G20
भारत 2023 INDIA

BIOFUELS STUDY
Report

वसुधैव कुटुम्बकम्

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ii. Boston Consulting Group (India) Private Limited, Nariman Bhavan, 14th Floor, 227, Nariman Point, Mumbai 400021 (India), E-mail: bcg-info@bcg.com, Fax: +91 22 6749 7001

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पंकज जैन
सचिव
Pankaj Jain
Secretary

सत्यमेव जयते

भारत सरकार
पेट्रोलियम एवं प्राकृतिक गैस मंत्रालय
शास्त्री भवन, नई दिल्ली-110 001
Government of India
Ministry of Petroleum and Natural Gas
Shastri Bhawan, New Delhi - 110 001
Tel. : 011-23383501, 011-23383562
Fax : 011-23070723
E-mail : sec.png@nic.in

Universal & equitable access to energy is critical to ensuring sustained economic growth and socio-economic mobility. Yet, lack of access to affordable and stable energy supplies continues to remain a challenge for many countries across the globe. The Sustainable Development Goal 7 clearly states "Ensure access to affordable, reliable, sustainable and modern energy for all". In parallel, countries are working on ushering a stable energy transition which safeguards their energy needs while reducing the carbon footprint.

In this context, the importance of Biofuels as a sustainable and cleaner choice cannot be overemphasized. Biofuels are uniquely positioned to help meet growing energy demands & offer a strategic alternative to traditional fossil fuels, while also effectively repurposing agricultural and municipal waste and decarbonizing transportation. Biofuels also provide a relatively mature clean energy technology with minimal change in existing infrastructure.

In this direction, India has made significant progress in biofuel development, with programs such as the Ethanol Blended Petrol Program and National Biodiesel Mission. Several interventions by the Government of India have enabled the following:

- an increase in average ethanol blending from 1.53% - ESY 2013-14 to 10.02% - ESY 2021-22,
- roll out of E20 fuels, commissioning of Asia's first 2G Ethanol bio-refinery at Panipat, Haryana,
- commissioning of 40 compressed bio-gas plants with a total capacity of ~225 tons per day,
- launching of M15(petrol blended with 15% Methanol),
- research and testing of 15% Methanol in Diesel etc.

This has resulted in the target of 10% blending being achieved months before the scheduled date and advancing of the target of 20% blending from 2030 to 2025. Long term offtake agreements have also been signed with 130 dedicated Ethanol Plants in deficit states with total offtake assurance of Ethanol quantity of 4.3 billion litres per annum. 20% Ethanol blending by 2025, will result in forex savings of more than 6.6 billion US dollar per annum, reduction of GHG emissions of 21.6 million MT per annum and increase the farmers cumulative income by over 5.1 billion US dollar per annum, while creating thousands of employment opportunities.

Through this report we showcase India's bioenergy story which has potential to be replicated in other countries while also highlighting the value biofuels can bring to energy security, decarbonization, and circular economy. The report serves as a guide for all stakeholders in the biofuel value chain to work together towards a low-carbon future and collaborate across new energy frontiers like Sustainable Aviation Fuel and Renewable diesel. The report also identifies challenges in the sector and makes a strong case for greater partnership between countries in complimenting aims to add value for all entities working towards a more sustainable future.

[Pankaj Jain]

Preface - Lead Knowledge Partner

This report is an effort to bring back the conversation around biofuels to the table. As one of the earlier discovered low carbon sources of energy, biofuels have been around for more than 15 years. Despite its significant benefits and maturity in terms of technological advancement, biofuel failed to take off in the way most entities believed it would. While investigating the root cause of the underwhelming adoption despite steady interest in biofuels, the true untapped potential of biofuels was unearthed.

As each country charts its course on the decarbonization journey, biofuel has a role to play in every country's energy agenda, despite the drastically varying priorities. As a proven solution in hard to abate sectors, biofuels proved relevant in countries that focus on other cleaner alternatives of renewables. At the same time, biofuel can play a major role in reducing greenhouse gas emissions for countries that are heavily reliant on fossil fuels via its bridge fuel applications. Given the dynamic nature of countries' energy agendas, biofuel can have a significant impact in the short as well as the long term in most countries within the G20.

Challenges facing biofuel adoption are multifaceted problems that can only be solved by collaborative action. While bioenergy collaborations have historically driven countries to develop policies and fuel biofuel adoption, the most critical challenges it faces today can only be resolved with on-ground collaborative action by multiple stakeholders across the biofuel value chain.

This report highlights the ambitious vision for biofuels and the need for a collaboration to drive this vision to reality. It is expected that this report will provide a strong rationale and guidance to various stakeholders.

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Acronyms and abbreviations

1	ATJ - Alcohol to Jet
2	BPCL - Bharat Petroleum Corporation Limited
3	CAGR - Compound Annual Growth Rate
4	CBG - Compressed Biogas
5	CORSIA - Carbon Offset and Reduction Scheme for International Aviation
6	DFG – Damaged Food Grains
7	DHDS - Diesel Hydro Desulphurisation Unit
8	EBP - Ethanol Blended Petrol
9	ESG - Environmental, Social and Governance
10	ESY – Ethanol Supply Year (1st Dec to 30th November)
11	FAME - Fatty acid methyl ester
12	FCCU - fuel cell control unit
13	FFV - flexible fuel vehicles
14	GFT - Gasification Fischer-Tropsch
15	GHG - Greenhouse Gas
16	HEFA - hydro-processed esters and fatty acids
17	HPCL - Hindustan Petroleum Corporation Limited
18	HVO - Hydrotreated vegetable oil
19	IATA - International Air Transport Association
20	ICAO - International Civil Aviation Organization
21	IEA - International Energy Agency
22	IOCL - Indian Oil Corporation Limited
23	IRENA - International Renewable Energy Agency
24	ISCC - International Sustainability & Carbon Certification
25	MPP - Mission Possible Partnership
26	MSP - Minimum Support Price
27	NOC - National Oil Company
28	NZE - Net Zero Emissions
29	OEM - Original Equipment Manufacturer
30	PtL - Power-to-Liquid
31	PtX - Power-to-X
32	RED III - Renewable Energy Directive III
33	RD - Renewable Diesel
34	SAF - Sustainable Aviation Fuel
35	SCJ – Sugarcane Juice
36	SATAT - Sustainable Alternative Towards Affordable Transportation
37	UCO - Used Cooking Oil
38	WTW - Well-to-wheel

Executive Summary

As the world embarks on the journey to address the climate change crisis there are multiple pathways available for this journey and biofuel is a critical spoke across many of these decarbonization journey. Till date, given the unique nature of each country's energy demands and energy goals, each country has paced biofuel adoption in accordance with its respective agenda. Hence, the percentage contribution of biofuel in the energy mix of different countries varies from 0% to 7%, hinting at the varying degree of interest that different countries have in biofuels. Testament to the varying degree of interest is the penetration of biofuels in the transportation sector. While the adoption of biofuels in transportation has globally increased from 2% to 4% in the past 10 years, certain countries have seen significant blend rates which goes to show that adoption has been primarily driven by government policy targets. Current production levels indicate that biofuel remains 'off the track' vis-à-vis global Net Zero Emissions aspirations - but there is tremendous headroom for growth.

BCG Analysis shows that there is vast feedstock potential to be unlocked which could result up-to 5x increase in biofuels produced. The analysis shows that the significant increase could be achieved majorly using waste sources, without tapping into the food sources. To unlock this potential advancement on both technology as well as feedstock management is needed, and funding is not a constraint.

To unlock growth in Biofuel several challenges need to be resolved. While feedstock challenges continue to be the primary roadblock for producers due to lack of quality feedstock, competing demand for feedstock and a fragmented and complex waste supply chain, technology concerns pose a significant challenge to biofuel adoption given the negligible commercial viability of advanced biofuel production. While significant investments into biofuel R&D and production could solve some of these challenges, fundraising has been a major concern due to uncertainty of profit margins. Also, the high capital expenditure has stemmed biofuel adoption as cost parity with fossil fuels is difficult to achieve.

However, if these challenges could be addressed, the true potential of biofuels could be unleashed. Biofuel producers are thus exploring ways to further optimize the costs of production and improve the commercial viability of biofuels by leveraging synergies with existing operations and technologies, encouraging technology interventions and improvements and by enhancing feedstock quality, availability, and affordability.

Unlocking this true benefit will enable complying nations to avail the following benefits: Biofuels could have a significant impact in five key areas – lowering GHG emissions as they could result in up to 80% reduction in well-to-wheel emissions as compared to their fossil fuel counterparts; reducing import dependency and thereby boosting energy security; enabling circularity by employing waste for wealth creation and delivering wider socioeconomic benefits. In addition to their energy potential, they also offer downstream applications in the form of bio-based chemicals and polymers.

To realize this vision, multiple stakeholders need to come together across the entire value chain including feedstock providers, policy makers, financial institutes, oil marketing companies, certification agencies, industry associations, members of academia and end consumers. The coordinated efforts of each of these stakeholders is critical to realize the untapped potential of biofuels. To achieve the biofuel vision, the coordinated focus of all key stakeholders is required across 5 levers - technology, feedstock, policy, investment, and consumers. While steady progress has been made on the policy front and in increasing awareness regarding the bioeconomy, the need of the hour is to propose an alliance that focuses on operational impact and simultaneously focuses on all 5 levers and brings together all concerned stakeholders.

As we aspire to increase biofuel adoption, it is important to look at the India's biofuel journey. Driven by focus across 5 levers (technology, feedstock, policy, investment, and consumers) India's average ethanol blending has increased from 1.53% during ESY 2013-14 to 10.02% in ESY 2021-22., creating a blueprint for other developing countries to follow.

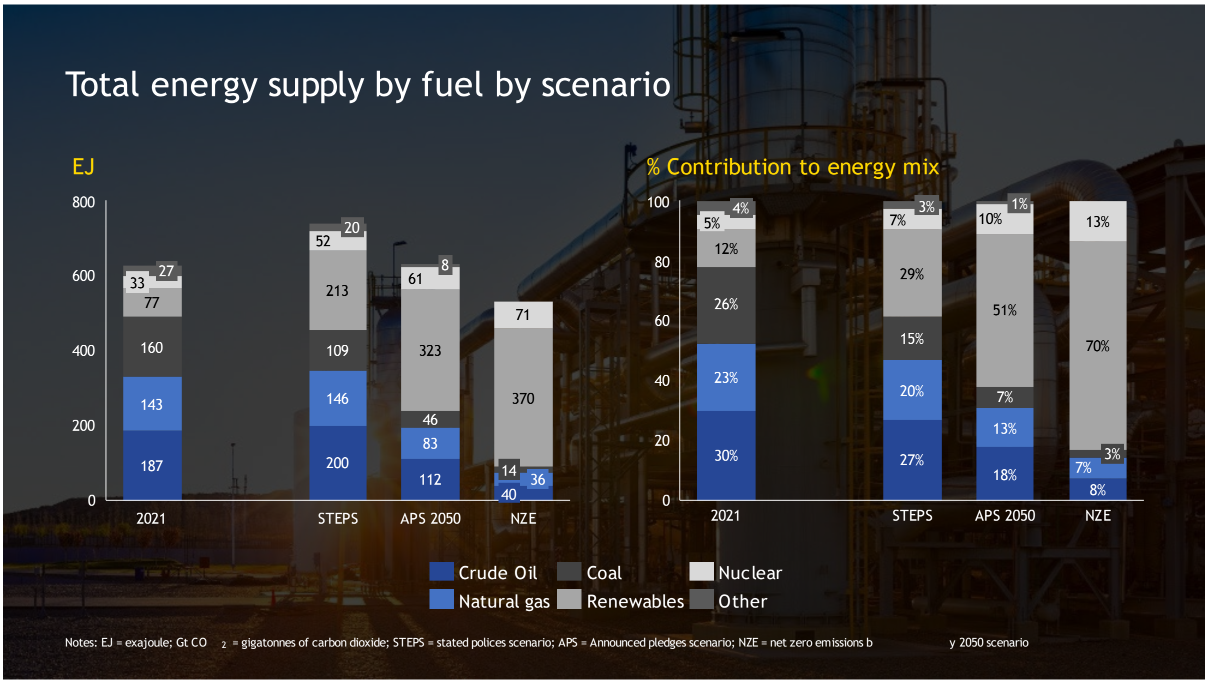
Chapter 1: Vision for biofuels

Introduction:

Biofuel to play a pivotal role in decarbonization

In recent decades, fossil fuels have dominated energy supplies across the world, accounting for as much as ~80% of the global energy mix. While this dominance is expected to recede gradually, they will remain relevant in at least a few decades to come. A recent analysis by BP outlook states that oil and gas will contribute to 44% of the energy mix by 2050, which would be well below their erstwhile peak, but still a significant share. Demand for fossil fuels remains stubborn – according to World Oil Outlook 2022, gasoline demand will increase 10% by 2030, despite global commitments towards decarbonization. At the same time, low-carbon pathways are facing headwinds of grid integration and supply chain issues around critical minerals. This raises the need for alternative pathways – and biofuels could be one of the most pragmatic ways forward.

Fig 1. Contribution to energy mix by fuel types



Biofuels are emerging as a critical avenue for the decarbonization of fossil fuels, and one of the most accessible routes to climate change mitigation. They offer a compelling proposition for developing and developed countries alike, to expedite the energy transition and balance energy security with emissions reduction, even as nascent renewables grapple with the challenges of material availability, intermittency, and wider commercial viability.

Fig 2. Role of biofuel in decarbonization

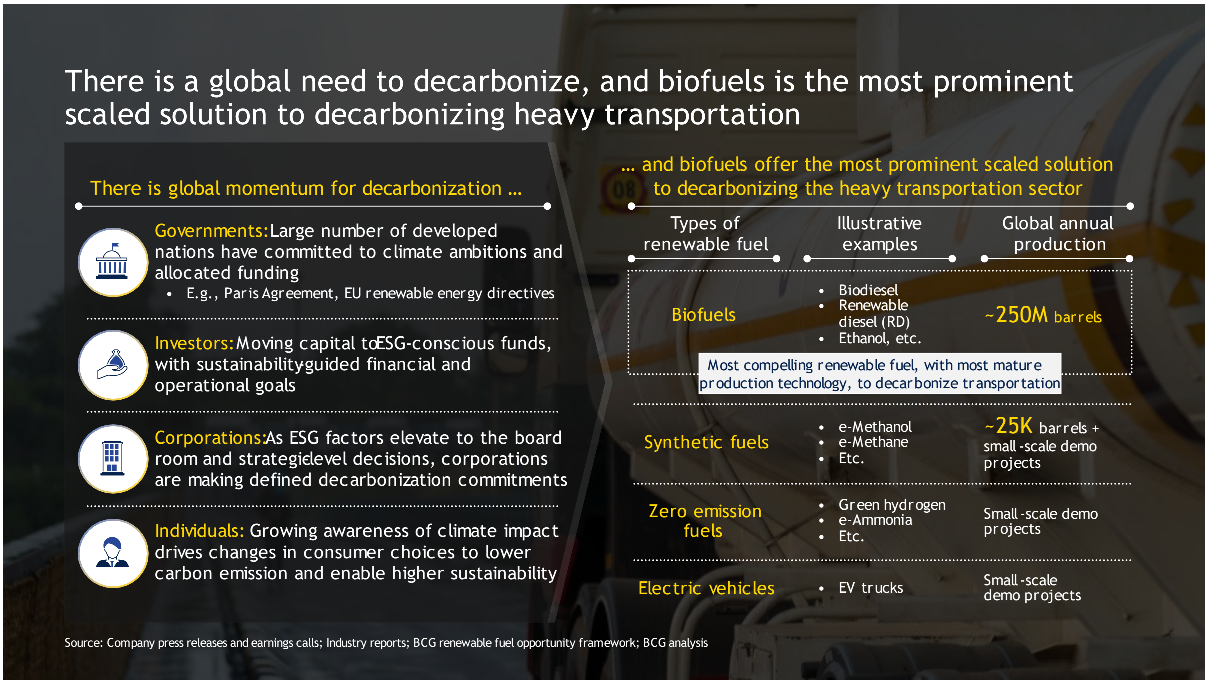
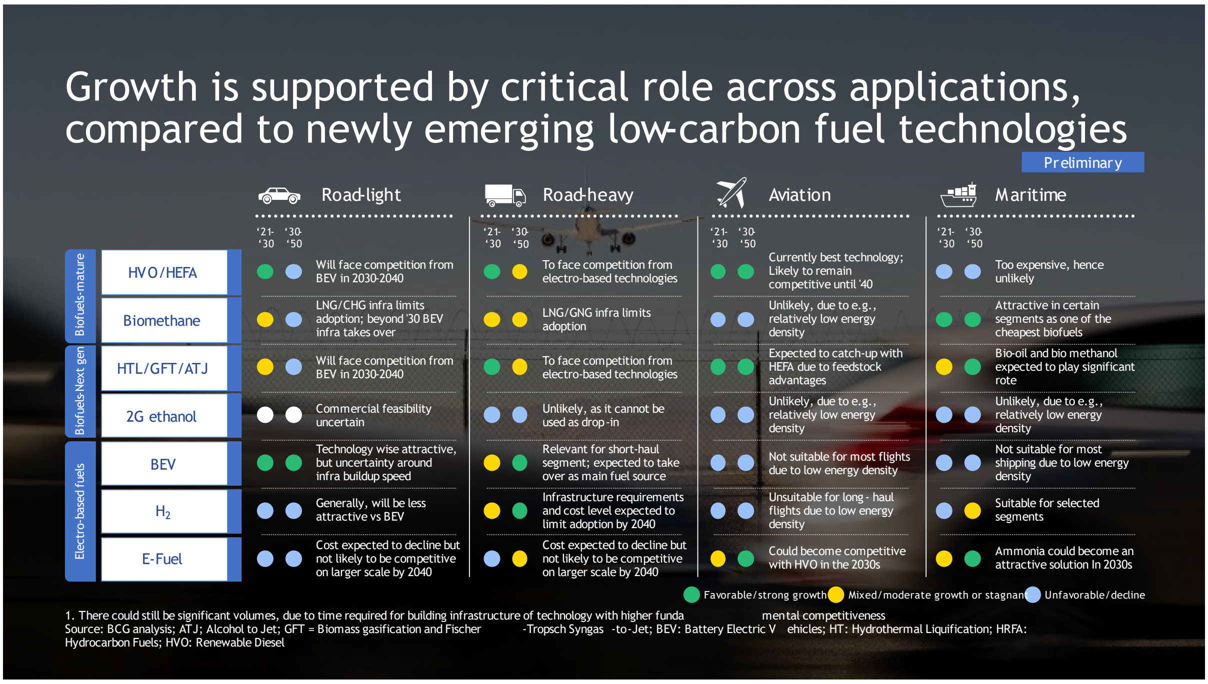


Fig 3: Biofuel to play a critical role across applications both in medium and long term

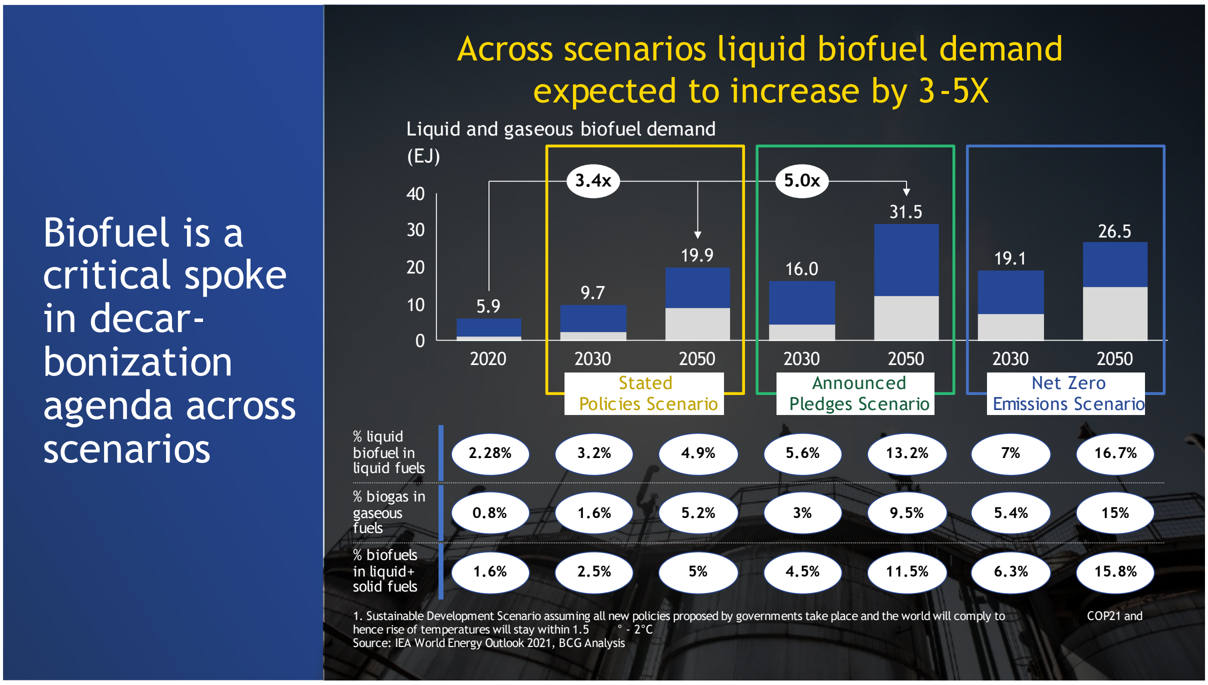


Biofuels could have a significant impact in five key areas – lowering GHG emissions; reducing import dependency; boosting energy security; enabling circularity and delivering wider socioeconomic benefits. In addition to their energy potential, they also offer downstream applications in the form of bio-based chemicals and polymers.

Biofuel Potential

The biofuel sector is growing rapidly, and while detailed estimates vary across scenarios and assumptions, there is consensus on their growing importance. Liquid biofuel production today stands at 3.901 EJ. Of this, Sustainable Aviation Fuel (SAF) production stood at approximately 100 million liters in 2021. Meanwhile, global biogas production is ~778.75 GJ per year. The global biogas market stands at USD 39 billion in 2022 and is projected to cross USD 50 billion by 2026, with the bulk of this growth in the EMEA region.

Fig 4. Robust demand growth expected for Biofuel across scenarios



BCG analysis shows that, given the right conditions, the true potential of liquid biofuels for G20 countries could be as much as 5x the current production, from ~ 3.41 EJ today to ~19.09 EJ.

Fig 5. Based on biomass potential and liquid biofuel attractiveness, different growth scenarios can shape up

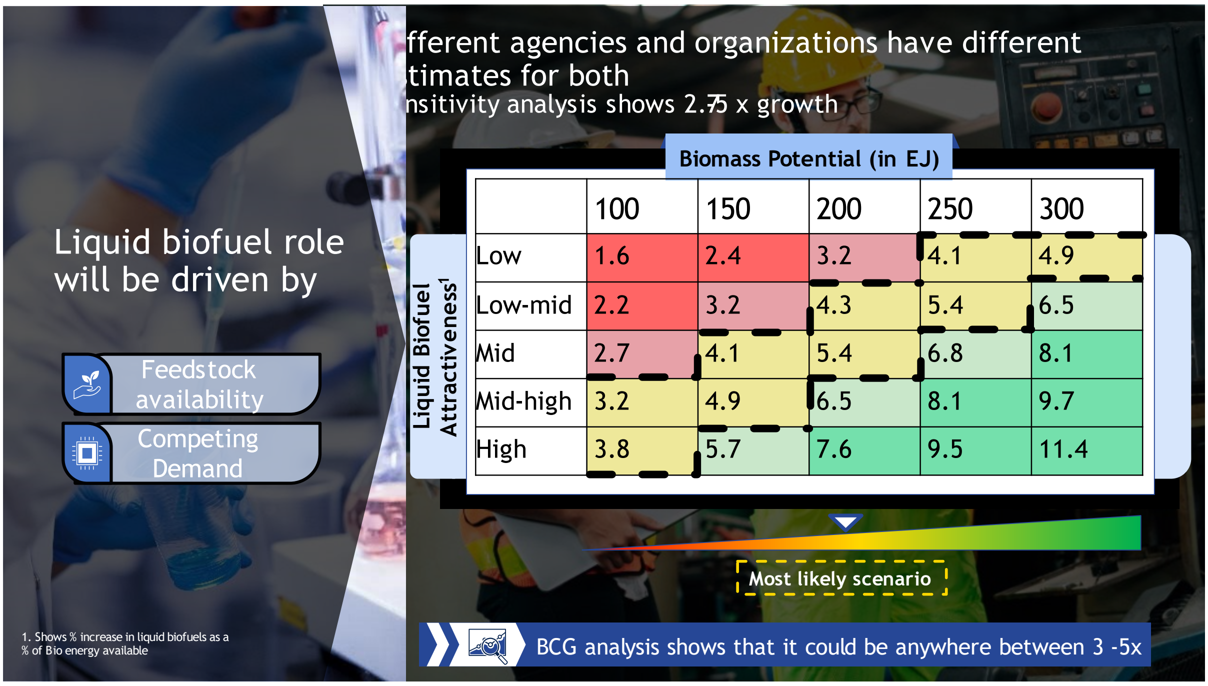
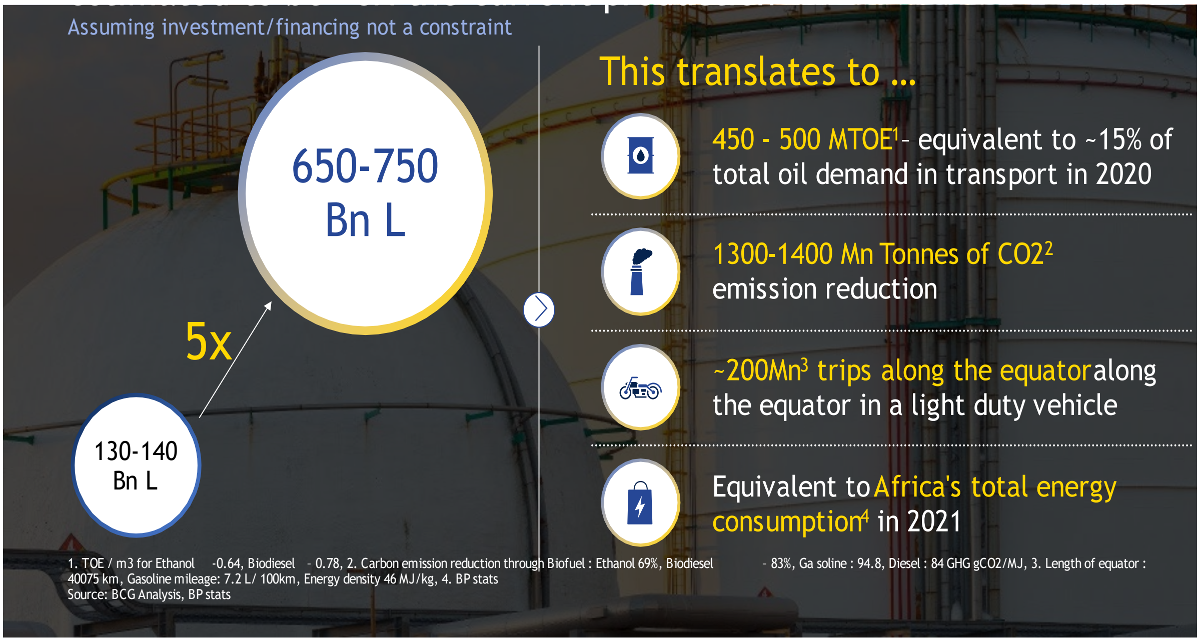


Fig 5 Growth will translate into multiple benefits



Realizing full potential of the Biofuel Vision could cut global CO_2 emissions by 1,300-1,400 million tons, delivering additional energy equivalent to:

1) ~15% of total oil demand in transport in 2020, or around 450-500 MTOE
2) 200 million trips along the equator in a light vehicle

3) Africa's total energy consumption in 2021

Our analysis shows that the majority of the uplift in potential is driven by 2G biofuel, through technology sharing and process improvements for enhancing feedstock availability

Fig 6. Potential growth vision for Biofuel

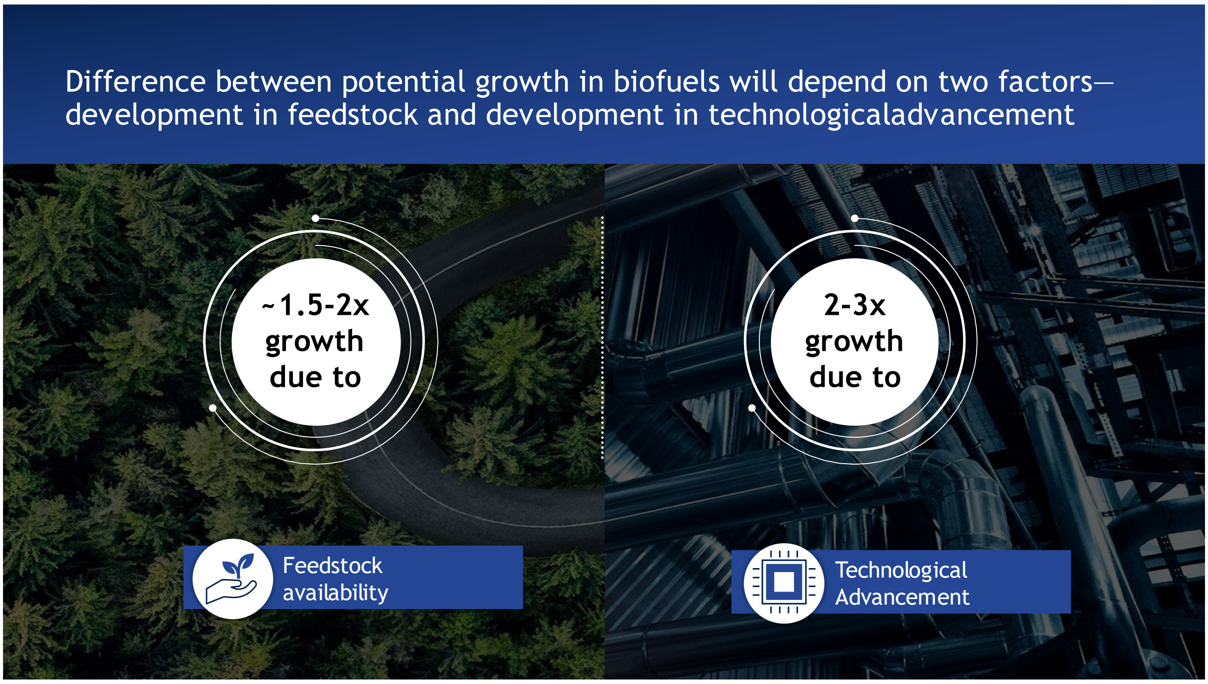


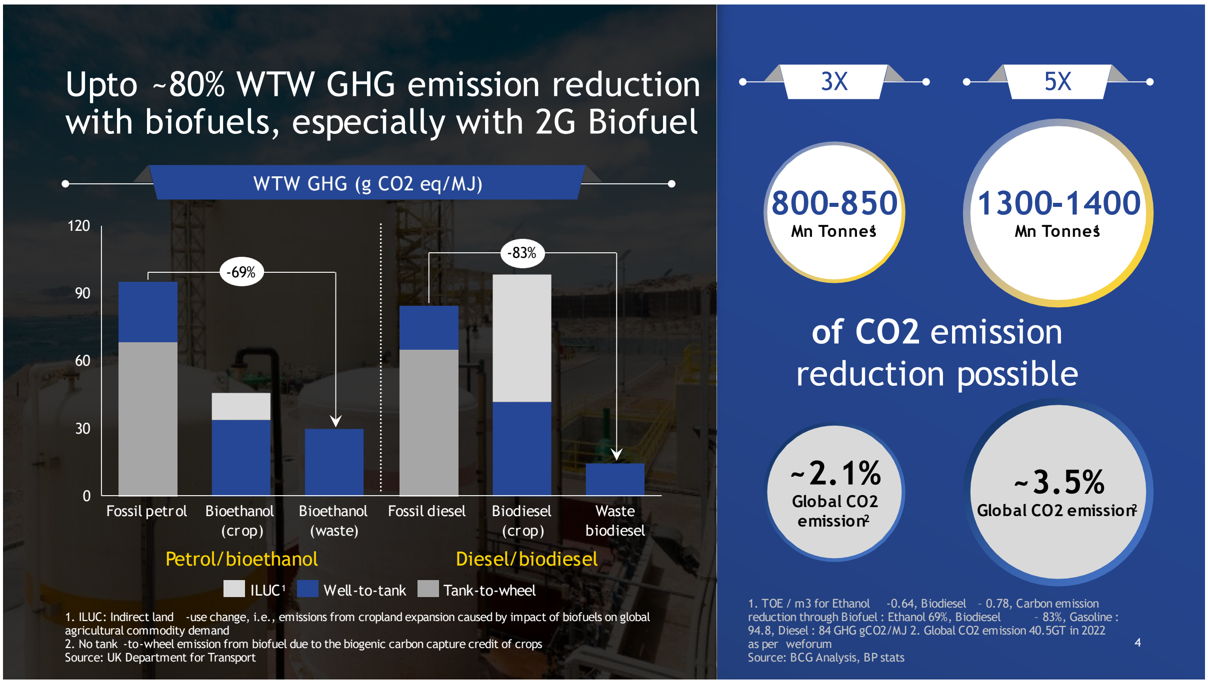
Fig 7. Benefits of achieving vision

Deep dive into the key benefits of Biofuel vision

Decarbonization and emission reduction

Biofuels can deliver up to 80% Well-To-Wheel carbon emission reduction, with the potential to be even carbon-negative through integration with carbon capture technology. Achieving the vision of 19 EJ could reduce carbon emissions by up to 1,400 million tons. That is equivalent to 3.5% of global CO_2 emissions today and would significantly accelerate progress towards decarbonization.

Fig 8. Carbon emission reduction by adopting biofuels



Biofuels are especially critical in decarbonizing long-haul transport sectors such as aviation and maritime. Sustainable Aviation Fuel (SAF) blends are already technically compatible with fuel delivery and airport fueling infrastructure. Adoption is currently constrained by high production costs, but long-term trends are encouraging, as SAF appears to be the most viable route to decarbonizing the airline industry, which has set ambitious decarbonization aspirations targets. Maritime biofuel should also see an increase in demand, especially to comply with IMO 2020. However, they still face headwinds in adoption due to their lower value premium vis-à-vis fossil fuel-oil, and the need for infrastructural modifications. E.g. >2x storage capacity required due to biomethanol's low energy density. HVO can still be used without any retrofitting.

Circularity and waste management

BCG's analysis shows that 2G biofuels can generate as much as 4.5 PWh energy (equivalent to ~17% of global electricity demand) from waste like forest biomass, agricultural residue, municipal solid waste etc. This could offer a compelling solution to the world's growing waste disposal crisis. The World Bank estimates that 2.01 billion tons of municipal solid waste are generated globally each year, of which at least 33% is not managed in an environmentally safe manner. In lower-income countries, 93% of this waste is dumped, triggering health hazards, ecological degradation, and methane emissions. Global waste output is projected to grow to 3.40 billion tons by 2050. Biofuels offer a unique way to re-purpose energy from various kinds of waste – including MSW, agri residue, forest residue, used cooking oil and industrial waste. The IEA projects that the share of biofuels produced from wastes and residues will increase from 8% today to 45% by 2030 in the NZE scenario.

Wider socioeconomic benefits

Biofuels have the potential to transform energy access and waste management, which are both critical for developing countries with large populations. They offer vital new avenues of sustainable economic development, heralding job creation, prosperity, and improved quality of life. IRENA estimates that global biofuel-led employment in 2021 stood at 2.4 million, with the bulk of these jobs linked to the agriculture supply chain, planting and harvesting feedstock. Bioenergy remains the biggest employer amongst renewables even among countries with highly mechanized operations such as the US (322,600 jobs) and the EU (141,600 jobs). Going forward, IRENA estimates bioenergy to continue to be the second-largest contributor to employment generation amongst renewables, after solar.

Buffer against market shocks

Biofuels could drive a significant reduction in fossil fuel dependency in the transport sector, providing up to 18.85-20.95 EJ, equivalent to 15% of total oil demand in transport in 2020. This could be a strategic and economic game-changer for import-dependent nations like India, China, and the UK. Biofuels could also aid mitigate the impact of recurrent volatilities in the oil and gas sector.

Long-term energy security

Biofuel supply is expected to increase from ~160 billion liters to 240 billion liters by 2027 under the IEA's accelerated case scenario. Biofuel is a clean, reliable, sustainable energy alternative that could boost the energy security and self-sufficiency of every nation. Adoption could be expedited further with the support of short-term policy targets like RED III and factors like higher taxation on fossil fuels, reduced price gap and better compatibility with existing engines.

Downstream product applications

Biofuel production also plays a critical role in supporting industries like the chemical, pharmaceutical industry, and the food & beverages industry. For instance, according to Allied Market Research, the renewable methanol market was valued at $672.9 million in 2019, and is projected to reach $959.6 million by 2027, registering a CAGR of 4.5%. Renewable methanol can be used to produce a wide range of polymers and fuels. It is also used in the chemical industry to produce acetic acid and formaldehyde, and as a de-staining agent, often included in the production of hydrocarbons, olefins, and some aromatic compounds. Similarly, bioethanol has seen pharmaceutical application in the production of medical wipes, antiseptics, pills, extracts, and tinctures. It is frequently used as an ingredient in skincare, pain relief and antidote products. The current output of bioethanol in the pharmaceuticals market stands at 3.37 billion liters and is expected to grow by 4.32% till 2027, powered by increases in global healthcare spending.

Valorization of by-products

Biofuel production also generates by-products with widespread industrial applications. Among the most prominent by-products is crude glycerin, which is obtained from the production of biodiesel. Technical-grade (crude) glycerin is used produce chemicals such as epichlorohydrin, propylene glycol and polyether polyols. Global consumption of refined glycerin stands at $2.5 billion and is expected to grow 4.3% from 2020-25, with multifarious applications from chemicals to personal and oral care products. Furfuryl is another by-product obtained while producing ethanol. Furfuryl alcohol is the primary use of furfuryl, followed by solvent applications in lubricating oils and butadiene extraction, as well as additional applications in the chemical and pharmaceuticals industry. Furfuryl consumption stood is expected to grow to 14,300 metric tons by 2024. Another by-product, acetic acid, is used in downstream value chains like the polyester, polyvinyl acetate, and polyvinyl alcohol industries. Global consumption of acetic acid stood at 15.5 million metric tons in 2021 and is expected to grow to 19.1 million metric tons by 2026.

Chapter 2:

Where we are on the journey?

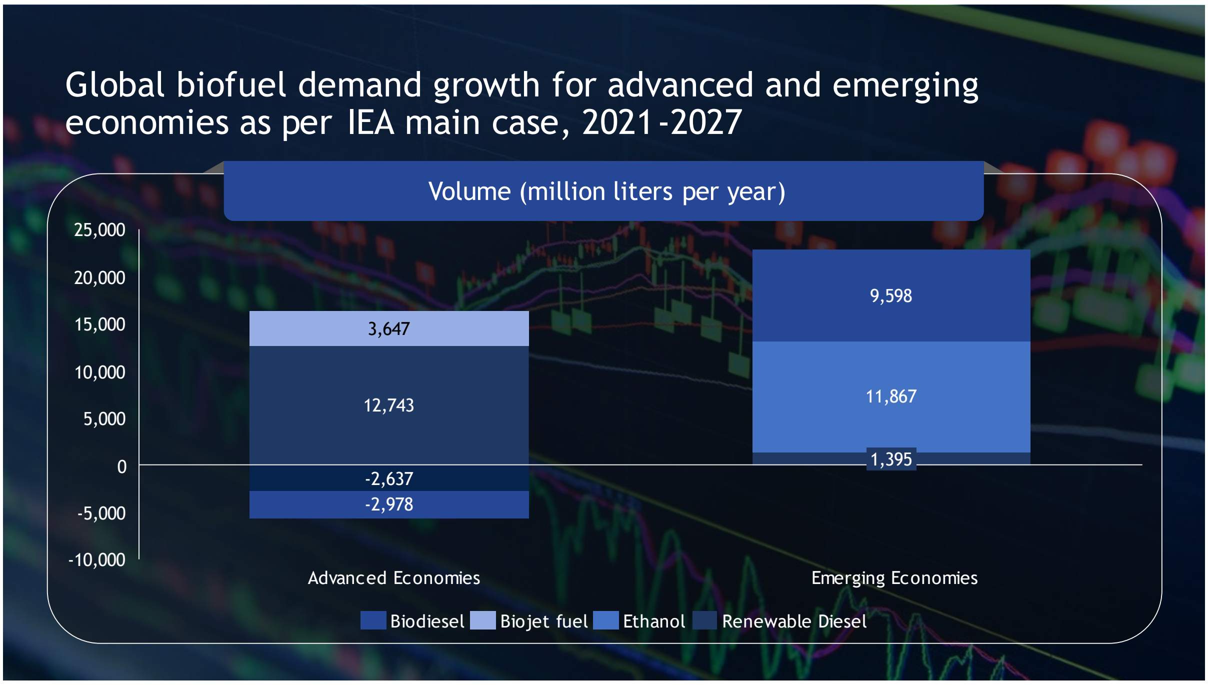
Tracing biofuel output and consumption patterns

Total global biofuel production today stands at 1,747 thousand barrels of oil equivalent per day, and growing, with the US leading the way at 643 thousand barrels of oil equivalent, followed by Brazil at 376 thousand barrels and EU at 236 thousand barrels. Other leading producers include Indonesia at 140 thousand barrels, China at 64 thousand barrels, and India at 37 thousand barrels per day. G20 countries contribute to

~80% of the global production and consumption of biofuels.

Countries around the world have adopted different outlooks to biofuels and paced adoption accordingly, and biofuels now accounting for 0 to 7% of G20 country's energy mix. The precise trajectory of adoption is often determined by factors like feedstock availability, favorable policy incentives, overall fuel consumption profile and demand patterns for gasoline vis-à-vis diesel. Renewable Diesel has been the largest growth contributor in biofuels in 2021-22 due to attractive policies in the US and Europe. Biofuel consumption patterns differ between developed and developing economies, usually linked to wider fuel demand. Developing countries such as Brazil, India, and Indonesia, with robust gasoline and diesel demand, are expected to see biofuel growth driven by ethanol and biodiesel. Conversely, in developed economies such as the EU, a fall in demand for liquid transport fuel will restrict growth in ethanol and biodiesel. Instead, in such geography's growth is likely to be driven by renewable diesel and biojet fuel driven by the need to reduce GHG emissions.

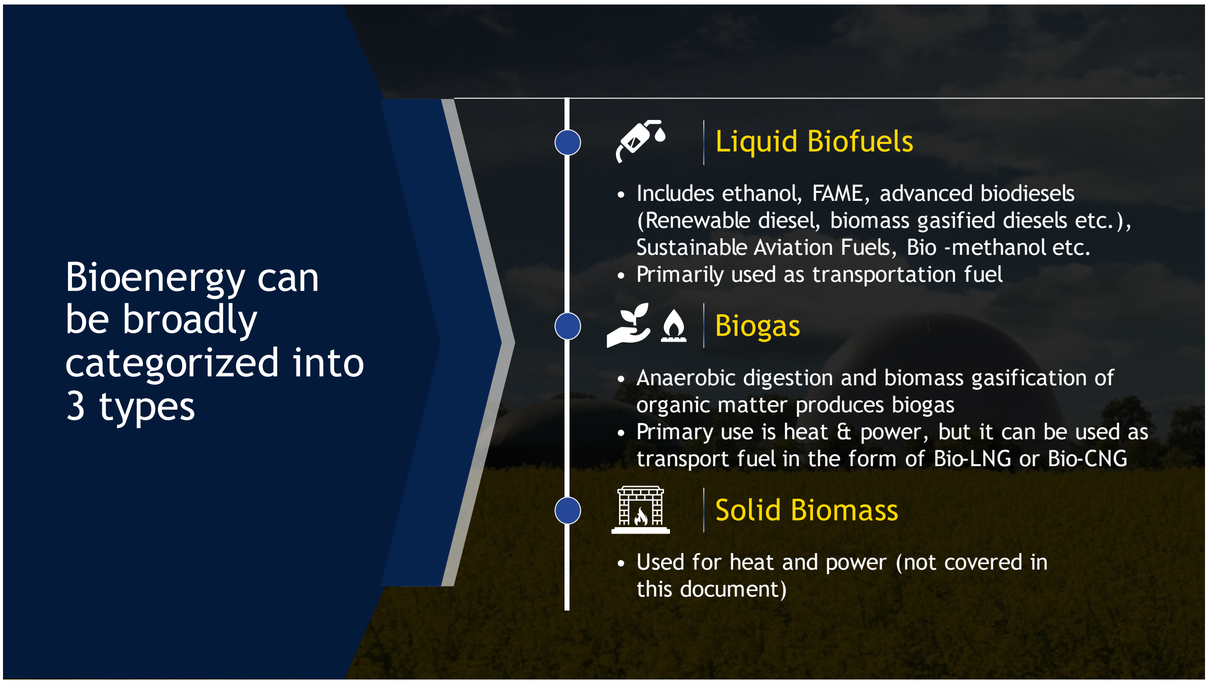
Fig 9. Biofuel demand in advanced versus emerging economies



Going forward, biofuel demand is expected to reach 240 000 MLPY (as per the IEA accelerated case) by 2027. Among G20 countries, the US, Canada, Brazil, Indonesia and India are expected to drive 80% of this demand growth, and Renewable diesel is expected to be the key growth driver due to conducive policies in the US (tax credits, renewable fuel standard etc.) and Europe. Overall, the biofuel share in transport fuel consumption is expected to increase from 4.3% to 5.4% by 2027.

As we are deep diving into the current status, it is important to evaluate by individual biofuel type

Fig 10. Different types of bioenergy

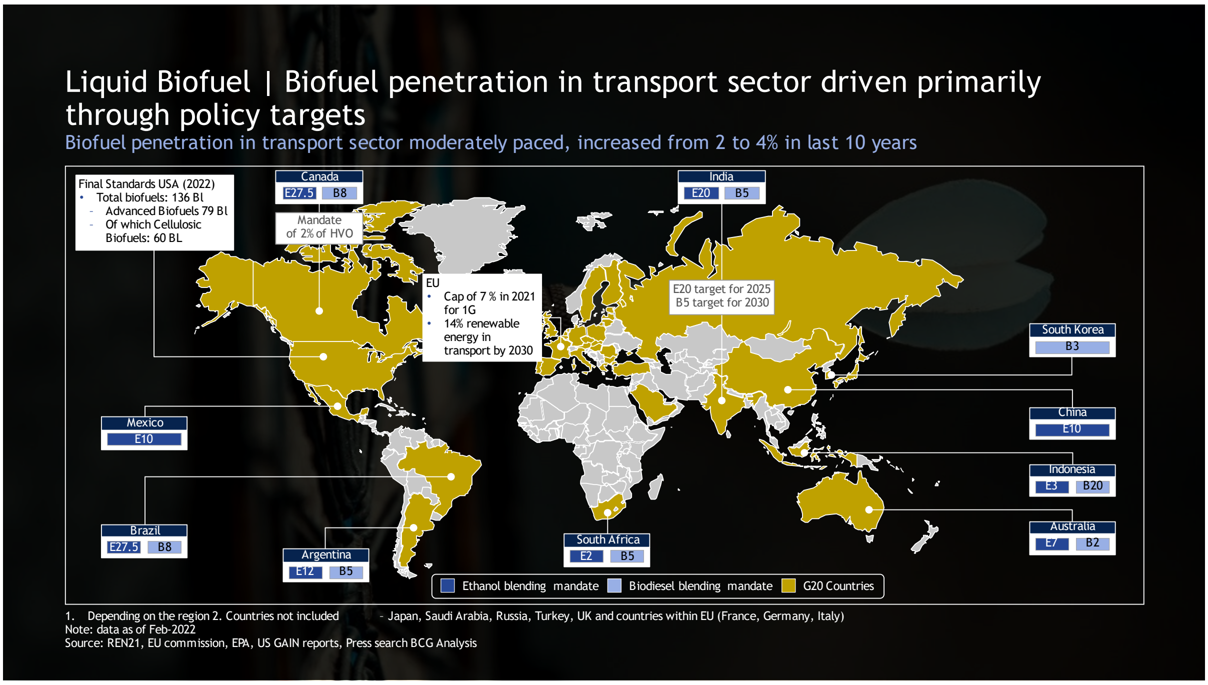


Ethanol and Biodiesel

Liquid biofuels have seen moderate growth in the transport sector, rising from 2% to 4% in the last decade. This has been driven primarily through policy targets for ethanol and biodiesel blending by various nations. As per IEA report Ethanol demand rose 3% during 2021-22, with India accounting for one-third of the growth, on the back of government support like guaranteed pricing for ethanol and advancing of ethanol blend targets. Brazil and US also continued to be key players. Brazil's large flex-fuel vehicle fleet offers customers the flexibility to switch between ethanol and gasoline depending on the prices, thereby reaping the benefits of depressed ethanol prices during last year - ethanol prices were ~30% lower than gasoline.

Biodiesel prices saw a hike in H2 2022, driven by higher agricultural commodity prices. This was a consequence of vegetable oil export losses from regions affected by geopolitical tensions, as well as supply chain disruptions, rising fuel prices, rising fertilizer prices and export restrictions. Many countries responded by reducing or freezing their biodiesel/ FAME blend targets. For instance, Brazil's upcoming 13% biodiesel mandate from March 2022 was reduced to 10%. Finland lowered its biodiesel distribution obligations in recognition of high fuel prices, while Sweden froze its emission targets for 2023, though the 2030 target remains unchanged. As the market recovers, Indonesia is expected to account for most of the biodiesel demand, driven by its 30% blend mandate and 4% rise in diesel demand.

Fig 11. Adoption of biofuel and mandates globally



Renewable diesel/ Hydrotreated Vegetable Oil (RD/HVO)

RD/ HVO expanded by 3800 MLPY, or 40%, in 2021-2022. The US accounted for most of this growth thanks to favorable policies like the Inflation Reduction Act and Renewable Fuel Standard. Growth in renewable diesel is primarily driven by advanced economies seeking to reduce GHG emissions. RD derives its popularity from its stability in long-term storage as well as extreme operating temperature/ pressure conditions, coupled with its value proposition as a drop-in fuel. Demand for RD has also been boosted by increasing biodiesel blending targets, coupled with blending and operational issues surrounding FAME (risk of technical issues above 20%, deposits, corrosion and degradation in fuel systems given physical/chemical properties, ~2.5% higher NOx emissions for B20 and >13% higher NOx emissions for B100 when compared to diesel, Cloud point up to -5 deg C, Cetane no. ~51 - low burn efficiency in engines). FAME demand is already stagnant in developed markets like the EU and is set to decline further even as HVO is poised to grow.

Sustainable Aviation Fuel

The aviation industry is responsible for ~2.5% of global emissions. In the BAU scenario, the industry's emissions would climb a staggering 300% by 2050. In 2021, the member airlines of the International Air Transport Association (IATA) pledged to achieve net-zero carbon emissions in operations by 2050. IATA and Mission Possible Partnership (MPP) also published their independent industry paths to Net Zero, targeting 65-75% reduction in emissions through SAF adoption. However, SAF adoption alone cannot decarbonize aviation – it will also take significant process improvements, emerging technology, and other solutions. In this context, IEA has estimated Biojet fuel demand to grow 37x (3,900 ML p.a.) by 2027, accounting for 1% of jet-fuel consumption.

Several industry associations and governments have introduced policies and incentives to encourage the adoption of biojet fuel. In the US, the Inflation Reduction Act (IRA) is offering USD 3.3 billion of support for SAF from 2023-31. The SAF Grand Challenge Roadmap aims to supply at least 3 billion gallons of SAF per annum by 2030, and enough to meet 100% of aviation fuel demand (around 35 billion gallons per year) by 2050. In the EU, the REFuel EU target of 2% by 2025 is expected to propel biojet fuel demand. Japan has set itself a target of 10% sustainable aviation fuel by 2030. On the industry front, the International Civil Aviation Organization (ICAO) set up a Carbon Offset and Reduction Scheme for International Aviation (CORSIA) in October 2022, and has set a target of net zero by 2050.

Despite these measures, SAF adoption is held back by high production costs, low feedstock availability, limited capacity and limited regulatory support. Of the 4 main pathways to SAF production (HEFA, GFT, ATJ and PtL), HEFA is the most advanced and is already being produced at a commercial scale. However, it has limited dedicated capacity and is more often co-produced with HVO. Meanwhile, GFT, ATJ are being piloted for commercial production, while PtL is in its early pilot phase. Production costs remain a tall barrier – compared to A1 jet fuel, HEFA costs 2x, GFT and ATJ cost 3-5x and PtL costs 7-10x. Notwithstanding the challenges, HEFA (Hydro processed Esters and Fatty Acids) has already established itself as a quality biojet fuel. It has powered over 1,000 flights with KLM, Lufthansa and SAS, and is now available at five airports – Bergen, Brisbane, Los Angeles, Oslo and Stockholm with Oslo providing biojet/HEFA through its hydrant system rather than a segregated supply. Furthermore, Neste is expanding its capacity to produce 1 million tons of HEFA annually in Singapore.

Biogas

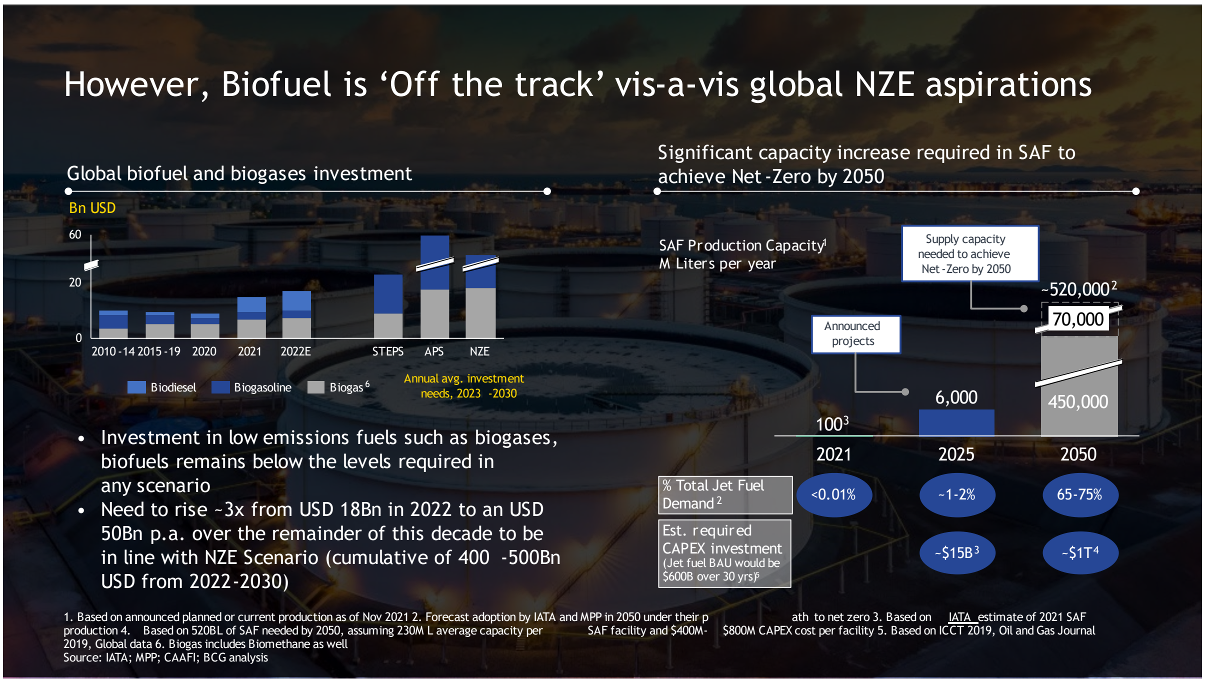
Biogas adoption has been powered by strong energy sector demand, driven by carbon neutrality targets. Biogas has particularly strong prospects for demand growth given its superior GHG abatement properties. It enables emission reduction through four key routes – (1) avoiding methane emissions from untreated feedstock; (2) using by-product (digestate) as a fertilizer instead of synthetic fertilizers; (3) replacing fossil fuels with a cleaner alternative; and (4) enabling renewable Ptx through Biogenic CO_2, a by-product of the biogas anaerobic digestion process.

Biogas can also be directly injected into the gas distribution networks for easier adoption. As a result, utilities, gas distribution and commercial/industrial applications such as chemicals and steel manufacturing are expected to drive growth for biogas. Supply remains healthy as biogas has proven to be one of the most cost-effective biofuel options. It also offers the most sustainable technology to meet the demand for organic waste treatment.

However, Biofuel is 'Off the track' vis-a-vis global NZE aspirations

Biofuel remains ‘off the track’ vis-à-vis global NZE aspirations – but there is tremendous headroom for growth

Fig 12. Biofuel is ‘Off the track’ vis-a-vis global NZE aspirations



Chapter 3: Key hurdles to be addressed to achieve the true potential of the biofuel vision

Despite the significant potential of biofuels, adoption hasn't quite reached its full potential yet. This is largely attributable to two key obstacles – feedstock supply issues, and technological limitations and can be unlocked by supportive policy framework and investments.

Feedstock supply issues

Global biofuel prices are closely linked to developments in feedstock prices as well as crude oil prices, distribution costs and blending policies. Biofuel feedstock, especially for 2G biofuel, is quite fragmented, with a complex supply chain where availability can be unpredictable.

They often must compete with other commercial applications of feedstock – for instance, forest residue is also used in paper manufacturing. At the same time, some of the readily available feedstock, such as sewage, tends to be of low quality, which can lead to higher production costs. The sector is also resolving concerns around sustainable land use and ethical feedstock sourcing. These factors result in high production costs compared to fossil fuels, and hence adoption thus far has been driven through policy targets.

Technological limitations

1G technologies are already significantly consolidated, but 2G technology is steadily maturing. Greater investment could accelerate technological progress, but several potential technologies are jostling for limited funding and feedstock, constraining their development, deployment. This is accompanied by high production costs, especially for advanced biofuels. As for the more advanced 3G and 4G technologies, the former currently has a negligible commercial scope and the latter is still at the concept stage. 3G biofuel is produced using non-arable land for example by cultivating algae, which has much higher yields and lower resource inputs than traditional energy crops. Annual production of Algal 3G biofuel is a meager 38 million liters (0.00253% of the total global production). While companies such as Synthetic Genomics and ExxonMobil have set ambitious targets, with aims to produce 10,000 barrels of algae biofuel per day by 2025, the commercial scale is still quite negligible. Meanwhile, 4G biofuel are the early concept stage, attempting to combine genomically prepared microorganisms and genetically engineered feedstock (e.g., cyanobacteria engineered to increase oil yields).

However, these challenges can be circumvented through a right mix of policy framework coupled/supported by robust investments in the biofuel ecosystem

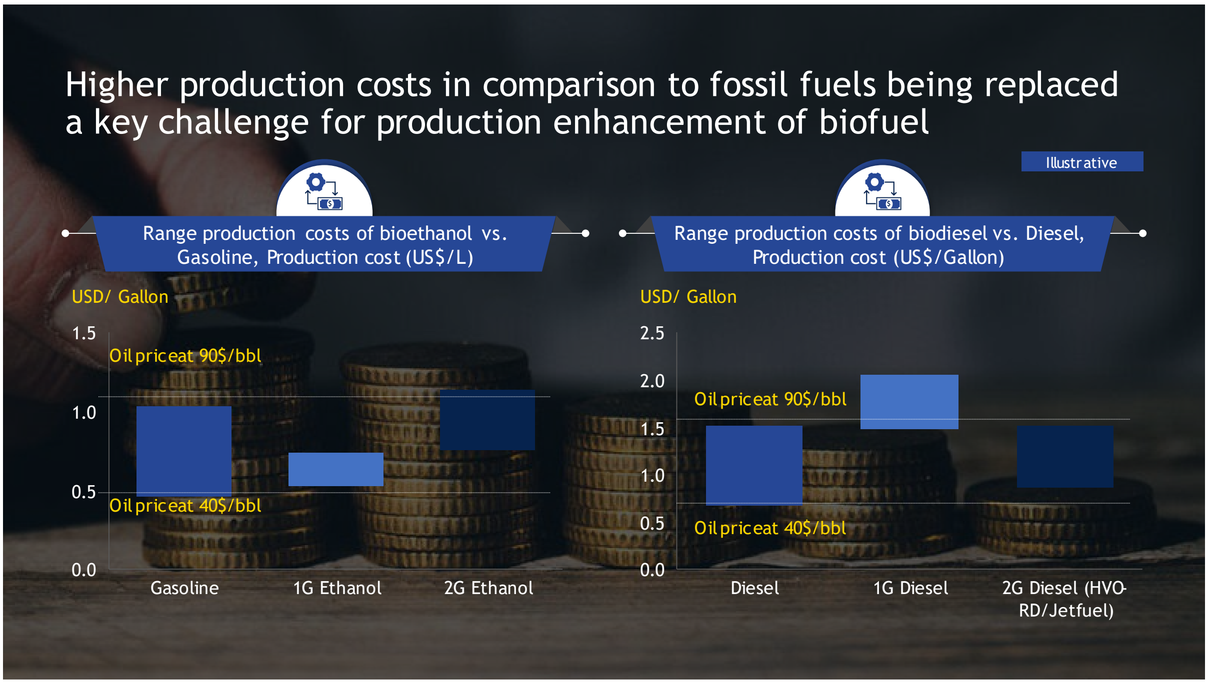
Policy framework

Policymakers have a vital role to play in fostering investor confidence and reducing uncertainty in the bioenergy sector. One effective measure for achieving this is by streamlining permit procedures and reducing setup and manufacturing lead times. Furthermore, policymakers should also introduce new guidelines for incentivizing sustainable and ethical feedstock sourcing. An example of this is India's Minimum Support Price (MSP) for oilseeds. Additionally, a uniform global certification framework, such as the International Sustainability & Carbon Certification (ISCC) system, can be established to recognize and promote sustainability and GHG savings across all forms of biomass, including feedstocks for bioenergy and biofuels production. Finally, a global framework for policy coordination and dialogue among nations is crucial to ensuring consistency and collaboration in sustainable energy policies.

Biofuel Investments

Investment in the biofuels sector is crucial for overcoming technology limitations and ensuring a stable supply of feedstock. Advanced technologies, such as an 800 ktoe biodiesel plant, require significant capital investment, with costs reaching up to USD 1.3 billion for capex alone. Additionally, investments in downstream infrastructure, such as blending terminals and pipelines, are necessary for the expansion of biofuels. Despite the potential for profit margins in the biofuels industry, variability in feedstock, biofuels, and byproduct prices can create unpredictability and discourage investors. However, according to the International Energy Agency (IEA), investments of at least USD100-270 billion in biofuels by 2030 are necessary to meet the targets outlined in current policies. This significant investment will not only help to overcome current barriers but also open new opportunities in the biofuel sector, making it an attractive option for investors.

Fig 13. Production cost comparison for Biofuel versus Fossil Fuels

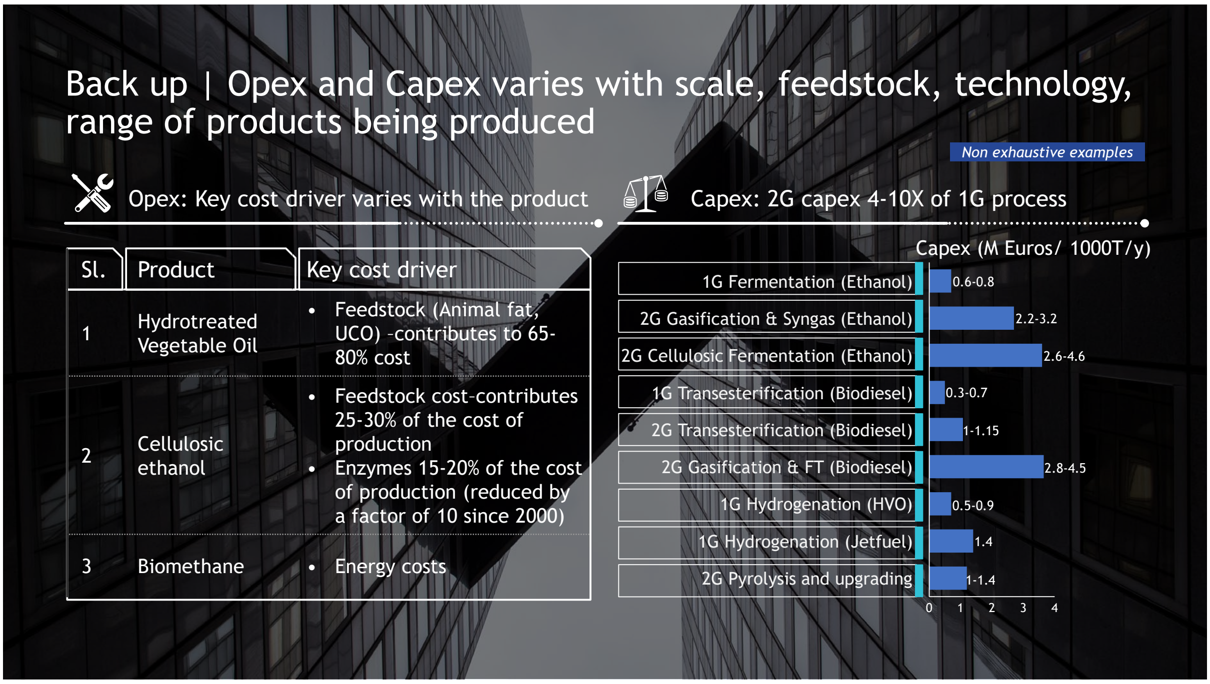


Case in Point: *SAF today is between 2-10x more expensive than conventional jet fuel. Aviation fuel contributes to ~25% of the operating expenses for airlines, which is equivalent to USD 40 per passenger. SAF usage would add an additional USD 40-350 per passenger, assuming 100% SAF use (though only 50% blend with A1 Jet fuel is permitted at present). If passed on to the passenger, this would translate to a 20-190% increase in the ticket price, at the same margins as today.*

Optimizing production costs to transform viability

Opex and capex vary significantly with the scale, feedstock, technology maturity and range of products being produced.

Fig 14. Opex and Capex variation with scale



Biofuel producers are thus exploring ways to further optimize the costs of production and improve the commercial viability of biofuels:

1) **Leveraging** synergies with existing operations and infrastructure can help reduce the burden of investment:

   a. **Co-processing of biofuels in existing refineries** reduces capital costs and the burden of access to hydrogen. Biofuels can be upgraded within FCCU, using Hydrogen from DHDS. However, the blend rate into fossil stream is limited to 2-10%.

   b. **Integration of technologies:** using 1G biofuel co-product as feedstock for a 2G plant can deliver up to 10-25% capital cost savings through shared processes and infrastructure, depending on the site. However, acceptance of the process depends on regulatory acceptance of the usage of genetically modified yeast in the fermentation process for the manufacture of biofuel, which is also transferred into the byproducts (used as animal feed).

   c. **Process step integration:** combination of enzymatic hydrolysis and fermentation stages in single unit can boost yields while lowering the capex.

   d. **Brownfield refineries**: these units can provide lower capex, especially for high-capacity plants. An example of this is ENI's USD 300 million investment in its Gela facility over four years to set up a biorefinery of 1 Bn L capacity. However, there are several hurdles to their expansion. Firstly, oil & gas decommissioning is not expected to accelerate until 2035. Thus, despite some rationalization, brownfield availability may be limited. Secondly, despite the use of existing infrastructure, high capex may be required to convert a facility to a biorefinery (equivalent to the cost of a smaller, new biofuels facility). Another hurdle is the sheer scale difference - oil & gas facilities are ~10X the size of typical biofuels facilities, and local feedstock access may be constrained at this scale.

2) **Technology interventions and improvements** can help facilitate better cost structures for private players.

   a. **Energy efficiency:** utilization of by-products like heat and steam through Combined Heat and Power units can help reduce operating expenses.

   b. **Integrated input production**: enzymes are a significant cost factor, especially for fermentation-based ethanol production. Integrated enzyme production and increased enzyme activity (leading to enhanced production yield per ton of feedstock) can lead to improved process efficiencies and lower costs. Some biofuel plants around the world are exploring the replacement of high-cost input for enzyme (glucose) with relatively low-cost input (biomass).

   c. **Technology and process improvements**: producers are striving to improve the conversion efficiency of liquid hydrocarbons which can be used as drop-in fuels (e.g., FT gasoline, diesel, and kerosene have very low conversion rates and high specific investment costs)

   d. **By-product valorization**: lignin, glycerin and other by-products could generate alternative revenue streams. For instance, biogas produces digestate as a by-product, which can be used as a fertilizer, further contributing to decarbonization by replacing synthetic fertilizers.

3) **Enhancing feedstock quality, availability and affordability** is a key concern for biofuels manufacturers. In a typical ethanol fermentation unit, feedstock can account for as much as 25-50% of the total cost of production, while for HVO Feedstock (Animal fat, UCO), it accounts for as much as 65-80% of the cost.

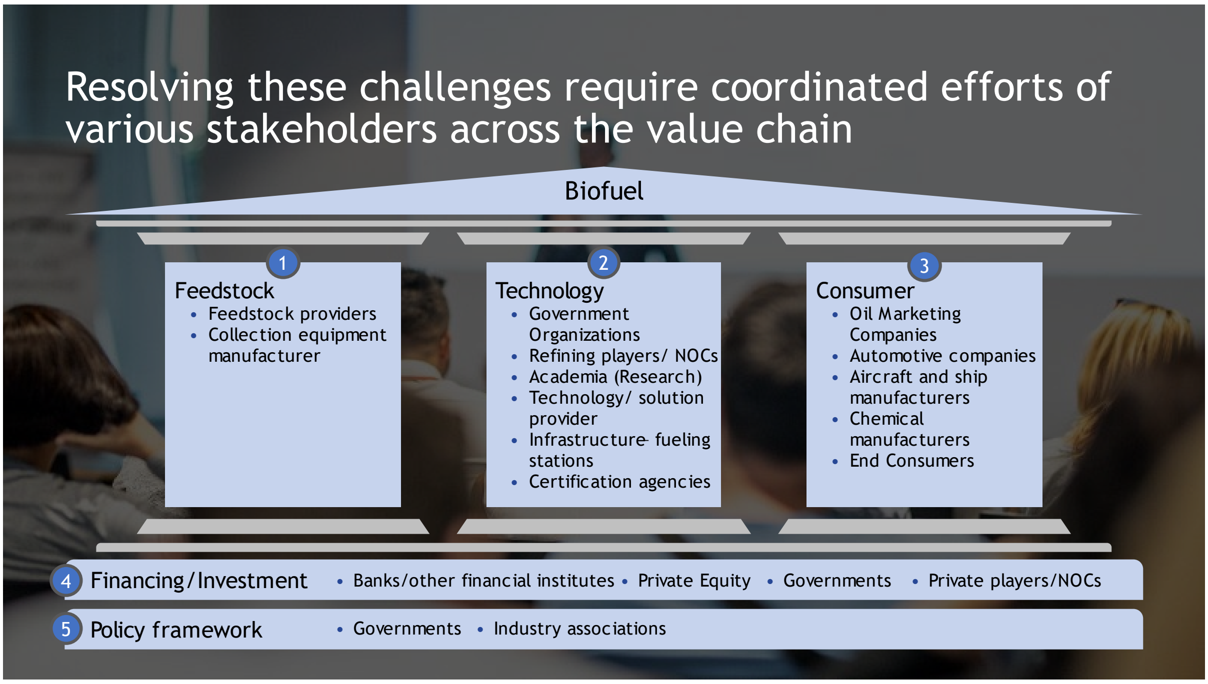
   a. **Long-term supply contracts:** hike in feedstock prices due to shortages can affect profitability of biofuels plants. Hence, long-term supply agreements can help hedge against supply risks associated with feedstock.

b. **Vertical integration**: In addition to long-term supply contracts, some private players have integrated backwards to ensure feedstock access. For instance, British bio-power group Drax have invested in wood pellet mills in the US; Neste and other HVO companies have acquired UCO collection entities; VPM is developing energy crop supply chains in South America.

As an emerging technology, biofuels will inevitably have higher production costs than fossil fuels for now. Therefore, in this phase, adoption should be driven more through policies and on-ground support on implementation until the commercial scale and economics become undeniable – and this is where governments, public-private partnerships and academic collaboration comes into the picture.

A global collaboration driving coordinated efforts of stakeholders is critical at this juncture to unlock the true potential of Biofuel

Fig 15. Global collaboration critical to unlock the true potential of Biofuel



Realizing the biofuel vision will require significant commitments in technology, investment, feedstock supply, policy, and demand-side support to achieve cost parity. There is an urgent need for concerted effort between stakeholders across the value chain and across countries. Governments and industry – including feedstock and technology providers, equipment manufacturers, infrastructure providers, oil marketing companies and certification agencies – should join forces to advance biofuel technology deployment and penetration. Alongside them, banks and other financial institutions as well as private equity, public bodies and NOCs will have to step up financing and investment. This will pave the way for greater R&D by government agencies, academia and private players/NOCs, which will in turn influence production and delivery volumes, driving profitability through optimization.

A global template for unlocking the biofuel vision

Biofuel adoption in India has been successfully accelerated on the back of the National policy on Biofuel 2018 and its subsequent amendment in 2022 coupled with a combination of clear mandates and targeted incentives. India's experience could form a global template for G20
countries to achieve the biofuel vision. This would require coordinated efforts across five key levers – technology, feedstock, policy, investment, and consumers:

1) **Technological development** – countries must promote technological innovation across all segments of the value chain to improve cost efficiency and conversion efficiency. There are already inspiring examples of technology-sharing between nations to share learnings and accelerate time to market, such as the Brazil-Mozambique bilateral partnership, where Brazil was the technology provider and Mozambique feedstock provider.

2) **Feedstock** – countries must expand and secure feedstock sources to help the sector achieve its full production potential. They should collaborate to develop an efficient supply chain network for waste and residue feedstock access. They should ramp up supplies using advanced and cost-effective equipment, processes and infrastructure for feedstock collection, segregation, and storage. They can draw on the help of advanced analytics solutions for feedstock tracking and tracing e.g., organic cotton tracking using advanced analytics by SAS and BCI.

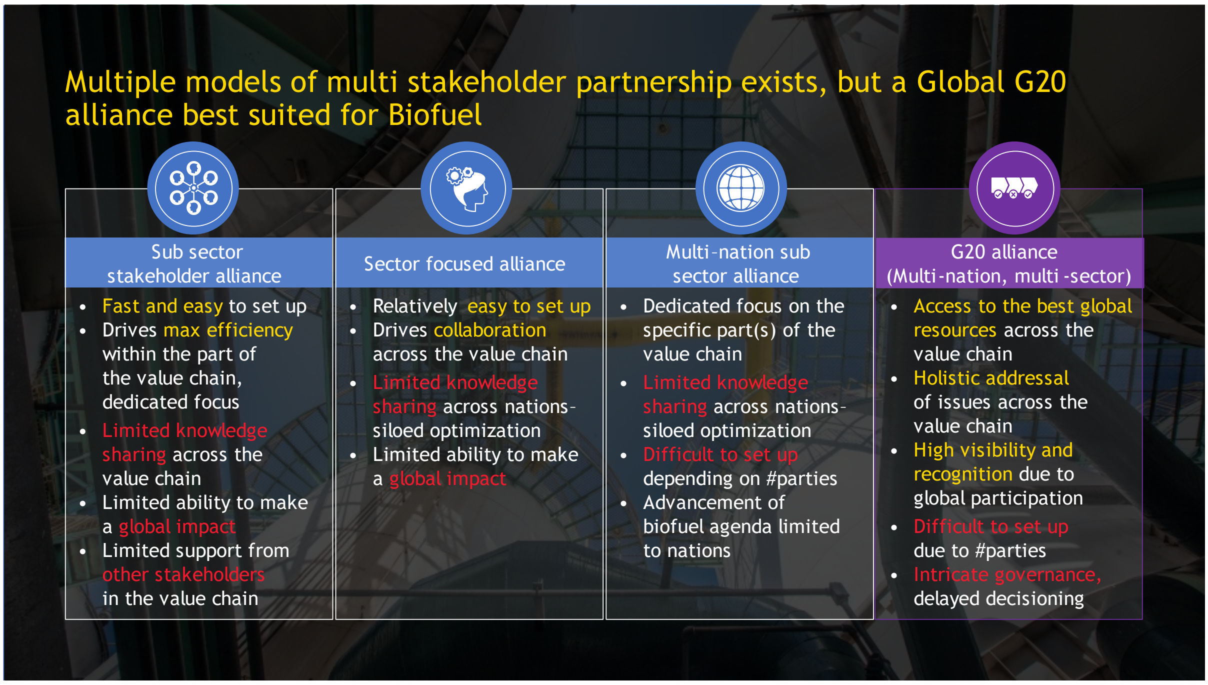
3) **Financing and investment** – countries should offer grants and funds to encourage advanced biofuels research. In addition, they should devise favorable financial terms for biofuel manufacturers to aid them in securing investment for capacity building and infrastructure augmentation, along the lines of India's targeted financial assistance to enhance ethanol distillation capacity. Given the unpredictability of profit margins, countries could assure long-term contract stability to reassure interested players, just as solar players were supported by government-led power purchase agreements in the US. Countries could also explore tripartite agreements between biofuels manufacturers, financial institutions, and oil marketing companies, to ensure favorable terms for debt funding for biofuels projects. They could also introduce subsidies to build cost parity, along the lines of Indian government subsidies for organic farming.

4) **Policy framework** – Policymakers should articulate a clear, strong commitment to reduce uncertainty and strengthen investor confidence. They could help by streamlining permit procedures to reduce setup and manufacturing lead times. For instance, Singapore launched the simplified Credit Treatment Scheme to enable easier market registration for solar consumers. Countries should also introduce new policy guidelines for incentivizing sustainable and ethical feedstock sourcing, like the MSP (Minimum Support Price) for oilseeds in India. At a global level, there is a growing need for an overarching framework for dialogue and policy coordination among nations, along the lines of the Global Geothermal Alliance or the International Solar Alliance.

5) **Consumers** – this also calls for concerted efforts to encourage end-consumer adoption by driving technological innovation from the demand side (i.e., OEM manufacturers).

At present, investment in low-emission fuels such as biogas and liquid biofuels remains below the levels required under all IEA scenarios. To meet the NZE Scenario – i.e., cumulative of USD 400-500 billion from 2022-2030 – investment must increase ~3x from USD 18 billion in 2022 to USD 50 billion per annum by 2030. Given the impetus required, there is an urgent need for coordinated efforts among G20 members, to pool in their knowledge, resources and work towards achieving the common goal of biofuel vision.

Fig 16. Multiple models of multi stakeholder partnership exists



Chapter 4: International Biofuel alliance: A blueprint for success

The proposed International Biofuel Alliance:

The objective of the alliance

The proposed alliance would promote synergies in biofuel research and development among developed and developing countries. It would facilitate transnational government interaction, industrial cooperation and academic engagement, in order to improve the deployment, marketability, penetration and profitability of biofuels. This would give countries a buffer against energy price volatility and supply shocks, while achieving environmental goals.

Defining the priorities of the alliance

The alliance would coordinate a global framework of incentives to expedite cooperation among member countries to promote biofuel accessibility and sustainability. It would define common technical standards across nations to promote biofuel R&D and technological collaboration. It would also support quality standardization, uniform certification and trading across member countries to further encourage biofuel uptake.

As the biofuel industry matures, the alliance would promote greater investment and funding through favorable financing terms for players, as well as voluntary contributions from members. It could augment members' capacity and increase adoption further through support for new business models driven by collaborative research and process improvements.

The alliance would also nurture the biofuel ecosystem through conferences, workshops and fundraising efforts to promote new ideas and best practices. It could even build a central knowledge repository and resource center to raise awareness and offer training programs.

A five-year roadmap

Over the next five years, the alliance would collaborate with stakeholders across the value chain on a series of vital initiatives. On the supply side, the aim is to double production capacity among key biofuel suppliers. The alliance would seek to standardize biofuels and encourage high-volume commodity training of biofuels on global trading forums. It would also create training programs and standards for a highly qualified biofuel workforce in the G20.

To encourage demand, the alliance would also have to encourage cost parity for 2G technology and expedite progress on the commercialization of 3G. These initiatives would need financial firepower, with USD 100 billion to be earmarked for biofuel R&D by 2030 to encourage wider adoption. The alliance would also coordinate biofuel incentives across G20 nations to pave the way for future technologies to adapt to the industry's needs.

Fig 17. Example design basis for International Biofuel Alliance

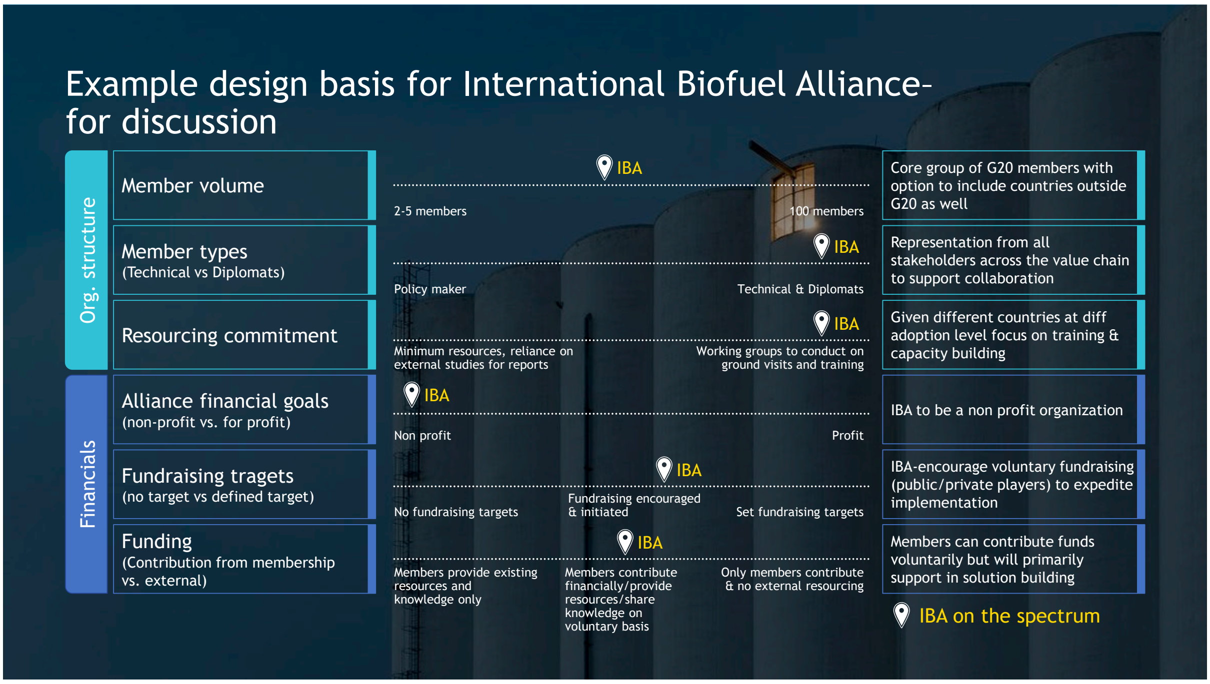
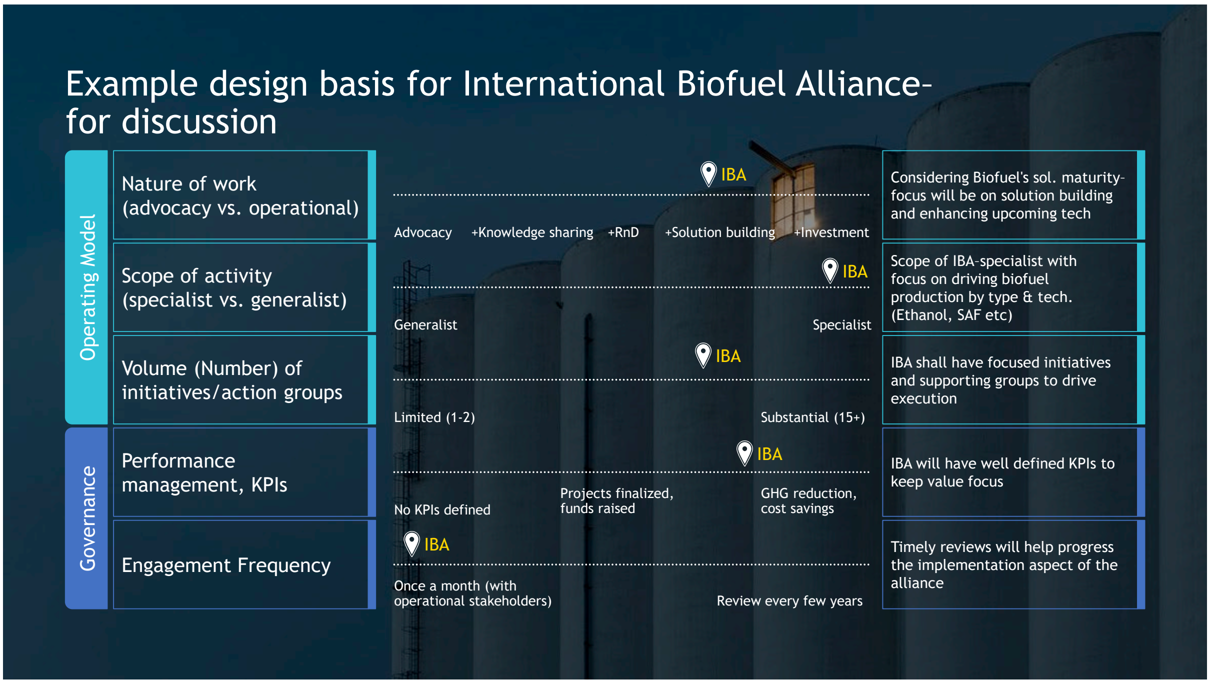
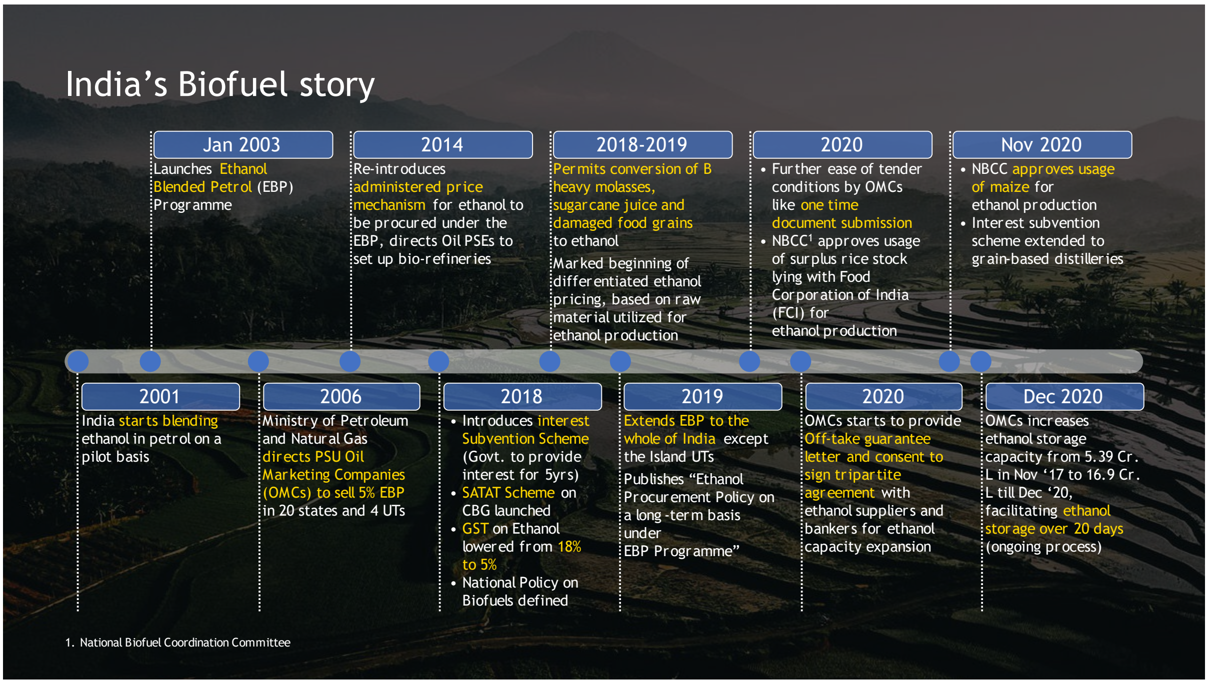


Fig 18. Example design basis for International Biofuel Alliance



Spotlight on India – a trailblazer in biofuels

Fig 19. India's Biofuel story



India has made great strides in unlocking the true potential of biofuels, extending even beyond its original policy targets.

India's ethanol consumption has outgrown production due to the increasing demand, although Biodiesel demand is still catching up. The country's ethanol supplies grew to 433.6 crore liters in ESY 2021-22.

To promote SAF, Indian Oil Marketing companies are setting up plants at three locations in the state of Karnataka, Maharashtra and Haryana. India is also pursuing innovative consortium partnerships to promote SAF.

In addition to liquid biofuel, Sustainable Alternative Towards Affordable Transportation (SATAT)" was launched on 1st October, 2018 to promote biogas as well. Oil and Gas Marketing Companies (OGMCs) viz. IOCL, HPCL, BPCL, GAIL and IGL are inviting expression of interests from potential entrepreneurs to procure CBG from their projects. Till Dec'22 OGMCs participating in SATAT have issued 3826 Letters of Intent to entrepreneurs for procurement of CBG under SATAT initiative and commissioned 40 CBG plants with a total capacity of ~225 Tons per day.

Under this initiative various enablers such as assured price for off-take of CBG with long term agreements by Oil and Gas Marketing Companies, Central Financial Assistance to CBG/biogas plants under Umbrella Scheme of National Bio Energy Programme of Ministry of New and Renewable Energy; inclusion of bio manure produced from CBG plants as Fermented Organic Manure (FOM) and Liquid Fermented Organic Manure (LFOM) under Fertilizer Control Order 1985; inclusion of CBG projects under 'White Category' by Central Pollution Control Board (CPCB) on case to case basis; inclusion of CBG projects under Priority Sector Lending by RBI; loan products from various Banks for financing of CBG projects; directions from Department of Fertilizers for mandatory off-take of FOM by Fertilizer companies etc. have been provided to increase the production of CBG.

Further, Ministry of Petroleum and Natural Gas has issued guidelines for co-mingling of domestic gas for supply for Compressed Natural Gas (Transport) & Piped Natural Gas (Domestic) segments of City Gas Distribution (CGD) Networks for synchronization of CBG with CNG in CGD Network.

India has already started reaping the benefits of its efforts on biofuels across multiple levers:

1) **Decarbonization:** India's biofuel adoption has delivered GHG emission reduction to the tune of 31.8 Million metric tons by November'22 in last 8 years.

2) **Energy security:** India reached its milestone of 10% ethanol blending nearly 5 months ahead of schedule, achieving a forex saving of INR ~50,000 crore. By 2025, at 20% blending level, ethanol demand will have risen to 1,016 crore liters, and the industry will have grown over 500% from ~INR 9,000 crore to ~INR 50,000 crore. This has been achieved through significant investment in associated infrastructure – India's ethanol distillation capacity has increased ~2X in the past 8 years, with a 50%

increase in number of distilleries in just 6 years.

3) **Socioeconomic benefits:** Ethanol production has helped expedite payments of ~INR 49,000 crore to farmers as of December 2022.

4) **Circularity:** Under the Pradhan Mantri JI-VAN (Jaiv Indhan-Vatavaran Anukoolfasalawashesh Nivaran) Yojana scheme, Government of India is providing financial support to commercial projects as well as demonstration projects for second generation (2G) ethanol projects with a total financial outlay of approximate $300 million US for the period from 2018-19 to 2023-24. Four 2G plants are already at an advanced stage of development – IOCL Panipat (30 million liters, BPCL Bargarh (30 million liters), HPCL Bhatinda (30 million liters) and Numaligarh Refinery Limited (~55 million liters). IOCL also unveiled Asia's first 2G Ethanol Bio-Refinery at Panipat Haryana in August 2022. This project is expected to reduce Greenhouse Gases equivalent to about 3 lakh tonnes of CO2e emissions per annum.

Furthermore, the advancement of the 20% biofuel blending mandate from 2030 to 2025 will have ancillary benefits too, freeing up INR 35,000 crore worth of gasoline for export, and reducing CO_2 emission by 21.6 MnT.

How India became a frontrunner in ethanol adoption

Fig 20. India's ethanol and biofuel production and consumption

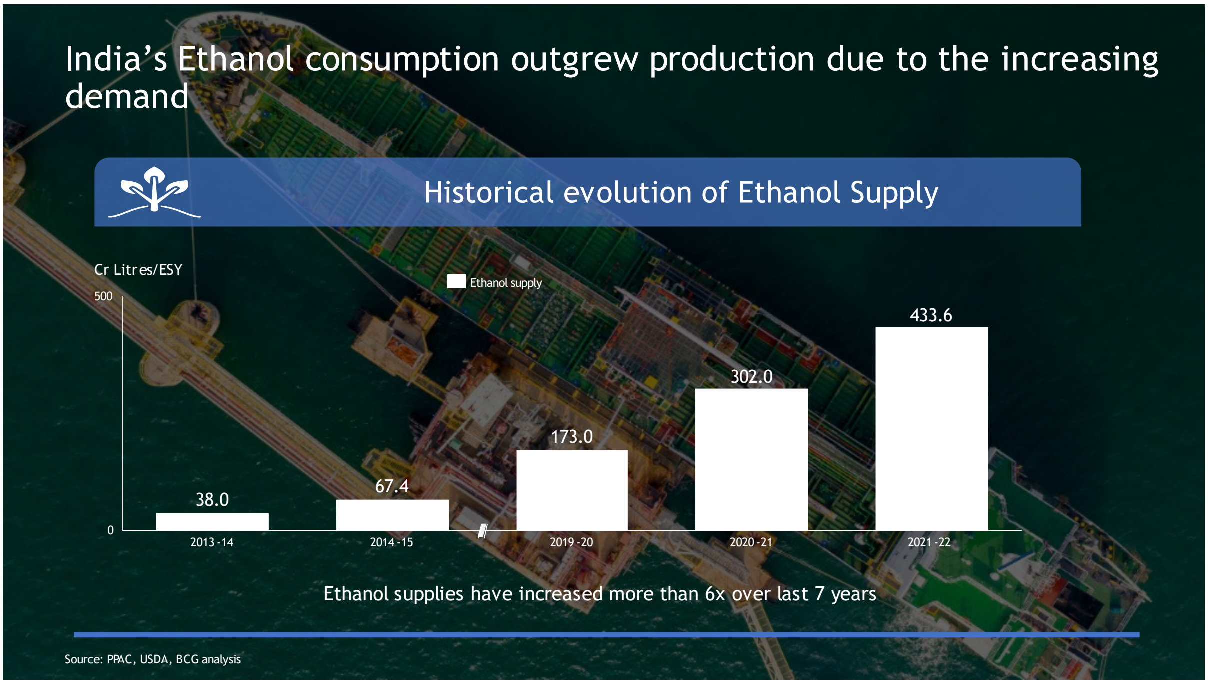
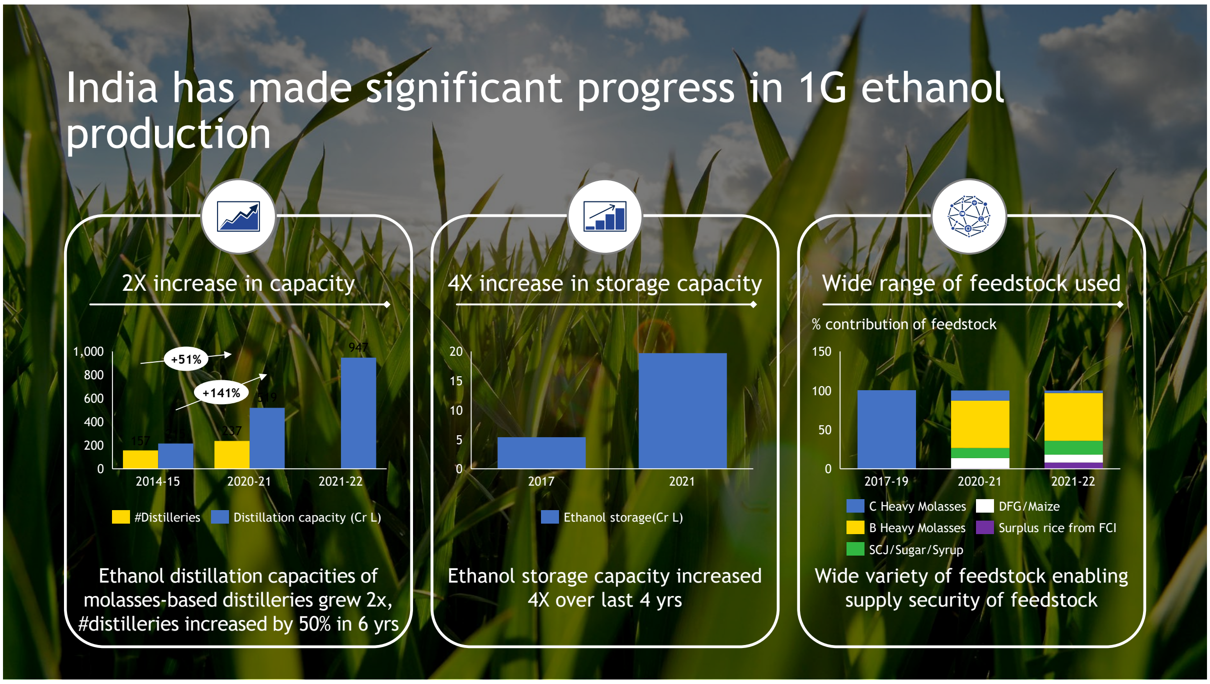


Fig 21. India's ethanol production



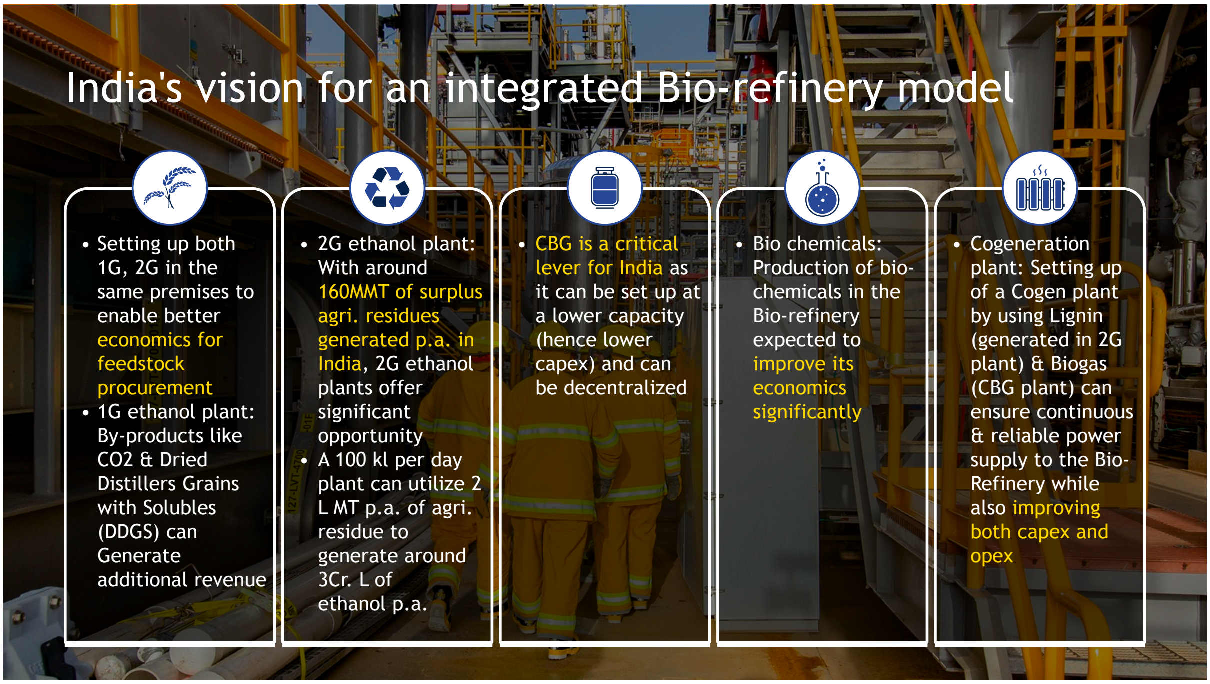
India's ethanol supplies have increased more than 6x over the last 7 years to 433.6 crore liters. The country achieved the milestone of a 10% ethanol blending rate five months ahead of schedule and it has now advanced its 20% ethanol blending target from 2030 to 2025.It has also set a target for 5% biodiesel blending by 2030.

Ethanol adoption has been accelerated by a combination of clear mandates and attractive incentives. India introduced Ethanol Blended Petrol (EBP) in 2003, and the government initially mandated public-sector Oil Marketing Companies to sell 5% EBP in 2006. A decade later, it introduced the administered price mechanism for ethanol to be procured under EBP and directed public-sector oil companies to set up bio-refineries. In 2018, the government subsidized interest rates and lowered taxes for ethanol from 18% to 5%, driven by a new National Policy on Biofuels. It has since systematically introduced differentiated ethanol pricing, expanded EBP programme to the entire country and published a long-term Ethanol Procurement Policy.

In 2020, oil marketing companies entered into an agreement with ethanol suppliers and bankers for ethanol capacity expansion. It also permitted the use of surplus rice stocks and maize for ethanol production. The Ministry of Environment and Forests simplified environmental clearances to enhance the ease of doing business. The government has also made significant investments in infrastructure, expanding ethanol storage capacity 4X over the last 4 years to ~20 crore liters, besides increasing the number of distilleries by 1.5x.

Driving the future of ethanol in India

Fig 22. India's vision for an integrated Bio-refinery model



India plans to further increase ethanol distillation capacity by >3x to 17 billion liters per annum by 2025. Significant measures are underway to achieve this growth, including a financial assistance scheme by the Department of Food and Public Distribution and long-term offtake agreements have been signed for design capacity of 745 crore liters per annum for ethanol production. The government is also updating regulatory standards for vehicles to run on E20 fuel from 2023 and flex-fuel vehicles from 2024.

On the demand side, around 17 crore two-wheelers and 3 crore four-wheelers in India today are already E10-compliant. A joint study commissioned by Indian Oil, the Automotive Research Association of India, and the Society of Indian automobile manufacturers to assess the impact of E20 fuel on the performance and durability of E10 vehicles is under progress. Material Compatibility tests conducted as part of the study indicate the effects of E20 fuel on metal samples are comparable with those of E10 baseline fuel.

To usher in a fleet compatible with its vision for biofuels, India is now planning a phased rollout of high-blend rate compatible vehicles. The initial rollout of new E20 material-compliant vehicles will begin from February 2023, while oil marketing companies have been directed to make E20 fuel available in select pumps across 15 cities in 9 states the same month. Major OEMs are gearing up to roll out two-wheelers with flex-fuel engines from mid-2024, and four-wheelers with flex-fuel engines from mid-2025.

The Ministry of Heavy Industries has also approved a Production-Linked Incentive scheme for the automobile and auto component industry, *which inter alia* includes auto components of flex-fuel engines. This will expedite demand-side investment through clear incentives of up to 13% for flex-fuel vehicles and their components. The government has also offered for the component upgrade cost for FFVs to be fully compensated. The government expects this comprehensive package of mandates and incentives to help grow the industry from INR 9,000 crore to INR 50,000 crore by 2025.

Lessons from the Indian model of transnational biofuel collaboration

India's bilateral partnerships with the US and Brazil offer a template for global biofuel collaboration. The US-India Strategic Clean Energy Partnership was designed to promote sustainable biofuel production and facilitate public-private dialogue on biofuel development and deployment. It is driven by the US-India Public-Private Biofuel Task Force, an industry-led body, which shares information and policy development inputs and identifies research and deployment projects for mutual benefit. The ambit of this cooperation has also expanded to include the Sustainable Aviation Fuel and Renewable Diesel Trilateral Cooperation agreement with Brazil, which will accelerate R&D and explore policy options to bring SAF to market.

Meanwhile, India and Brazil have launched a new Center of Excellence on Ethanol. They have established a technical exchange initiative focused on improving the production efficiency of sugarcane/molasses ethanol and introduced higher ethanol blending in the fuel pool. Their Joint Working Group on Bioenergy Cooperation is now leading a bilateral alliance to implement and scale up ethanol blends (E20+), flexible fuel vehicles, biodiesel, biogas/ biomethane policies, technology development and advanced fuels like SAF and ethanol.

Conclusion

Biofuels can help both developed and developing countries find a pragmatic balance between decarbonization and energy security. Achieving the true potential of biofuels would give countries across the world a credible buffer against market shocks and volatilities, while curbing emissions and delivering wide-ranging socioeconomic benefits for generations to come.

In key sectors like transport, biofuel blends are already compatible with existing infrastructure, which could enable a smoother energy transition. However, this emerging sector still needs focused investment in technological development, feedstock supply and consumer initiatives to correct decades of underinvestment and achieve cost parity. It will also require a strong, collective policy commitment from major nations. Through coordinated operationalization-oriented efforts by all stakeholders across nations, and global public-private-academia, we can expedite biofuel technology deployment, adoption and profitability.

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