VeK
POLICY ADVISORY & RESEARCH

INDIA'S BIOFUEL LANDSACPE

Policies, Market Trends, and Future Prospects

Policy Note

March 2025

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1.0 Introduction

1.1 What are Biofuels.

Renewable energy has become a cornerstone of world efforts to combat climate change and decrease dependence on fossil fuels. Biofuels, one of renewable energy sources are non-hazardous fuel derivatives of numerous organic sources such as biomass and organic waste. They are a transformative approach to reducing greenhouse emissions by 46%[1], contributing to the global green energy transition and Net Zero Targets. Among numerous renewable electricity assets, biofuels stand out as a promising solution. Any hydrocarbon fuel that is produced from an organic matter (living or once-living material) in a short period (days, weeks, or even months) is considered a biofuel. Biodiesel, bioethanol, methane, and hydrogen are biofuels produced by several countries using different types of biomass. Biofuel produced from biological materials can be used as a substitute for diesel due to low emission levels. Using biofuels offers multifaced benefits, as illustrated in Figure 1.0.

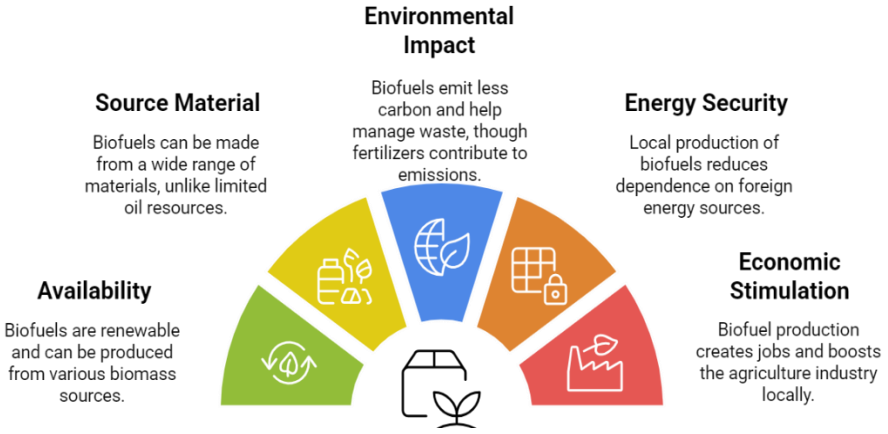


Figure 1.0 Advantages of Biofuels

1.2 Classification

Biofuels are of multiple types, mainly classified on the basis of the raw materials used in generating them, given in the table below.

Category	Type	Raw Materials	Uses	Key Characteristics
First-Generation (Conventional)	Bioethanol	Sugarcane, Corn, Wheat	Transportation fuel, blending with petrol	Food-based feedstock, well-established production process

[1] Energy Economic Times. (2023, September 13).

	Biodiesel	Vegetable oils (soybean, palm), animal fats	Transport, power generation	Food-based oils, simple production process (transesterification)
	Biogas	Organic waste, manure	Heating, electricity generation	Anaerobic digestion of organic material
Second-Generation (Advanced)	Cellulosic Ethanol	Agricultural residues, wood, grasses	Transportation fuel	Non-food biomass, more complex production
	Biodiesel	Used cooking oil, non-food crops	Transport, aviation (bio-jet fuel)	Waste-to-energy, more sustainable than first-generation
	Biogas	Municipal solid waste, lignocellulosic biomass	Power generation, cooking	Reduces landfill waste and GHG emissions
Third-Generation (Advanced)	Algal Biofuel	Microalgae, seaweed	Aviation, marine transport	High yield, can grow in non-arable land
Fourth-Generation (Advanced)	Synthetic Biofuel	Genetically modified organisms and CO_2	Transport, industrial use	Carbon-negative potential, still in R&D stage

Biofuels can be classified as First, Second, Third and Fourth Generation. First-generation biofuels are produced from food crops containing sugar, starch, or vegetable oil, utilising established technologies such as fermentation and transesterification. Second-generation biofuels are derived from non-food biomass like agricultural residues, perennial grasses, energy crops, and forestry waste; these biofuels aim to address the limitations of first-generation biofuels by using more sustainable feedstocks. Third-generation biofuels are produced from algae; these biofuels offer advantages over first- and second-generation biofuels, including rapid growth rates and the ability to be cultivated in environments not suitable for traditional agriculture. Lastly, the Fourth-Generation Biofuels, representing the most advanced stage of bioenergy development, are designed to be carbon-negative by integrating carbon capture and storage processes, thereby removing more CO_2 from the atmosphere than they emit during production and use.

Majorly, states have been focusing on conventional biofuels; however, it comes with its limitations[2] like—jeopardising food safety owing to a trade-off between fuel and food, Excessive land

[2] Doshi et al., 2016; Juneja et al., 2013

requirement, High agricultural inputs, High investment cost, Hostile retail prices, and lower efficiency and yield.

Due to these restrictions, researchers were looking for substitute feedstock and acknowledged a 3rd generation feedstock bio-fuel identified as algae, which insinuates numerous benefits as it does not rely on edible crops, does not release elevated gaseous pollutants, and does not require fertiliser or productive land

Ethanol is one of the primary First-Generation biofuels, naturally produced through the fermentation of sugars by yeasts or through petrochemical processes like ethylene hydration. It is widely used as an alternative fuel source and in various industries as a chemical solvent and the synthesis of organic compounds. Its primary role is in blending with petrol or diesel, offering significant advantages such as increased Research Octane Number (RON) of the blend, fuel-embedded oxygen and higher flame speed, helping in complete combustion and reducing vehicular emissions. However, ethanol has about two-thirds the energy content of gasoline, meaning more fuel is needed for the same power output. Despite this, ethanol's high-octane number allows engines to run at higher compression ratios without knocking, improving efficiency. With proper engine adjustments, ethanol can be a highly efficient fuel.[3]

2.0 Global Overview of Biofuel Market

Today, the global market faces three major challenges: depletion of fossil fuels, volatility in crude oil prices and stringent environmental regulations. Alternative biofuels specific to geographies can address these issues, continuously being recognised. The global biofuels market size was calculated at USD 132.13 billion in 2024, growing to USD 141.00 billion in 2025, and is predicted to surpass around USD 257.61 billion by 2034, poised to grow at a CAGR of 6.9% between 2025 and 2034. Only the North American biofuels market size accounted for USD 50.20 billion in 2024 and is anticipated to grow at the fastest CAGR of 7.10% during the forecast year.[4] According to the IEA, due to Net Zero targets, there will be 3.5-5x the growth potential of biofuels by 2050, creating a huge opportunity for exports for all countries.[5]

Forging dominance in exporting biofuels, the U.S. itself exported 1.9 billion gallons of ethanol worth $4.3 billion in 2024. However, investments in sustainable aviation fuel (SAF) and renewable diesel are also increasing, showing strong industry momentum. Countries worldwide are also considering 2nd generation biofuels, which are more sustainable.

Worldwide, transportation has the maximum consumption of oil, based on Figure 2.0. Hence, to address this industry, Ethanol Blending Programmes are being rolled out in various countries.

[3] IndianOil R&D (May. 2018)
[4] Precedence Research. (n.d.).
[5] Press Information Bureau. (2023).

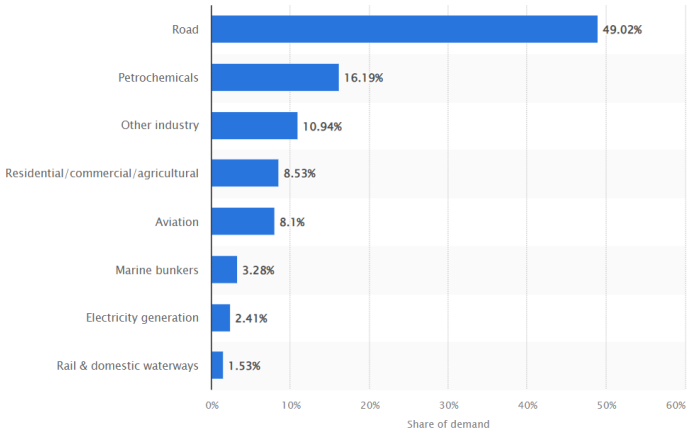


Figure 2.0 Distribution of oil demand in OECD in 2023 by sector

Credits: Statista

The table in Annexure 1 highlights the global ethanol blending policies and price comparisons, showcasing how countries promote biofuels. Brazil and the U.S. have well-established mandates, with Brazil achieving high ethanol blending levels and the U.S. focusing on renewable fuel standards. Regarding pricing, ethanol in India is relatively more expensive than in the U.S. and Brazil, with variations based on feedstock sources. The higher cost in India, particularly for ethanol derived from surplus rice, may impact competitiveness and large-scale adoption.

Brazil's biofuel program stands out as the most successful in the world due to its long-term commitment, stringent legal framework, and large-scale ethanol adoption. Unlike many countries, Brazil has seamlessly integrated ethanol into its transport sector, with nearly 80% of its vehicles running on flex-fuel technology. This widespread use is backed by a well-developed supply chain with a people-centred approach, with programs like PRONATEC and the Low-Carbon Agriculture Program empowering smallholder farmers, making biofuels a mainstream energy source rather than an alternative. Moreover, in 2024, Brazil also launched the 'New Industry Brazil', targeting a 50-percent increase in biofuels' share of the transport energy mix by 2033. Brazil is also developing a Future Fuel Program [6]to promote ethanol, biodiesel, and sustainable aviation fuel blending under the Global Biofuel Alliance, a splendid contribution towards the biofuel industry initiated under India's presidentship of G20 in 2023 along with the US and Brazil accounting for 85% of global ethanol production and 81% of consumption[7]The alliance has expanded to include 24 countries and 12 organisations, including the World Bank, the World Economic Forum, and the International Energy Agency.

Apart from Brazil, the US, as stated, is a leading nation in biofuels; however, with the recent policy shifts under the Trump administration, including the reduction of biofuel incentives under the Inflation Reduction Act's "45Z" tax credit and a renewed emphasis on fossil fuel production with the slogan "drill baby, drill", it presents a complex scenario for India's biofuel industry. Historically, the U.S. has been a significant player in the global biofuel market, with policies that have influenced international

[6] International Energy Agency. (n.d.).
[7] Press Information Bureau. (2023, September 9).

demand and supply dynamics. For instance, more than 40% of U.S. grain has been utilised for energy production due to mandates like the Renewable Fuel Standard (RFS)

The recent policy changes may lead to a decrease in U.S. biofuel production, potentially opening avenues for India to increase its biofuel exports to meet the existing demand in the U.S. market. This opportunity aligns with India's National Policy on Biofuels, which aims to augment ethanol production capacity from 7 billion litres in 2021 to 15 billion litres by 2025

The U.S. is the single largest oil-producing country (it produced 19,358 thousand barrels per day in 2023 with a global share of 20.1 per cent) and has substantial power to influence the global oil market. Increased U.S. oil production could lead to a surge in global energy supplies, potentially driving down prices.[8] Such a decline may render fossil fuels more economically attractive than biofuels, potentially discouraging producers and consumers in India from investing in or utilising biofuels. This scenario poses a risk to India's objective of achieving a 5% biodiesel blend by 2030, which necessitates approximately 4.5 billion litres of biodiesel annually.

Trump's appeal to U.S. oil producers to extract more oil may have significant implications for the global energy market, including Russia, the Middle East, OPEC+ countries, including India since it is the third largest importer of oil. This may result in these countries shifting towards producing cheaper fossil fuels than biofuels to compete with the increased US supply of crude oil, leading to a paradigm shift in the goals of Net Zero and SDGs, thus decreasing the demand for biofuels. [9]

Despite these uncertainties, the biofuel industry remains optimistic. Producers are innovating to make biofuels cheaper, more efficient, and widely available. Additionally, growing support for low-carbon energy policies and corporate sustainability goals are expected to keep biofuels relevant in the global energy transition.

3.0 India's Journey in Biofuel

The biofuels industry has a huge potential for a market like India, which is majorly agrarian. Crops like wheat, rice, and sugar generate field residue of 500 million tonnes of biomass[10] which are available in the form of stubble, stalks, etc. This potential becomes even more significant considering India's heavy dependence on oil imports, which places it in a volatile position amid geopolitical shifts and disturbances. Therefore, securing energy supply chains amidst fluctuating oil prices is crucial for India's long-term energy stability.

India started its biofuel journey by enacting the Indian Power Alcohol Act of 1948 (Act No. 22 of 1948). Its primary objective was to empower India's 'power alcohol' industry.[11] However, a significant shift occurred in 2002 when the Ministry of Petroleum and Natural Gas issued a notification introducing the Ethanol Blending Programme (EBP). From January 2003, this notification required 5% ethanol blending with petrol, leading to the abolition of the Power Alcohol Act of 1948.[12] Despite this policy shift, the EBP remained largely ineffective due to the inaccessibility of sugar molasses, a flawed ethanol pricing

[8] Tufts University. (n.d.).
[9] Schmitt, B. (2024, November 26).
[10] Clean India Journal. (2023, November).
[11] Cleveland, C. J., Kaufmann, R. K., & Stern, D. I. (2000).
[12] Aradhey, A. (2010).

formula, bureaucratic hurdles from state organisations, delayed procurement, and several other operational challenges. [13] To address these limitations, the government introduced the National Policy on Biofuel in 2009, which was not up to the desired mark and was an "unrealistic" attempt[14] due to factors like land restrictions for the cultivation of biofuel crops, rational problems in feedstock cultivation, discrepancies in state tax structures, distinct species of non-edible oil feedstock and their suitability and other organisational limitations.

Acknowledging the energy sector's shifting landscape and the previous act's shortcomings, the policy was substantially revised in 2018. This policy aimed to reduce India's dependency on fossil fuels, promote sustainable development, and address environmental concerns. It established the framework that is still relevant today, leading to an upward trajectory for the fuel ethanol industry and market after a long history of policies that failed to advance the sector. It included the Ethanol Blending with Petrol Program (EBP) with the target of reaching E20 by 2030. The 2018 Policy was further amended in 2022. These amendments included moving the 2030 target to 2025 and making additional feedstocks eligible for producing biofuels like sugarcane juice, B-heavy molasses, C-heavy molasses, broken rice, damaged grains, and maize.[15] In 2023, India reached its highest level with a national 12 per cent blending rate, reaching E-10 in June 2022 for the 2022/2023 year. India aims to reach per cent (E-20) by October 2025.[16]

Furthering its aim to increase biofuels production, according to Ministry of Petroleum & Natural Gas,[17] the government has also approved financial assistance for biomass collection, addressing supply chain challenges while encouraging industry innovation by broadening permitted feedstocks for biofuel production. Additionally, India is exploring sustainable aviation fuel, targeting 1% blending by 2027 and 2% by 2028 while investigating innovative technologies like alcohol-to-jet and waste-to-fuel conversion.

The Government has also announced the mandatory blending of Compressed Biogas in the CNG (Transport) and PNG (Domestic) segments of the CGD Sector, encouraging investment and facilitating the establishment of 750 CBG projects by 2028-29. This will help save forex, promote a circular economy, and achieve Net Zero Emissions.
Moreover, noting the rise in Maize cultivation area, yield per hectare, and production in the last few years, the government has initiated work to develop maize as a feedstock for biofuels. In that regard, the development of high-starch-yielding varieties, improvement in the quality of maize DDGS (Dried Distillers Grain Solids) by removing aflatoxins, and faster registration of new seed varieties with high starch have been initiated.

Building on these initiatives, Prime Minister Narendra Modi, during Energy Week 2025, reaffirmed India's commitment to achieving 20% ethanol blending (E20) in petrol by October 2025. The country has already launched E100 fuel, and E20 petrol is now available at over 15,600 fuel stations. India is simultaneously working on expanding its renewable energy capacity to 500 GW, making Indian Railways a net-zero emitter, and producing five million metric tonnes of green hydrogen annually. In the hydrocarbons sector, the country has significant untapped reserves within its 3.36 million square

[13] Ray, S., Miglani, S., & Goldar, A. (2011).
[14] Biswas, P. K., & Pohit, S. (2013).
[15] Das, S., & Brown, J. (2024, July 24).
[16] Press Information Bureau. (2024).
[17] The Economic Times. (2024, January 30).

kilometre sedimentary basin, with only 10% currently under exploration.[18] Plans are in place to increase this coverage to 16% by the end of 2024, though it still falls short of the long-term target of one million square kilometres by 2030. Additionally, India's refining capacity is projected to grow from 256 million tonnes to 309 million tonnes by 2028.

Continuing this momentum, the Biofuels Annual Report[19] highlights that, on the demand side, total ethanol consumption is estimated to reach 7.1 billion litres (BL), with 6.2 BL allocated for fuel use. However, restrictions on sugar feedstocks and broken rice to prevent inflationary food prices, coupled with a low sugar production year, are expected to cause a decline in the ethanol blending rate to 11.5% in 2024. India had initially achieved its current ethanol blending target of E-12 in April 2023, but meeting E-20 by 2025 presents significant challenges. To ensure sufficient ethanol supply, the administered ex-mill price for C Heavy Molasses (CHM) ethanol under the Ethanol Blended Petrol (EBP) Programme has been increased by 3%, from ₹56.58 to ₹57.97 per litre for the 2024-25 Ethanol Supply Year.

Furthermore, over the last decade, ethanol blending by Public Sector Oil Marketing Companies (OMCs) has led to foreign exchange savings of more than ₹113,007 crore and crude oil substitution of about 193 lakh metric tonnes. Ethanol blending has increased significantly from 38 crore litres in 2013-14 to 707 crore litres in 2023-24, achieving an average blending rate of 14.60%. Despite this progress, meeting future targets will require overcoming challenges related to feedstock availability, refining capacity expansion, and maintaining affordability.

Further, "Pradhan Mantri JI-VAN (Jaiv Indhan - Vatavaran Anukool fasal awashesh Nivaran) Yojana" 2019 has been amended in August 2024 for granting financial assistance for setting up Advanced Biofuel Projects.

The Union Budget has played a crucial role in supporting biofuels by allocating funds for ethanol production infrastructure, incentivising farmers for diversified feedstocks, and promoting research into advanced biofuels. Policy measures such as higher price guarantees for ethanol, tax benefits for biofuel-related investments, and financial support for bio-refineries are helping accelerate India's transition towards a more sustainable energy future.

4.0 Challenges in Furthering Biofuels in India

4.1 Food vs Fuel

The biggest challenge regarding biofuels is the debate on Food vs. Fuels. India has largely focused on 1st generation biofuels produced from food crops leading to food insecurity. Globally, the demand for greener fuels is displacing food crops. However, the dilemma regarding the risk of diverting farmland or crops for biofuel production remains. Many studies have confirmed that biofuel mandates were a leading driver of the 2008 food crisis, driving up prices by pushing demand for grain and vegetable oil.[20] A case in point is Jatropha cultivation in Chhattisgarh, where farmers were encouraged to shift from food crops to biofuel plants due to higher profits, government incentives, and promises of a

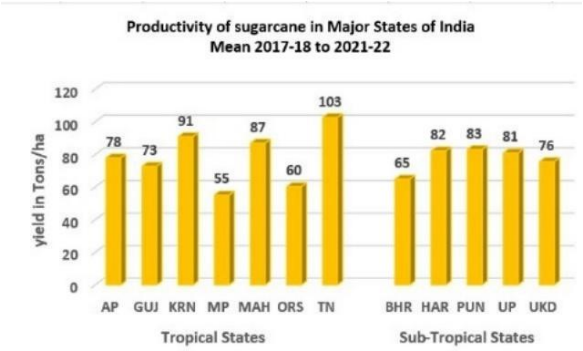
[18] India Brand Equity Foundation. (2025, February 14).
[19] Foreign Agricultural Service, U.S. Department of Agriculture. (2024).
[20] Economic Times. (2023, September 12).

stable market. However, Jatropha's low yields, long maturation period, and lack of buyers led to economic distress and reduced food availability, forcing many farmers to abandon the crop.

The twin problems of agricultural expansion and deforestation are worsening, and many nations plan to use even more crop-based biofuels to meet their renewable energy goals. We need to be cognizant that encouraging the conversion of food crops to energy through artificial policy incentives or mandatory blending targets can be risky. Industries need to be responsible and check that they are actually converting waste to fuel rather than depleting other natural resources. A long-term, sustainable approach to biofuel production can help India become a champion for sustainable biofuels.

4.2 Agricultural Productivity

Already burdened with the dilemma of using agricultural products to produce biofuels, the added pressure of unstable agricultural productivity might hamper the goal of E2O by October 2025. For example, Uttar Pradesh has the highest land allocation to sugarcane, yet its agricultural productivity is lower than many states. Rice production is also expected to decline in FY25. Hence, there is a need to increase agricultural productivity in order to lead the biofuels market.



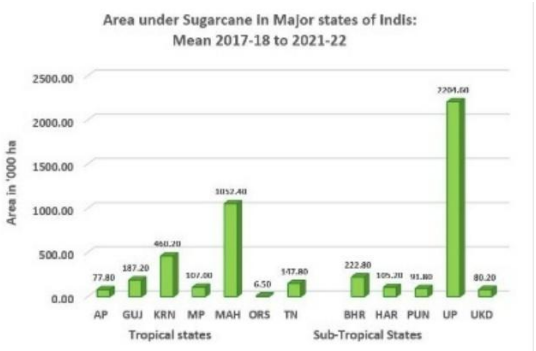


Figure 3.1 Productivity of sugarcane in major states. **Figure 3.2 Area under sugarcane in major states**

Credits: ICAR

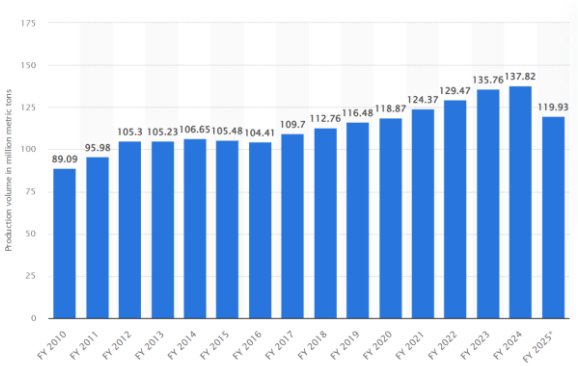


Figure 3.3 Production of rice FY10-FY25

Credits: Statista

4.3 Sustainability of 1st generation vs other biofuels

The government seems to largely focus on 1st generation biofuels, which are produced from food crops, and there seems to be a lag in 2nd and 3rd generation biofuels, which are far more sustainable

which even other countries are producing. Crops such as sugarcane and rice are highly water intensive, thus defeating the purpose of sustainable biofuels.

4.4 Export vs domestic production

Another lesser talked about challenge is the lower domestic price of sugarcane production compared to the world price, which may induce the farmers to export their raw materials instead of producing biofuels. Theoretically, this opportunity could lead them to earn USD 64/tonne over the domestic market if they could export today. Though the government has restricted sugar exports, this seems like a lost opportunity for the farmers for extra credit.[21](Figure 4.0)

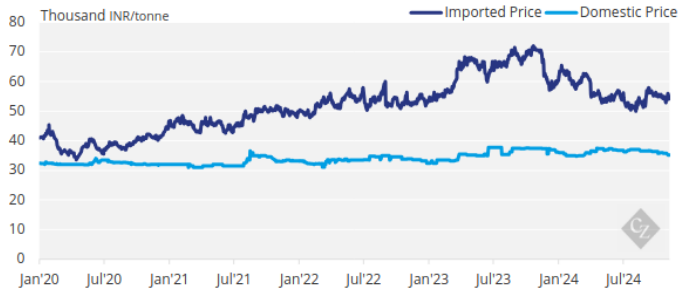


Figure 4.0 Price Comparison of Domestically Produced vs Imported White Sugar

Credits: CZ Insights

4.5 Adaptability of E20 in India

India faces mechanical, infrastructural, and policy challenges in adopting E20 and higher ethanol blends. While post-2008 vehicles are E10-compatible, transitioning to E20 demands engine modifications and older vehicles face reduced fuel economy. The high cost of retrofitting flex-fuel vehicles (₹17,000–₹25,000) and the lack of widespread E100 availability further hinder adoption.[22]

Additionally, infrastructure limitations such as ethanol storage tanks, compliant fuel dispensers, and underground pipelines pose logistical challenges. About 50% of fuel stations supply only E0, requiring significant upgrades. Policy guidelines on the pricing and labelling of ethanol blends are also needed for a smooth transition. Without nationwide E20 availability, cost incentives, and synchronised efforts from automakers and fuel providers, India is not yet fully prepared for a large-scale ethanol fuel shift.

Apart from the aforementioned challenges, some general challenges prevent the biofuels industry from truly boom in India, which are illustrated in Figure 5.0 given below

[21] Ohiduzzaman, S. (2024, November 27).
[22] NITI Aayog. (2021).

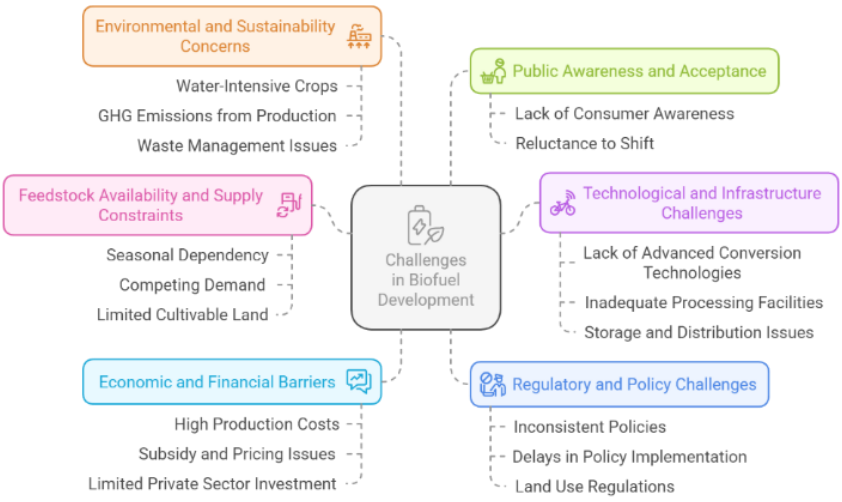


Figure 5.0 Challenges in the Biofuels Development

5.0 Analysis of States' initiatives to promote Biofuels

The role of states in promoting biofuels becomes extremely important. Under Entry 14, List-II (State List) in Schedule 7 of the Indian Constitution,[23] agriculture-related laws are enlisted, which also empower the state government to make laws related to biofuel feedstock plantations, which result in Union government-regulated petroleum-based companies with other private industries signing an MoU with state governments to promote biofuel feedstock on government-owned wasteland or unused lands through the method of contract farming with various farmers. In this initiative, state governments have taken an interest in being part of the bio-diesel mission and promoting biofuel feedstock plantations with various instruments, including incentives and policies. Such states are Odisha, Uttarakhand, Rajasthan, and others. Moreover, 475 projects, with over 40 already operational, are being set up in states like Punjab, Haryana, Western Uttar Pradesh, and Karnataka. The conversion ratio of rice straw to CNG is approximately 5:1 in tonnes.

The state-wise analysis of biofuels reveals significant disparities in bio-energy and ethanol production across India, with Maharashtra emerging as the leader, followed by Karnataka. Madhya Pradesh exhibits a unique trend, with a sharp spike in bio-energy capacity but a relatively lower number of small biogas plants. This suggests that bio-energy in the state is concentrated in a few large plants rather than distributed in small-scale systems. In contrast, despite being an agricultural hub, Uttar Pradesh shows moderate bio-energy capacity and a limited number of small biogas plants, indicating that its biofuel potential remains underutilised. Punjab and Haryana, known for their crop residue availability, also exhibit moderate bio-energy capacity but have room for expansion in biogas production. Assam also shows potential for a higher capacity for the production of biofuels.

[23] Inter-State Council Secretariat. (n.d.).

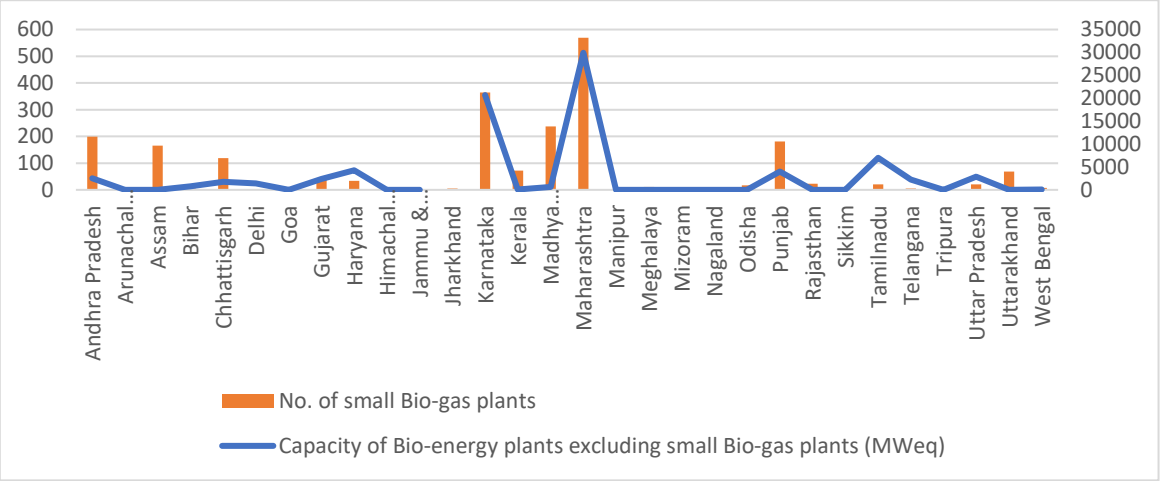


Figure 6.1 Shows the capacity of bio-energy plants excluding small bio-gas plants (MWeq) and no. of small Bio-gas plants of States/UTS

Credits: Based on the data Ministry of New and Renewable Energy in Annexure 2

The second graph in Figure 6.2 highlights ethanol production, where Maharashtra again dominates, particularly in molasses-based ethanol, with an installed capacity significantly higher than other states. Uttar Pradesh also performs well in this segment but does not match Maharashtra's scale. Karnataka and Tamil Nadu exhibit noticeable ethanol production, while states like Gujarat and Odisha show moderate activity. Grain-based ethanol projects remain limited nationwide, with only a few states like Bihar, Punjab, and Madhya Pradesh showing some capacity. This indicates a reliance on molasses-based ethanol, leaving room for diversification. Additionally, north-eastern states remain backwards in the production of biofuels.

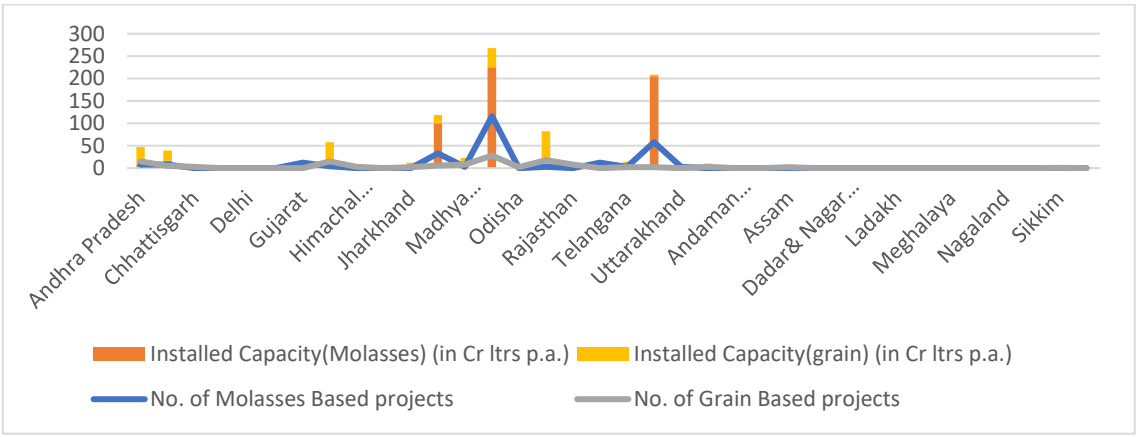


Figure 6.2 Showing the number of Molasses and Grains based projects with their respective installed capacity in States/UTs

Credits: Based on the data of the Ministry of Consumer Affairs, Food & Public Distribution Annexure 3

Overall, Maharashtra leads the biofuel sector with high bio-energy capacity and ethanol production, while Karnataka, Madhya Pradesh, and Uttar Pradesh also play significant roles. However, several states, particularly in eastern and northeastern India, have minimal biofuel infrastructure, highlighting untapped potential. Expanding grain-based ethanol production and strengthening decentralised bio-

energy projects could enhance biofuel adoption across more states, supporting India's renewable energy goals.

5.1 Some states in focus.

5.1.1 Maharashtra

Maharashtra stands as India's leading biofuel producer, with a bio-energy capacity of 513.034 MWeq, significantly ahead of states like Uttar Pradesh (48.671 Mweq) and Karnataka (355.308 Mweq). The state has made substantial progress in ethanol and biogas production, critical in India's transition towards sustainable energy. With 33,195 small biogas plants, Maharashtra has developed a strong decentralised bio-energy network, allowing rural communities to harness organic waste efficiently.[24] Additionally, the Maharashtra Energy Development Agency (MEDA) has been actively promoting bio-CNG, biomass-based power projects, and biogas plants, offering financial incentives and subsidies to encourage adoption.[25]

Maharashtra is also a key player in ethanol production, with industry estimates projecting ethanol output to reach 1,40 crore litres in 2024. The state has 118 sugar mills and over 85 operational distilleries, making it a vital hub for molasses-based ethanol production. However, to maintain steady ethanol production, the state government strategically banned molasses exports in 2023-24, ensuring that local distilleries have sufficient raw material for ethanol and alcohol production. This move aligns with India's National Biofuel Policy, which aims to achieve 20% ethanol blending in petrol by 2025-26 to reduce fossil fuel dependence and carbon emissions.[26]

Despite Maharashtra's dominance in biofuel production, challenges remain. Irregular monsoons and fluctuating sugarcane yields have impacted ethanol production, with the sector facing potential supply constraints due to climate-related uncertainties. Additionally, while the state leads in biofuel infrastructure, technological upgrades and improved storage facilities are needed to optimise ethanol production efficiency. Recognising this, Maharashtra has begun investing in second-generation (2G) ethanol production,[27] which utilises agricultural residues like paddy straw and bagasse, thereby reducing reliance on sugarcane and mitigating supply risks.

The state's proactive approach to biofuel development, combined with policy support and infrastructure expansion, positions Maharashtra as a critical driver of India's bioenergy future. If sustained investments continue, Maharashtra could further solidify its leadership in ethanol and biogas production, contributing significantly to India's net-zero emissions target by 2070 and 45% reduction in GDP emission intensity by 2030.

5.1.2 Karnataka

Karnataka significantly contributes to India's biofuel sector, particularly in ethanol production, biodiesel, and biofuel integration in public transport. The state has taken substantial steps to promote biofuels through policy initiatives and financial support. Karnataka received ₹119.90 crore for 36 ethanol projects, aiming to produce 144 crore litres of ethanol annually, aligning with India's national

[24] Press Information Bureau. (2023, February 1)
[25] Maharashtra Energy Development Agency. (n.d.).
[26] The Economic Times. (2022, August 7).
[27] Advanced Biofuels USA. (2023).

goal of achieving 20% ethanol blending by 2025-26 [28](PIB, 2023). This effort enhances energy security, reduces reliance on fossil fuels, and supports sugarcane farmers, as molasses remains a primary feedstock.

Despite progress, biodiesel production faces significant challenges. The lack of a stable supply of raw materials, high production costs, and weak supply chains hinder large-scale biodiesel adoption[29] Jatropha cultivation, once promoted as a major biodiesel source, has not yielded the expected results due to fluctuating yields and market uncertainties. Additionally, inadequate infrastructure and limited private sector investment slow Karnataka's biofuel growth compared to leading states like Maharashtra.

One of Karnataka's most notable initiatives is the integration of biofuels in public transportation. The Karnataka State Road Transport Corporation (KSRTC)[30] successfully piloted ethanol-blended diesel, significantly reducing carbon emissions and fuel dependency. Such efforts showcase Karnataka's commitment to sustainable mobility. However, scaling these projects requires stronger financial incentives, better distribution networks, and increased awareness among consumers and businesses.

While Karnataka has made advancements in biofuel production, addressing raw material shortages, enhancing policy execution, and increasing investments in infrastructure will be crucial for sustained progress. With strategic intervention, Karnataka has the potential to become a leader in India's biofuel revolution, contributing significantly to national energy goals.

5.1.3 Uttar Pradesh

Uttar Pradesh is emerging as a key player in India's biofuel sector, focusing on ethanol and biogas production. The state is one of India's top ethanol producers with an annual installed ethanol capacity of 2.053 billion litres from molasses-based projects and 34 million litres from grain-based projects. This is supported by 118 sugar mills and over 85 operational distilleries, making Uttar Pradesh well-positioned for further biofuel expansion. Additionally, the state has a bio-energy plant capacity of 48.671 Mweq, though it lags behind Maharashtra (513.034 Mweq) and Karnataka (355.308 Mweq), highlighting room for growth.

To accelerate green energy adoption, Uttar Pradesh plans to establish 100 compressed biogas (CBG) plants, leveraging its vast organic biomass, sugarcane bagasse, and agro-waste resources. This aligns with India's broader goal of achieving net-zero emissions by 2070 and reducing GDP emission intensity by 45% by 2030. Moreover, the state has 3,997 small bio-gas plants, but this number remains far below Karnataka (21,278) and Madhya Pradesh (13,978), indicating the potential for greater decentralised bio-energy production, particularly in rural areas.

Despite its progress, the state faces challenges, particularly a 4.5% decline in sugar production due to factors like red rot disease, which could impact ethanol output. Since sugarcane is a primary feedstock for ethanol, fluctuations in agricultural yield pose risks to biofuel production. Additionally, limited infrastructure and investment in small-scale biogas plants hinder the full utilisation of available biomass resources.

[28] PIB(2023)
[29] Deccan Herald. (2023).
[30] Karnataka Bioenergy Development Board. (n.d.).

However, the National Biofuel Policy and initiatives like Ethanol Blended Petrol (EBP) provide opportunities for Uttar Pradesh to expand its biofuel sector. Increased investment in bio-refineries, ethanol plants, and waste-to-energy projects could significantly boost clean energy production while strengthening the sugar industry. With its agricultural strength, strong ethanol production base, and government support, Uttar Pradesh has the potential to bridge the gap with Maharashtra and Karnataka and play a leading role in India's transition to sustainable biofuels.

6.0 Way Forward for Biofuels in India

6.1 Diversification of Feedstock for Ethanol Production

The reliance on sugarcane for ethanol production poses sustainability challenges due to its high water. To mitigate this, India must promote the use of less water-intensive crops such as maize, sweet sorghum, and other high-starch food grains. Encouraging research and development in second-generation biofuels, including lignocellulosic biomass and agricultural residues, can enhance ethanol production without straining water resources.[31] Additionally, incentivize farmers to cultivate drought-resistant and water-efficient crops such as maize and sweet sorghum.

Micro-algae offer economic, social, and environmental benefits as a 3rd generation biofuel feedstock, surpassing terrestrial crops due to their high lipid yield, adaptability, and resilience to climate change. [32]They grow yearly, have a high oil content, and require significantly less land than traditional biofuel crops. With a short doubling time and a 20-30 times higher growth rate, algae allow multiple harvests in a short period.[33] Bio-diesel from micro-algae is carbon-neutral, as CO_2 released during combustion is reabsorbed by algae. Besides fuel, algae provide valuable by-products for food, nutraceuticals, bio-fertilizers, industrial enzymes, and surfactants. [34]They can thrive in seawater, freshwater, brackish water, and even sewage water, reducing dependence on fertile land.[35] Algae-based biofuel requires far less land than traditional fossil fuel replacements, consuming less than 1/17th of the corn cultivation area in the U.S. Governments support this sector through cost-sharing and subsidies, reducing investment risks and promoting production.[36]

6.2. Strengthening Oil Marketing Infrastructure

To seamlessly integrate ethanol into the fuel supply chain, India must expand ethanol storage facilities across different regions to manage supply fluctuations. Upgrading existing fuel distribution networks to handle higher ethanol blends efficiently and improving logistics for ethanol transportation and distribution will be crucial. Establishing digital marketplaces for transparent trading in clean biomass-based products can facilitate farmer participation and ease access for traders and consumers.[37]

6.3. Regulatory Reforms and Environmental Clearances

[31] NITI Aayog. (2021).
[32] Ziolkowska & Simon.
[33] Chisti, 2007
[34] Griffiths et al., 2011
[35] Cheng & He, 2014
[36] Su et al., 2015
[37] Baxi, S. (2023, September 13).

Streamlining regulatory procedures through a single-window clearance system for ethanol production units could help accelerate approvals. Clear environmental compliance guidelines while promoting sustainable ethanol production practices will ensure minimal ecological impact. Additionally, regulatory frameworks should support diverse feedstocks, including second-generation and advanced biofuels, to enhance biofuel adoption.[38] (NITI Aayog, Biofuel Policies in India: An Assessment of Policy Barriers).

6.4. Economic Incentives and Market Development

To accelerate biofuel adoption, introducing tax benefits and subsidies can encourage investments in ethanol infrastructure. Ensuring pricing policies that make ethanol-blended fuels attractive to consumers while maintaining affordability will further drive adoption. Incentivising automakers to develop and promote flex-fuel vehicles will create demand for higher ethanol blends, contributing to energy security and reduced dependence on fossil fuels. (Economic Times Energy, Biofuel Policies in India).

6.5 Public Awareness and Industry Collaboration

Public awareness campaigns should highlight the benefits of ethanol blending for energy security, reduced greenhouse gas emissions, and environmental sustainability. Industry-government collaborations will be vital to ensuring the smooth adoption of ethanol policies. Manufacturers must also improve their connection with potential customers by procuring agro-waste from farms to produce biofuels. Buyers also need more control over fuel quality, as their access to sellers is limited. To achieve these goals, establishing digital marketplaces can facilitate transparent trading in clean biomass-based products, enabling broad participation and easy access for farmers, traders, and consumers.

6.6 Policy Reforms and International Cooperation

The Indian government could consider revisiting and refining its biofuel policies to facilitate more effective implementation. Establishing a permanent secretariat for the GBA in India might encourage more coordinated efforts with global stakeholders. It could be beneficial to engage non-member countries, particularly in the Global South, where bioenergy has the potential to provide a competitive pathway to net-zero emissions and enhance rural income generation. Financial institutions could be encouraged to support biofuel projects, and there may be opportunities to leverage private sector investments to foster innovation in bioenergy.

India can successfully transition towards a sustainable and self-reliant biofuel economy by adopting a multi-pronged approach that includes feedstock diversification, infrastructure expansion, regulatory simplification, and international cooperation. Ensuring long-term investment in research and development, alongside well-structured policy interventions, will be critical to achieving the country's energy security and decarbonisation goals.

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Annexure 1

Country	Roadmap / Mandate for Ethanol Blends	Program	Implementation By	Vehicle Type
Brazil	National policy mandates the blending of 18-27.5% ethanol in gasoline (currently ~27%).	National biofuels policy (Dec 2017)	Ministry of Mines and Energy (MME)	Mainly flex-fuel; some vehicles use E27
United States	Renewable Fuel Standard (RFS) mandates annual blending targets. EPA updates based on availability.	Renewable fuel standard (RFS) program	Environmental Protection Agency (EPA)	Flex-fuel or E30+ vehicles
European Union (EU)	10% of transport fuel to come from renewable sources (biofuels) by 2020.	Renewable energy directive	European Commission	Flex-fuel and normal vehicles
China	Government proposed nationwide 10% ethanol blending target.	Fuel quality standards	National Energy Administration	Primarily normal vehicles
Thailand	Alternative Energy Development Plan (AEDP) aims to increase renewable energy share from 7% in 2015 to 25% in 2036.	AEDP	Ministry of Energy	Primarily normal vehicles
Source: NITI AAYOG ROADMAP FOR ETHANOL BLENDING IN INDIA 2020-25 https://www.niti.gov.in/sites/default/files/2021-06/EthanolBlendingInIndia_compressed.pdf				

Annexure 2

S.No.	State	Capacity of Bio-energy plants excluding small Bio-gas plants (Mweq)	No. of small Bio-gas plants
1	Andhra Pradesh	43.732	11581
2	Arunachal Pradesh	0	69
3	Assam	0	9641
4	Bihar	13.72	254
5	Chhattisgarh	30.23	6896
6	Delhi	24	0
7	Goa	0.34	8
8	Gujarat	41.31	2454
9	Haryana	72.91	1965
10	Himachal Pradesh	0	115
11	Jammu & Kashmir	0	17
12	Jharkhand		292
13	Karnataka	355.308	21279
14	Kerala	1.6	4208
15	Madhya Pradesh	10.392	13875
16	Maharashtra	513.034	33196
17	Manipur	0	0
18	Meghalaya	0	667
19	Mizoram	0	255
20	Nagaland	0	0
21	Odisha	0	954
22	Punjab	68.159	10557
23	Rajasthan	0	1312
24	Sikkim	0	0
25	Tamilnadu	120.29	1202
26	Telangana	38.74	309
27	Tripura	0	
28	Uttar Pradesh	48.671	1201
29	Uttarakhand	0.59	3997
30	West Bengal	1.36	448
	Total	**1384.386**	**126885**
Source *Based on the data Ministry of New and Renewable Energy* https://pib.gov.in/PressReleasePage.aspx?PRID=1911482			

Annexure 3

State/UT	No. of Molasses Based projects	Installed Capacity(Molasses) (in Cr ltrs p.a.)	No. of Grain Based projects	Installed Capacity(grain) (in Cr ltrs p.a.)	Total Installed Capacity (in Cr ltrs p.a.)
Andhra Pradesh	8	8.6	15	38.8	47.4
Bihar	8	16.3	5	22.8	39.1

Chhattisgarh	0	0	3	4.8	4.8
Daman & Diu	0	0	0	0	0
Delhi	0	0	0	0	0
Goa	0	0	0	0	0
Gujarat	12	15.3	0	0	15.3
Haryana	4	8.6	15	49.1	57.6
Himachal Pradesh	0	0	3	2.7	2.7
Jammu & Kashmir	0	0	0	0	0
Jharkhand	0	0	2	12.4	12.4
Karnataka	33	100.2	6	18.5	118.7
Madhya Pradesh	3	4.8	8	18	22.8
Maharashtra	116	225.3	28	42.7	268
Odisha	0	0	2	3.1	3.1
Punjab	3	5.1	18	76.8	82
Rajasthan	0	0	8	12.2	12.2
Tamil Nadu	12	17.4	0	0	17.4
Telangana	3	6.8	2	7.3	14.1
Uttar Pradesh	58	205.3	2	3.4	208.7
Uttarakhand	3	5.8	0	0	5.8
West Bengal	0	0	3	10.2	10.2
Andaman &Nicobar	0	0	0	0	0
Arunachal Pradesh	0	0	0	0	0
Assam	0	0	2	3.6	3.6
Chandigarh	0	0	0	0	0
Dadar& Nagar Haveli	0	0	0	0	0
Kerala	0	0	0	0	0
Ladakh	0	0	0	0	0
Manipur	0	0	0	0	0
Meghalaya	0	0	0	0	0
Mizoram	0	0	0	0	0
Nagaland	0	0	0	0	0
Pondicherry	0	0	0	0	0
Sikkim	0	0	1	2.2	2.2
Tripura	0	0	0	0	0
Total	**263**	**619.4**	**123**	**328.5**	**947.9**

Source: Data based on the Ministry of Consumer Affairs, Food & Public Distribution
https://pib.gov.in/PressReleasePage.aspx?PRID=1885392

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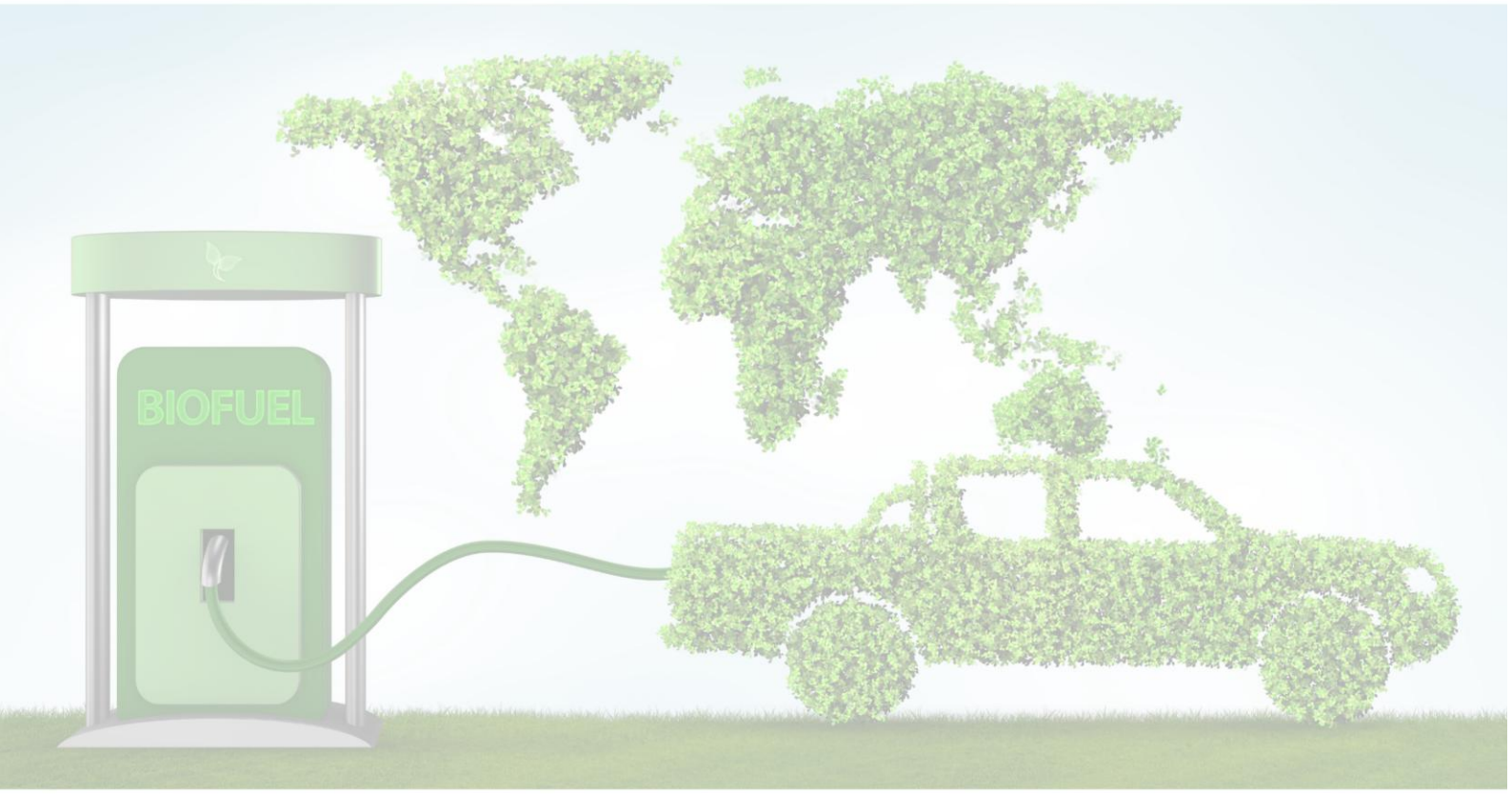

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