

BRAZIL'S BIOFUEL INDUSTRY

LESSONS, CHALLENGES AND OPPORTUNITIES



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FOREWORD

Brazil's experience in the development of sustainable biofuels represents a valuable example of how innovation, policy design and long-term vision can drive the decarbonisation of the energy sector. It offers key insights and a compelling model for countries seeking to advance their own energy transitions while fostering economic growth and social inclusion.

According to IRENA's 1.5°C Scenario, sustainable fuels – including biofuels and green hydrogen derivatives – will play an increasingly important role in the global energy transition. Their share in total final energy consumption is expected to reach around 10% by 2030 and at least 20% by 2050; however, this will require concerted action, international collaboration and the mobilisation of investment at scale. International co-operation is also vital in establishing sustainability criteria and ensuring their application.

The Brazilian experience highlights the crucial need for strategies and clear policy frameworks that enhance sustainability, reduce investment risks and foster innovation. These include: creating appropriate institutional environments; establishing consistent long-term objectives through effective policies; encouraging constructive discussions between public and private stakeholders; promoting international collaboration; and supporting research and development to unlock the next generation of biofuel technologies.

As we navigate the road from Baku to Belém, the focus must shift from commitment to implementation. We encourage countries to deepen cooperation – bilaterally, regionally and multilaterally – to unlock the full potential of sustainable fuels in global decarbonisation efforts. Through shared learning, coordinated action and collective ambition, we can accelerate the deployment of sustainable solutions; to this end, the Brazilian experience may inspire policy makers to translate ambition into tangible progress.

Francesco La Camera

Director-General

International Renewable Energy Agency



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EXECUTIVE SUMMARY



The goal of the Paris Agreement to keep global temperature rise to within 1.5°C of pre-industrial levels will not be met without sustainable biomass and biofuels. The role they will play in the global transition and the diversification of renewable energy sources will also bring significant benefits in terms of energy and supply chain security.

Under IRENA's 1.5°C Scenario, drawn from the Agency's *world energy transition outlook* workstream, sustainable biomass should account for at least 15% of final energy consumption (55 Exajoules [EJ]) by 2050, equating to around three-times today's level.

Ethanol and biodiesel are well-established markets in road transport and many other new applications are under development, such as bio-based sustainable aviation fuels (SAF); bio-bunkers for maritime use; and sustainable biomass for a variety of industrial applications such as heating. They are essential solutions for the transport sector and the decarbonisation of hard-to-abate sectors.

Consequently, global production will need to increase whilst global trade barriers are reduced, if the energy transition is to be competitive and beneficial to local communities. Scaling up investments on the ground is crucial at both the regional and national levels. Regions such as South America have significant sustainable biomass potential, according to IRENA's forthcoming *Regional energy transition outlook: South America* report, and are well placed to assist global decarbonisation efforts.

Learning from successful cases and champions is an effective way to accelerate the energy transition. For example, around 25% of final energy consumption in Brazil is met by biomass (in all forms), which contributes to the 50% share of renewable energy in the country's primary energy mix.

Indeed, energy security crises such as the oil shocks of the 1970s, combined with the need for diversification, and the search for affordability and competitiveness, have all been important drivers for the decisions by Brazil's policy makers to implement biofuels policies and programmes. A similar constellation of interests is developing in more places around the globe today. Therefore, this report presents the following key conclusions:

- Legal frameworks, stable long-term policies and clear perspectives all provide clear positive signals for the development of the biofuels sector among investors, consumers and industry. A successful biofuels sector requires multiple, co-ordinated governance regimes, covering national energy planning, transport planning, climate and environmental policies, land use and agriculture policies, and industrial and innovation policies.

- It is essential to ensure that a nascent biofuels industry adopts clear, transparent and traceable sustainable practices in relation to employment, the environment and society – third party independent certification is a necessary step in this regard. Establishing a successful and sustainable industry requires a roadmap with clear milestones that accentuates coordination among the various stakeholders, especially at government level.
- Developing a sustainable biofuel sector will also bring positive results for the economy in terms of job creation, local development and supply chain diversification. Therefore, it is well suited for both for sustainable development goals and decarbonisation.
- The biofuel sector in Brazil has benefitted from tax benefits, biofuel blend programmes, financial incentives, support for flex fuel cars, regulation of technical certification, and carbon trade markets. This report provides a description of the evolution of these instruments in Brazil.
- International co-operation can play an important role in promoting the development of sustainable fuels, such as promoting technology exchange, sustainable best practices, the removal of trade and regulatory barriers, setting certification and standards, and raising awareness for funding requirements and opportunities.

This report, issued at the request of the Brazilian COP30 Presidency, is part of IRENA's contribution to showcasing existing solutions and fostering plans for the acceleration of the energy transition under the COP30 Activation Groups. It informs also the Global Coalition for Energy Planning (GCEP) initiative, led by Brazil, with IRENA as Secretariat. National policy makers and regional energy forums, such as OLADE, ASEAN, and African countries, may find it particularly useful as a guide or roadmap to complement their energy transition strategies, plans and policies.



1. INTRODUCTION

Modern bioenergy is expected to play an increasingly vital role in the energy transition. It accounts for a sizeable portion of total final energy consumption in the coming years and will need to contribute 12% by 2030 and 15% by 2050 in the 1.5°C Scenario (BNDES, 2008; IRENA, 2024a).¹

However, realising bioenergy's full potential requires a comprehensive approach (encompassing a suitable institutional framework, consistent long-term goals, productive engagement with private stakeholders, international co-operation, and innovation) to address key barriers to wider bioenergy deployment such as policy uncertainty, technology readiness, cost and financing issues, limited market access, supply chain complexities and sustainability risks (IRENA, 2024a).

Aligned with the International Renewable Energy Agency's (IRENA's) global perspective, Brazil's experience, particularly with bioethanol, exemplifies a compelling model for sustainable decarbonisation. It offers a low-cost and competitive pathway, significantly contributing to global energy transitions. By fostering market competition through a conducive regulatory environment and strategically employing tax policies to influence fuel consumption, Brazil actively supports the shift towards biofuels.²

The Brazilian experience highlights the crucial need for implementing strategies and policies that enhance sustainability and address investment barriers. This includes creating an appropriate institutional framework, establishing consistent long-term objectives through effective policies, encouraging constructive discussions with private stakeholders, pursuing international collaboration, and advancing innovation to facilitate the development of biofuels in the energy mix.

This report focuses on the Brazilian experience and perspectives on ethanol, biodiesel and some advanced biofuels. It does not cover other bioenergy carriers (such as solid biofuels and biogas).



¹ The IRENA 1.5°C Scenario outlines an energy transition pathway designed to restrict the rise in global average temperature to 1.5°C above pre-industrial levels by the end of the century. This strategy prioritises readily available technological solutions that can be scaled up to meet this objective (IRENA, 2024a).

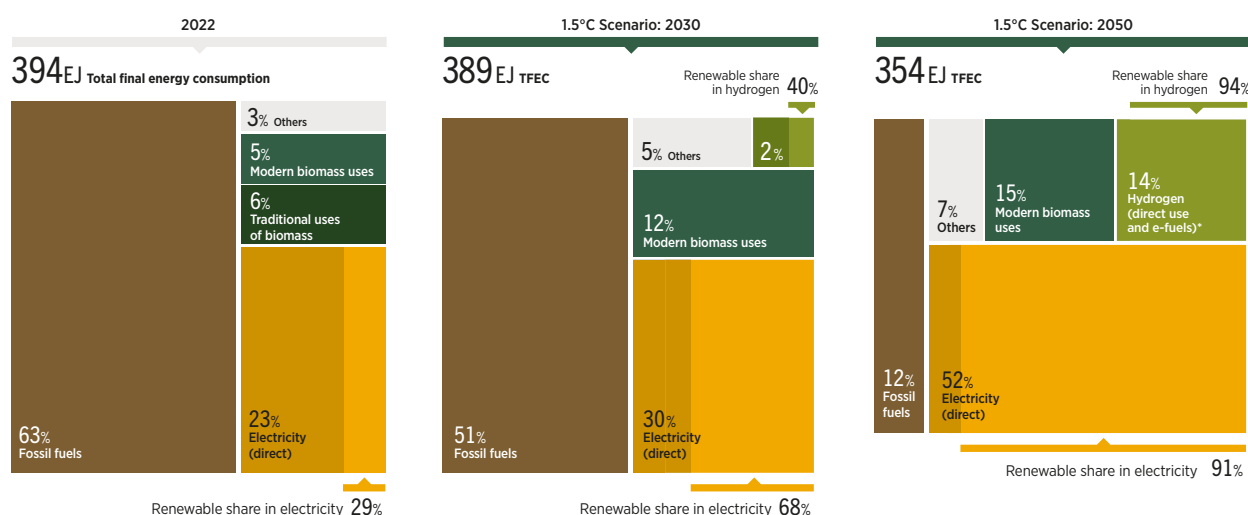
² Brazil's regulatory framework supports the biofuel industry by avoiding direct government intervention in fuel pricing and promoting market competition. Federal taxes such as CIDE (Contribution for Intervention in the Economic Domain), PIS/COFINS (federal social contributions) and the state-level ICMS tax (value-added tax) play a role in regulating fuel economics. The government actively employs tax policies to incentivise ethanol consumption relative to gasoline consumption, thereby contributing to the energy transition.

2. THE IMPORTANCE OF MODERN BIOENERGY IN THE ENERGY TRANSITION

Considered one of the key enablers together with efficiency and electrification (the main drivers to support the 1.5°C goal), modern bioenergy offers existing and promising solutions to the decarbonisation of the global energy mix, and is also relevant in those sectors where direct electrification may be challenging (IRENA, 2022).

IRENA (IRENA, 2024a) estimated that by 2050, about 15% of the energy mix will need to come from direct use of modern biomass, tripling from the level in 2022, in the 1.5°C Scenario.

Figure 1 The essential role of sustainable fuels in decarbonising the global energy mix



Source: (IRENA, 2024a).

Note: EJ = exajoules; e-fuels = electric-fuels; TFEC = total final electricity consumption.

Liquid biofuels will be a key component in this expansion, particularly in the decarbonisation of the transport sector. According to IRENA (IRENA, 2023), bioenergy consumption in transport will need to grow threefold between 2020 and 2050 under the 1.5°C Scenario, complementing the increasing adoption of electric vehicles and improvements in fuel efficiency.

For road transport, increasing biofuel blending ratios is crucial for decarbonisation, as exemplified by Brazil and Indonesia, where biofuels are projected to reach 35% of final energy consumption by 2050, and India's 20% blending ratio target for ethanol in gasoline by 2030 (IRENA, 2023). In the aviation sector, sustainable aviation fuels (SAFs) provide the high-energy-density, dispatchable fuel required, seamlessly integrating with existing infrastructure. They are projected to account for 24% of the total energy consumption in aviation by 2050, in IRENA's 1.5°C Scenario (IRENA, 2023). Although more limited, the shipping sector will also see a role for biofuels, expected to contribute 10% to its energy mix by 2050 (IRENA, 2022).



Beyond transport, modern bioenergy significantly contributes to decarbonising the industrial and buildings sectors. In IRENA's 1.5°C Scenario, its use in industry will rise fourfold from 2020 to 2050, primarily by replacing fossil-based feedstocks and energy in chemical production, cement and metals industries. In buildings, the use of modern biomass is anticipated to increase threefold from 2030 to 2050, transitioning away from inefficient traditional biomass forms towards bioheat, biogas and bioelectricity (IRENA, 2022).

Furthermore, modern bioenergy plays a dual role in enhancing overall energy system flexibility and enabling negative emissions. Bioenergy with carbon capture and storage (BECCS) is a critical technology for achieving net-zero goals, capable of capturing and storing approximately up to 4.5 gigatonnes of carbon dioxide by 2050, thus directly removing carbon from the atmosphere (IRENA, 2022). Bioenergy can also provide dispatchable electricity, complementing the variable nature of solar and wind power, thereby bolstering grid stability and resilience.

The success of scaling bioenergy is intrinsically linked to its sustainability. Modern bioenergy is envisioned as an integral part of the broader bioeconomy, leveraging diverse sources such as agricultural residues, biogenic waste and by-products from ecosystem management. This approach aims to maximise greenhouse gas (GHG) reductions and avoid negative impacts on food security, biodiversity and land-use change. While residues and wastes are prioritised due to their lower carbon footprint, their practical mobilisation faces logistical and economic constraints, necessitating the exploration of energy crops on underutilised low-carbon land without compromising food security and biodiversity (IRENA, 2022). Life-cycle emissions, particularly those related to land-use changes, are a key consideration, emphasising the importance of sustainable landscape management and the integration of carbon dioxide removal mechanisms such as BECCS.

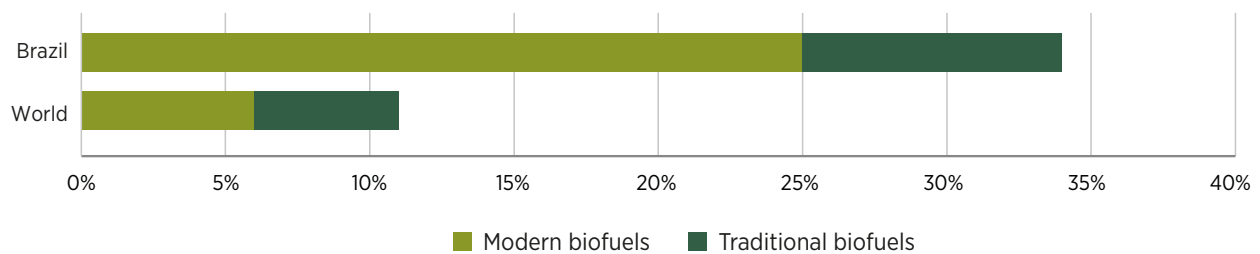
Finally, the realisation of bioenergy's full potential hinges on a robust enabling framework. This includes addressing existing barriers such as policy uncertainty, technological readiness, cost and financing challenges, and supply chain complexities (IRENA, 2022).

The remainder of this paper will delve into Brazil's experience, demonstrating how its approach – characterised by suitable institutional structures, consistent long-term objectives, engagement with private stakeholders, regional development and sustainability goals – offers a compelling model for the successful integration of modern bioenergy into a national energy mix.

3. OVERVIEW OF BIOENERGY IN BRAZIL

Bioenergy from sugar cane, firewood, corn, soybeans and other sources accounted for nearly 33% of Brazil's primary energy production in 2024, making it the most relevant renewable source in its energy mix. Sugar cane biomass and biodiesel represent approximately 19% of the country's primary energy production. In the world, bioenergy accounted for approximately 11% of total final energy consumption in 2022, with roughly half of this amount corresponding to the growing use of modern bioenergy through efficient and environmentally friendly technologies, such as liquid biofuels (IRENA, 2024a) (Figure 2).³

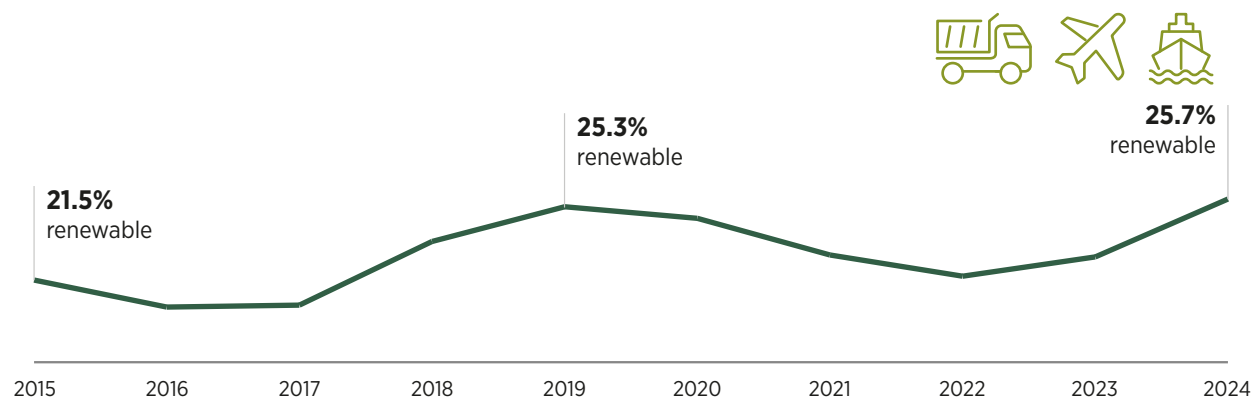
Figure 2 Share of bioenergy in total final energy consumption (2023)



Sources: (MME/EPE, 2024a; REN21, 2024).

In the transportation sector, the renewable share of bioenergy accounted for 3.9% of the world's total final energy consumption in transport in 2021 (REN21, 2024), while in Brazil, it reached 25.7% in 2024 (Figure 3).

Figure 3 Evolution of the renewable energy share in the total energy consumption of the transport sector



Source: (MME/EPE, 2024a).

³ According to IRENA, traditional methods include cooking on inefficient and potentially harmful stoves, whereas modern bioenergy encompasses technologies such as the production and use of liquid biofuels, biogas and bioelectricity generation in industry, buildings and transportation (IRENA, 2024a).

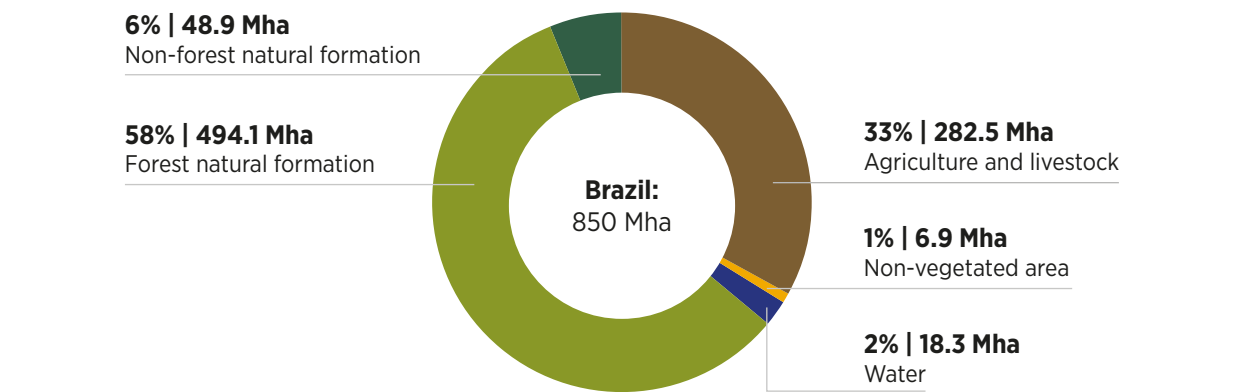
Renewable energy accounts for almost 65% of the industry's energy mix in Brazil, whereas sugar cane bagasse is expected to account for 22% in 2023 (MME/EPE, 2024a). Worldwide, the share of renewable energy in the industry sector's total final energy consumption was 16.8% in 2021 (REN21, 2024).

The importance of bioenergy is becoming more consolidated in Brazil's energy mix through the diversification of biofuels and expansion of their production, which aligns with national goals for decarbonisation, environmental protection and economic development. Brazil is the world's second-largest producer of ethanol and third-largest producer of biodiesel, but it has yet to introduce green renewable diesel⁴ or sustainable aviation fuel (USDA, 2024).

A natural concern regarding bioenergy production is its potential to compete with food production for land. In this regard, Brazil has made significant progress in managing land use for bioenergy production, striking a balance between conservation and agricultural expansion.

The country kept the largest share of its territory (64%) covered in natural vegetation, primarily forests. One-third of the Brazilian territory is used for agriculture and livestock (Figure 4). Facing complex land allocation and forest conservation challenges in such an extensive share of its territory, the country has implemented command and control measures, national policies, and environmental legislation to conserve natural resources while promoting sustainable farming practices (BNDES and CGEE, 2024).

Figure 4 Land use and land cover in Brazil in 2022



Source: (BNDES and CGEE, 2024).

Note: Mha = million hectares.

The country's sugar cane ethanol (first-generation biofuels [E1G]) production relies on areas with suitable soil and climate conditions for high-productivity cultures and high-yield plant species, using relatively small agricultural areas. Concentrated in the Central-South and Northeast regions, it has primarily expanded over degraded pastures, with 98% of this expansion occurring on previously used agricultural lands. Less than 1.6% of the area used for sugar cane was natural vegetation in 2000, indicating a low risk of deforestation (BNDES and CGEE, 2024). Notably, the area designated for sugar cane cultivation has consistently remained in the range of 8 Mha to 9 Mha over the past decade (EPE, 2024). By focusing on recovering natural vegetation and reducing its suppression, sugar cane production commits to environmental standards and biofuel production policies (BNDES and CGEE, 2024).

⁴ Green renewable diesel is a biomass-based diesel. It can be used as an additive to transport fuels, heating oil or aviation fuel, and is characterised by its ability to reduce GHG emissions by 50% or more (EPE, 2020).

More recently, the production of bioethanol from corn has expanded significantly. Corn is grown as a secondary crop after the main soybean crop is harvested, requiring no additional land for its production. As a result, optimised soil management is used, eliminating competition for land with other primary crops and reducing the overall inputs required for production (BNDES and CGEE, 2024).

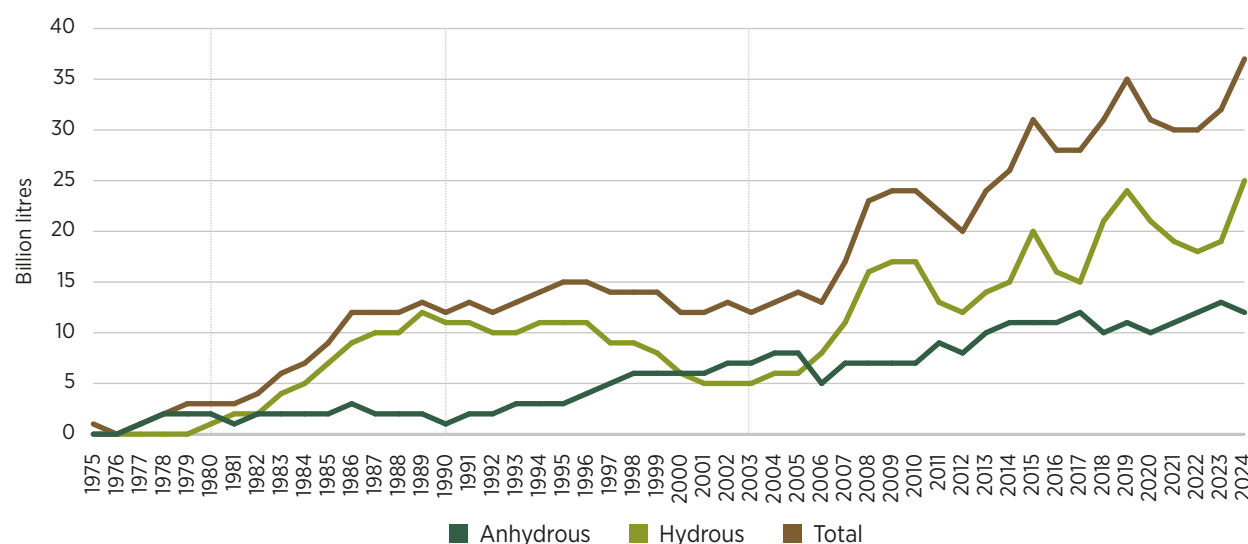
Technological advancements in agriculture and industry have led to significant cost reductions in Brazil, bringing biofuel prices close to those of conventional fuels. However, the competitiveness of biofuels is often skewed due to distortions in the price of fossil fuels (BNDES and CGEE, 2024). Policies such as California's Low Carbon Fuel Standard and Brazil's RenovaBio (see section 5.2.1.1) can help make low-carbon biofuels, such as bioethanol, more competitive.

3.1 BIOETHANOL

Ethanol is a notable option among liquid biofuels due to its versatility and efficiency in combustion engines and turbines. It is a drop-in technology that can be implemented using existing infrastructure. This helps enhance energy security by diversifying energy sources and reducing reliance on fuel imports.

Brazil's ethanol market, with over 30 billion litres of consumption per year, is the second-largest globally, following the United States. The country has a long history with ethanol, primarily using sugar cane as the feedstock. Favourable weather conditions and previous investments in new sugar cane varieties and field renovations have improved productivity and yields.

Figure 5 Ethanol consumption, 1975-2024



Source: (MME/EPE, 2025).

High mechanisation has significantly increased productivity in the production of bioethanol from sugar cane in Brazil. The adoption of mechanised sugar cane harvesting was motivated by i) economic factors (cost reduction); ii) social factors (workforce reskilling and labour market reinsertion); and iii) environmental factors (laws, protocols and incentive programmes to eliminate burning before harvesting). Currently, 92% of sugar cane harvesting in Brazil is done mechanically, maintaining the trend of increasing mechanisation in the sector.

In the Central-Southern region, which is responsible for more than 90% of Brazil's sugar cane production, with predominantly flat areas favourable for machine harvesting, harvest mechanisation already accounts for approximately 99% of the total (BNDES and CGEE, 2024).

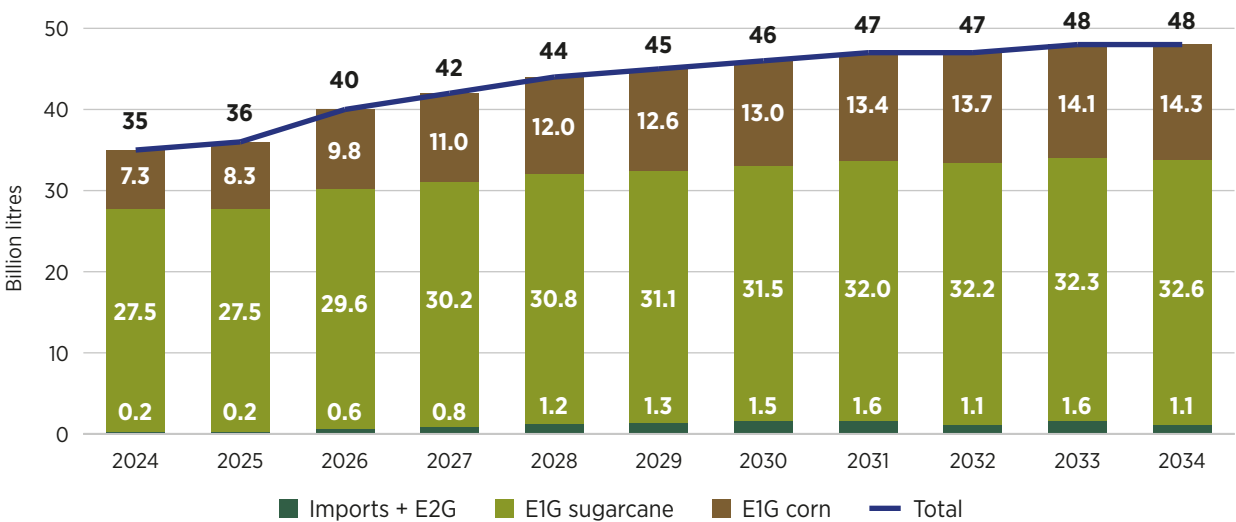
Since 2017, corn ethanol production has surged due to increased grain availability and lower production costs, especially in the Central-Western region, where cheap corn supplies and poultry operations utilise distillation by-products to support the ethanol industry (USDA, 2024). *Second crops* became predominant in corn ethanol production, which in turn accounted for approximately 20% of the total ethanol production in 2024.

Moreover, Brazilian bioethanol from sugar cane and a secondary-crop corn boasts one of the best global carbon footprints (BNDES and CGEE, 2024). Sugar cane production employs sustainable agricultural practices such as crop rotation, waste management and utilising degraded areas, which reduce GHG emissions and enhance soil health quality.⁵ Additionally, sugar cane bagasse, a by-product, is used for electricity co-generation, thereby further reducing carbon intensity (USDA, 2024). Corn bioethanol is cultivated as a secondary crop after soybeans, requiring no additional land.⁶ As mentioned, this method ensures optimised soil management and reduces input usage. As a result, Brazilian bioethanol achieves a carbon footprint reduction of 70% to 82% compared with gasoline, reaching up to 90% in optimal cases (BNDES and CGEE, 2024).

3.1.1 Perspectives

Over the next decade, the Brazilian ethanol supply is projected to grow at 3.8% per year, reaching 48.5 billion litres by 2034 (Figure 6). This growth will primarily be driven by sugar cane, accounting for approximately 70% of production, with the remainder supplemented by corn ethanol. The second-generation (2G) ethanol production is anticipated to utilise a small fraction of the available bagasse and straw, reaching 1.2 billion litres by 2034 (MME/EPE, 2024b).

Figure 6 Ethanol domestic supply forecast



Source: (MME/EPE, 2024b).
Notes: E1G = first-generation biofuels; E2G = second-generation biofuels.

⁵ Crucially, by implementing crop rotation, where corn follows soybeans, this system effectively capitalises on the atmospheric nitrogen biologically fixed in the soil by the preceding soybean crop. This practice not only significantly enhances soil fertility but also substantially reduces the demand for synthetic nitrogen fertilisers for the subsequent corn (MAPA, 2020).

⁶ The second corn crop is currently larger than either the first crop or the third crop where this is planted.

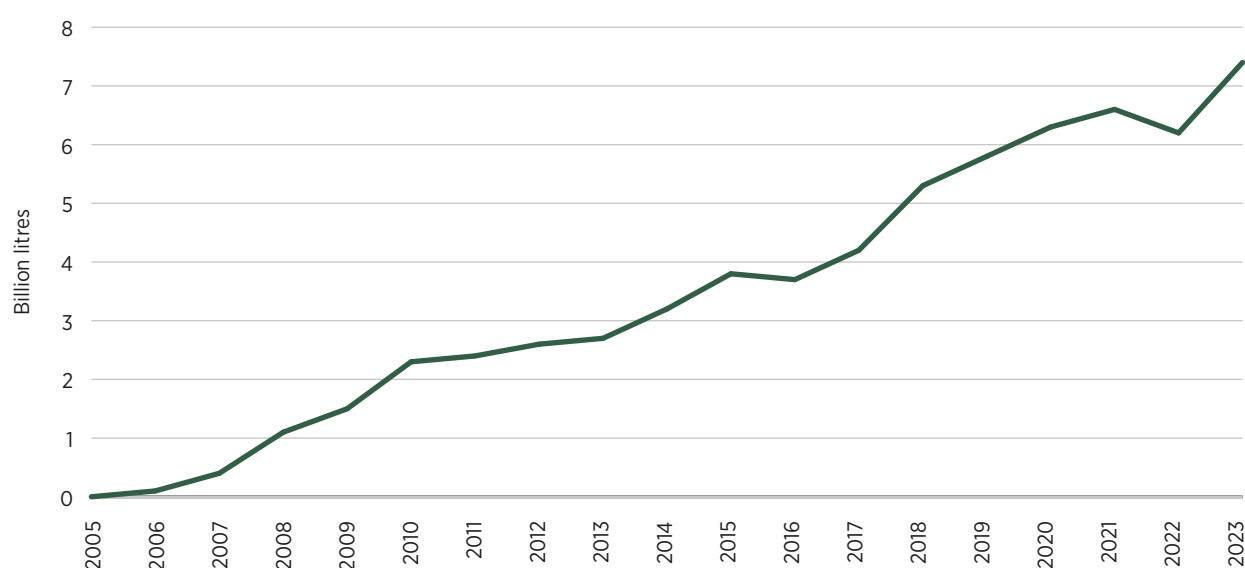
The production volume of hydrous ethanol is expected to amount to 35 billion litres, while anhydrous ethanol is projected to reach 13 billion litres. Regarding ethanol imports, targeted acquisitions of anhydrous ethanol from the international market will be made, capitalising on specific seasonal windows of opportunity (MME/EPE, 2024b).

3.2 BIODIESEL

Brazil hosts the world's third-largest biodiesel industry, following the United States and Indonesia. The country's biodiesel production growth has been driven by an expanding diesel market and increased blending mandates under the National Programme for the Production and Use of Biodiesel (PNPB – see Section 5.1.3), established in 2005 (MME/EPE, 2024b).

From 2005 to 2023, the industry sold 67.5 billion litres of biodiesel domestically (Figure 7). The current mandatory blending percentage is 14%, and as per the National Council for Energy Policy (CNPE) resolution, it will increase to 20% by 2030 (see Section 5.1.4.2).⁷

Figure 7 Biodiesel consumption evolution, 2005-2023



Source: (MME/EPE, 2024a).

Overall, the biodiesel market in Brazil is primarily domestic, driven by concerns about the impact of imports on the local workforce and the contribution to gross domestic product (GDP) from the soybean chain. Biodiesel imports are rare and restricted to exceptional circumstances. Despite its robust production capabilities, Brazil does not export significant amounts of pure biodiesel (B100) or blends above B30. However, Brazil has become a major exporter of used cooking oil and tallow to the United States, where they are used in biodiesel

⁷ The PNPB allows for voluntary biodiesel use in specific cases beyond the mandatory blending, such as for captive fleets and in agricultural, industrial and experimental applications. Some companies with authorisation from the National Agency of Petroleum, Natural Gas and Biofuels (ANP) are already using pure biodiesel (B100) in their fleets and vessels (MME/EPE, 2024b).

and renewable diesel production (USDA, 2024). Moreover, strategic initiatives from the government were implemented to diversify feedstocks and increase social inclusion through programmes such as the Social Biofuel Stamp (Box 1).

Box 1
The Social Biofuel
Stamp programme

The Social Biofuel Stamp programme, launched in 2004 under the name Social Fuel Stamp, aims to boost rural economies, promote sustainable agriculture, ensure food security and diversify agriculture in Brazil by linking biodiesel production to the success of family farming (MME/EPE, 2024b). The Social Biofuel Stamp is issued by the Ministry of Agrarian Development (MDA) and should be renewed every five years.

The programme grants financial and market advantages to biodiesel manufacturers who significantly incorporate family farmers enrolled in the National Programme for Strengthening Family Farming (PRONAF) into their supply and production structures. These advantages include reduced federal tax rates, which have also been granted priority in biodiesel auctions in the past.

Federal regulation requires fuel distributors to purchase at least 80% of their biodiesel sales from biodiesel producers who hold a Social Biofuel Stamp. Other key requirements for participation in the programme include providing free technical support to these farmers and sourcing a minimum percentage of feedstock from their operations. While imports are permitted, domestic sourcing, particularly from family farmers, is strongly encouraged (MME/EPE, 2024b).

The programme also addresses compliance and due diligence issues. Biodiesel producers must maintain detailed records of their feedstock purchases and biodiesel sales to demonstrate compliance with programme requirements. The Ministry of Agriculture, Livestock and Food Supply (MAPA) conducts regular audits to ensure that producers comply with programme rules and regulations.

However, challenges still remain. Ensuring adequate technical support and that family farmers genuinely benefit from the programme requires ongoing monitoring and evaluation. Additionally, fluctuating feedstock prices can impact the economic viability of biodiesel production, calling for adjustments to programme policies and regulations (MME/EPE, 2024b).

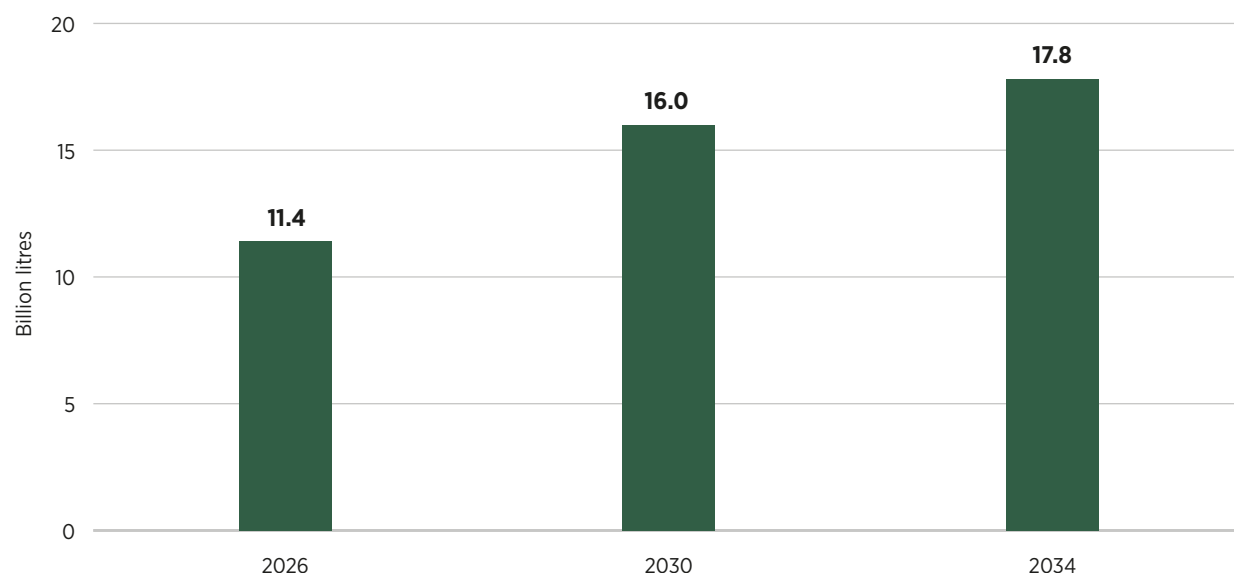
The regulator must have previously approved biodiesel supply contracts, which should have a minimum duration of two months. Imported raw materials are not prohibited, and import guidelines are left to the regulator. The potential use of biodiesel in the maritime sector is also being explored to meet emission reduction targets. Biodiesel pricing in Brazil is closely linked to soybean oil,⁸ which accounts for about 80% of production costs.

⁸ Brazil is a leading global producer of soybeans, accounting for nearly 40% of the global output and 55% of exports. The South and Midwest regions are major production hubs, contributing 42% and 40% of biodiesel output, respectively (USDA, 2024).

3.2.1 Perspectives

The Energy Research Office projects that biodiesel consumption will hit 17.8 billion litres by 2034, factoring in the mandatory Fuel of the Future Law (see Section 6.2) blending rates, which will achieve 20% [B20] by 2030 (EPE, 2024).

Figure 8 Biodiesel consumption forecast



Source: (EPE, 2024).

3.3 INDUSTRIAL CAPACITY: BIOREFINERIES

By diversifying their product portfolios, biorefineries can add significant value to biomass and related production processes. Product diversification leverages synergies across industrial operations, optimising the use of energy, materials and facilities. This, in turn, reduces production costs, minimises environmental impacts and lessens vulnerability to market price fluctuations (BNDES and MME, 2022).

More importantly, biorefineries are not merely a technical component of biofuel production, but they are seen as a central element in the transition to a low-carbon economy, integrating sustainability, innovation and economic development and representing a new investment frontier in the energy transition (MME/EPE, 2024b). Competitive biomass supply costs could enable the transition of sectors such as petrochemicals to produce green chemicals and second-generation biofuels (E2G) within the same facility.

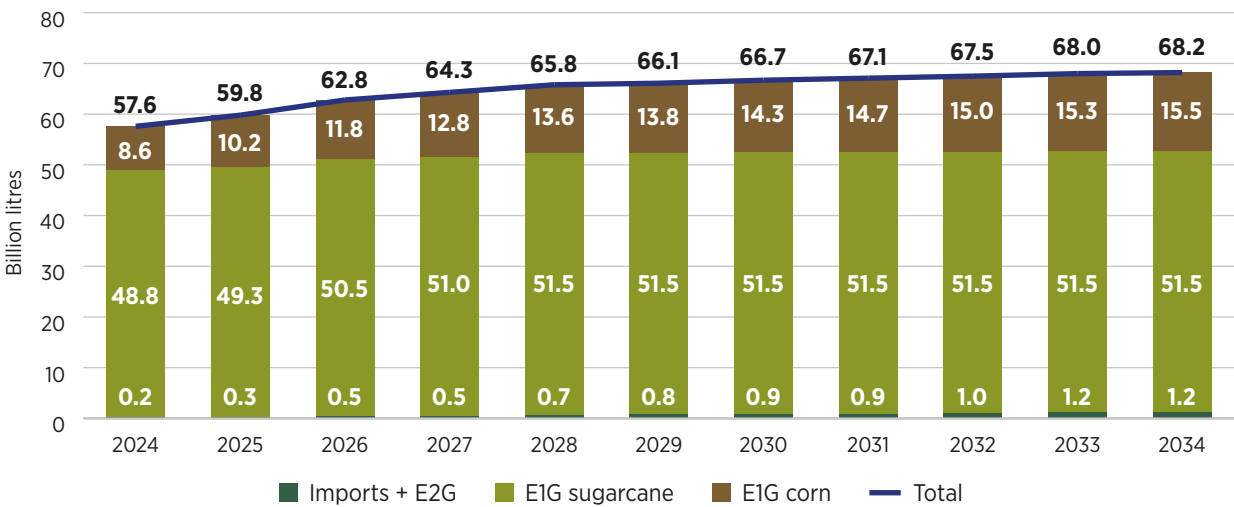
In Brazil, sugarcane biorefineries are a good example of this model, producing ethanol, sugar, electricity and co-products such as animal feed protein, biogas/biomethane, biofertilisers, bioplastics and biochemicals. E2G could play a crucial role in strengthening and diversifying Brazil's bioeconomy by repurposing existing refining structures to convert a range of inputs into high-value products (MME/EPE, 2024b).

The successful evolution of biorefineries depends on the establishment of new regulations. These regulations are crucial for addressing issues such as raw materials, products and the circular economy, ultimately shaping a new business model: the bioeconomy. In Brazil, existing ethanol and biodiesel plants operate under

comprehensive regulations covering fuels, electricity and environmental issues. This accumulated experience across the agricultural, industrial, regulatory, distribution and final consumption phases of the Brazilian biofuel sector provides a solid foundation for advancing biorefinery development (MME/EPE, 2024b).

In the next ten years, in Brazil, planned investments in ethanol biorefinery capacity are estimated at roughly BRL 40 billion (Brazilian reais) (approximately USD 6.6 billion), mostly for corn ethanol, which accounts for USD 3 billion, and E2G, which represents USD 2.6 billion (MME/EPE, 2024b). These investments will allow ethanol production capacity to reach 68 billion litres by 2034 (Figure 9).

Figure 9 Ethanol production capacity forecast



Source: (MME/EPE, 2024b).

Notes: E1G = first-generation biofuels; E2G = second-generation biofuels.

4. INSTITUTIONAL GOVERNANCE

The CNPE establishes the directives for the use and production of biofuels. It is also responsible for the mandatory blending of ethanol and biodiesel in the gasoline and diesel pools.

The Ministry of Mines and Energy (MME) is the central authority in developing policy frameworks, ensuring market stability, fostering investment and maintaining regulatory co-ordination across Brazil's evolving biofuels industry. It is responsible for evaluating fuel supply conditions and overall market evolution, including contingency measures to minimise supply disruption risks during exceptional circumstances. It also proposes guidelines for the regulator, the ANP, to follow and co-ordinate the process of grants and authorisations throughout the biofuels sector.

The ANP implements the national biofuel policy, focusing on energy security and the functioning of the fuel market, which includes specifying the quality standards for biofuels.



5. POLICIES, PLANS, PROGRAMMES AND OTHER GOVERNMENT INITIATIVES

Brazil's five decades of experience formulating and implementing policies to promote bioenergy production and use highlight the critical role of government initiatives in supporting the integration of bioenergy into the energy mix. These initiatives include direct incentives to bioenergy through energy, climate and tax policies, among others, and indirect incentives through policies aimed at the automotive and agricultural sectors.

5.1 ENERGY POLICIES

Brazil's energy policies supporting biofuels have primarily emerged from concerns regarding energy security and the adverse effects of fuel imports on the nation's balance of payments (Goldemberg, 2006). The first major initiative, Proalcool, was introduced in 1975 in response to the 1973 oil crisis, to replace gasoline with ethanol. In the 1990s, the government transitioned to a market-driven framework for the fuel sector while still addressing biofuel production through mandatory blending regulations. By 2005, social goals were integrated into the government's biodiesel expansion plan. More recently, Brazil launched the RenovaBio programme, which creates private incentives for expanding biofuels via a decarbonisation credits market.

5.1.1 National Alcohol Programme (Proalcool)

Proalcool was established in 1975 to promote fuel ethanol production and mitigate the impact of the 1973 oil crisis on the current account deficit by reducing oil imports (Aguilar *et al.*, 2024). Initially, the programme focused on producing anhydrous ethanol for blending with gasoline. However, following the second oil shock in 1979, the government also implemented measures to incentivise the production of hydrated ethanol as a direct substitute for automotive gasoline used in light-duty vehicles (BNDES and CGEE, 2024; EPE, 2020).

Proalcool successfully replaced a significant portion of gasoline consumption, increasing the share of sugarcane-derived bioenergy in the total energy supply from 4.5% in 1975 to 14.4% in 1987. By 1991, about 60% of light-duty vehicles ran on hydrous ethanol.⁹ However, the decline in international oil prices that began in the mid-1980s, combined with reduced government support and the sector's shift towards sugar production for global markets, led to fuel ethanol shortage crises. These crises eroded consumer confidence, leading to a decline in demand for ethanol-fuelled vehicles. This trend reversed only in 2003 with the introduction of flex-fuel technology (EPE, 2020) (BNDES, 2008).

The government terminated Proalcool in the 1990s when it implemented a deregulation process for the ethanol market (BNDES, 2008).

⁹ Conversely, anhydrous ethanol's growth was directly tied to mandatory blending requirements (see section on ethanol).

5.1.2 Plan for the Production of Vegetable Oils for Energy Purposes

In 1980, following the success of Proalcool and the oil supply crises of the 1970s, Brazil initiated its biodiesel programme, known as the PRO-OLEO (Plan for the Production of Vegetable Oils for Energy Purposes) initiative. This programme required a 30% blend of vegetable oils or their derivatives with fossil diesel, with the ultimate goal of complete substitution. The proposed method for biofuel production was the transesterification of vegetable oils. Similar to Proalcool, the decline in international oil prices in the mid-1980s ultimately led to the halt of PRO-OLEO in 1986 (Ekbom, 2023).

5.1.3 The National Programme for the Production and Use of Biodiesel

The PNPB was established in 2005 with three main institutional objectives: implement a sustainable programme for biodiesel production and use while promoting social inclusion; ensure competitive pricing, quality and supply of the product; and produce biodiesel from a variety of oilseeds across different regions. Another objective was to reduce dependence on mineral diesel (BNDES, 2008).

The programme initially allowed the voluntary blending of 2% biodiesel (B2) into commercial diesel. This blending requirement became mandatory in 2008 and has gradually increased to the current 14% (B14) blend, as detailed in the biodiesel section.

The PNPB supports research, development and innovation throughout the production chain, from the agricultural phase to industrial production processes, including storage. The regulations allow biodiesel production from various oilseeds, enabling the participation of both agribusiness and family farming. The ANP regulates fuel quality standards and oversees the production and commercialisation of biodiesel, while fuel distributors and refineries are responsible for blending biodiesel with fossil diesel.

5.1.4 Mandatory blending

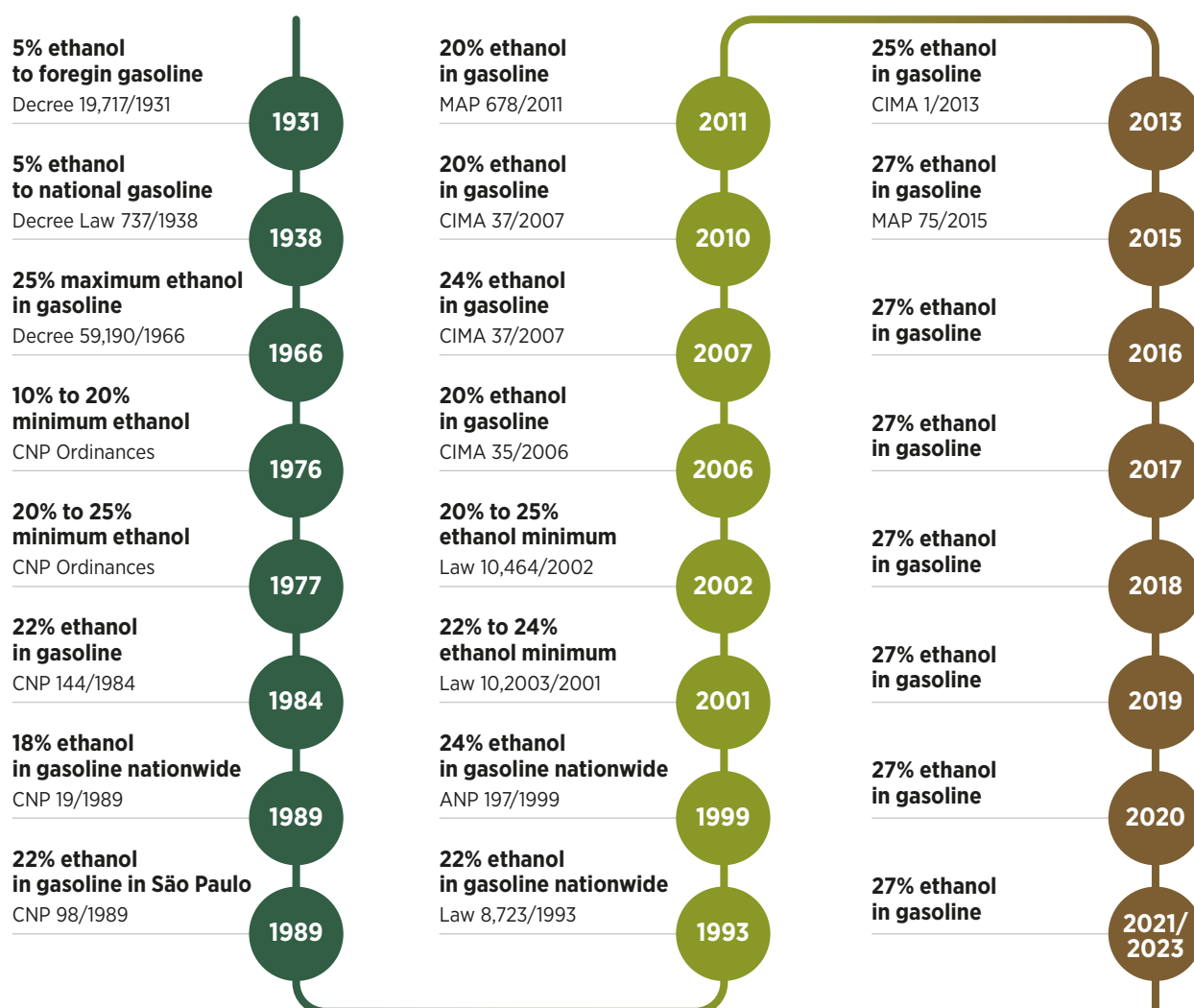
Mandatory blending was used as an instrument to assure energy security by reducing oil imports (Aguar *et al.*, 2024).

Ethanol

Brazil has a long history of mandatory ethanol blending into gasoline, dating back to the 1930s (Figure 10). Blend levels have adapted over time in response to changes in oil prices, wars, economic crises, sugar production surpluses and the magnitude of the effects of gasoline imports on the balance of payments. The government maintained the ethanol blend mandate even after deregulating the fuel market in the 1990s (BNDES, 2008).

Adequate fuel specifications and technological advancements in internal combustion engines (ICEs), which now incorporate digital electronic monitoring, have significantly improved efficiency and addressed challenges such as cold starts and material compatibility (BNDES and CGEE, 2024).

The Fuel of the Future Law, enacted in 2024, allows ethanol blends in gasoline to range from 22% to 35% (an increase from the previous range of 18% to 27.5%). Since 2015, Brazil has specifically mandated a 27% blend of anhydrous ethanol in all regular and additive gasoline, supported by extensive testing on emissions, economy and ICE performance. Additionally, in March 2025, the Brazilian government announced the technical feasibility of a 30% ethanol blend in gasoline after the conclusion of performance and compatibility tests.

Figure 10 Historical evolution of the ethanol blending mandate in Brazil

Source: Ekbohm (2023).

Notes: CNP = National Petroleum Council; CIMA = Interministerial Sugar and Ethanol Council; MAP = Ministry of Agriculture and Livestock.

Biodiesel

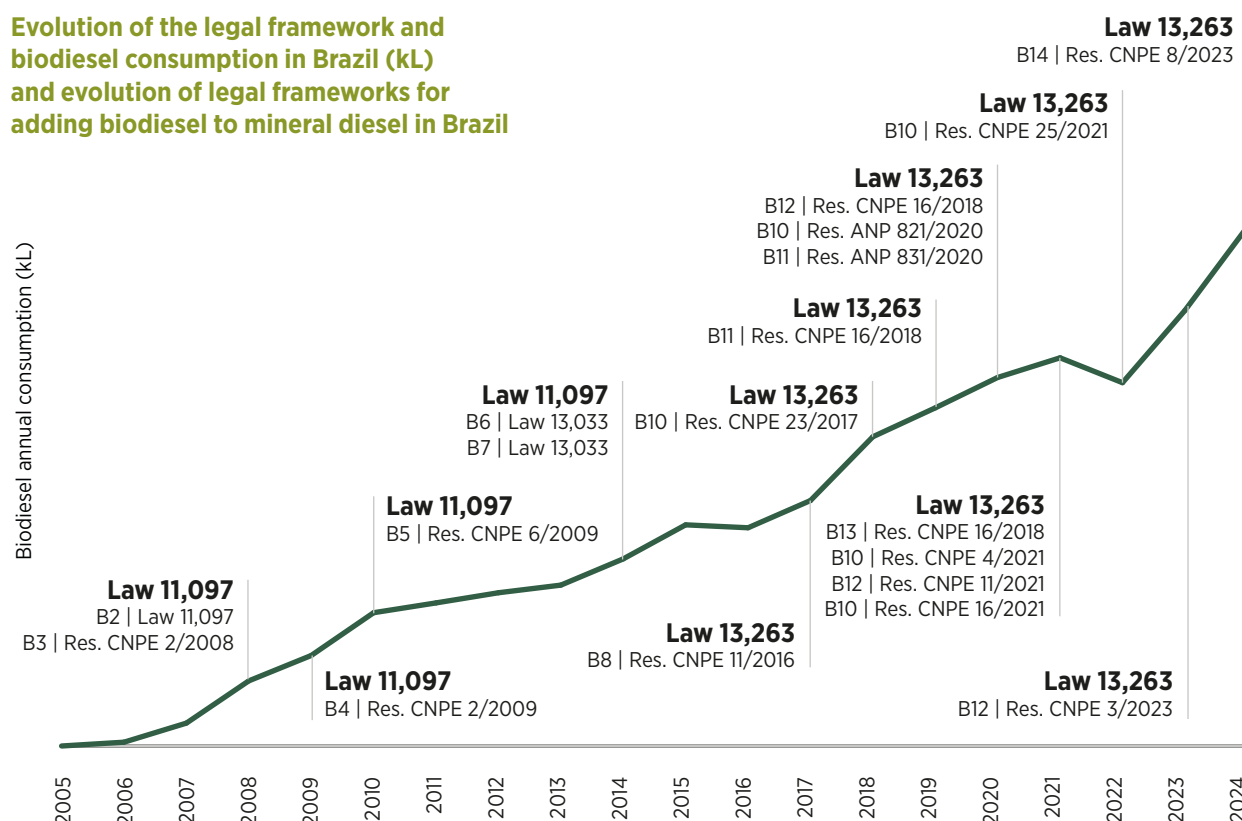
The mandatory addition of a minimum percentage of biodiesel to diesel oil was established in 2008 at 2% (B2) (Figure 11). Since then, the biodiesel blending mandate has been revised several times due to allegations regarding biodiesel quality, distributors' lack of compliance with decarbonisation goals and complaints about high costs (USDA, 2024).

As the Brazilian market matured, the CNPE gradually increased the percentage until reaching B5 in January 2010, three years before the date established by law. In the following years, the mandate levels were steadily increased, conditioned on extensive testing of engine performance.

Since March 2024, the current mixture of biodiesel in diesel commercialised in the whole country has been 14%. The Fuel of the Future Law establishes a range of mandatory biodiesel blends between 13% and 25%, with annual targets starting at 15% in 2025 and increasing to 20% by 2030. The CNPE will raise the mandate level according to the technical feasibility assessments.

Figure 11 Historical biodiesel blending mandate in Brazil and biodiesel annual consumption

Evolution of the legal framework and biodiesel consumption in Brazil (kL) and evolution of legal frameworks for adding biodiesel to mineral diesel in Brazil



Source: (MME/EPE, 2024b).

Note: kL = kilolitre.

5.2 CLIMATE POLICIES

5.2.1 The Brazilian Nationally Determined Contribution

A key aspect of Brazil's Nationally Determined Contribution (NDC) commitment involves increasing the production and use of biofuels, particularly advanced biofuels such as E2G. Although Brazil's NDC encompasses the entire economy without sector-specific targets, the country aims to increase the share of biofuels in its energy mix to approximately 18% and renewable energies to 45% by 2030.

Biofuels play a crucial role in reducing GHG emissions in Brazil. In 2023, the significant use of biofuels in Brazil's energy mix avoided 85.6 million tonnes (Mt) of carbon dioxide equivalent (CO₂eq) of GHG emissions (EPE, 2024). Since the introduction of fuel engines in 2003, the demand for bioethanol has surged, resulting in the prevention of an estimated 600 Mt CO₂eq emissions in Brazil (UNICA, 2020).

The National Biofuels Policy (RenovaBio)

Brazil introduced the National Biofuels Policy, known as RenovaBio, in 2017, which is in line with its climate commitments. This policy aims to reduce GHG emissions in the transportation sector and promote the expansion of bioenergy in the national energy mix. RenovaBio seeks to achieve an annual ethanol production of 50 billion litres by 2030 (BNDES and MME, 2022).

Unlike Proalcool, RenovaBio does not involve financial incentives from the government. Instead, it emphasises private incentives through a decarbonisation credits (CBIOS) market similar to the US Renewable Identification Number (RIN) market (Aguiar *et al.*, 2024).

Biofuels¹⁰ are valued based on their ability to mitigate GHG emissions compared with fossil fuel alternatives. The CNPE sets annual GHG emissions targets for fuel distributors, who, aside from complying with ethanol blending, must purchase CBIOS¹¹ to meet their quotas based on their market share. CBIOS are issued by biofuel producers (or importers) who, once registered in RenovaBio, receive an efficiency score based on their GHG mitigation efforts compared with fossil fuels. Higher production volumes and lower carbon intensity lead to more CBIOS.

Certification through life-cycle assessment¹² ensures that biofuels are evaluated for their efficiency in reducing GHG emissions. The ANP oversees the certification process, ensuring that biofuels meet environmental compliance and help preserve native vegetation.¹³

Since 2020, CBIOS have been traded on the Brazilian Stock Exchange. Despite economic challenges, compliance rates have remained high, reflecting the strict enforcement of policies. Ethanol dominates the CPIO market, with biodiesel and biomethane making up smaller portions. Between 2019 and 2023, 105 million CBIOS were issued, avoiding 105 Mt CO₂eq (USDA, 2024). It is expected that 61 million to 83 million CBIOS will be traded by 2034 (Table 1).

Table 1 RenovaBio CPIO targets and projected emissions mitigation values

CBIOS (millions)	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Target	40.39	48.09	52.37	56.41	61.24	64.08	67.13	68.81	71.29	72.54
Upper band	-	55.30	60.23	64.87	70.43	73.70	77.20	79.14	81.98	83.42
Lower band	-	40.88	44.51	47.95	52.05	54.47	57.06	58.49	60.59	61.66

Source: (IRENA, 2024b).

Although RenovaBio provides incentives, its support for advanced biofuels such as E2G, SAFs and hydrogenated vegetable oils (HVO) is less specific than international programmes, such as the US Renewable Fuel Standard or the European Union's Renewable Energy Directive (BNDES and MME, 2022).

¹⁰ RenovaBio covers cellulosic ethanol, sugar cane and corn ethanol, biodiesel and hydrogenation-derived renewable diesel (HDRD), aviation biokerosene, and biomethane.

¹¹ Each CPIO represents one tonne of CO₂eq avoided by using biofuels instead of fossil fuels, incentivising lower GHG emissions.

¹² Based on a life-cycle assessment compared with fossil fuels, the carbon intensity of biofuels is calculated based on a "well-to-wheels" approach developed by Embrapa, the Brazilian Agricultural Research Corporation (USDA, 2024).

¹³ RenovaBio promotes the use of land that has already been cultivated and prohibits the use of raw materials from areas of native vegetation that were deforested after 2018. Additionally, rural properties are monitored to ensure compliance with the Forest Code, the primary legal framework for protecting native vegetation in Brazil (BNDES and CGEE, 2024).

5.3 TAX POLICY

In Brazil, federal and state taxes are levied on transportation fuels, with state taxes representing the largest portion. The country employs federal tax differentiation policies to distinguish between biofuels and fossil fuels, such as those that contrast ethanol and biodiesel from gasoline and diesel. Indirect tax policies are applied to the automotive industry.

5.3.1 Direct instruments

The fuels and biofuels sector has historically benefited from direct subsidies or tax incentives to encourage production and reduce consumer prices. Tax policy is influenced by various evolving objectives, the most common being inflation control; balancing ethanol supply and demand, which is sensitive to sugar and gasoline prices; and managing public sector budgets (USDA, 2024).

The Constitutional Amendment No. 123, enacted on 14 July 2022, aims to establish a competitive advantage for biofuels over fossil fuels, particularly in terms of taxation, as a measure to foster the biofuel industry and to address the social impacts of the extraordinary rise in oil and fuel prices. The amendment adds a clause to Article 225 of the Constitution that mandates the maintenance of a favourable tax regime for biofuels used in final consumption. This ensures that biofuels will have a lower tax burden compared with fossil fuels, promoting their competitiveness.

Until specific legislation is enacted, the competitive differential for biofuels will be maintained by ensuring that the percentage difference between the tax rates for fossil fuels and their biofuel substitutes, as of 15 May 2022, remains unchanged. Additionally, for 20 years following the amendment's promulgation, federal law cannot establish a competitive differential for biofuels below the level stipulated in May 2022. Any changes in tax rates for fossil fuels, whether through new laws or judicial rulings, will result in automatic adjustments to the tax rates for biofuels to maintain the same competitive differential.

This amendment strengthens Brazil's commitment to supporting biofuels as a critical component of its energy mix, ensuring biofuels remain competitive in the market relative to fossil fuels.

5.3.2 Indirect instruments

Federal tax incentives apply to flex-fuel light-duty vehicles, representing a reduction in the share of taxes on the manufacturer's suggested retail price of up to 2.8 percentage points, depending on the vehicle size (ANFAVEA, 2024).

Additional tax benefits are granted through the Special Incentive Regime for Infrastructure Development (REIDI). Oriented to qualified infrastructure projects, REIDI suspends certain federal tax contributions on acquisitions, leases and imports of goods and services directly connected to approved infrastructure initiatives. These tax advantages apply during a designated time frame following the qualification of the entity managing the project.

The MME has established the framework and protocols for approving energy infrastructure projects under this incentive programme. These guidelines cover various energy sectors, including electricity generation and transmission, natural gas production and processing, and pipeline development. The MME's regulations define how energy projects can qualify for and benefit from these tax incentives, supporting broader infrastructure development goals within the national energy landscape.

5.4 PUBLIC FUNDING AND LOW-INTEREST CREDIT LINES

The Climate Fund, established in 2009 as part of Brazil's National Policy on Climate Change, is one of the main government's financial supports for projects to reduce GHG emissions and foster climate adaptation. Focusing on renewable energy, efficient equipment and climate-related innovation, it offers direct financing with favourable rates and up to 25-year terms and is managed by the Brazilian Development Bank (BNDES) (reimbursable resources) and the Ministry of the Environment (non-reimbursable funds). Funded by government revenues, donations and financing returns, it allocated roughly BRL 300 million (approximately USD 55 million) annually between 2011 and 2023.

In 2023, USD 2 billion was added from sustainable bonds issued by the Brazilian Treasury, directed according to the Year's Resource Application Plan. Despite the increased budget for 2024, concessional funding decreased. Original funds pay oil revenue participation at 1% interest, while bonds offer 8% for wind and solar projects and 6.15% for renewable hydrogen, energy storage, efficiency and sustainable fuels (IRENA, 2024c).

The government offers direct or indirect incentives and subsidised credit lines for biofuel production, especially through the BNDES, which focuses on expanding production capacity, fostering innovation, enhancing positive externalities and promoting sustainability (IRENA, 2024b).

BNDES emphasises environmental and climate change mitigation indicators in its loans and investments. Its funding lines offer extended terms and favourable rates linked to environmental goals, such as reducing GHG emissions, financing biofuel transportation, distribution infrastructure and biorefineries. Bioenergy projects benefit from diverse business and financing models, including consortia involving complementary agents such as biomass producers, system developers, financial agents and biofuel purchasers (IRENA, 2024b).

The Finem credit line funds projects for sustainability, biogas, biomethane production, ecosystem conservation, energy efficiency and efficient vehicle acquisition. Financing terms depend on the project type.

The RenovaBio line, launched in 2021, offers interest rate discounts to biofuel producers for improved environmental performance. It sets targets for reducing carbon emissions according to each client's current energy and environmental efficiency (USDA, 2024).

BNDES also supports research, development and innovation projects related to biofuels. Over the last 20 years, the bank has disbursed approximately USD 11 billion (BRL 70 billion) to enhance sugar cane production and the biofuel industrial sector, including innovations such as E2G and genetically modified sugar cane varieties (IRENA, 2024b).

The bank also promotes technological innovation through partnerships with Embrapii,¹⁴ providing up to BRL 75 million (approximately USD 12 million) in non-reimbursable funds. This funding supports the development of new biofuel technologies, including E2G. Additionally, BNDES is adapting its Fundo Clima programme to offer competitive credit rates for advanced biofuels.

Through a joint initiative with Finep (the federal innovation agency), BNDES provides various instruments to support bioenergy projects, from basic research to investment in E2G production and essential inputs such as enzymes and equipment.

¹⁴ Embrapii is the Brazilian Company for Research and Industrial Innovation, a federal entity created in 2013 to enhance technological research institutions and promote innovation within Brazilian industry.

Finep also provides competitive interest rate financing for companies and non-profit institutions, with lower rates for highly innovative projects. It offers non-reimbursable funding for technological development through economic grants and co-operative projects. In partnership with the MME, Finep allocates non-reimbursable resources to the automotive chain, including biofuel technologies.

Besides BNDES and Finep, other governmental institutions such as the Research Support Foundation of the State of São Paulo (FAPESP) and the National Council for Scientific and Technological Development (CNPq) also have research and development funds to support the production and development of biofuels in Brazil (BNDES, 2008).

The government also offers indirect funds such as Plano Safra, the financial programme of MAPA, which, through a specific programme called RenovAgro (the programme to finance sustainable agricultural systems), supports sugar cane, corn, soybeans and other farming inputs for biofuel production. Other favourable credit conditions are provided, particularly in cases associated with adopting sustainable agricultural practices and converting pasture and degraded land to cropland (USDA, 2024).

5.5 OTHER INCENTIVES

The government has provided additional incentives for biofuels, including public auctions, to further promote their use in Brazil.

Public auctions were utilised until 2021 to economically support the biodiesel production chain. However, the ANP concluded that this auction model was inefficient and imposed excessive public intervention in private transactions.

In 2022, the government implemented a new market model for biodiesel trading, allowing biodiesel producers and distributors to negotiate directly with each other. This model enables over-the-counter (OTC) contracts to secure 80% of the biodiesel supply for a two-month period, mirroring the auction calendar. The remaining can be traded on the spot market. Fuel distributors with at least a 5% market share in any fuel category in 2020 must commit 80% of their traded volume to OTC contracts. This decision effectively rules out the reintroduction of auctions for biodiesel pricing and trading among private parties (USDA, 2024).

Box 2 Estimating employment in Brazil's biofuel sector

Brazil is among the top biofuels producers worldwide and employs the largest workforce in the sector.

In the biodiesel sector, Brazil is the world's third-largest producer after Indonesia and the United States. Continuing its growth trajectory, Brazil's biodiesel production was estimated at 9.7 billion litres in 2024, up from 7.6 billion litres in 2023 (ABIOVE, 2025). Rio Grande do Sul accounts for a quarter of output, and altogether, the south and mid-West parts of the country for about 40% each (USDA, 2024).

One way to calculate jobs is by estimating the share of applicable employment in the soybean industry (the largest feedstock for biodiesel). The Center for Advanced Studies in Applied Economics (CEPEA, 2025), in conjunction with the Brazilian Association of Vegetable Oil Industries (ABIOVE) publishes employment figures for Brazil's soybean sector. The soybean supply chain employed 2.28 million people (including agricultural and other inputs, industrial equipment, services) in 2023. The percentage of soybean output used for biodiesel production (3–4%) yields a figure of biodiesel-related jobs in the order of 150 000. Strong output growth may have raised this to 190 000 jobs in 2024. Soybean represents three quarters of biodiesel feedstock. Thus, a rough extrapolation suggests that including other feedstock (various vegetable oils) brings 2024 employment to some 258 000 jobs.

This may be a conservative estimate. A different methodology, based on employment factors for different feedstock, suggests that biodiesel-related employment in Brazil may have amounted to 383 800 jobs in 2024, up from 320 900 jobs in 2023. This calculation is based on employment factors for individual feedstocks (Da Cunha and Da Silva, 2014); the 2024 shares of the feedstocks were derived from (ABIOVE, 2025). The employment factors were modified with an assumed annual rate of improvement in labour productivity, to approximate mechanisation impacts.

Following the United States, Brazil is the second-largest **bioethanol** producer in the world. One method to estimate jobs is to assess the applicable share of employment in the sugarcane sector (the principal feedstock for bioethanol). According to the Sugarcane and Bioenergy Observatory (UNICAdata, 2025), total employment in Brazil's sugarcane-energy sector in 2024 was 751 377 jobs. About half of these can be regarded as biofuels jobs, reflecting the portion of Brazil's sugarcane crop that is used to produce ethanol (as opposed to sugar). UNICA data indicates that close to two thirds of sugarcane jobs were in agriculture, almost a quarter in industry, and the rest in other sectors. Many relate to mechanisation efforts, implying that manual jobs will likely continue to decline in future.

Government data indicate there were 378 100 bioethanol jobs as of 2024 (including sugarcane harvesting and feedstock processing), up from 367 500 jobs in 2023 (MTE, 2025). Despite growing mechanisation, employment has steadily expanded, given rising output. Geographically sugarcane-based jobs are mostly in the country's centre-South, especially the state of São Paulo, while corn-based operations are concentrated in Mato Grosso in the centre-West region of Brazil (USDA, 2024). Corn is increasingly used as another feedstock, thus total employment is higher than the above numbers indicate.

Altogether, Brazil may have had some 762 000 jobs in biofuel-related activities in 2024.

6. NEW POLICIES ON BIOFUELS UNDER THE BRAZILIAN ENERGY TRANSITION

6.1 THE NATIONAL ENERGY TRANSITION POLICY

The National Energy Transition Policy (PNTE), launched in 2024, aims to restructure the Brazilian energy mix to make it more sustainable and aligned with the country's GHG emissions reduction goals. It is responsible for the guidelines for energy security, universal energy access and the reduction of energy inequality.¹⁵

The National Energy Transition Plan (Plante) serves as a long-term action plan designed to achieve the objectives of the PNTE by directing government and stakeholder efforts towards a sustainable energy matrix with low carbon emissions, contributing to the national goal of net GHG emissions neutrality by 2050. Plante is characterised by its long-term horizon, sectoral and transversal approach, and periodic review (every four years) to adjust to changes in the energy landscape and ensure the relevance of its actions. Besides the goal of expanding the share of renewable energy sources, including biomass, in the Brazilian energy matrix, it also encourages the use of low-carbon fuels (such as biofuels and low-emission hydrogen), energy efficiency, and technological innovation in clean energy technologies.

In addition, the government established a platform for dialogue with civil society and the productive sector through the National Energy Transition Forum (Fonte). Its main goal is to develop recommendations and enhance transparency and public participation in energy policy formulation, ensuring that the transition respects regional diversity and promotes social inclusion.

6.2 FUEL OF THE FUTURE LAW

The Fuel of the Future Law, established in 2024, aims to promote sustainable fuels and fuel technologies for transportation by integrating various biofuels while fostering innovation and technological advancement. This law seeks to enhance environmental and energy efficiency in the fuel life cycle and includes several initiatives (e.g. for biomethane). It integrates RenovaBio with the Mover programme and the Brazilian Vehicle Labelling Programme. It also establishes the National Sustainable Aviation Fuel Programme (ProBioQAV) and the National Green Diesel Programme (PNDV). The law proposes increasing the mandatory ethanol blend in gasoline, regulating synthetic fuels, and creating a carbon capture and storage framework.

ProBioQAV encourages the research, production and marketing of SAF. Starting in 2027, air operators must reduce GHG emissions in domestic operations using SAF, gradually increasing from 1% to 10% by 2037, with a 1% annual increase from 2029.

¹⁵ *Política Nacional de Transição Energética. Available (only in Portuguese) at: www.gov.br/mme/pt-br/assuntos/secretrias/sntep/dte/cgate/pnte.*

The PNDV promotes the research, production, marketing and energy use of renewable diesel. The CNPE annually sets the mandatory minimum renewable diesel content in the diesel blend, capped at 3% through 2037.¹⁶

Implementing BECCS technology aims to enable Brazilian bioethanol to have a negative carbon footprint, significantly reducing GHG emissions. To support this, the Fuel of the Future Law establishes a legal framework for CO₂ capture and geological storage, allowing its injection into underground reservoirs to meet GHG reduction targets. The ANP is responsible for regulating and authorising these activities, with 30-year renewable licences restricted to companies or consortia established in Brazil, requiring operators to ensure safety requirements.

6.2.1 Advanced biofuels

Advanced biofuels, such as biomethane derived from various biogas sources, SAF, and second-generation ethanol, are increasingly attracting interest. They represent a significant technological advancement in reducing the transportation sector's dependence on fossil fuels and are expected to attract substantial investment over the next 20 years (BNDES and MME, 2022).

Second-generation ethanol

Second-generation ethanol (E2G) utilises lignocellulosic biomass, including plant structural fibres such as stalks, leaves and other agricultural residues, thereby maximising the energy and chemical potential of the crops and their waste.¹⁷

E2G is a significant advancement in Brazilian biofuel technology. It is primarily produced from sugar cane bagasse, which reduces concerns about the competition between biofuel and food production and mitigates direct and indirect emissions from land-use changes. In particular, E2G's carbon footprint is approximately 90% lower than gasoline and about half that of first-generation ethanol, resulting in a 15% increase in decarbonisation credits (BNDES and MME, 2022).

Brazil's extensive experience in first-generation ethanol production makes its E2G production competitive in export markets, especially when leveraging infrastructure and equipment from both first-generation ethanol and sugar production. Facilities in Brazil are already producing and marketing this fuel, primarily for international markets (especially in countries that favour advanced biofuels),¹⁸ indicating that key technological challenges have been overcome despite existing challenges in reducing production costs (IRENA, 2024b).

In 2024, Brazil was projected to produce 51 million litres of cellulosic ethanol (USDA, 2024). By 2031, the country's potential production could represent up to 12% of the total ethanol supply (BNDES and MME, 2022). Brazil presents a notable competitive edge in international markets thanks to lower biomass availability costs, significantly reducing its E2G production costs (Pelkmans, 2024).

¹⁶ The ANP defines renewable diesel as a biofuel composed of paraffinic hydrocarbons suitable for diesel engines, produced through various methods, including hydro-treatment and biomass synthesis. Among these, only HDRD is commercialised at scale in some countries as of 2024, and despite pressure from producers, there is no blend mandate in Brazil (USDA, 2024).

¹⁷ E2G utilises agro-industrial residues as raw material. Its production integrates new technologies into the industrial process to fractionate lignocellulosic materials into advanced sugars and lignin. The sugars are primarily used for E2G production and, to a lesser extent, for the production of high-value biomolecules. Lignin, a by-product, can be immediately utilised as a fuel for energy generation, but its valuation as a macromolecule or for derivative production can provide additional benefits to the biorefinery. The combination of products related to E2G production is determined on a case-by-case basis, depending on market demand, the conversion processes involved, technology maturity and commercialisation prices.

¹⁸ The international market for advanced biofuels offers differentiated remuneration and faces fewer entry barriers in various countries (BNDES and MME (2022)).

Sustainable aviation fuels

Sustainable aviation fuels (SAFs) are not yet commercially produced in Brazil, but several ethanol plants have obtained international certification. Industry estimates suggest Brazil could make 12 billion litres of SAFs annually from waste, meeting domestic and export demands (USDA, 2024).

This is especially noteworthy considering the global context: the aviation sector accounts for about 2-3% of worldwide anthropogenic emissions, yet global SAF production capacity is still in the early stages, making up less than 1% of total aviation fuel use, and expected to reach approximately 0.5% of global aviation fuel needs by the end of 2024 (IRENA, 2024d). IRENA's analysis shows that SAF will need to contribute a significant 40-60% of aviation emissions reductions by 2050 (IRENA, 2024d).

In 2021, the ANP authorised various production routes for SAFs in Brazil, marking a step forward in the industry's development. Globally, a significant challenge for SAF adoption remains its cost, which is typically two to three times higher than conventional fossil jet fuel (IRENA, 2024d).

Brazil is actively promoting its SAF industry through various initiatives that align with global policy trends emphasising supply incentives, such as ProBioQAV. These ambitious projects are projected to significantly impact emissions reduction targets. Between 2027 and 2034, they are expected to collectively meet, on average, 41% of the GHG emissions reduction targets set by the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)¹⁹ and ProBioQAV. Furthermore, these efforts anticipate accounting for 12% of the projected aviation fuel demand between 2030 and 2033.

Key legislative and collaborative frameworks underpin this development. The Fuel of the Future Law, for instance, established the National Biojet Fuel Programme to encourage research, production, commercialisation and use of biojet fuel produced from biomass. The Brazilian Network of Biojet Fuel and Renewable Hydrocarbons for Aviation (RBQAV) and regional platforms are actively advancing research in SAF production and market integration. The National Civil Aviation Agency (ANAC) further facilitates this through its SAF Connection forum. This platform unites public and private stakeholders to discuss and develop proposals for decarbonising Brazil's aviation sector through SAF use.

Such multi-stakeholder engagements and robust policy frameworks are crucial for overcoming the inherent barriers of the nascent SAF industry and driving its development – a challenge observed across regions worldwide (IRENA, 2024d)

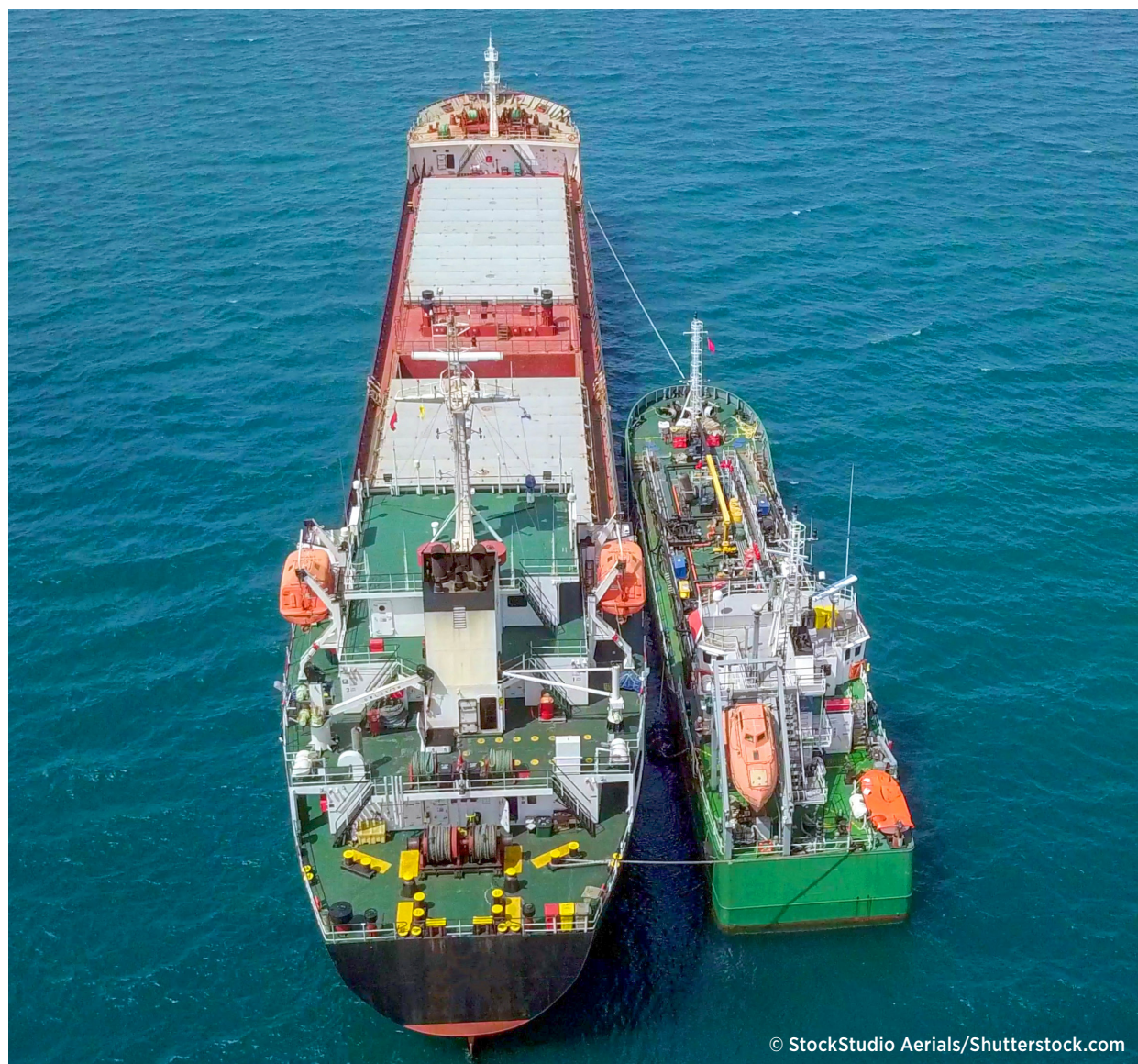
Hydrogenation-derived renewable diesel

HDRD,²⁰ which is produced using the same vegetable oils or animal fats as biodiesel, is not yet produced at a commercial scale in Brazil. Petrobras is leading efforts in HDRD production, with a new biorefinery expected to be operational by 2025 (USDA, 2024). Efforts are under way to create SAF via the HEFA (hydrotreated esters and fatty acids) process and HDRD, particularly using HVO.

According to the Fuel of the Future Law, a minimum blend of up to 3% green diesel in diesel is mandated. The CNPE will establish the minimum blend requirement annually.

¹⁹ Within the CORSIA framework, a net-zero target by 2050 and a carbon-neutral growth path (long-term global aspirational goal) were established (IRENA, 2024a). The International Air Transport Association further emphasises SAF's crucial role, estimating it will need to account for 65% of the aviation sector's required emissions reduction by 2050 globally (IRENA, 2024a).

²⁰ Renewable diesel (referred to "green diesel" in Brazilian legislation) is typically used as a full replacement to petroleum diesel because, unlike biodiesel, it has no blending limit in unmodified diesel engines designed to run on petroleum diesel.



Co-processed diesel and jet kerosene

Co-processed diesel (“R diesel” in Brazilian legislation) comprises fossil crude oil and biogenic renewable content. The reduction in emissions associated with the renewable portion is reported to be at least 60% compared with crude oil-based diesel. As with HDRD and all renewable types of diesels, co-processed diesel also requires no engine modification.

Petrobras is currently the only company co-processing diesel on a commercial scale in Brazil, with expansion plans to produce 10.6 billion litres by 2027. Petrobras is driving for its inclusion in biofuel mandates.

Bunker fuel

In 2024, the ANP approved the commercialisation of maritime fuel oil (bunker fuel) containing 24% biodiesel, marking Brazil's first authorisation for renewable-content bunker fuel. This aligns with the International Maritime Organization's strategy to achieve net-zero GHG emissions from shipping by 2050.

6.3 THE NEW INDUSTRY BRAZIL PLAN

Launched in 2024, the New Industry Brazil Plan aims to stimulate industrial growth by 2033 through subsidies, low-interest loans, tax incentives and federal investments. In the bioeconomy sector, funding and credit access will prioritise technological solutions for reducing GHG emissions through carbon capture, utilisation and storage and BECCS, biotechnology advancements for biomass production and processing for biofuels, and innovations in renewable diesel, synthetic fuels, and SAFs, low-carbon hydrogen, and bio-products and bio-inputs from renewable sources (USDA, 2024).

The New Industry Brazil Plan intends to elevate the share of biofuels in the transportation energy matrix from the current 21% to 50% by 2033. One of the measures already implemented includes expediting the schedule for increasing the biodiesel blending mandates. Public financing options will be available through calls supported by Finep and BNDES (USDA, 2024).

6.3.1 Green Mobility and Innovation Programme

In 2024, the federal government launched the Green Mobility and Innovation Programme (Mover), replacing previous initiatives.

Mover's guidelines promote the use of biofuels such as ethanol and biodiesel, other low-carbon fuels, and alternative propulsion methods (e.g. electric vehicles). Its core objectives include regulating the vehicle market and tax regime with clear goals for energy efficiency, material recyclability, and accessibility and structuring green taxation. The programme also encourages local research and development investment through fiscal benefits and supports the industrial and technological development of auto parts and input suppliers. Furthermore, it has a broad scope, encompassing agricultural and road machinery (BNDES and CGEE, 2024).

The programme aims to advance sustainability and innovation in the automotive sector, providing financial credits of BRL 19 billion (approximately USD 3 billion) between 2024 and 2028. The programme's credits are intended for companies that invest in research and development to produce electric and hybrid vehicles and will offset federal taxes, encouraging investment through tax incentives.

Mover includes "well-to-wheel" carbon emissions measurements covering the entire energy source cycle and establishes the National Fund for Industrial and Technological Development (FNDIT). However, starting in 2027, it sets more stringent sustainability requirements for light-duty vehicles, buses, and trucks through a comprehensive "cradle-to-grave" life-cycle assessment. This assessment includes the carbon footprint of all vehicle components, production stages, usage, disposal and the life cycle of energy sources, including fuels.

7. TECHNOLOGICAL INNOVATIONS

In addition to policies promoting bioenergy, technological innovations have played a pivotal role in advancing the bioenergy industry in Brazil, significantly impacting its economic and environmental landscape.

One of the most transformative innovations was the introduction of flex-fuel technology in 2003. This innovation marked Brazil's second bioethanol expansion phase, with flex-fuel cars offering drivers the flexibility to use gasoline (containing anhydrous ethanol at the required blend) or hydrous ethanol (E100) at any proportion. This adaptability allowed vehicle owners to choose their fuel based on price, autonomy, performance or availability, leading to outstanding consumer acceptance (BNDES, 2008).

The outstanding acceptance of flex-fuel cars revitalised the domestic market's demand for hydrous bioethanol, creating new opportunities for the expansion of Brazil's sugar cane industry.

Despite the success of bioethanol production expansion in Brazil, with increased production efficiency and a progressive reduction in environmental impacts, there is still considerable potential for adopting incremental improvements and process refinements in converting biomass into energy vectors. These improvements present low risk and yield good short-term results, and they should be encouraged as they are more accessible and less risky than disruptive innovations (IRENA, 2024b).²¹

New possibilities for sugarcane-based bioenergy production, such as utilising lignocellulosic by-products to produce bioethanol and electricity, are highly dependent on processes still under development and are supported by the government, the private sector and academic institutions, primarily located in the state of São Paulo, the country's largest sugarcane-producing state.²²

²¹ Examples of incremental innovations include measures related to biomass production, such as biological pest control, nutrient recycling through irrigation with sugar cane vinasse, direct planting, and optimising harvesting and transport. Regarding bioenergy conversion, improvements can be made through more efficient extraction systems, enhanced boiler and steam systems control, and increased co-generation. Despite being well-known and readily available, these techniques have yet to be widely adopted in more conservative production units or those with limited financial access, offering a viable path to enhance bioenergy production chains (IRENA, 2024b).

²² A key player in Brazil's sugar cane industry is the Sugar Cane Technology Centre (CTC), an innovation centre established in 1969. The CTC is renowned for its agricultural research, having launched over 60 sugar cane varieties used in Brazil. While primarily focusing on agricultural research, the CTC also innovates across the entire production chain, including rural administration, cultivation and energy systems. The CTC's contributions have been pivotal in advancing innovations and improving bioethanol production efficiency in Brazil's sugar-alcohol agro-industry (BNDES, 2008).

8. LESSONS FROM THE BRAZILIAN EXPERIENCE WITH BIOFUELS

8.1 ADEQUATE REGULATORY FRAMEWORK AND INSTITUTIONAL GOVERNANCE

A sustainable regulatory framework for bioenergy is essential for a market to succeed, even when favourable natural conditions and economic potential exist. This framework should clearly define responsibilities and align goals with long-term strategies that can adapt to the broader environment. In Brazil, the national alcohol programme (Proálcool), launched in the 1970s, was a government-led market development effort that used direct subsidies, guaranteed purchases, and research and development initiatives to support the early stages of the ethanol industry. Conversely, the RenovaBio programme (National Biofuels Policy), introduced in the late 2010s, is better suited for a more market-oriented biofuel industry, implementing a decarbonisation credits system (CBIOs) that offers predictable carbon pricing and targets, thus directly encouraging long-term investments by private sector players.

Furthermore, effective governance is crucial to maximising opportunities related to the bioenergy expansion while minimising its potential negative impacts. Through good governance, sustainable bioenergy addresses the risks associated with land and resource use, impacts on food security, ecosystems, carbon stocks, and challenges in managing equity, justice, economic competitiveness and affordability. The Brazilian Forest Code, mandating the protection of Permanent Preservation Areas (APPs) and Legal Reserves (RLs) on rural properties, including those cultivating biomass for bioenergy, demonstrates a broader governance commitment to environmental sustainability. Moreover, effective governance ensures that bioenergy systems align with the Sustainable Development Goals, safeguarding food and energy security, climate justice, biodiversity, land and water rights, and local development priorities (BNDES and CGEE, 2024).



8.2 BALANCED AND PREDICTABLE PUBLIC POLICIES

The significance of balanced and predictable public policies in bioenergy cannot be overstated. Biofuel programmes rely heavily on these policies, as there are no known cases of successful market introduction without government support (IRENA, 2024b). Such support often involves mandates for biofuel use, creating favourable long-term funding conditions, a carbon price or a more balanced tax framework that incorporates the positive externalities associated with biofuel production and use, and raising awareness of the relative contributions made by biofuels.

Fuel specifications and blending mandates should be carefully defined and implemented. Given the diverse range of bioenergy technologies and biofuels, the Brazilian experience suggests that a gradual implementation approach is more suitable. Starting in limited markets with low blending levels, such as ethanol/gasoline and biodiesel/diesel blends up to 10% biofuel (E10 and B10), can help gain more knowledge without creating significant issues. These blending levels can be adopted quickly; however, higher levels may require market assessments and further evaluation of engine performance, which could lead to engine modifications. These mandates could initially target captive fleets or be regionalised.

When access to long-term funding is limited, government support can help address challenges. In Brazil, BNDES and FINEP offer long-term financing programmes tailored to the investment and research and development needs of the private sector in the (bio)energy sector.

A carbon price or a more balanced tax framework that acknowledges the positive externalities of bioenergy is also crucial for the competitiveness of biofuels (IRENA, 2024b). Reducing distortions in the price competitiveness of biofuels caused by subsidies to fossil fuels can be achieved through, for example, carbon-credit mechanisms such as Renovabio.

Finally, any biofuel market development programme should include a communication plan for users, retailers, and taxpayers to explain the implications and justifications for biofuel use, such as reducing emissions and supporting the Sustainable Development Goals (SDGs). Publishing progress indicators on energy, socio-economic, and environmental results achieved and projected can also be helpful. Overcoming policy barriers (such as lack of continuity in energy policy, legal uncertainty, institutional weaknesses, difficulties aligning state players, and bureaucratic obstacles) requires inclusive and effective dialogue

8.3 THE POWER OF COLLABORATIVE INTERNATIONAL ENGAGEMENT

Whether through bilateral, regional, or multilateral efforts, international co-operation is a powerful tool for realising the full potential of biofuels in global decarbonisation efforts. Biofuels offer a variety of benefits that can be adapted to different nations and communities. By co-operating, experts, legislators, regulators, and industry representatives can learn from one another's experiences and best practices, improving policy, production efficiency, and sustainability, thus contributing to a stable biofuels market domestically and internationally.

Over the past five decades, Brazil has developed substantial expertise in bioenergy and has been sharing this knowledge with other countries through technical co-operation and capacity-building initiatives. Programmes such as the Global Bioenergy Partnership, the Biofuture Platform²³ and Brazil's Sustainable Mobility:

²³ *The Biofuture Platform, launched in 2016 with 22 member countries, promotes technology co-operation, consensus on sustainability, biomass governance, financing mechanisms and policy convergence.*

Ethanol Talks exemplify how country-led efforts can foster experience exchange and co-operation in the expanding biofuels market. India, benefiting from its collaboration with Brazil, has boosted biofuel production and the use of flex-fuel vehicles to reduce transportation emissions. Furthermore, the Global Biofuels Alliance, launched by India during its G20 presidency in 2023, now includes 25 countries and 12 international organisations, offering a platform for technical co-operation on biofuel policies (BNDES and CGEE, 2024).

In 2024, under Brazil's G20 presidency, discussions within the Energy Transitions Working Group (ETWG) stepped up. Countries showed commitment to increasing renewable energy, enhancing energy efficiency and reducing dependency on fossil fuels. Brazil set three ETWG priorities: accelerating energy transition financing; addressing the social dimensions of the energy transition; and exploring innovative perspectives for sustainable fuels. Emerging energy sources such as hydrogen and sustainable fuels prompted Brazil and its partners to influence international certification and carbon accounting debates. Consistent standards and methodologies are essential to avoid market distortions and ensure fair competition among energy sources.

Dialogue among governments, industry, financial institutions and multilateral agencies can improve knowledge and provide benchmarks for promoting bioenergy. Brazil and its partners have actively participated in international debates on certification and carbon accounting in light of the emerging market for new energy sources, such as hydrogen and sustainable fuels. There have been intense discussions about the need for consistency, common standards and comparability in carbon accounting methodologies based on life-cycle analysis. These efforts are essential to prevent market distortions, avoid discriminatory measures and create a level playing field for all energy sources

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