TECHNICAL NOTE

Investments and Operating and Maintenance Costs in the Biofuel Sector: 2025 - 2034

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EPE CONDUCTS STUDIES AND RESEARCH TO SUBSIDIZE THE FORMULATION, IMPLEMENTATION AND EVALUATION OF BRAZILIAN ENERGY POLICY AND PLANNING.

WITH THIS TECHNICAL NOTE, EPE PRESENTS THE ASSUMPTIONS AND ESTIMATES OF INVESTMENTS (CAPEX) AND OPERATIONAL AND MAINTENANCE COSTS (OPEX) RELATED TO THE MAIN BIOFUELS FOR THE PERIOD 2025-2034.

INCLUDED ETHANOL (SUGAR CANE - 1G AND 2G - AND CORN), BIODIESEL, BIOMETHANE (FROM THE SUGAR ENERGY SECTOR), SUSTAINABLE AVIATION FUEL (SAF) AND GREEN DIESEL, IN ADDITION TO THE CO-PROCESSING OF VEGETABLE OIL AND TECHNIQUES SUCH AS BECCS.

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Investments and Operating and Maintenance Costs in the Biofuel Sector: 2025 - 2034

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Summary

List of Tables

List of Charts

List of Figures

Introduction

The purpose of this Technical Note is to disclose the assumptions and investment estimates (CAPEX, capital expenditure) and operational and maintenance costs (OPEX, operational expenditure) related to biofuels for the period 2025-2034. This includes ethanol (from sugarcane - 1G and 2G - and corn), biodiesel, biomethane (from the sugar-energy sector), sustainable aviation fuel (SAF), green diesel, as well as co-processing of vegetable oils and techniques such as bio-CCS. The supply and demand values for biofuels are based on the Biofuels Supply Report of the Ten-Year Energy Expansion Plan 2034 (PDE 2034) and the average scenario of the document Scenarios for Ethanol Supply and Otto Cycle Demand 2025-2034 (EPE, 2024a, 2024d).

It is noted that the studies to estimate the share of indicative investments ("scenario-based") were prepared when the Fuel of the Future Bill was still under consideration in the National Congress. Given the promulgation of Law No. 14,993/2024, enacted by President Lula on October 8, 2024 (BRASIL, 2024), and that the regulation of the proposals is expected to occur in the coming years, it is likely that the total investments to be made will exceed the estimate provided in this Technical Note. In this regard, at the end of the document, a series of sensitivity analyses are presented to estimate the potential investments that may materialize with the Future Fuel Law. The current legislation regarding the mandatory blending percentages of biofuels in commercial fuels was considered.

This technical note considers investments for the period from 2025 to 2034. To be comparable to the values indicated in PDE 2034, the values for the period between 2024 and 2034 are presented in the appendix. Additionally, the reference used for monetary values was December 2023, in accordance with the PDE 2034.

1. Ethanol

The projection for national ethanol production will reach 48.5 billion liters by 2034, according to EPE (2024a) and the average growth scenario presented in EPE (2024d)[1]. In addition to the contribution of first-generation sugarcane, volumes of corn ethanol and lignocellulosic ethanol will reach 14.3 billion liters and 1.1 billion liters, respectively, by 2034. The amount of sugarcane allocated for biofuel production is estimated at 384.2 million tons, approximately 53% of the total.

First-Generation Sugarcane Ethanol

In the study period (2025-2034), it is estimated that two new *greenfield* sugarcane units[2] and one reactivation will be implemented, increasing the nominal crushing capacity by 4.5 million tons (equivalent to an ethanol production capacity[3] of 380 million liters) (ANP, 2024a). Additionally, the expansion of ethanol production capacity in existing plants is estimated to be 2.3 billion liters, according to the National Agency of Petroleum, Natural Gas, and Biofuels - ANP (2024a).

For the evaluation of investments required in the medium term, it was assumed that the units would be mixed (being able to produce both ethanol and sugar), with an optimized technological profile and an average size of 4 million tons of nominal crushing capacity, with an average investment of R$ 605.8/tc[4] (IBGE, 2024; FGV, 2024; LNBR, 2022). For the expansion of existing units, an average investment of R$ 271.7/tc was adopted (NOVACANA, 2024a; FGV, 2024). These values consider land leasing, agricultural machinery, and the industrial section with optimized cogeneration, as detailed in Table 1.

Table 1. CAPEX Estimate for First-Generation Sugarcane Mills

CAPEX	R$ (dez. 2023) / tc
New units (*Greenfield*)	**605.8**
Industrial (includes optimized cogeneration)	482.4
Agricultural machinery (includes trucks)	96.7
Lease (Midwest region)	26.7
Expansion of existing plants (*Brownfield*)	**271.7**

Source: EPE based on IBGE (2024), FGV (2024), LNBR (2022) and NOVACANA (2024a)

Thus, the investments in industrial capacity, solely for first-generation sugarcane ethanol, will amount to approximately R$ 5.4 billion, of which around R$ 3.9 billion refers to expansions, and the remainder corresponds to *greenfield* units.

[1] For the projection, the mandatory blending percentage of anhydrous ethanol in gasoline C was considered to be 27%
[2] One of these units is of small scale, with an ethanol production capacity of 3 m^3/day (ANP, 2024a).
[3] It considers 200 harvest days.
[4] CAPEX was given per ton of sugarcane, as it is possible to allocate part of the ATR (Apparent Theoretical Recovery) to produce sugar, which does not occur in E2G (second-generation ethanol) and corn ethanol units.

The cost of forming the sugarcane fields considered the participation of each producing region (Center-South and Northeast) and their respective costs, recorded in the 2023/24 harvest (PECEGE, 2024). It was also assumed that 17% of the area is planted cane (new + renewed) relative to total cane. This resulted in an average cost of approximately R$ 37.6/tc. The investment in forming the sugarcane fields for ethanol was estimated at R$ 22.3 billion.

Regarding operational costs (OPEX), the indicator of R$ 2.23 per liter was used, based on biomass costs (87%) and industrial costs (13%) from the Center-South region, and ethanol production per year, which results in a total value of R$ 645.4 billion over the entire period (PECEGE, 2024 and EPE, 2024b). The OPEX calculation considered the sugarcane allocated for ethanol production from all units in operation each year.

Lignocellulosic Ethanol

For lignocellulosic ethanol (2G, second generation), it is assumed that twelve units will be attached to first-generation units, with an average specific ethanol production capacity of 82,000 m^3/year during the study period. The investment estimate is based on the values of commercial units currently operating in Brazil and the announcements made since 2022 for projects of this type, establishing a factor of R$ 14.60 per liter (RAÍZEN, 2024a, 2024b). Thus, the total investments amount to R$ 14.4 billion between 2025 and 2034.

The projected volume for 2G production is also considered, with an expected 1.1 billion liters in 2034 (EPE, 2024a). The estimated operational cost, updated to December 2023, is R$ 1.88 per liter (LNBR, 2022), resulting in an OPEX of R$ 12.6 billion.

Corn Ethanol

Regarding corn ethanol (which includes soybeans and other cereals, for simplicity), the reference scenario projects an increase of ethanol production capacity by 6.9 billion liters, considering the expansions and constructions authorized by ANP (seven units), in addition to expansions and new indicative units, most of which will be *full*[5] (ANP, 2024a). Thus, the total production capacity will reach 15.5 billion liters in 2034, with production reaching 14.3 billion liters.

The CAPEX for the installation of a *flex* plant is R$ 1.29 per liter, and for a *full* plant, it is R$ 2.55 per liter (LNBR, 2022; IBGE, 2024). The OPEX was only considered for the latter type of unit and is equivalent to R$ 1.86 per liter (IBGE, 2024; NOVACANA, 2024a). For the *flex* unit, it was assumed that this expense would be allocated to the sugarcane ethanol production unit.

Thus, between 2025 and 2034, the estimated investment in the construction of corn ethanol plants is approximately R$ 17 billion, with operational costs amounting to R$ 113.3 billion.

[5] That is, plants that are entirely dedicated to processing corn for ethanol production. In the case of *flex* plants, these are typically sugarcane mills that are adapted to processing corn during the off-season of the sugarcane harvest, to maintain ethanol production during this period. There are also possibilities for parallel production during the harvest season.

Ethanol Transportation Infrastructure

With the projected expansion of the ethanol market, strengthened by the significant growth in corn ethanol supply and increased storage capacity by plants, it is necessary to invest in diversifying the modes used in distribution, to make the transport system of the production surplus as efficient as possible. Currently, most of the ethanol produced is transported through roadways; however, the railway and pipeline modes represent alternatives with lower greenhouse gas (GHG) emissions, which can be better explored (EPE, 2024b).

EPE published the Indicative Oil Pipeline Plan (PIO), aimed at improving the analysis of logistical supply flows by developing technical, socioeconomic, and environmental feasibility studies for pipeline transport projects and associated systems, with a view to meeting existing national demands (EPE, 2024c). With the increase in corn ethanol production in the Midwest region, it is likely that the interest in expanding the pipeline network to transport ethanol to this region will grow.

Logum Logística S.A. is making investments in a project to build its own pipelines and use existing ones, with an annual transportation capacity of 9.0 billion liters[6]. R$ 220 million was invested in optimizing operations, with a high concentration in the Center-South region of the country, which is part of the R$ 3 billion investment package (INFOMONEY, 2023).

Table 2 summarizes the ethanol investments for the period from 2025 to 2034, for both *brownfield* and *greenfield* units.

Table 2 CAPEX and OPEX Estimates for Ethanol Between 2025 and 2034

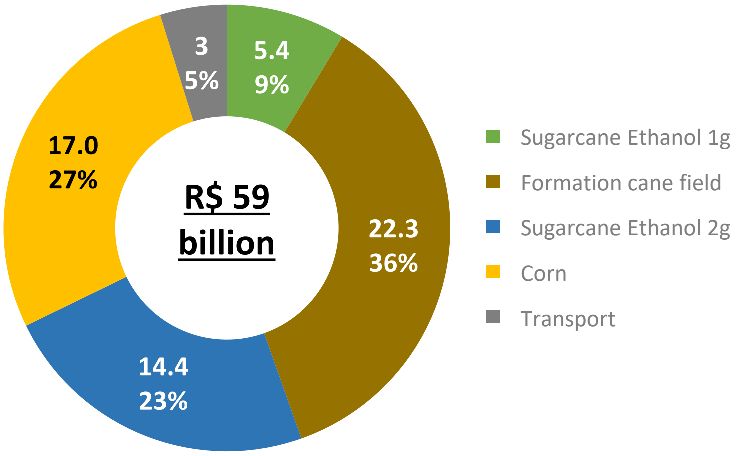
ETANOL	*CAPEX* (R$ Billion)	*OPEX* (R$ Billion)
Sugarcane Ethanol 1G	5.4	81.2
Formation of the cane field	22.3	564.2
Sugarcane Ethanol 2G	14.4	12.6
Corn Ethanol	17.0	113.3
TOTAL	**59.1**	**771.3**
Transport	**3.0**	**n/a**

Source: EPE based on IBGE (2024), FGV (2024), LNBR (2022), INFOMONEY (2023), NOVACANA (2024a), RAÍZEN (2024a, 2024b)

Chart 1 presents the participation and values of industrial CAPEX and formation of sugarcane for ethanol between 2025 and 2034.

[6] In 2023, more than 4.3 billion liters were moved, equivalent to 12% of the national production.

Chart 1: CAPEX for ethanol between 2025 and 2034 (billions of R$ and %)



Source: EPE based on IBGE (2024), FGV (2024), LNBR (2022), INFOMONEY (2024), NOVACANA (2024a) and RAÍZEN (2024a, 2024b)

It should be noted that, when incorporating the investments related to sugar production, the values for first-generation sugarcane would reach R$ 6.7 billion for the industrial sector and R$ 42.2 billion for the formation of the sugarcane fields (totaling R$ 48.9 billion), while operational costs would reach R$ 1.3 trillion by the end of the period.

2. Biodiesel

The consumption of biodiesel is determined by its percentage to be added to the projected demand for diesel B, which reaches 83.5 billion liters in 2034[7] (EPE, 2024a). Additionally, there is the possibility of biodiesel being used in the maritime sector as an alternative for decarbonizing this segment of transportation. In 2024, ANP authorized, on an exceptional basis, the sale of marine fuel (bunker) by Petrobras, with a mixture of up to 24% biodiesel by volume (EPE, 2024a). As a result, the estimated additional consumption of biodiesel could reach up to 1.1 billion liters for blending into bunker fuel (EPE, 2024a).

Regarding the regulation of biodiesel use, on April 1, 2023, the biodiesel blend was changed to 12%, according to CNPE Resolution No. 3/2023 (CNPE, 2023a), which also established its gradual increase, on the same day and month, to 13% (B13) in 2024, to 14% in 2025, and to 15% in 2026. However, in December of the same year, CNPE Resolution No. 8/2023 updated the blending percentage, establishing a 14% blend for March 2024, and a 15% blend for March of the following year (CNPE, 2023b).

[7] Projection based on the information provided in the PDE 2034 Study Papers (EPE, 2024a).

Recently proclaimed, the Fuel of the Future Law establishes a schedule for the gradual increase in mandatory biodiesel blending percentages in diesel B, conditioned on the technical feasibility assessment and evaluation of the targets by the National Energy Policy Council (CNPE). The schedule starts with a 15% blend from March 2025, increasing by one percentage point each year until reaching 20% in 2030. However, in this investment note, the current regulation, CNPE Resolution No. 8/2023, is considered, where the 15% blend remains until 2034.

In this study cycle (2025-2034), investments calculations were based on data from ANP regarding the expansion and construction of new biodiesel units (ANP, 2024a). According to information provided in May 2024, the four expansion requests amount to 0.33 billion liters, and the construction of seven new units adds up to 0.89 billion liters.

For this total (1.22 billion liters), an average CAPEX of R$ 0.68/liter/year for new units and R$ 0.49/liter/year for expansions was applied (BIODIESELBR, 2024), representing investments of R$ 0.77 billion from 2025 to 2034.

It is noted that, with a utilization factor (UF) of 92% due to planned shutdowns and adverse events, the effective biodiesel production capacity would be around 15 billion liters by the end of the period. This would result in approximately 16% idle capacity when compared to the production of 12.5 billion liters and 9% when adding biodiesel for bunker export.

Considering that soybeans will remain the main feedstock used in biodiesel production, with approximately 70% on average during the study period (ABIOVE, 2024a), the investment projection for its processing capacity is based on the implementation of units with a capacity of 4,000 tons/day, at an estimated cost of R$ 589 million (ABIOVE, 2024b). These units produce bran, food soy oil, and oil for other purposes, including biodiesel production.

For the analysis of additional crushing capacity required, only the complementary demand for soybean oil for biodiesel production and the soybean crushing capacity of 69 million tons per year as of December 2023 (ABIOVE, 2024c) were considered. It should be noted that investments required for processing other types of oilseeds were not considered, although there are public policies aimed at greater diversification of feedstocks, promoting regional biomass[8]. It is estimated that it will be necessary to implement sixteen soybean processing units, totaling 23.4 million tons per year in crushing capacity, which would represent an investment of R$ 13.8 billion by 2034. This increase, compared to 2023 (which required an investment of R$ 4.2 billion), is justified by the expected expansion in the demand for oils for biofuel production in the Diesel cycle, including the mandatory blending percentage, bunker, green diesel, coprocessing, and SAF (via the HEFA route[9]) (EPE, 2024a).

[8] Grease materials (a mixture that reaches the plants without specific characterization) and bovine tallow account for 15% and 7% of the raw materials in biodiesel production, respectively (still significantly below soybean oil).
[9] Paraffinic kerosene synthesized from fatty acids and hydroprocessed esters.

The OPEX for biodiesel production was estimated based on the average sales prices of volumes traded between producers and distributors in 2023 (ANP, 2024b) and information from industry experts (UBRABIO, 2019), resulting in a factor of R$ 0.67/liter. The operational costs between 2025 and 2034 are estimated at R$ 77.5 billion. It is worth noting that biodiesel production units have an intermittent profile throughout the year, and since January 2022, the sector has a commercialization system based on free negotiations between producers and distributors (CNPE, 2020). Therefore, it is estimated that this cost indicator has a wide range.

3. Biomethane from Sugarcane Sector

The Future Fuel Law establishes the National Decarbonization Program for the Producer and Importer of Natural Gas and Incentive for Biomethane, with the aim of promoting two types of projects for the biofuel: connection to gas transportation and distribution networks and the fueling of vehicles powered by methane. As a tool, the Law establishes that CNPE will be responsible for defining annual targets for the reduction of GHG emissions in the natural gas sector, to be achieved either directly by purchasing or using biomethane, or through the acquisition of biomethane guarantees of origin certificates (CGOB). The Gas for Employment Program, promoted by the Federal Government to better utilize the natural gas produced in the country, may also positively impact biomethane.

Therefore, the convergence of the Future Fuel and Gas for Employment programs is observed, with biomethane becoming a key element in expanding the gas supply network while reducing its carbon footprint. The use of biomethane as a fuel in the transportation sector, particularly for fueling heavy-duty vehicles, also aligns with the legacy of RenovaBio.

Public policies indicate a scenario of significant growth for biomethane, which is already reflected in the registered construction of plants within the ANP for the short term, with plants expected to be completed by 2026. The investments related to these plants are evaluated below, while projections for new plants from 2027 onward are addressed in the Annex.

Considering the requests for construction and expansion of biomethane plants registered within the ANP (ANP, 2024a), there has been an acceleration of projects this year. While four projects were registered in 2023, by May 2024, there were 23 projects registered, linked to both the sugarcane sector and the municipal solid waste (MSW) [10] sector. Of the total, 16 are expected to be implemented starting in 2025, with five in the Southeast region, five in the South region, four in the Central-West region, and two in the Northeast (ANP, 2024a).

[10] In recent years, municipal solid waste and sanitation plans have been increasingly structured, as well as the launch of the National Solid Waste Plan document in 2022 (MMA, 2022). This document already clarifies the potential for linking waste and biogas production.

Based on the information from requests for inclusion in the Special Incentive Regime for Infrastructure Development (REIDI), investment factors specific to each plant were obtained and applied to projects without information. The 16 projects add up a production capacity of 902 thousand Nm^3/day and a CAPEX of R$ 2.4 billion (ANP, 2024a; BNDES, 2024; MME, 2022), resulting in an investment factor of R$ 2,701.5 per Nm^3/day. The OPEX for the entire horizon is estimated at R$ 384.5 million.

Based on the same investment premise, the resources required to develop the biomethane potential from the waste of the sugarcane sector can be evaluated. The base used was the PDE 2034 (EPE, 2024d), which estimated the potential for biogas production through the anaerobic digestion of vinasse and filter cake[11] in 2034, in the reference scenario, at 6.4 billion Nm^3 of biogas, equivalent to 3.5 billion Nm^3 of biomethane[12]. Thus, the estimated CAPEX for installing the capacity necessary to achieve this biomethane supply would be around R$ 31.5 billion. It was assumed that biomethane production would take place in areas adjacent to the sugarcane plants, utilizing part of the existing facilities.

The operation and maintenance costs were calculated based on data provided by BNDES (2020a; 2020b), referring to the profile of a biogas production plant with a capacity of 33 million Nm^3/year and 18.2 million Nm^3/year of biomethane. Considering the sector's production potential, an accumulated expense between 2025 and 2034 of around R$ 4.7 billion for biomethane is estimated, with a reference factor of R$ 0.142/Nm^3.

4. Sustainable Aviation Fuel

Similarly to the case of biomethane, the Future Fuels Law also aims to promote the expansion of domestic SAF production. To achieve this, one of its guidelines is the National Sustainable Aviation Fuel Program, ProBioQAV, which mandates airlines to reduce greenhouse gas emissions on domestic flights through the utilization of SAF. The mandatory reduction period begins in 2027, with an annual reduction target of 1%, which will gradually increase until it reaches 10% in 2037.

On the international stage, the International Civil Aviation Organization (ICAO) has set carbon-neutral growth targets starting in 2020 and aims for net-zero emissions by 2050, through CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation), a market-based mechanism designed to support the process of emission reductions in the sector.

[11] If the sustainable collection of 20% of the straw and tops is made feasible, an additional 5.4 billion Nm^3/year of biogas would be added to the sector's potential, representing 3 billion Nm^3 of biomethane, totaling 11.8 billion Nm^3/year of biogas and 6.5 billion Nm^3 of biomethane in 2034, with a total investment of R$ 58.5 billion.

[12] For simplification, it was assumed that all biogas production will be purified to generate biomethane, meaning there will be no allocation for electricity generation from this input.

In order to estimate the investments over the next decade, a survey of commercial projects already disclosed by companies in the sector was conducted. Figure 1 identifies three projects with the highest likelihood of implementation, using the HEFA route and jointly producing SAF and Green Diesel:

- Brasil BioFuels (BBF) will use palm oil, soybean oil, and corn as raw materials, with an expected start of operations in 2026 (BRASIL BIOFUELS, 2024);
- ACELEN, will use soybean oil and corn in the first phase, with plans to use macauba oil in the future, with implementation scheduled for 2027 (ACELEN, 2024); and
- Petrobras will use soybean oil and beef tallow, with implementation expected in 2029 (PETROBRAS, 2024a).

The total production capacity of these projects is 2.2 billion liters per year, with 50% allocated to SAF and 50% to green diesel. The estimated investments will amount to approximately R$ 17.5 billion, with R$ 8.7 billion allocated to each. Therefore, considering the investment weighted by volume, the estimated CAPEX for the announced HEFA route projects is R$ 7.02 per liter of SAF. In turn, the operational costs related to the production of the biofuel in these plants will remain around R$ 3.42 per liter of SAF, resulting in an OPEX of R$ 37.6 billion by the end of the period.

In the annex, the estimated investment range for meeting the targets set by CORSIA and ProBioQAv is presented.

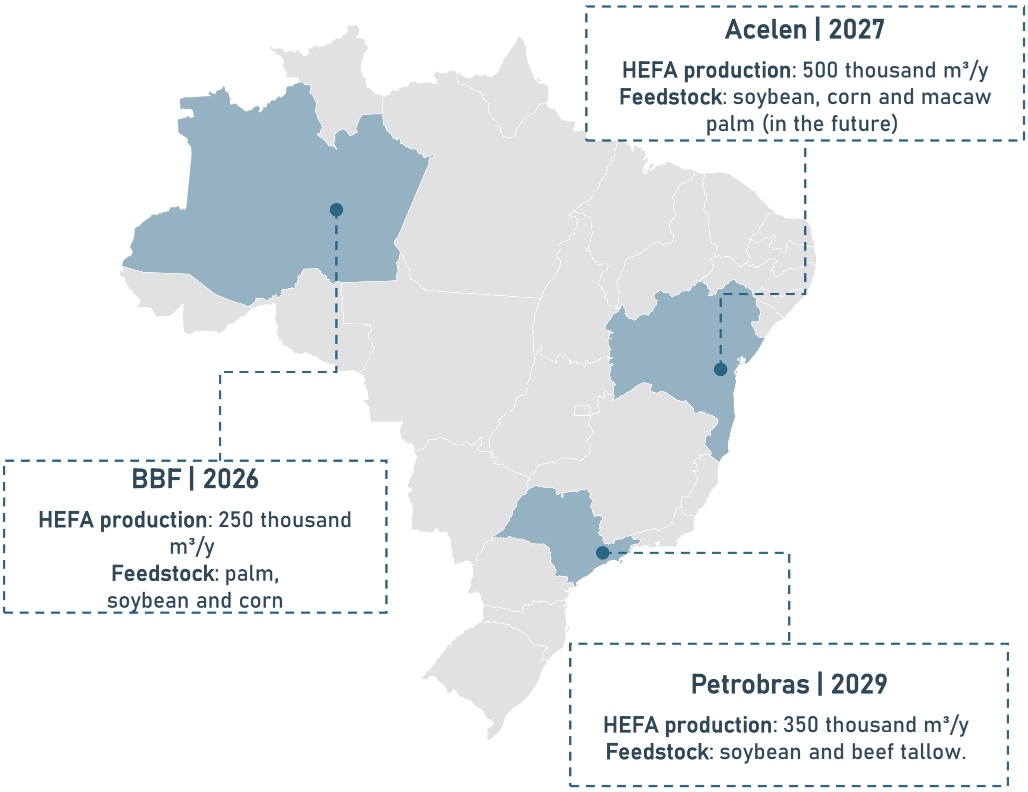


Figure 1: Projects for Sustainable Aviation Fuels (SAF)

Source: EPE, adapted from ACELEN (2024), BRASIL BIOFUELS (2024) and PETROBRAS (2024a).

5. Green Diesel and Other Biofuels

Green diesel, a renewable fuel formed by a mixture of hydrocarbons with a chemical composition similar to fossil fuels, stands out as a drop-in alternative for use in diesel cycle engines. There are economic challenges to be overcome for the viability of this scenario, including the definition of the technology for its production and the selection of feedstocks that can be used in the process. Initiatives to produce HVO-type green diesel have already emerged, using soybean oil, palm oil, and macauba oil (EPE, 2024a).

Similarly to SAF, green diesel also has a specific program established by the Fuel of the Future Law. The National Green Diesel Program (PNDV) aims to encourage production from renewable biomass, setting an annual mandatory minimum participation of up to 3% to be added to fossil diesel. The CNPE will be responsible for determining the annual minimum participation of biofuel. A voluntary addition above the 3% threshold is also allowed, only if it is prior reported to the ANP.

With the PNDV, there is an expectation of investment growth in green diesel over the next few years. As an alternative to diesel, which does not require modifications for its use, the demand for this biofuel is expected to increase in the future.

As indicated in the section related to SAF, there are projects under construction for the joint production of SAF and HVO, with a total production capacity of 2.2 billion liters per year, with 50% allocated for SAF and 50% for green diesel. Therefore, the estimated CAPEX for green diesel is R$ 8.7 billion. The operational cost related to the production of the biofuel in these plants is estimated at R$ 3.42/liter, resulting in an OPEX of R$ 37.6 billion by the end of the period.

Coprocessing of Vegetable Oil

Another process related to the Diesel cycle is the production of co-processed diesel, a fuel derived from the co-processing of vegetable oil with mineral diesel, carried out at the refinery. The result is a fuel with renewable content and, therefore, a lower carbon footprint. Petrobras, through its *Biorrefino* program, aims to commercialize co-processed diesel, totaling a production capacity of 63 mbpd from the REPAR, RPBC, REPLAN, REDUC, and REGAP[13] units. An estimated R$ 3.0 billion will be invested by 2028 (PETROBRAS, 2024b; CNN, 2023).

[13] Presidente Getúlio Vargas Refinery (REPAR), 29 mbpd (Operating); Presidente Bernardes Refinery in Cubatão (RPBC), 9 mbpd (Operating); Paulínia Refinery (REPLAN), 6 mbpd; Duque de Caxias Refinery (REDUC), 6 mbpd; Gabriel Passos Refinery (REGAP), 13 mbpd.

Carbon Capture and Geological Storage of Biogenic Carbon (Bio-CCS)

Among the solutions that could be developed from the Fuel of the Future Law and other programs such as RenovaBio, there is also bio-CCS or BECCS (BioEnergy with Carbon Capture and Storage). Bio-CCS refers to the capture and geological storage of carbon dioxide derived from biomass. The primary and most immediate opportunity for this process occurs in ethanol plants. The potential for carbon capture during alcohol fermentation could reach 35 million tons of CO2/year by 2034 (EPE, 2024a). Bio-CCS can significantly reduce the carbon intensity of ethanol, making it competitive and attractive, which could increase investments in such technology.

The projected investments for the installation of this type of venture are around R$ 460 million, as announced by FS Bioenergia (NOVACANA, 2024b), with R$ 110 million already invested. Being the first Bio-CCS project of its kind in Brazil, advancements are expected along the learning curve, so that the costs of subsequent projects are lower than those incurred in this case. The regulatory certainty provided by the Fuel of the Future law may also help unlock the CCS chain in the country and support the feasibility of future projects.

6. Consolidation of CAPEX and OPEX Estimates

The Fuel of the Future law is expected to have significant impacts on biofuel production in Brazil, as it encourages local generation and greater use of biofuels for the country's decarbonization. As a result, it is estimated that increasing investments will be made in the sector in the coming years.

Thus, based on the study cycle for the 2034 horizon (EPE, 2024a; 2024d), the investments (CAPEX) and operational costs (OPEX) for ethanol, biodiesel, biomethane, SAF, green diesel, co-processing of vegetable oils, and bio-CCS are estimated to be approximately 100 billion and 924 billion reais, respectively.

Table 3. CAPEX and OPEX estimates for biofuels between 2025 e 2034

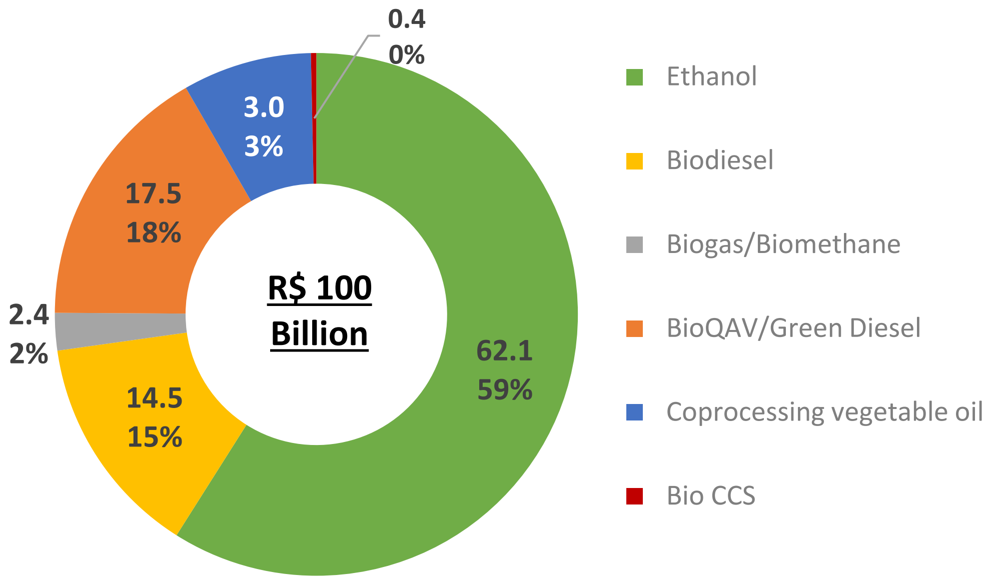
	CAPEX (R$ Billion)	OPEX (R$ Billion)
Ethanol	62.1	771.3
Biodiesel	14.5	77.5
Biomethane[1]	2.4	0.4
SAF / Green Diesel	17.5	75.2
Coprocessing of Vegetable Oil	3.0	n/a
Bio-CCS	0.4	n/a
TOTAL	**99.8**	**924.4**

Note 1: For biomethane, only the projects under construction in the sugarcane sector are considered.

Source: EPE

Chart 2 shows the share and CAPEX values for biofuels, including the formation of sugarcane fields for ethanol production, between 2025 and 2034.

Chart 2: CAPEX for biofuels between 2025 e 2034 (billion R$ and %)



Source: EPE

Considering investments related to sugar production (1st generation sugarcane), the total *CAPEX* for biofuels is R$ 121 billion, and the *OPEX* is R$ 1.374 billion.

Sustainable Aviation Fuels (SAF)

Among the biofuels that could be enhanced by the Fuel of the Future Law, SAF stands out as one of the main options, as it has a specific program, ProBioQAV, with emission reduction targets to be achieved from 2027 to 2037, in addition to international targets set by CORSIA. Considering that these targets aim emission reductions and not volumetric mandates, the demand may vary according to the carbon intensity of the routes and raw materials used.

Therefore, considering the period of this study, the demand for SAF in 2034 may vary between 2.1 billion liters (lower carbon intensity levels) and 6.5 billion liters (higher carbon intensity). On the other hand, it is known that the composition of routes and raw materials for SAF production will depend on the evaluation of a series of factors, such as the availability of energy and financial resources, infrastructure, costs, carbon intensity, geopolitical aspects, among others. Thus, through a multicriteria assessment, it was estimated that the demand for SAF in 2034 could reach around 3 billion liters (EPE, 2024a)[14].

Currently, as analyzed in this document, the HEFA route is the most commonly used by the projects already announced, due to its higher technological readiness level and more extensive international history. However, Brazil may stand out in SAF production from other routes, such as AtJ (Alcohol to Jet) and FT (Fischer Tropsch), which are promising not only to meet the growing demand but also for their carbon intensity reduction potential (EPE, 2024e). Thus, an analysis was conducted on the investment potential for both lower and higher carbon intensity pathways, as well as those indicated in the multicriteria analysis, calculating possible CAPEX values for the realization of such projects.

Through Table 4, it is possible to observe that the multicriteria analysis pathway has the lowest total investment, even though it does not present the lowest (average) CAPEX. This is due to the weighting of the cost of each route by volume, considering their respective carbon intensities/raw materials, that is, the emissions reduction potential, linked to the CAPEX of each route, compared to the other pathways.

Table 4. Potential Investments for SAF [15]

Fuel	CAPEX (R$/liter)	Total Investment (R$ Billion)
Pathway with Lower Carbon Intensity (FT Route)	43.39	89.0
Pathway with Higher Carbon Intensity (ATJ Route)	15.82	102.2
Pathway from the Multicriteria Analysis	21.94	65.9

Source: EPE based on Capaz et al. (2020), ICS (2022), GIZ (2022), Sharhriar, M & Khanal, A. (2022), IEA Bioenergy (2021).

[14] For more information, access the document "Caderno sobre Combustíveis Sustentáveis de Aviação no Brasil" (EPE, 2024e).

[15] The values for the AtJ and FT routes are based on various studies that primarily reflect projects carried out outside of Brazil. It becomes relevant to include the tropicalization of costs, applying a 30% increase factor.

Increase in biodiesel content

This item seeks to assess the need for additional investments in biodiesel production capacity and vegetable oil extraction, considering the Fuel of the Future Law, which proposes a gradual increase in its blending percentage with diesel B, compared to the estimated scenario in the 2034 PDE reference scenario, with the current blend (B15).

To explore possible alternatives for national Diesel cycle fuel supply, the PDE 2034 (EPE, 2024a) conducts a sensitivity analysis in which the biodiesel percentage in diesel B reaches a 20% blend (B20) by 2030, remaining at that level until 2034. It is found that the demand for biofuel reaches 16.7 billion liters by 2034.

In addition to the increase in the blending percentage, the demand for biodiesel in the waterway transport sector (hydro and *bunker*) could reach 1.1 billion liters by 2034, leading to a total demand of 17.8 billion liters in that year.

On the other hand, the effective production capacity may reach 14.9 billion liters by 2034, according to the requests for expansion and construction permits from the ANP, as of May 2024.

Thus, under the given infrastructure conditions and projected demand, the country would face a *deficit* of 2.9 billion liters in production capacity and an additional need for 19 million tons of soybean crushing capacity, which would require investments of R$2 billion and R$11.2 billion, respectively, totaling R$13.2 billion, distributed between 2029 and 2034.

Entry of Biomethane Plants

The ANP's registration of plants under construction, by its nature, only identifies ongoing projects, which limits the horizon for the entry of new plants in the short term. As of the May 2024 database, the listed projects had a maximum completion deadline of 2026.

This item aims to estimate the additional investments in biogas plants for the remainder of the period considered in this document (until 2034), by creating a preliminary scenario for the entry of new plants per year starting in 2027, limited to the sugar-energy sector. This scenario uses 2024 as the reference year, which, according to updated ANP records in November 2024, could add five new biogas plants associated with sugarcane units[16]. It is proposed that, starting in 2027, it would be possible to replicate the expansion observed in 2024, leading to additional 40 biogas units by the end of the period.

Based on data from the plants registered with ANP, an average capacity of 40,000 Nm^3/d ay of biogas per plant was adopted. The investment factor of R$ 2,701.50 per installed Nm^3/day was maintained. Under these conditions, the annual investments would amount to approximately R$ 540.3 million, totaling an additional R$ 4.3 billion between 2027 and 2034, solely from sugarcane residues.

[16] Of these units, one had obtained an operating license, three indicated completed works, and one was expected to be completed in December of the same year, according to ANP records from November 2024.

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Annex

Results for the 2024-2034 Period

Table 5 presents the CAPEX and OPEX for the 2024-2034 period, deflated to December 2023, to enable comparison with the investment, results outlined in the PDE 2034.

Table 5. CAPEX and OPEX Estimates for Biofuels between 2024 and 2034

	CAPEX (R$ Billion)	*OPEX* (R$ Billion)
Ethanol	66.8	836.6
Sugarcane 1G	5.4	88.5
Sugarcane Plantation	24.3	615.0
Sugarcane 2G	15.6	12.9
Corn	18.5	120.1
Transportation	3.0	n/a
Biodiesel	14.7	83.7
Biogas/Biomethane	2.4	0.482
SAF / Green Diesel	17.5	75.20
Vegetable Oil Coprocessing	3.0	n/a
Bio-CCS	0.4	n/a
TOTAL	**104.8**	**996.0**

Source: EPE

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