added to exports, the total value of ethanol amounts to 46.4 billion liters.

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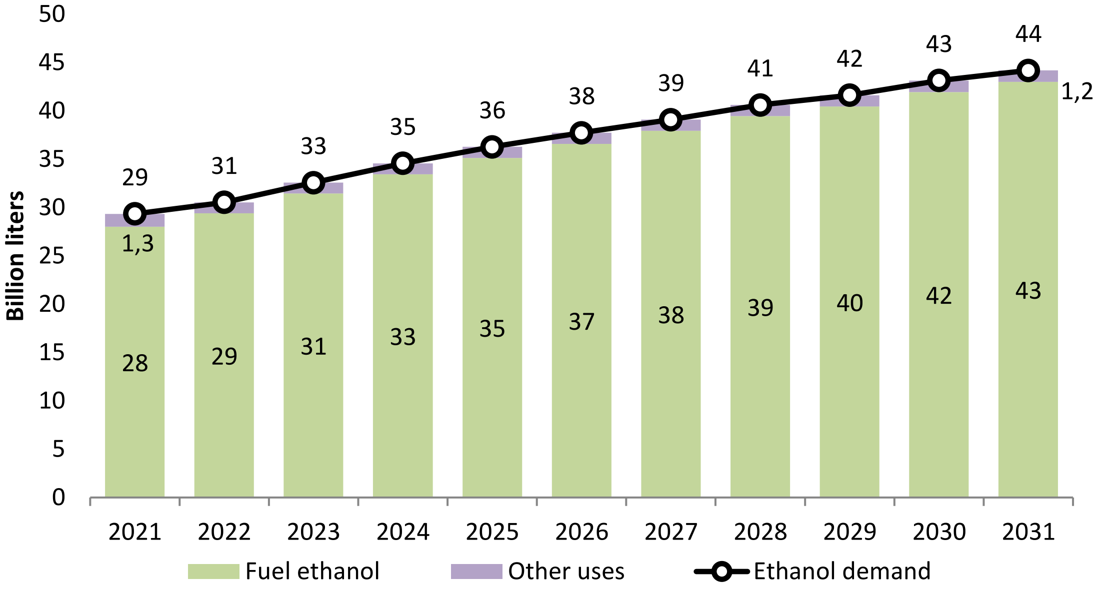
[15] In December 2019, India signed a Memorandum of Understanding with Brazil to upgrade its ethanol production facilities and cooperate in developing the technology needed for blending ethanol. The agreement allows for technical assistance with the objective of creating a sugar-alcohol system, which would provide flexibility, seeking higher returns, by alternating the crushing of cane between sugar and ethanol (USDA, 2020b).

Chart 8 - 5: Total ethanol demand forecast



Source: prepared by EPE

8.2.3 LOGISTICS

The road mode continues to represent most of the ethanol transport in Brazil, despite having higher energy and environmental costs than the others (railway, pipeline and waterway). Due to the projected expansion of the ethanol market over the next ten years, in addition to the increase in storage capacity, it will be necessary to invest in the diversification of the modes used in distribution, to make the transport system more efficient.

Among the investments in the pipeline mode, there is the project of Logum Logística S.A, for the construction of its own pipelines and the use of existing ones, with a total length of 1,054 km. The estimated value for the project is BRL 5.2 billion, of which BRL 1.2 billion has already been invested in the sections built and currently in operation. The static storage capacity is 617 million liters and the annual handling capacity is 6 billion liters [48].

The sections of the pipelines that are already in operation are:

- The government's: Ribeirão Preto (SP) – Paulínia and Uberaba (MG) - Ribeirão Preto (SP);
- Subcontracted: Paulínia (SP) - Barueri (SP); Paulínia (SP) - Rio de Janeiro (RJ) and Guararema (SP) - Guarulhos (SP).

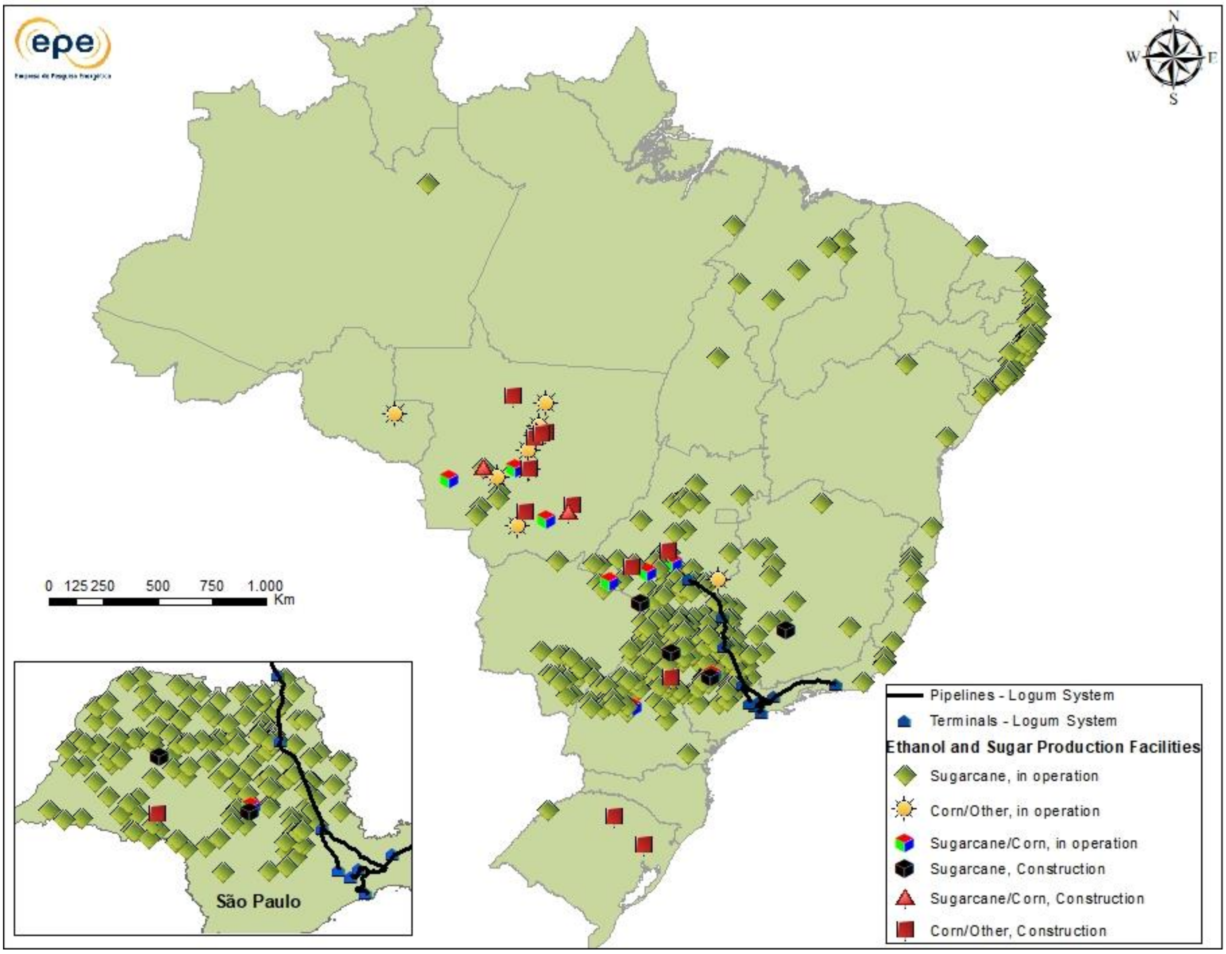
In 2020, the volume of handled ethanol was 2.1 million liters, 16% less than in the previous year [48]. In 2021, the company carried out its first export operation through the system (40 million liters of ethanol), destined to the California market, in the United States [49].

Among the next expansion projects is the new connection in the state of São Paulo, which will link the Guararema land terminal to the distribution bases in São José dos Campos. With 42.5 km, this pipeline will also pass through Santa Branca and Jacareí, with a capacity of 40 million liters per year [50]. This project was approved by the MME, which is part of the REIDI tax incentive program[16]. As a result, investments in goods and services, estimated at BRL115 million (with PIS/Cofins), are now BRL109.57 million, a reduction of 4.7% [51].

Two actions are subsequently planned: to extend the system to the Baixada Santista, reaching Cubatão and the Port of Santos; installation of a new terminal in the south of Goiás, approaching the corn ethanol producing region [52].

This set of measures will contribute to improving the country's logistics capacity, making Brazilian products more competitive in the domestic and international market. **Figure 8 - 1** summarizes the location of Brazilian sugar and alcohol plants, as well as the existing and future logistics infrastructure.

Figure 8 - 1: Brazilian sugar-ethanol plants and logistics infrastructure



Source: EPE, based on (LOGUM, 2021, (MAPA, 2021).

Box 8 - 1: Sensitivity analysis for ethanol supply

Seeking to anticipate possible threats to the domestic supply of fuel for light vehicles, a sensitivity analysis was carried out for the supply of ethanol and demand for the Otto cycle. This analysis considers a less favorable

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[16] The Special Incentive Scheme for Infrastructure Development (REIDI) benefits companies with projects to implement infrastructure works in the transport, port and energy sectors. In an ordinance of October 24, 2019, the MME started to include pipeline projects for the transport of fuels (MME, 2019a).

Box 8 - 1: Sensitivity analysis for ethanol supply

scenario for the sugar-energy sector, in relation to both public policies (tax differentiation between gasoline and ethanol, for example), regarding the actions of companies to reduce production costs and the financial restructuring of indebted groups.

In this scenario, RenovaBio would not be fully successful in its objectives, as hydrous ethanol would lose competitiveness against C gasoline and the economic attractiveness of the sugar-energy sector would not be enough to induce relevant investments. Thus, it considers the entry of three sugarcane ethanol facilities in the medium term and of flex and full corn plants, identified by the ANP as under construction and with a defined timetable for completion of the work (position in June of 2021). Agricultural productivity will be 75.4 tc/ha at the end of the period, lower than that presented in the reference scenario.

As a result, the forecast of processed sugarcane in 2031 would be around 673 million tons (97.3 million tons less than shown in Graph 8-2), which would result in a total ethanol supply of 34.1 billion liters, 12.3 billion liters lower than the baseline scenario.

Considering the purpose of ensuring the national energy supply, this analysis was based on the reference Otto cycle demand of this PDE. In this case, it was found that the volumes of gasoline A and anhydrous ethanol would reach, respectively, 35.5 billion liters (increase of 8.2 billion liters) and 13.1 billion liters (increase of 3.0 billion liters). This increase is a consequence of the lower volume of hydrous ethanol made available by producers to the fuel market, approximately 17.6 billion liters (15.3 billion liters lower than the reference scenario).

Based on the average production of gasoline in the last 5 years in Brazilian refineries (26.3 billion liters), imports of this fuel would reach approximately 9.2 billion liters in 2031 in this scenario, 4 billion more than the historical maximum [53].

8.3 Sugarcane bioelectricity

The energy use of residual biomass from the industrial processing of sugarcane, both in the production of heat and electricity, is intended for self-consumption and production of surplus electricity to the National Interconnected System (SIN).

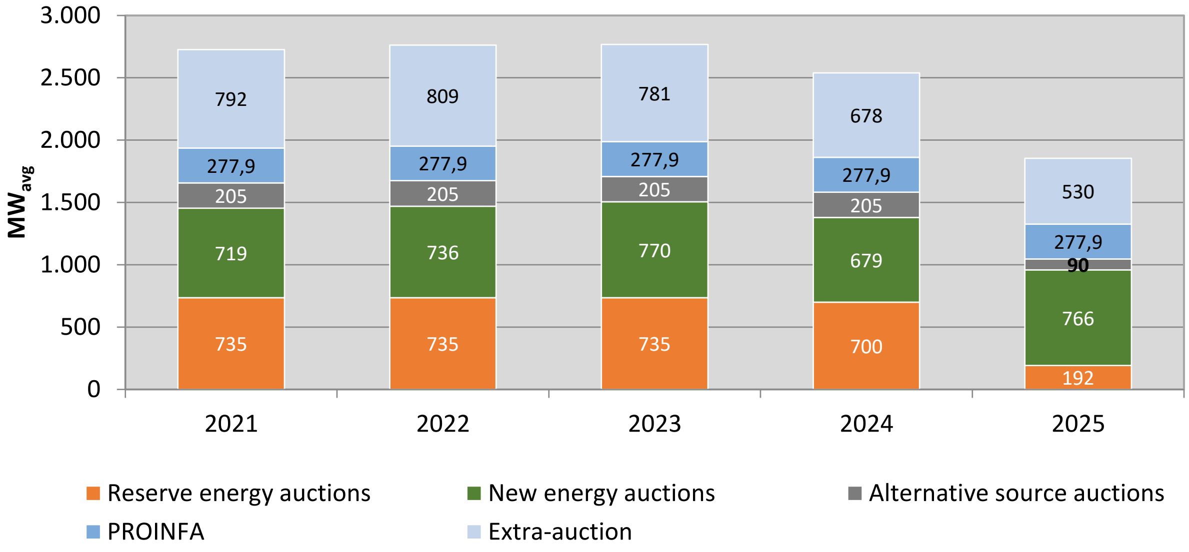
Government initiatives to encourage the renovation and improvement of cogeneration facilities increased the efficiency of converting energy from biomass and, consequently, the generation of surpluses and their distribution, contributing to the diversification of the sector and the increase in its revenue. Data from the Generation Information Bank [54] record that the generation capacity of sugarcane biomass reached 12.1 GW in August 2021, an increase of more than 30% compared to 2016.

The extraction of sugarcane juice generates bagasse as residue, and the production of ethanol and sugar gives rise to a significant amount of filter cake and, in the case of the biofuel, vinasse. In addition to these, the sugarcane harvest also generates residual biomass composed of straw and tips. It is estimated that, within the ten-year timeframe, the main producing states will have mechanized harvesting in all their sugarcane fields, producing a significant amount of biomass that can be used for energy. A greater insertion of biogas is also projected, coming from the biodigestion of vinasse and filter cake, as will be presented in section 8.5.1.

Among the 369 sugarcane plants in operation in 2021, about 220 facilities sold energy and approximately 40% of these did so through energy auctions. By August 2021, 60 contests had been held, with energy sales from sugarcane plants occurring in 30 of them [55]. Over the last few years, the commercialization of bioelectricity in the regulated environment (ACR) has decreased, despite reducing its participation in the national electricity matrix. Even with the realization of future events, in which this amount can be increased, the free contracting environment (ACL) and the settlement of energy in the spot market (PLD) shall configure as the majority for the sale of energy in this segment.

Thus, the total contracted energy from these facilities in the regulated market (ACR) will reach approximately one GWavg by the end of 2025, in addition to the extra amount of 530 MWavg, which can be traded by sugarcane biomass plants in the ACL or PLD in the same year. The energy from PROINFA projects, of 278 average MW, is included in the amount contracted in the ACR [56]. According to article 23 of Law 14,182, of July 12, 2021, such amount may be extended “for a period of 20 (twenty) years after the current maturity date”, that is, until 2046 [57]. **Chart 8 - 6** presents the amount of energy already contracted in the regulated environment and that which can be traded in bilateral agreements or on the spot market. Note that the drop in energy amounts refers to the termination of existing contracts.

Chart 8 - 6: Contracted energy and extra auction of plants that women the Energy Auctions



Note: The energy sold through contracts prior to the new model for the electricity sector, established in 2004, was not considered.
Source: Prepared by EPE

Based on the forecast of the sugarcane biomass supply, two studies were carried out to estimate the supply of bioelectricity: (1) the calculation of the technical potential and (2) the construction of the bioelectricity export curve based on the historical behavior of the sector.

To project the bioelectricity supply, the supply of residual sugarcane biomass was estimated, which will be processed to meet the ten-year production of ethanol and sugar. On this amount, the average energy export factor for the SIN corresponding to each of the studies is applied, whose calculation methodology is detailed in the PDE 2024 [10].

Chart 8 - 7 shows the energy contracted in the ACR and the electricity export forecasts for the two studies: with the export factor of the winning plants in energy auctions (technical potential) and with the export factor based on history.

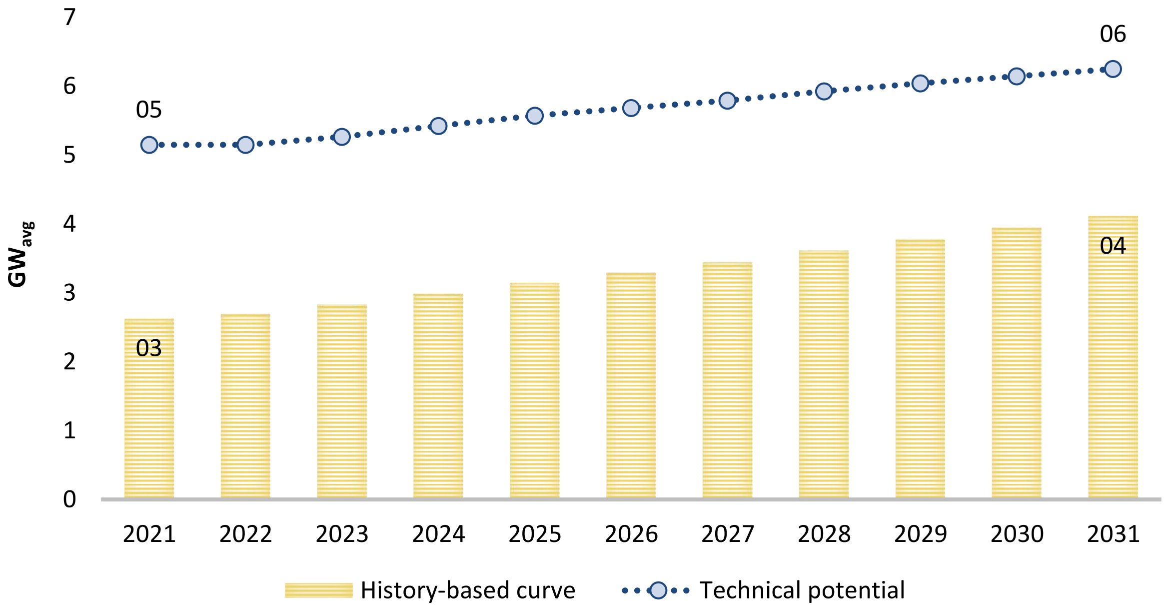
The technical potential reaches 6.2 GWavg for the year 2031, 2.1 average GW higher than the projected for the history-based curve. Additionally, an estimate was made of the potential for the use of straws and tips, considering that this biomass will only be available for plants in the Center-South region (about 90% of sugarcane in Brazil), given that, in this timeframe, most of the Northeast region won't be using mechanized harvesting yet.

Two distinct energy export factors found in literature were used: 500 and 787.5 kWh/ton of straw and tips, according to [58] and [59], respectively. The results indicate that the technical potential for energy export from the biomass of straws and tips, obtained using the factors listed above, would be 6.8 GWavg and 10.7 GWavg, respectively, at the end of the ten-year period.

In this sense, there is the use of other residues, such as vinasse, filter cake and, more recently, straws and tips. Still little used for energy generation in sugarcane plants, these inputs give rise to biogas, the result of its fermentation. As presented in section 8.5.1, the technical potential for producing biogas from vinasse, filter cake and sugarcane straw and tips, and for exporting electricity is quite significant.

The contribution of sugarcane biomass to the national energy scenario could become even more relevant if its technical potential is fully exploited.

Chart 8 - 7: Export potential of electricity generated by bagasse



Note: PROINFA included in ACR
Source: Prepared by EPE

8.4 Biodiesel

The National Program for the Production and Use of Biodiesel (PNPB) began in 2005 and, until September 2021, 81 auctions were held for the sale of biodiesel and 52.1 billion liters of biodiesel were produced by the domestic industry [60] [61].

The mandatory percentage in force in Brazil is 13% since March 1, 2021, according to CNPE Resolution No. 16/2018. The percentages originally established, however, underwent occasional adjustments in auctions throughout 2021 [62][17]. For the study timeframe, the percentage of 10% was considered throughout 2022, as decided by the CNPE [63]. From 2023, the forecast assumption adopted is that the addition of biodiesel to diesel will occur according to the possibilities provided for by law. Thus, the increase in the mixture is established in accordance with the timetable of the Resolution, which provides for a percentage of 15% from 2023, until the end of the ten-year series analyzed. In the current legislation, the addition of biodiesel in any proportion, up to B15, can be used by distributors who want to resell this mixture. There is also the possibility of voluntary (authoritative) use of this biofuel, in a percentage higher than the mandatory one for specific cases, such as captive fleets and railway, agricultural, industrial and experimental uses. However, it is estimated that there will be no significant volumes above the mandate on the timeframe of this Plan.

As of January 2022, a new biodiesel commercialization model will take effect, replacing the auctions, used since the beginning of the PNPB, which will be freely negotiated between biodiesel producers and distributors, in accordance with Resolution No. 14, from December 09, 2020. The following remain unchanged in this new format: (i) the acquisition of the product by the purchasers (refineries, distributors and importers of diesel oil A), whose volume must be delivered by the production facilities; (ii) the reserve of 80% of the volumes sold from plants that hold the Social Biofuel Seal (SBS)[18], maintaining the current rule of priority participation of family farming.

According to ANP Resolution No. 857/2021, biodiesel supply contracts will be previously approved by the ANP, similarly to what happens with anhydrous ethanol, and will be valid for at least two months (a period like that of the auctions). Given the possibility of multiple contractual arrangements in terms of deadlines and forms of payment, a new dynamic of the biodiesel market is expected, with a potential reduction in the prices of the product. In addition, this new model excludes the transaction cost currently in effect (BRL 25 reais per m³) charged by the company that intermediates the negotiation [64] and allows the importation of biodiesel, within the maximum limit of 20%, in addition to the portion served by SBS.

In the international scenario, the world produced 46.8 billion liters of biodiesel (FAME and HVO)[19] in 2020, of which Brazil contributed with 6.4 billion (13.7%), being the third largest producer, behind Indonesia (17.1%) and the United States (14.5%) [40]. Regarding the volumes transacted, the Brazilian share has never been significant, with only 3.8 million liters exported in 2020 [65]. The regulations in force in the country still restrict the biodiesel imports [66].

Raw Material

The main feedstocks used in the production of biodiesel are soybean, cotton oil, corn oils, beef tallow and residual oils. Although new feedstocks are progressively gaining ground, soybean oil must keep its leading position until 2030.

Brazil is the world's largest soybean producer and the largest player in the grain's foreign market [67]. Established in 1996 to favor exports of primary products and semi-manufactured industrialized products, the Kandir Law exempted the export of this raw material “in natura” from paying taxes (ICMS). This favored the export of grain, to the detriment of soybean processed in the form of protein bran and oil.

IBGE [67] projects a growth in soybean production, from 128 million tons (2020) to 133

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[17] As a preventive measure to guarantee supply to the domestic market, the ANP carried out three temporary mandatory percentage reductions throughout 2020. These actions were also necessary in the year 2021(ANP, 2021c). More information in (EPE, 2021b)

[18] The Social Biofuel Seal (SBS) is a distinction given to companies producing biodiesel that use, in their production chain, products from family farming. The objective is to guarantee income and encourage the social inclusion of producing families.

[19] FAME - Fatty acid methyl ester and HVO - hydrotreated vegetable oil.

million in 2021, an increase of 9.8%, a new national record. Soybean exports in 2020 were 83 million tons (12% higher than 2019) [68]. In 2020, there was an increase in exports of soybean oil, the main destinations being India and China, because of a significant reduction in oil and bran exports from Argentina, since this country, the main world player of these products, experienced a severe drought.

Beef tallow is the second most used biodiesel feedstock in Brazil. Also noteworthy is the growth of various inputs, such as residual oils.

Although still modest, the share of palm has progressively grown in the mix. The current percentage is 2.5%, with great expectation of increase over the decade.

Among the other oil-producing crops initially listed in the PNPB (highlighting cotton, castor bean and sunflower), currently, only cotton has a small representation in the feedstock basket for biodiesel production. The corn oil has emerged as a potential feedstock to be added to raw materials.

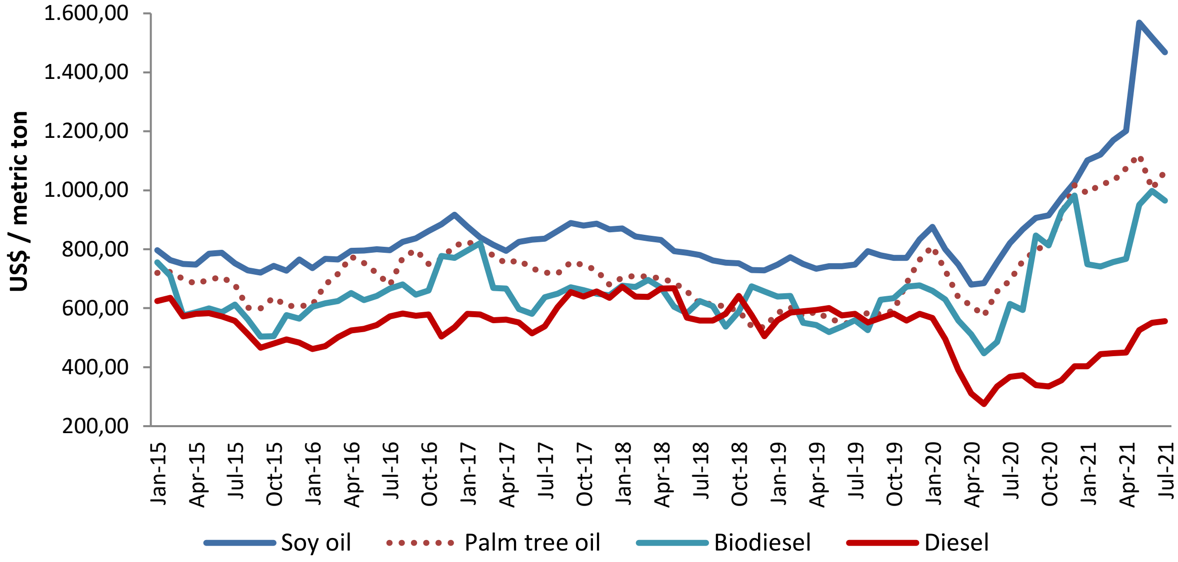
A promising crop that should gain relevance in the coming years is the macaúba palm. Several researches have been carried out to better understand of this oil tree, which extends in massifs dispersed throughout the entire Brazilian territory, confirming its adaptability to different national biomes and high productivity [69].

The use of residual oils for the manufacture of biodiesel has great economic and environmental appeal, as it adds value to a material that would be considered unusable, in addition to avoiding disposal in inappropriate places, significantly reducing negative environmental impacts. Although currently they are still not very representative in the domestic biodiesel production, recent data [53] indicate that residual oils were the materials that presented the highest percentage growth in the feedstock basket, next to palm oil and corn. As residual oils have a low acquisition cost, biodiesel produced from this raw material should be more competitive than those derived from other sources. The logistics of structured collection of residual oils and subsequent transfer to the plants is a key point to ensure the economy of the process.

There are few expectations for others raw feedstocks to occupy a prominent place within the timeframe of the PDE 2031. Based on this, it is essential to consider the technological advances achieved in recent years in production routes and new and alternative fuels to the Diesel cycle. To meet the expected increases in mandatory requirements, the producers must diversify the mix of feedstocks and products, which depends on the adhesion of market agents and the rapid regulatory framework of new technological production routes.

The feedstocks correspond, on average, to 80% of the total cost of producing biodiesel [70]. In this sense, studies conducted by EPE indicate a correlation between biodiesel prices in the domestic market and soybean and soybean oil prices. For the next ten years, it is expected that this price will follow the values of commodities in general. Next, the **Chart 8 - 8** shows the history of international prices for biodiesel, diesel and palm and soy oils.

Chart 8 - 8: International biodiesel, diesel and soy and palm tree oil prices



Note: Diesel nominal prices(domestic market), without ICMS. Biodiesel nominal prices(domestic market), with PIS/ COFINS, without ICMS. FOB plant price negotiated in regular ANP biodiesel auctions (No Petrobras margin). Soybean and palm oil export prices in metric ton (Gulf of Mexico).
Source: (ABIOVE, 2021b), (ANP, 2021b) and (INDEX MUNDI, 2021).

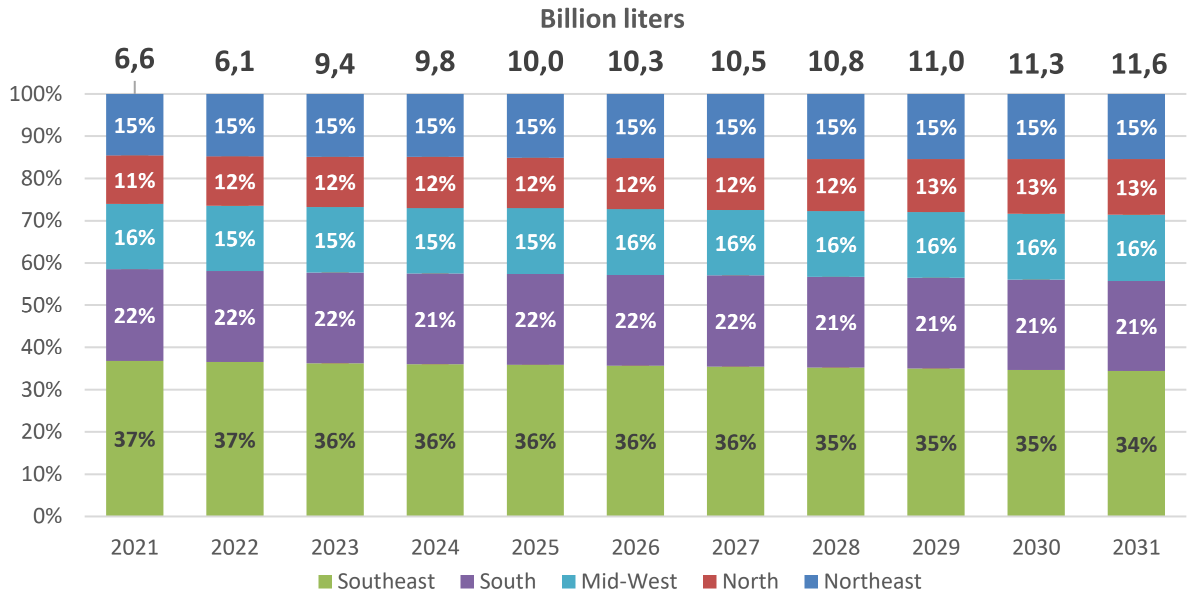
Although an atypical proximity between the prices of biodiesel and fossil diesel was observed from 2017 to 2019, since the end of 2019 a gap has been observed between the average sales values of these products, with a marked differentiation between these prices observed from September 2020, as shown in **Chart 8 - 8**. This is due to the considerable increase in Brazilian exports of soybeans, because of their prices on the international market, plus the favorable exchange rate for exports.

However, for the proper assessment of prices, it is necessary to consider the place of reference for the comparison. That is, the assessment of competitiveness requires the addition of logistical, tax and other costs incurred up to the distribution base where the blending will take place. The sale and export of glycerin/glycerol, especially to Asian markets, contributes to increasing the attractiveness of biodiesel.

BIODIESEL DEMAND

The biodiesel demand forecasts were obtained based on the forecast of regional consumption of diesel oil B presented in Chapter II, among other considerations already described. This result is displayed in **Chart 8 - 9**, broken down by geographic regions. The biodiesel processing capacity, the forecast of mandatory consumption and the regional and national balances for 2021 and 2031 are displayed in **Table 8 - 3**.

Chart 8 - 9: Biodiesel Demand



Source: Prepared by EPE.

Table 8 - 3: Biodiesel beneficiation capacity and mandatory consumption in 2020 and 2031

Region	2021			2031		
	Rated Installed Capacity	Mandatory consumption[1]	Balance	Rated Installed Capacity	Mandatory consumption	Balance
	Million liters					
North	320	756	-436	932	1525	-593
Northeast	880	971	-91	1240	1791	-551
South	4569	2437	-1613	5057	2443	-1313
Southeast	824	1413	3156	1130	3978	1079
Central-West	4728	1031	3697	5932	1818	4114
Brazil	11321	6609	4712	14291	11557	2734

Note: (1) Estimated consumption for 2021 based on July/2021.
Source: EPE based on (ANP, 2021b).

According to the nominal installed capacity registered in 2021, it is possible to meet the projected demand until the year 2027, with a utilization factor (FUT) of 92% for biodiesel plants. The current requests for expansion and construction of production facilities registered with the ANP [60], and their estimated investments of around 1 billion reais, should add a (nominal) overcapacity of 2.8 billion liters, which will represent an idleness of 19.5 % in 2031. Considering the effective capacity (FUT=92%), due to scheduled stoppages and adverse events, the biodiesel production capacity would be 13.1 billion liters, an amount still higher than the estimated demand for the year. New investments are expected to be incorporated in the coming years to meet the expected mix.

Analyzing the relationship between production and consumption of regional biodiesel and the forecasts for new installations indicated by the ANP, it appears that the North, Northeast and Southeast regions are not self-sufficient in 2021, a condition that will last until 2031.

Thus, the South and Central-West regions should maintain their leadership in the production of this biofuel, although demand is concentrated in the Southeast region. By stimulating the production of new crops, adapted to the soil and climate conditions of the North and Northeast Regions, these may also present great potential for growth in the production of biodiesel.

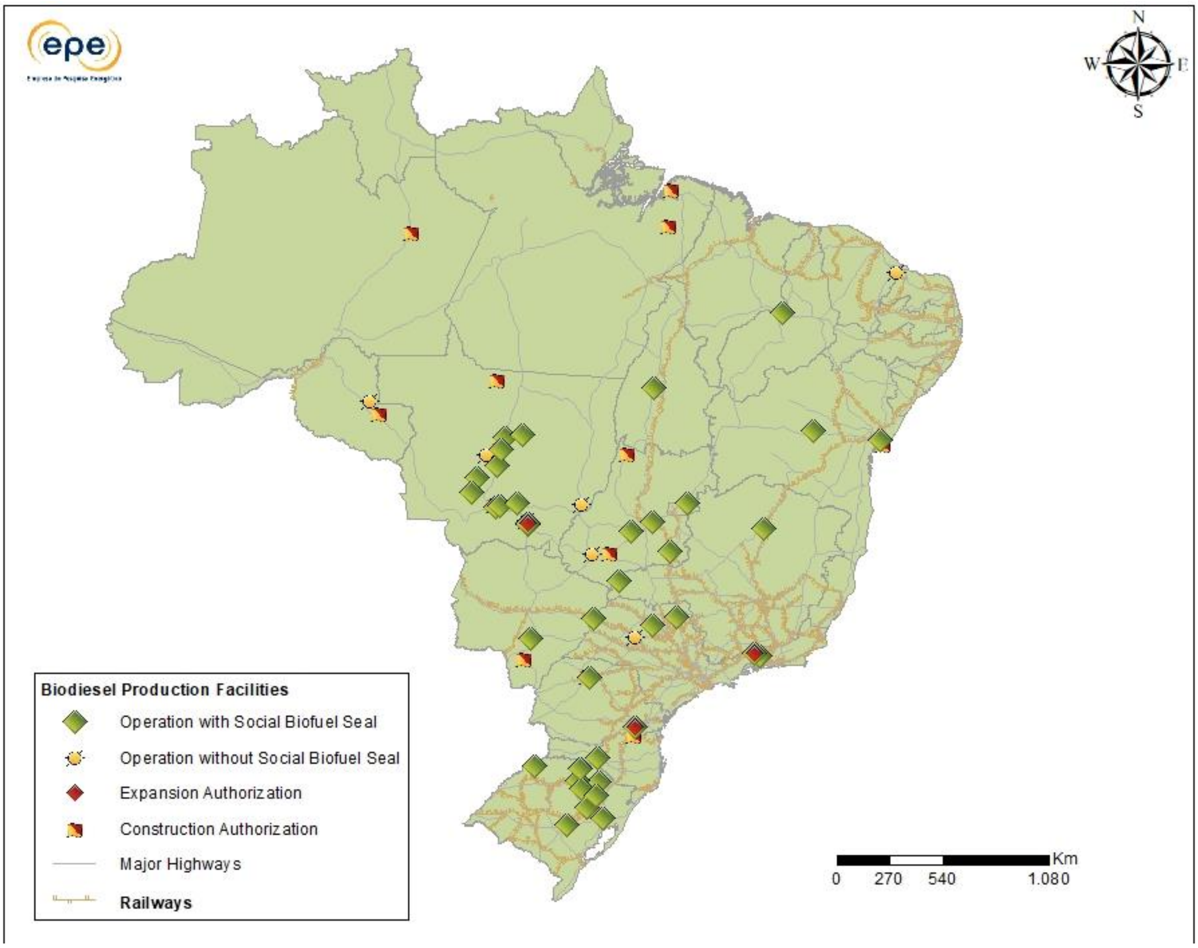
As the national balance is in surplus and regional oversupplies can be shifted to deficit regions, there are no impacts on the security of domestic supply.

OUTFLOW INFRASTRUCTURE FOR BIODIESEL PRODUCTION

The current biodiesel flow infrastructure is presented in **Figure 8 - 2**, in addition to the location of production plants already authorized by the ANP, distinguishing those that have or do not have the Social Biofuel Seal. Practically, all biodiesel production plants and fuel distribution bases are served by federal roads. Transport between them is basically done by road. In the medium term, the handling of biodiesel tends to remain in this mode, for reasons of scale.

The diversification of transport logistics used in the distribution of biodiesel contributes to the efficiency of the transport system. In this sense, the rail mode is an interesting alternative for some regions.

Figure 8 - 2: Biodiesel plants and current distribution infrastructure



Source: EPE based on (ANP, 2021b).

Box 8 - 2: Green diesel

Green diesel is a renewable fuel formed by a mixture of hydrocarbons with a chemical composition similar to that of fossil fuel (drop in), and can be produced from different routes, such as the hydrotreatment of vegetable and animal oil, also through the Fischer-Tropsch synthesis from renewable sources, as well as from fermentation processes and oligomerization of alcohols. The product resulting from these physical-chemical processes may compose the mixture of diesel oil B.

ANP Resolution No. 842/2021 (ANP, 2021) regulated the specifications and obligations regarding the quality control of green diesel for its commercialization in Brazil. Aiming at the interest of the National Energy Policy, on December 9, 2020, a Working Group was established through CNPE Resolution No. 13 to evaluate the insertion of biofuels for use in the Diesel cycle [71] [72].

The Working Group was responsible for analyzing possible special conditions for the insertion of biofuels in the diesel oil market, contemplating assessments on tax issues, volumetric mandates for adding biofuels to fossil fuels, dialogue with public policies currently in force, among other aspects. Its activities ended in October 2021, and a report will soon be released containing the technical, economic, tax, regulatory and other aspects related to the introduction of this new biofuel. The results of this analysis have the power to supply the CNPE with proposals for public policy guidelines for the insertion of biofuels in the diesel cycle, expanding the model currently in force.

Box 8 - 2: Green diesel

The hydrogenation process is part of the hydrotreatment stage, whose implementation and operation costs are high and demand substantial initial investments for its facilities today. However, there are possibilities for adapting plants producing biofuels and oil refineries to transform them into biorefineries, enabling the production of green diesel. There is no forecast of projects for these facilities with commercial production in Brazil. In general, it is estimated that a plant dedicated to the production of paraffinic hydrocarbons (the most frequently used standard internationally), from renewable raw materials, can only produce HVO (with bionaphtha and bio-LPG as by-products) or HVO, aviation biojet fuel, as well as bionaphtha and bio-LPG.

For comparative purposes, the volume produced by a facility of 400 million liters per year (usage factor of 92%) would be able to supply 0.4% of the total diesel A imported by Brazil (0.3% of the total demand of the fossil), for the ten-year period. Thus, given the biofuel needs indicated in this document, which show a doubling of biodiesel demand for the ten-year period (Table 8-3), green diesel may appear as an alternative supply for the Diesel cycle fuel market. .

8.5 Other biofuels

Considering the promising scenario for the energy use of biomass in Brazil, this section addresses other biofuels that can contribute to increase the diversity of the national energy matrix and enhance Brazil's competitive advantages in the generation of energy with renewable natural resources.

8.5.1 BIOGAS / BIOMETHANE FROM SUGARCANE

There are several technologies that allow the energy use of sugarcane products. Although the most traditional one occurs through the burning of bagasse and straw in boilers, this scope is being expanded with the production of biogas, using vinasse, filter cake and straws and tips from the sugar-energy sector, through biodigestion.

Biogas is obtained through the process of anaerobic digestion, defined as the conversion of organic material, through bacteria, into methane, carbon dioxide, inert gases and sulfur compounds, in an oxygen-free environment. Different substrates can be used for its production and the amount of biogas obtained depends mainly on the technology used in the digestion and on the substrate. This process occurs naturally in rice plantations and landfills, for example.

Methane is the main volumetric component of biogas (55%-70%), followed by carbon dioxide (30%-45%) [73]. Biogas has a calorific value between 4,500 and 6,000 kcal/m³, and can be consumed directly, or treated for separation and use of biomethane, whose energy content is similar to that of natural gas (9,256 kcal/m³) [5]. This renewable source can have several applications, such as electric generation, vehicular use and injection into natural gas networks. It is worth mentioning the opportunity created in the context of the New Gas Market. The production and use of biogas can serve to increase the supply of natural gas, as well as to reduce its carbon footprint, showing a positive synergy between fossil and renewable fuels in the energy transition process.

In Brazil, the greatest potential for biogas is found in the agricultural sector (agricultural residues and confined livestock), which includes both straw and butts, as well as vinasse and filter cake from the sugar-energy sector. There is also a considerable amount that can be obtained through municipal solid waste and sewage. Despite this considerable potential, its presence in the domestic energy supply is still modest (0.1%), but it has been showing rapid growth, of 27% p.y. in the last five years [53] [74]. Its installed capacity in distributed generation (DG) in 2020 reached 42 MW [75].

The forecasts to produce ethanol and sugar presented in this chapter indicate a high amount of waste from this sector, which can be destined to produce biogas. The methodology applied to this item considered vinasse and filter cake to produce biogas, which will be entirely destined for biodigestion. In this case, the biogas potential reaches 7.1 billion Nm³ [20] in 2031, representing 3.9 billion Nm³ of biomethane.

The technical potential for exporting electricity from biogas obtained from vinasse and filter cake was prepared based on data from Bonfim Plant, which won the 2016 A-5 energy auction and started commercial operation in February 2021. Estimates for this study cycle point to around 2.0 GW average in 2031. Considering only the plants belonging to the financially healthier groups in the sugar-energy sector in 2019 [76] [77], in a more conservative approach, this technical potential would reach approximately 1 GW average at the end of the ten-year period. Considering the use of sugarcane straw and tips, another 5.7 billion Nm³ of biogas could be added at the end of the study timeframe.

Additionally, considering the average consumption of diesel per ton of sugarcane for this segment, it is estimated that the total production of biomethane in the sugar-energy sector would be enough to supply about 60% of this demand.

Currently, a large part of the vinasse is used for fertigation in areas close to the plants. Due to the long period of use of this residue, there is a soil fatigue due to the excess of mineral salts, which drives its use for a new purpose. Its previous biodigestion tends to improve the fertigation process, as it reduces the suspended solids content and the fluid viscosity. In general, there is no reduction in the mineral salt content of the effluent at the end of the process, thus maintaining the characteristic of nutritional restoration in the irrigation soil.

8.5.2 SUSTAINABLE AVIATION FUELS

Aviation is responsible for the annual emission of approximately 2% of the total GHG [78]. Therefore, the airlines signed an agreement that defined a carbon neutral growth in the aviation industry from 2020, called CORSIA - Carbon Offsetting and Reduction Scheme for International Aviation [79]. For this, the use of emission compensation instruments, energy efficiency promotion and the use of alternative drop-in fuels, in particular biofuels and synthetic fuels, obtained through processes certified by ASTM[21] was established. Domestically, alternative aviation kerosene (alternative jet fuel) complies with ANP Resolution 856/2021 [80], which defines it as fuel derived from alternative sources, such as biomass, residual gases, solid waste, coal and natural gas.

Different routes for obtaining alternative aviation kerosene can be used in Brazil, according to [80] [81]: the thermochemical route, producing paraffinic kerosene synthesized by Fischer-Tropsch (FT SPK) and by Fischer-Tropsch with aromatics (FT-SPK/A) ; the chemical route, resulting in paraffinic kerosene synthesized from esters and hydroprocessed fatty acids (SPK-HEFA) and the biochemical route, producing isoparaffins synthesized from fermented and hydroprocessed sugars (SIP), alcohol for aviation fuel (ATJ-SPK),

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[20] Nm³ - normal cubic meter: volume of gas under normal conditions of pressure (1 atmosphere), temperature (0° centigrade) and 0% relative humidity.

[21] American Society for Testing and Materials International.

catalytic hydrothermolysis kerosene (CHJ) and paraffinic kerosene synthesized by bioderived hydrocarbons, fatty acids and hydroprocessed esters (SPKHC-HEFA). For each process listed, the mixing percentages of the product obtained from conventional QAV range from 10% to 50%.

For more in-depth studies on the forms of introduction of this alternative fuel in the national energy matrix, a subcommittee was created, called PROBioQAV, within the Combustível do Futuro (Fuel of the Future) Program. This aims to study ways of introducing sustainable aviation fuels into the energy matrix, as well as implementing an integrated policy to produce Biojet Fuel, green diesel (HVO) and green naphtha [6].

To comply with international environmental agreements, the use of alternative kerosene appears as one of the possibilities for reducing GHG emissions. This fuel is fundamental in the energy transition process, aiming at sustainable mobility in the air sector.

There are economic challenges to the use of alternative aviation kerosene. However, given the favorable edaphoclimatic conditions, several raw materials found in the Brazilian flora can be used to produce Biojet Fuel, such as babassu, sugar cane, macauba, palm, eucalyptus and soy. The economic attractiveness of planting oilseed species in agroforestry and crop-livestock forestry systems, including in degraded areas, should be evaluated, in accordance with the rules of the Forest Code, taking advantage of the availability of studies and scientific works in Brazil. For synthetic routes, the national potential is relevant, but still little explored.

In Brazil, there are initiatives to promote industrial development and deepen the knowledge of the technical-scientific community about Biojet Fuel. There is the Bill No. 9,321/2017, which aims to create the “National Biokerosene Program” to encourage research and the promotion of production using clean technology [82]. There are the Brazilian Network of Biokerosene and Renewable Hydrocarbons for Aviation (RBQAV) and the Minas Gerais and Zona da Mata de Biokerosene and Renewables Platforms, which have been working to stimulate research related to the production and insertion of this biofuel in the national market.

Moreover, there is a study for the installation of a pilot plant in Ceará, with the implementation of a renewable electricity network (wind or solar), to produce hydrogen and alternative aviation kerosene, with specifications higher than those required by world regulation. Among its differentials, that it will be a mobile plant and can be transported to airports with refueling difficulties, such as regional ones. An important link was established between governments (German and Brazilian), academia and the private sector, for the development of a disruptive technology with a neutral impact on the environment and society [83].

The COVID-19 pandemic has had a major impact on the world trade in oil, its derivatives and biofuels, especially for the airline sector, due to isolation and social distancing measures, the effects of which will spread for a few years, also influencing the demand for Biojet Fuel [31].

This exceptional situation brings an additional complexity to the estimation, in the ten-year period, of the volumes of sustainable aviation fuel, which is not yet present in the transport matrix. In the scope of the forecasts of this PDE, it is expected that its entry into the Brazilian energy matrix will occur from 2027, reaching about 130,000 m^3 in 2031. This corresponds to a market share of 1.4% of the total aviation fuel demand, being applicable to specific air routes, considering certified technologies.

For this analysis, it was adopted the premise introduction of a Biojet Fuel production facility, associated with the production of HVO, bionaphtha and LPG, of about 400 thousand m^3 per year, world average, in a production ratio of 35% for the main biofuel. The projected necessary investment would be in the order of 100 million dollars or 700 million reais (92% utilization factor).

8.5.3 ALTERNATIVE FUELS FOR MARINE USE

Maritime transport accounts for more than 80% of the global trade in goods. According to IEA data [84], international sea voyages have a carrying capacity of approximately 1.2 billion tons of freight, worth approximately US$7 trillion. This sector consumes more than 330 million tons of oil products every year.

Marine fuels can be classified into two categories: the first is formed by residual or marine fuel oils (bunker), which is produced from the mixture of heavy fractions from distillation (waste); the second category is formed by other diluent oils and oils produced from the lighter fractions of the refining process (atmospheric diesel, mostly), marine diesel (DMA) or marine gasoil (MGO) [85].

The IMO (International Maritime Organization) is the UN agency, composed of 174 Member States, responsible for ensuring the regulation and compliance with international rules, determined in ANNEX IV of the International Convention for the Prevention of Pollution Caused by Ships (MARPOL), whose work addresses issues relating to safety, energy efficiency, and giving emphasis to environmental protection in international maritime transport. These actions fit within the Agenda 2030 program (UN), whose main objective is sustainable development [86]. One of its main tasks was to establish new limits for the emission of sulfur into the environment, which have been in force since the beginning of 2020. The emission limits were set at: 0.5% for areas in general and 0.1% for emission control areas (ECAs). ECAs include the North Sea and the Baltic Sea. These limits are intended to reduce sulfur emissions by 77%, equivalent to an annual reduction of approximately 8.5 million tons of sulfur dioxide [84].

To meet these new emission limits and minimize costs of new processes, the maritime transport sector has sought several solutions. Alternatives include the use of exhaust gas scrubbers, in addition to the use of diesel and battery-powered vessels, or diesel and liquefied natural gas (LNG), or even the adoption of synthetic fuels and hydrogen. Among the efforts of this industry, an alternative that shows promise in the ten-year scenario is the use of biofuels, since their sulfur content is almost zero, and they attend the requirements for reducing CO_2 emissions. Note that the volumes of fuel consumed by vessels are always significant [84].

Similarly, to what is done for aviation fuels, within the Fuels of the Future Program, there is also the Marine Fuels Subcommittee, which is dedicated to specific studies for this segment [6].

Considering that the comparative prices between biofuels and fossil derivatives, especially the residual ones, it is assumed that, in an initial phase, the use of fuels of renewable origin for maritime transport could increase the logistical costs, since the with fuel represents up to 70% of costs in this sector.

The joint effort of biofuel producers, ship-owners and operators in addressing these challenges may enable the entry of this type of fuel into maritime transport in the medium and long term, contributing to meeting the IMO targets.

Box 8 - 3: Potential for biorefineries in Brazil

One of the great guidelines to avoid GHG emissions is the use of biofuels, mainly ethanol, biodiesel, green diesel, which are already produced on a large scale and, more recently, promising biofuels, such as biogas and Biojet Fuel. In order to make substantial advances, an increasing number of researchers and agents in the sector adopt

Box 8 - 3: Potential for biorefineries in Brazil

the possibility of replacing and/or adapting oil refineries by analogous structures, the so-called biorefineries, which are defined as “equipment and processes capable of transforming biomass in fuels, bioproducts and even the generation of electricity” [87].

In Brazil, plants producing sugar and ethanol and biodiesel would be classified as biorefineries, since they work with feedstocks from biomass and, in their final line, produce biofuels, energy and bioproducts (sugar, glycerin, bioplastics, biochemicals, etc.). Those that use only one type of raw material are classified as dedicated. The new second-generation biorefineries would operate with different routes and conversion platforms (thermochemical, biological, catalytic and physical) and would be configured to convert the diversity of raw materials and existing waste into biofuels and bioproducts.

These biorefineries, in their initial stages, will only be competitive if there are incentives from the government, through laws that can guarantee their penetration in markets in competition with their fossil-based counterparts.

Technical issues, such as the technological routes for the various raw materials, and even part of the regulatory legislation are already known, but they are dispersed among the various sectors of industry, economy and public sector. The basic challenge is the compilation and intersection, in addition to introducing the social component that cannot only legitimize this new activity, but also be appropriated by society. An example, albeit limited, is the Social Biofuel Seal (SBS), under the PNPB, which incorporates raw material producers into public policy.

The new production and market conditions may configure a new business model, the bioeconomy, for which new regulations for raw materials and products will be necessary. Today, the current ethanol production plants, for example, have a basic intersection in the regulatory environment of fuels, through the ANP, and that of electric energy, through ANEEL and in the environmental sector. Biodiesel plants appear basically as regulated within the fuel and environmental scenario.

The Brazilian biofuels production sector has knowledge and the learning curve accumulated in its phases: agricultural, industrial, regulatory, distribution and final consumption; this complex chain has made significant advances for the evolution of biorefineries and, consequently, for the bioeconomy. From this base and existing experience, it is necessary to disseminate objectives among the various actors involved to achieve ambitious goals that can mitigate adverse effects on the climate and protect the quality of life on the planet.

MAJOR POINTS OF THE CHAPTER
BIOFUEL OFFER

- *Biofuels will continue to play a relevant role in the Brazilian energy matrix in the next ten-year period. Added to the National Biofuels Policy (RenovaBio), the establishment of the Fuel of the Future Program confirms the positive developments and strengthening of the sector, projected for the next decade.*
- *Investments in sugarcane plantation renewal and adequate cultural treatment should promote a recovery of production indicators for this culture (agricultural productivity and industrial yield).*
- *The reduction in production costs, the efficiency of the production process and the increase in the competitiveness of ethanol against gasoline, associated with the need to increase ethanol production capacity, will motivate investments in greenfield facilities and in existing facilities.*
- *Ethanol production from corn will show significant growth and will reach eight billion liters in 2031 in the projected scenario.*
- *The total supply of ethanol will reach 46.4 billion liters in 2031, with 34.6 billion liters related to hydrated ethanol.*
- *The sugar-energy sector already has a prominent role in the production of ethanol and has been increasing its contribution to the electrical matrix with bioelectricity.*
- *An expansion of the bioelectricity generation period is expected, incorporating straws and tips and, in some cases, biomass other than sugarcane. It is estimated that the forecast based on history will reach 4.1 GW average and the technical potential for commercialization, from biomass, will be 6.2 GW average in 2031.*
- *A significant advantage for industries in the sugar-energy sector associated with bioelectricity is the guarantee of constant financial support provided by the commercialization of energy, as opposed to the seasonality of sugarcane production.*
- *For biodiesel, it is expected that soybean oil will remain as the main raw material in the decade. The demand for this biofuel will remain within the mandatory limits defined by law.*
- *The regulation of green diesel can bring opportunities for the insertion of paraffinic hydrocarbons from renewable biomass in the Diesel cycle, increasing the participation of biofuels in the transport matrix.*
- *It is important for the PNPB to develop alternative crops to soybeans. Among the vegetable oils, palm oil has the highest production volume in the international market, in addition to more competitive prices. In addition to palm, corn and macaúba oils appear as potential inputs to be added to raw materials for the national production of biodiesel.*
- *No potential bottlenecks were identified in relation to the installed biodiesel production capacity.*
- *Biogas from the sugar-energy sector will have a greater insertion in the energy matrix, being able to be used for electric generation, replacing diesel and mixed with fossil natural gas, in the gas pipeline networks. It is estimated that the production potential in 2031 will be 7.1 billion Nm^3 from vinasse and filter cake and 5.7 billion Nm^3 from sugarcane straws and tips.*
- *In Brazil, there are initiatives to create public policies and deepen knowledge about aviation biojet fuel, to make this biofuel economically viable. By 2031,* Biojet Fuel's *market share is expected to be 1.4% (about 130,000 m^3) of total aviation fuel demand, with specific airlines adopting certified technology routes.*