Role of Non-grain-based Biofuels in India's Energy Transition

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GLOBAL BIOFUELS ALLIANCE

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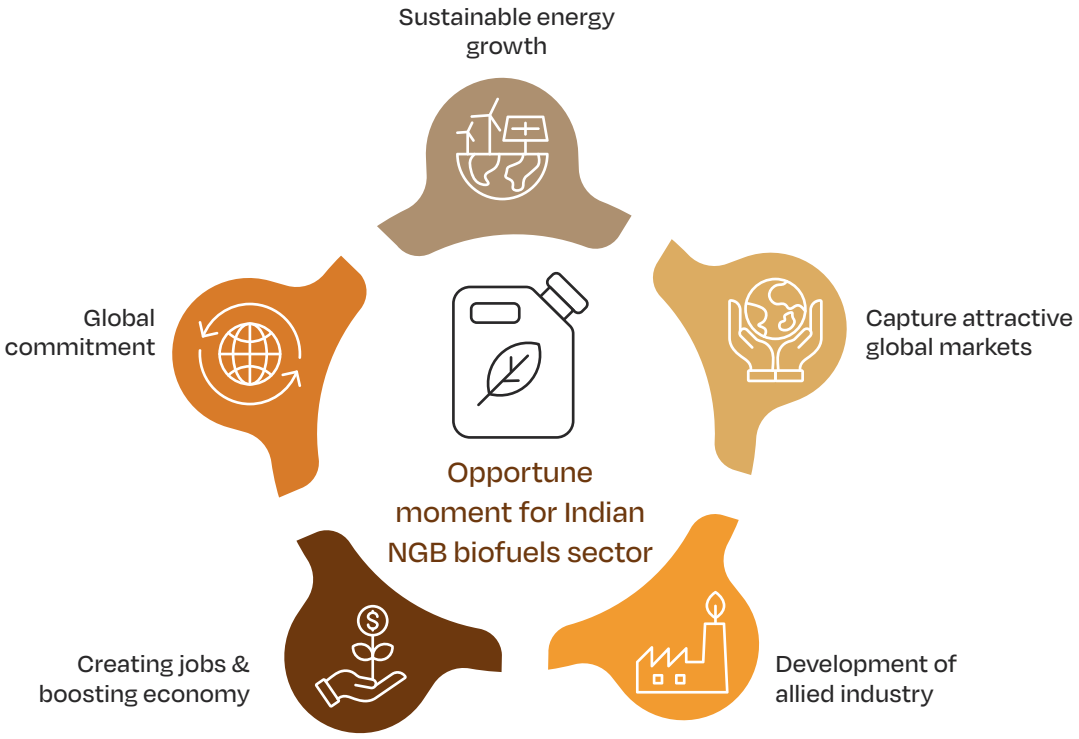
NON-GRAIN BASED BIOFUELS – WHY NOW | OPPORTUNE MOMENT FOR INDIA

The global non-grain-based (NGB) biofuels market is evolving, creating an attractive opportunity for the Indian NGB biofuels sector. This opportunity is driven by levers such as sustainable energy growth, global commitment, capturing attractive global markets, creating jobs & boosting economy, and development of allied industries.

Exhibit 1 | Levers driving growth of NGB biofuels sector in India



Sustainable energy growth

From a sustainability perspective, NGB biofuels are gaining acceptance as a strategic lever. Countries and corporations are considering NGB biofuels as an integral part of their decarbonization journeys. However, their ancillary impacts are not yet acknowledged completely. For example, NGB biofuels address concerns related to growing crops for fuel vs. food and the indirect implications of changes in land use iLUC. In addition, the contribution of NGB biofuels in the reduction of GHG emissions is 30-50% greater compared to food-based biofuels.

As India's energy demand continues to grow, and India needs to find avenues to support this energy growth sustainably, there is a strong case for India to leverage NGB biofuels on its path to decarbonization, especially in hard-to-abate sectors such as aviation and heavy transportation.

Global commitment

A favorable regulatory environment is contributing to increasing attractiveness of NGB biofuels sector. Countries are increasingly committing to adopting NGB biofuels to reduce carbon emissions, resulting in supportive policies and tax incentives. For example, in the U.S., the Renewable Fuel Standard (RFS), Blender's Tax Credit (BTC), and state-level Low Carbon Fuel Standards (LCFS) create stackable benefits, contributing to the increasing competitiveness of NGB biofuels. Similarly, the EU's RED III[1] raised the 2030 target for advanced biofuels in transport from 3.5% to 5.5%. India needs to capitalize on this trend by staying ahead of global norms and securing a leadership position. By developing a NGB biofuels sector, India can potentially address attractive global markets and also create a template for other developing economies and global south to follow.

Capture attractive global markets

The NGB biofuels market globally is expected to grow at a healthy rate of 23.7% CAGR, increasing from ~ $20 Bn in 2023 to ~ $75 Bn by 2029. This will create a significant revenue pool in the coming decade and by developing the NGB biofuels sector, India can aim to capture a significant part of this value pool. For example, India can aim to be a SAF export hub addressing both domestic and global markets.

Creating jobs and boosting economy

IMF projects that India needs to create 143-324 Mn jobs by 2050[2] and achieving this job generation will require shifting towards more dynamic sectors. In India, where ~45% of the workforce is engaged in agriculture and back-integrated sectors, unlocking NGB biofuels industry will lead to advancement of these sector by creating jobs. In addition, NGB biofuels offer a unique opportunity for farmers to enhance their regular income by turning waste into wealth. This additional stream of income can be particularly beneficial during times of market volatility or poor harvests of traditional crops and continue to drive economic growth at grassroot level.

Development of allied industry

By developing the NGB biofuels sector, Indian economy can see a development of allied sectors driven by increase in demand, stimulating growth and innovation in the manufacturing sector. Further there will be increase in demand for consumables such as enzymes and catalysts. Globally, the NGB biofuels allied industry is in a nascent stage. Consequently, by taking a pole position in the sector, India can develop an indigenous industry for equipment, technology, and enzyme production, thereby contributing to the 'Make in India, Make for World' vision.

Thus, there is a strong case for Indian NGB biofuels sector to capitalize on these evolving levers and secure a leadership position. In this context, this study assesses the potential and benefits of unlocking the NGB biofuels opportunity in India. The report also underscores the key questions that need to be deliberated by stakeholders, as well as key challenges that need to be addressed to unlock this potential. Finally, the study evaluates the solutions that would encourage the development and commercialization of this industry.

NGB BIOFUELS POTENTIAL AND BENEFITS IN ACHIEVING THIS VISION

What are NGB biofuels?

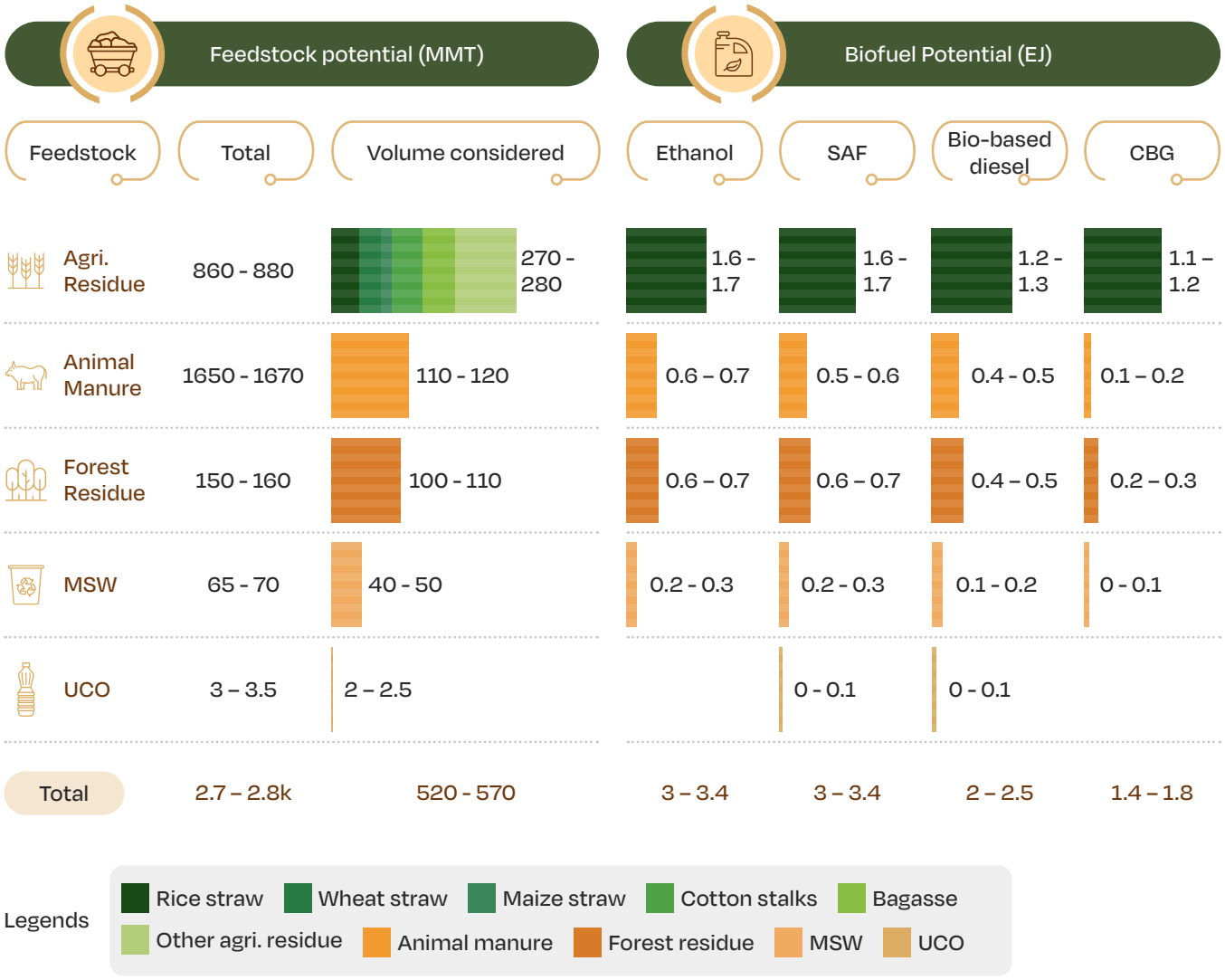
Biofuels can be defined based on several parameters including feedstock, GHG emission savings, technology maturity, product type, and quality. In the context of this paper, NGB biofuels are defined based on feedstock, and refer to biofuels produced from lignocellulosic feedstocks (e.g., agricultural and forestry residues), industrial wastes and residue streams, and other feedstocks which do not compete with food crops for land use. NGB biofuels feedstocks include the following:

- **Agricultural residues:** By-products left from farming crops, such as rice husks, cotton stalks, and bagasse, which remain after the primary product is harvested or are residues from the agricultural industry.
- **Animal manure:** Waste produced by livestock and poultry, which accumulates from animal husbandry activities.
- **Forestry residues:** Leftover materials from forestry operations, including branches, leaves, and wood chips, that are not used in primary wood processing.
- **Municipal solid waste:** Waste collected from residential, industrial, and commercial sources, encompassing a wide variety of organic and inorganic waste materials.
- **Used Cooking Oil:** Oil that has been previously used in cooking processes, typically collected from restaurants, households, and food processing facilities.

Potential of NGB biofuels in India

India has recently embarked on the journey of NGB biofuels and current production of NGB biofuels is only ~0.001 EJ[3]. However, driven by access to feedstock and supportive ecosystem, NGB biofuels production is expected to increase, with multiple NGB biofuels plants across biogas, 2G-ethanol and SAF expected to come online. Analysis conducted by BCG suggests that driven by access to 520 - 570 MMT of feedstock, 1.4 - 3.4 EJ of energy can be produced, contributing to 4 - 9% of the energy mix. The exhibit below details the NGB feedstocks available in India and the potential volume of each NGB biofuel that can be produced.

Exhibit 2[4] | Overview of biofuel potential by feedstock type

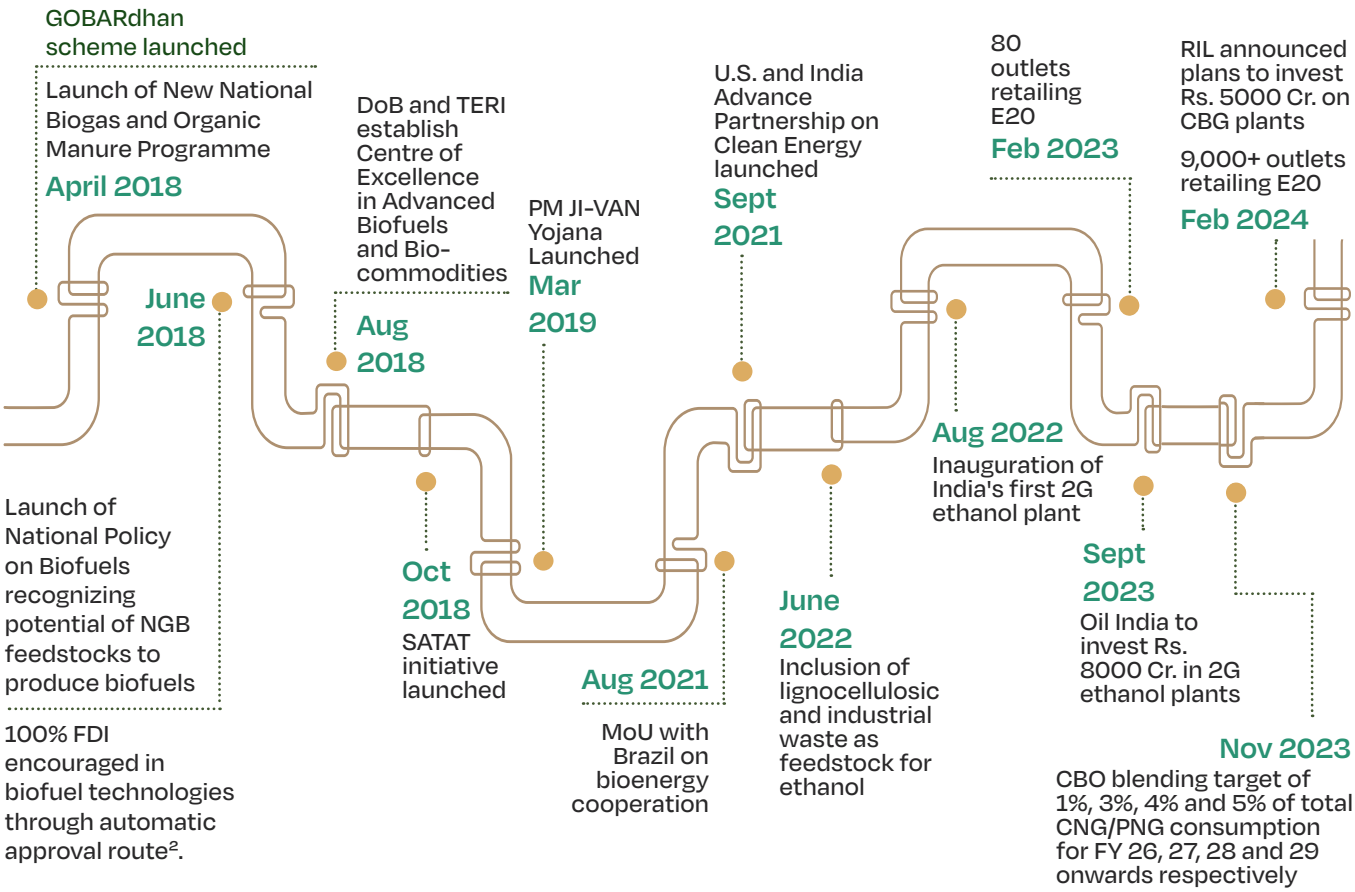


The total NGB feedstock available in India is 2700-2800 MMT, Further, as the overall economy of India will grow, the biomass is going to increase. However, after accounting for feedstock collectability, alternate requirement (e.g. soil enrichment for forest residue), and alternate usage (e.g. agriculture residue for cattle feed and compost), estimates suggest that India has excess NGB biomass of 520-570 MMT. For the purpose of this report, the NGB biomass available is considered to be 520-570 MMT.

This NGB biomass is spread across different feedstocks and across pathways, different feedstocks are better suited for the production of different biofuels. In this context, by leveraging different feedstocks for different products our estimate suggests that ~2.6EJ of energy, contributing to ~7% of India's energy mix can be produced. This energy translates to 30-40% displacement of each available fuel or displacing petrol, jet-fuel, CNG and PNG by more than 90% and displacing diesel by 10%[5]. Compared to current biofuel production levels, this is projected to increase the overall potential of biofuels by 15-20 times. More specifically, given that NGB biofuels are at a nascent stage, this can increase NGB biofuels production by 2000-2500x.

To unlock this potential, India has already made significant strides to build an ecosystem for NGB biofuels driven by both supply and demand side interventions (non-exhaustive list shown in Exhibit 3). This has generated remarkable results in setting a fast-paced upward trajectory for biofuels in India and has placed the industry at an inflexion point towards exponential growth.

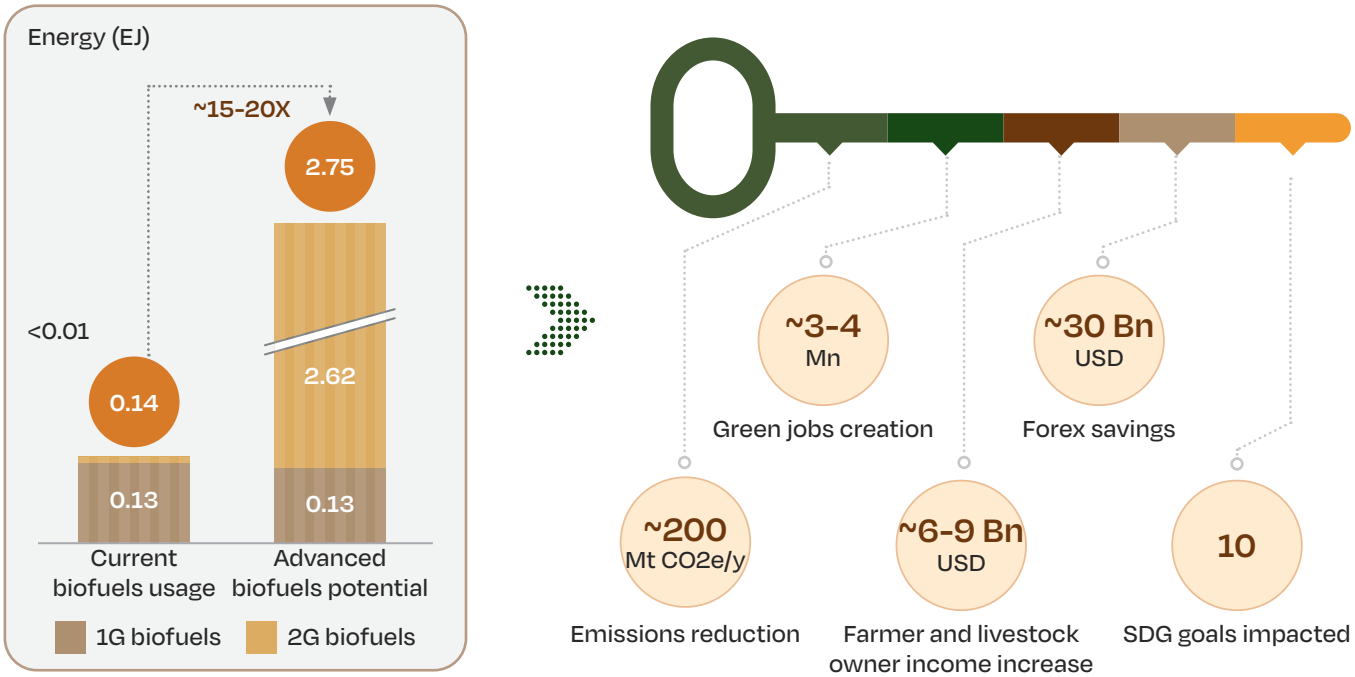
Exhibit 3[6] | India's NGB biofuels journey till July '24



Benefits delivered by unlocking NGB biofuels

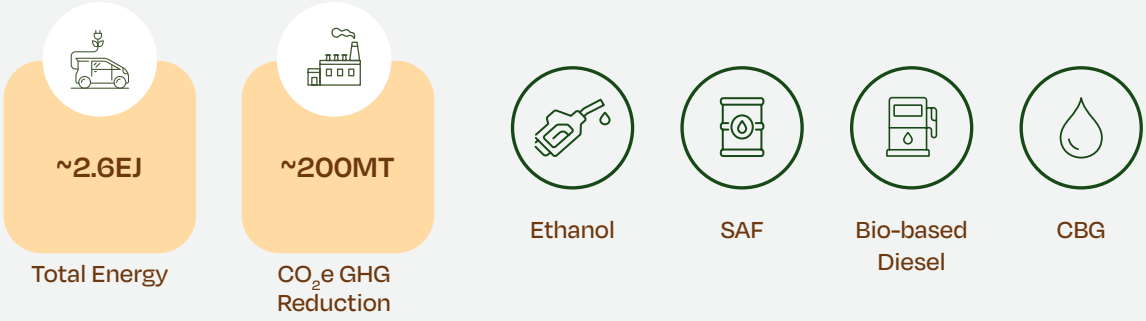
Unlocking this potential will create widespread socio-economic impact in the form of emission reduction, increased farmer income, job creation and forex savings, and will also contribute to 10 out of 17 SGD goals, showcasing the holistic impact of NGB biofuels.

Exhibit 4 | Realizing potential of biofuels will translate into multiple benefits



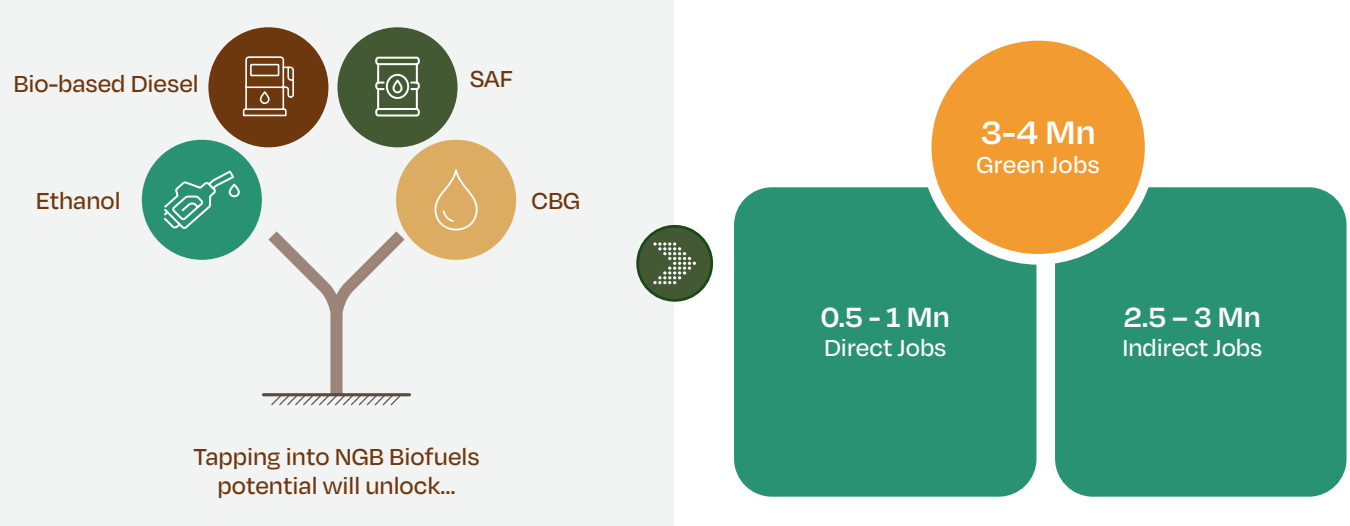
1. **Emission reduction and circularity:** Estimates indicate that CO_2 emissions cause 1.67 Mn deaths annually and result in health costs of nearly $37Bn, over 1% of India's GDP[7]. NGB biofuels offer a significant opportunity for India to meet its GHG emission reduction targets, potentially saving ~200 Mt CO_2 equivalent per year, which is 5% of India's total GHG emissions[8]. Additionally, the NGB biofuels industry can bolster India's circular economy by reusing waste (including MSW and UCO) and agricultural residues. This will not only reduce landfills and air pollution, but also directly improve the lives of at least a million people annually. For example, converting manure into biofuel prevents methane emissions from manure in landfills.

Exhibit 5 | Emissions reduction potential from NGB biofuels



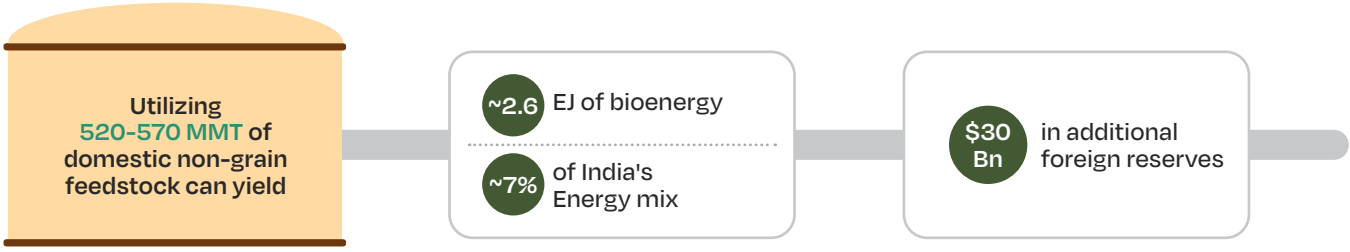
2. **Green jobs generation:** By unlocking NGB biomass of 520 - 570 MT, India can generate ~2.6 EJ of energy from NGB biofuels. This can potentially generate 3-4 Mn jobs spanning across agriculture, collection, transportation, plant operations, and end-use distribution. These jobs are expected to be distributed across different types of NGB biofuels produced leading to the overall development of the economy.

Exhibit 6 | Green jobs creation potential from NGB biofuels



3. **Energy security and Aatmanirbhar Bharat:** India is the 3rd largest oil and gas consumer globally and relies heavily on imports. A price hike of $10 per barrel can raise India's Consumer Price Index (CPI) by 0.5%[9]. Leveraging the NGB feedstock can contribute to over 7% of India's primary energy mix and ~ $30 Bn in foreign reserves savings. In addition, as India shifts towards NGB biofuels, it is also expected to build new indigenous technological capabilities and become Aatmanirbhar. This can lead to potentially sustained benefits in the form of increased investments, localization, and award of patents. Some of these benefits are not quantified in the study and will be in addition to the benefits showcased in Exhibit 4.

Exhibit 7 | Forex savings potential from NGB biofuels



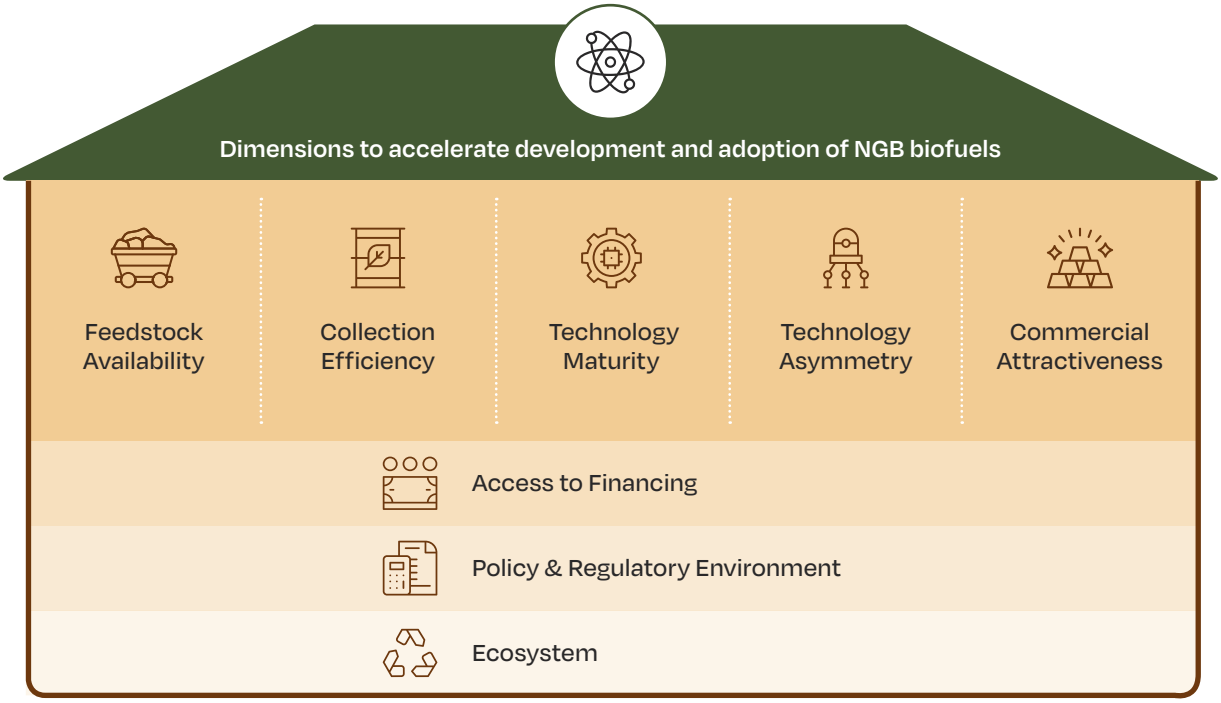
4. **Increasing farmers' income:** NGB biofuels can significantly contribute to India's agricultural and rural industry which employs over 150 million people and contributes ~15% to the Indian economy. The NGB biofuels industry can grow from its current level of $6-8Bn to over $100Bn, and contribute to $6-9 Bn yearly in additional income for farmers and livestock owners.

While NGB biofuels can offer significant benefits, to date India has unlocked a very limited potential of NGB biofuels. To fully unlock the vast possibilities of NGB biofuels, it is essential to explore innovative pathways and radically bold solutions that can create inflexion points for accelerated growth. However, India will need to make strategic choices and conquer several challenges to tap into this potential and reap the benefits. Addressing these obstacles will require a multifaceted approach spanning the entire value chain of NGB biofuels and requiring significant support for the industry to stand on its own feet.

NGB BIOFUELS PATHWAY FOR INDIA REQUIRES CHOICES ACROSS STRATEGIC PILLARS

While India has made initial strides in providing a strong platform to unlock the potential of NGB biofuels, choices and actions are needed across 7 strategic pillars to improve the attractiveness of this sector. These strategic pillars span across the entire value chain starting from the initial availability of feedstock to the intricacies of production and the integration into existing consumption infrastructure, with each stage presenting unique choices across feedstock, pathway, pre-treatment, etc. These choices need to be evaluated in conjunction with challenges requiring deliberation and action from all stakeholders.

Exhibit 8 | Structural pillars across the value chain impacting NGB biofuels adoption



Feedstock availability

India's feedstock potential of over 520 - 570 MMT is driven by a diverse array of sources such as agricultural and forest residues, animal manure, and MSW. However, the availability of this biomass varies by type of feedstocks, geography, and seasonality. For instance, the top 3 feedstock including cotton stalks, manure and forest residue account for ~50% of total available feedstock. Similarly, feedstocks like rice straws, cotton stalks and bagasse are concentrated in a few states such as Punjab, Gujarat, Maharashtra, UP and Karnataka, while the availability of feedstocks such as animal manure, UCO and MSW is fragmented.

Further, agricultural residues like rice straw and cotton stalks are available only during specific harvest seasons, leading to pronounced fluctuations in feedstock availability. This seasonality in feedstock availability makes it difficult to maintain a steady flow of raw materials throughout the year. Consequently, the NGB biofuels industry faces unpredictability in feedstock prices, which undermines long-term planning and investment in NGB biofuels infrastructure.

Exhibit 9 | Feedstock availability across India

India has hight volume and a diverse variety of feedstock spread across its geography

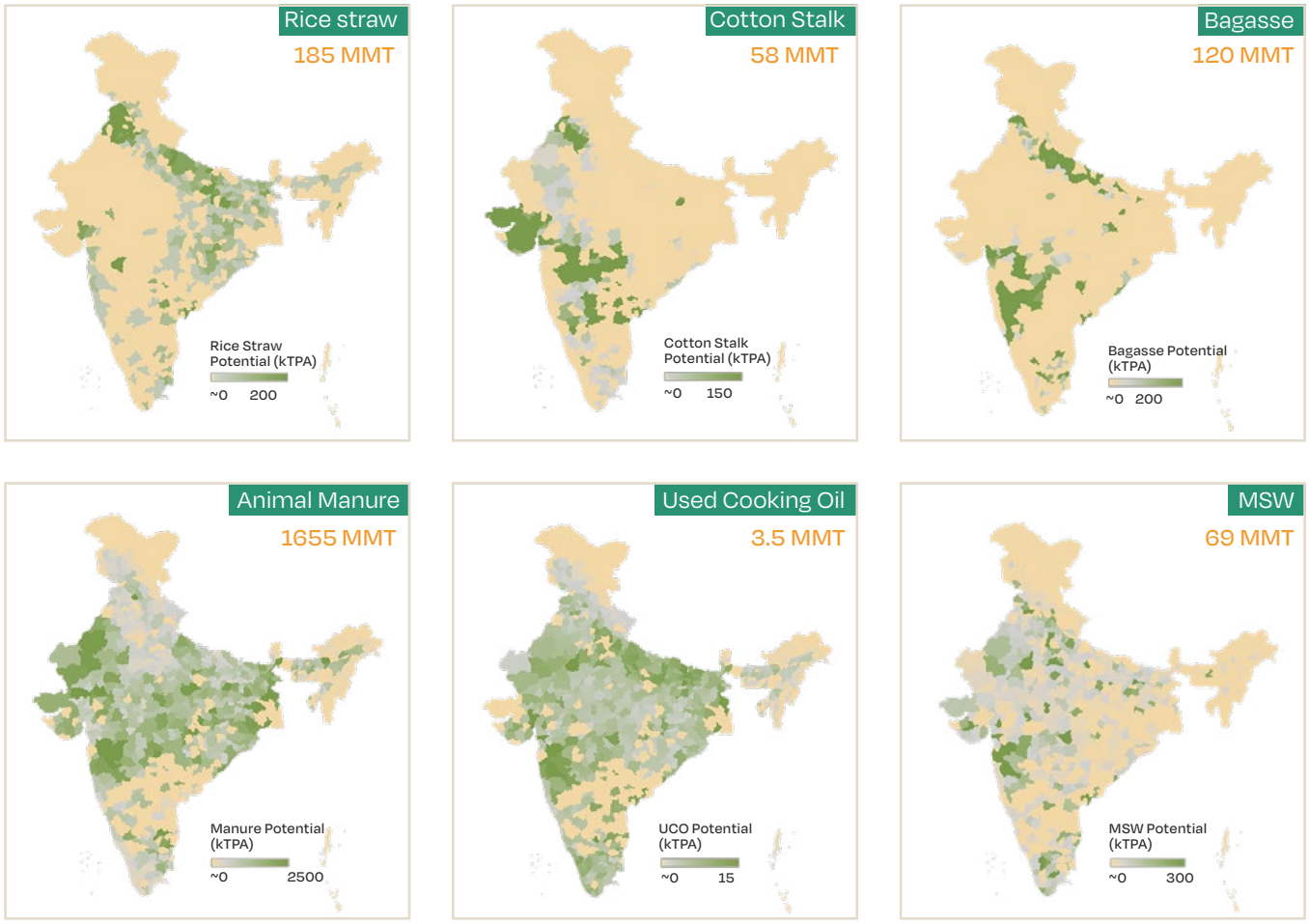
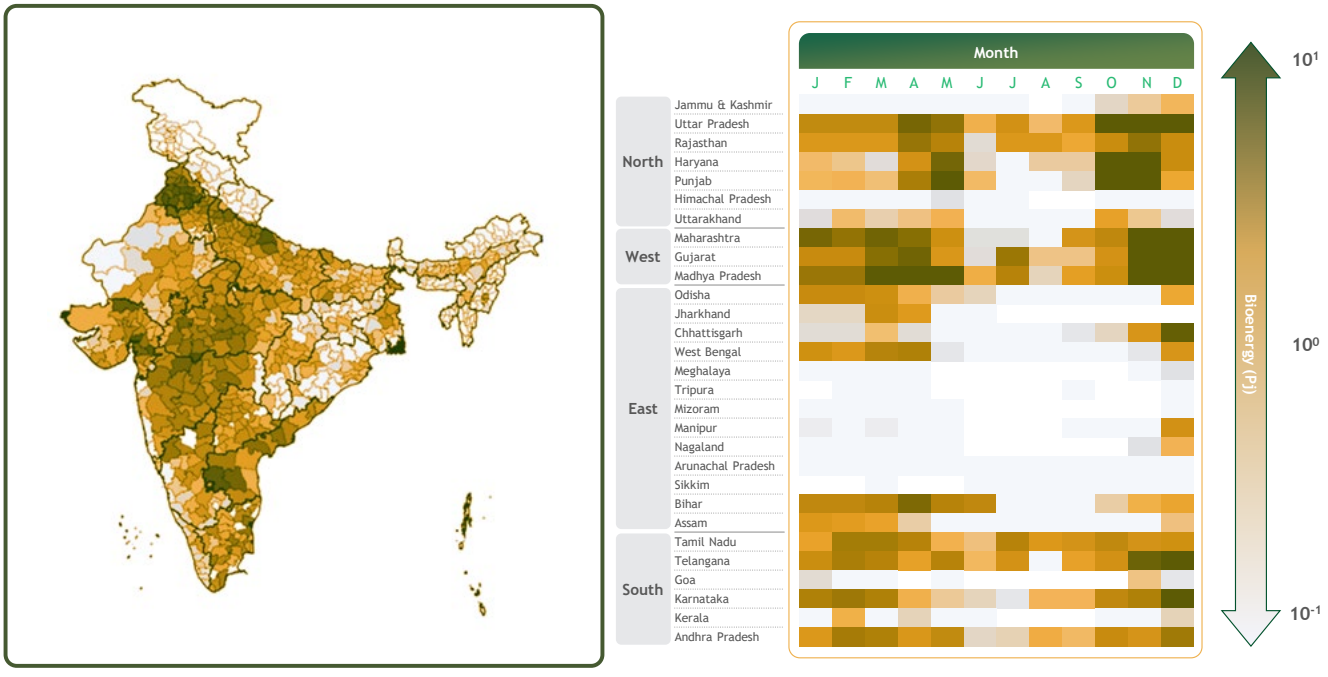


Exhibit 10[10] | Season-wise availability of NGB feedstocks



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Given this dispersion of feedstock across the country, there is an opportunity for India to adopt a waved approach. This approach will allow for scaling up in phases dependent on technological advancements and economic viability improvement.

Collection efficiency

Ensuring efficient, reliable, and sustainable collection of feedstocks is crucial to the development of the NGB biofuels sector. Collection efficiency is impacted by the concentration of feedstock, collection percentage, and awareness among farmers. For instance, data from rice straw collection in Punjab shows that as the quantity of straw collection increases from 5% to 30%, the cost reduces exponentially from about Rs. 1600 per tonne to less than Rs. 800 per tonne. Similarly, the district with higher feedstock concentration saw a 30-50% lower cost of feedstock at the same collection, and as awareness among producers increases the overall feedstock access also improves.

Exhibit 11[11] | Collection cost of rice straw across collection target

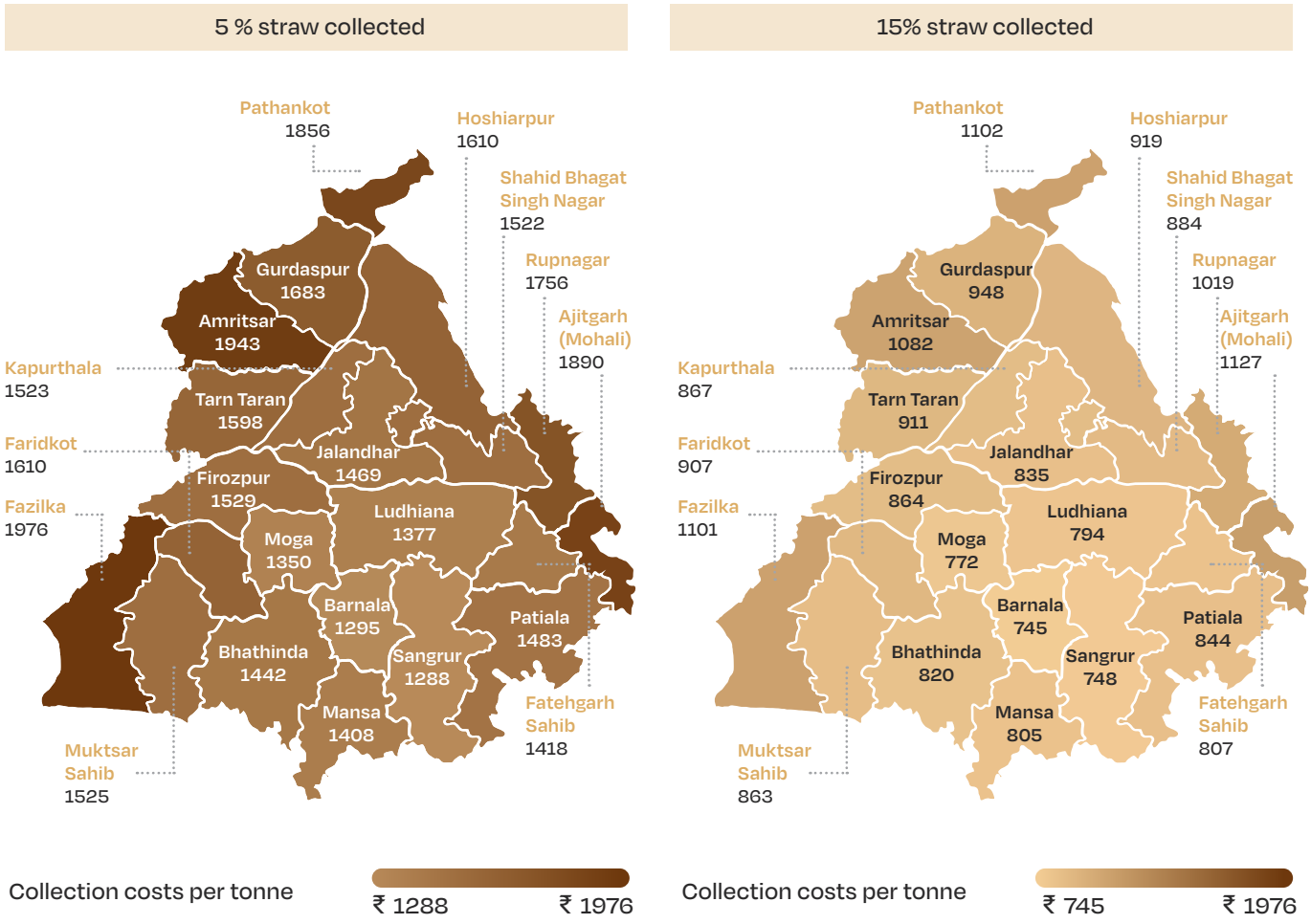
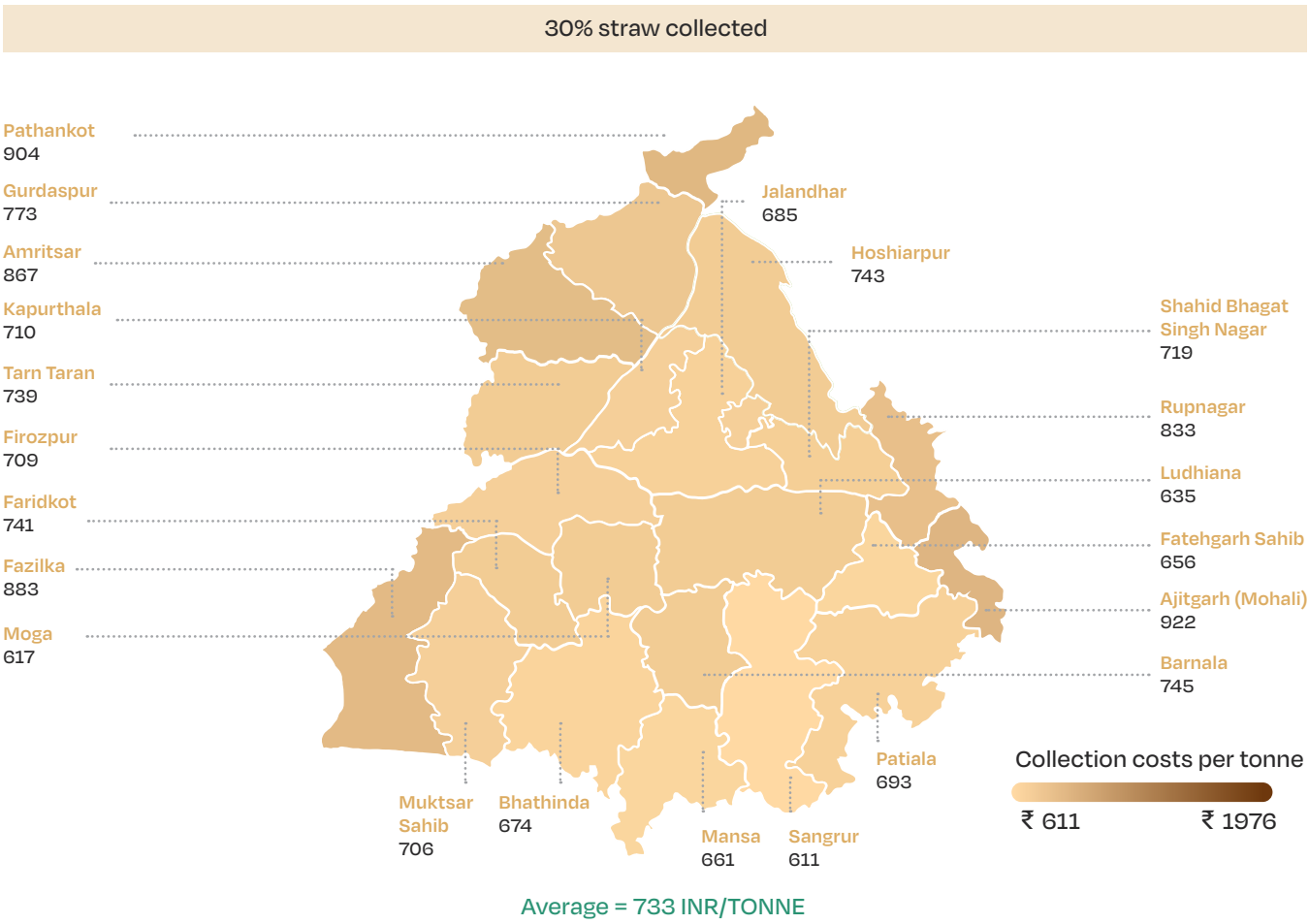


Exhibit 11 | Collection cost of rice straw across collection target



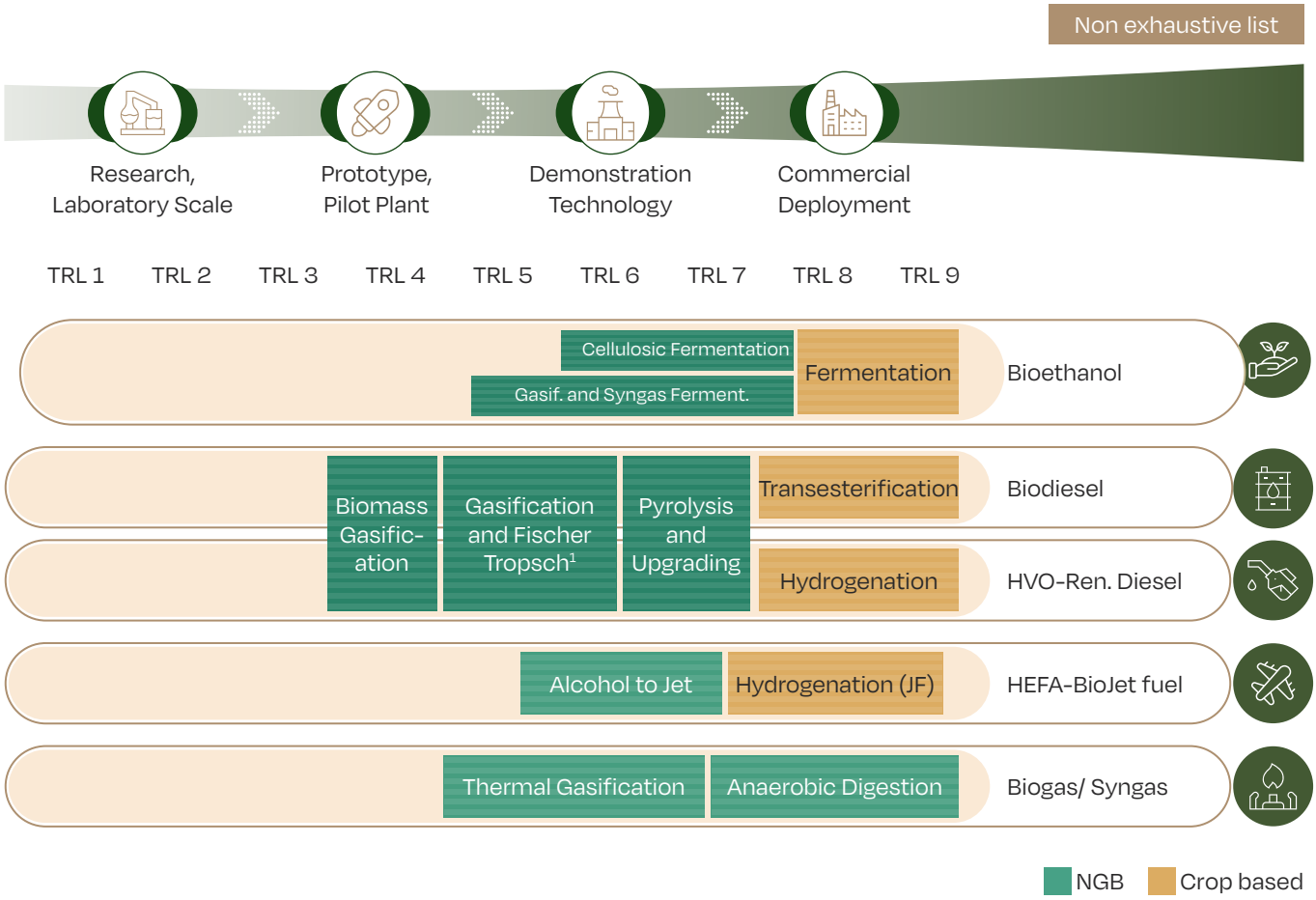
In this context, there is a need to evaluate if the approach for the development of NGB biofuels should be pan-India level or at select geographies leveraging existing ecosystem and awareness levels.

Technology maturity

Across NGB biofuels, the low effectiveness of production technology leading to high production costs remains a key challenge. The lack of technology maturity directly impacts the yield and economic viability of the project, especially when compared to crop-based biofuels. Further, the absence of demonstration plants for processing feedstocks like bagasse and cotton stalks also undermines investor confidence regarding the feasibility of these technologies commercially. While it is important to invest in diverse technology pathways to advance innovation, focused investments on select technology pathways can enhance scalability and facilitate a more robust ecosystem development.

As India charts the path forward, stakeholders need to develop a business case for investment in technology; capacity assessment for technology development; and investments in research, development and demonstration to identify technological pathways that best suit the Indian context for the production of NGB biofuels.

Exhibit 12[12] | Technology maturity of various pathways for biofuels production



Technology Asymmetry

Despite advancements, technology asymmetry presents a significant barrier in the NGB biofuels sector. Even though technology has advanced in certain countries, access to it is not evenly distributed globally. This inequality can extend to critical components such as specialized equipment and enzymes required for efficient biofuel production. To overcome these hurdles, a concerted effort is needed to ensure that advancements in NGB biofuels technologies are accessible to all, promoting a more equitable distribution of resources and knowledge. This effort should focus on establishing partnerships and collaborations that bridge these gaps, enabling technology transfer and capacity building on a global scale.

Commercial Attractiveness

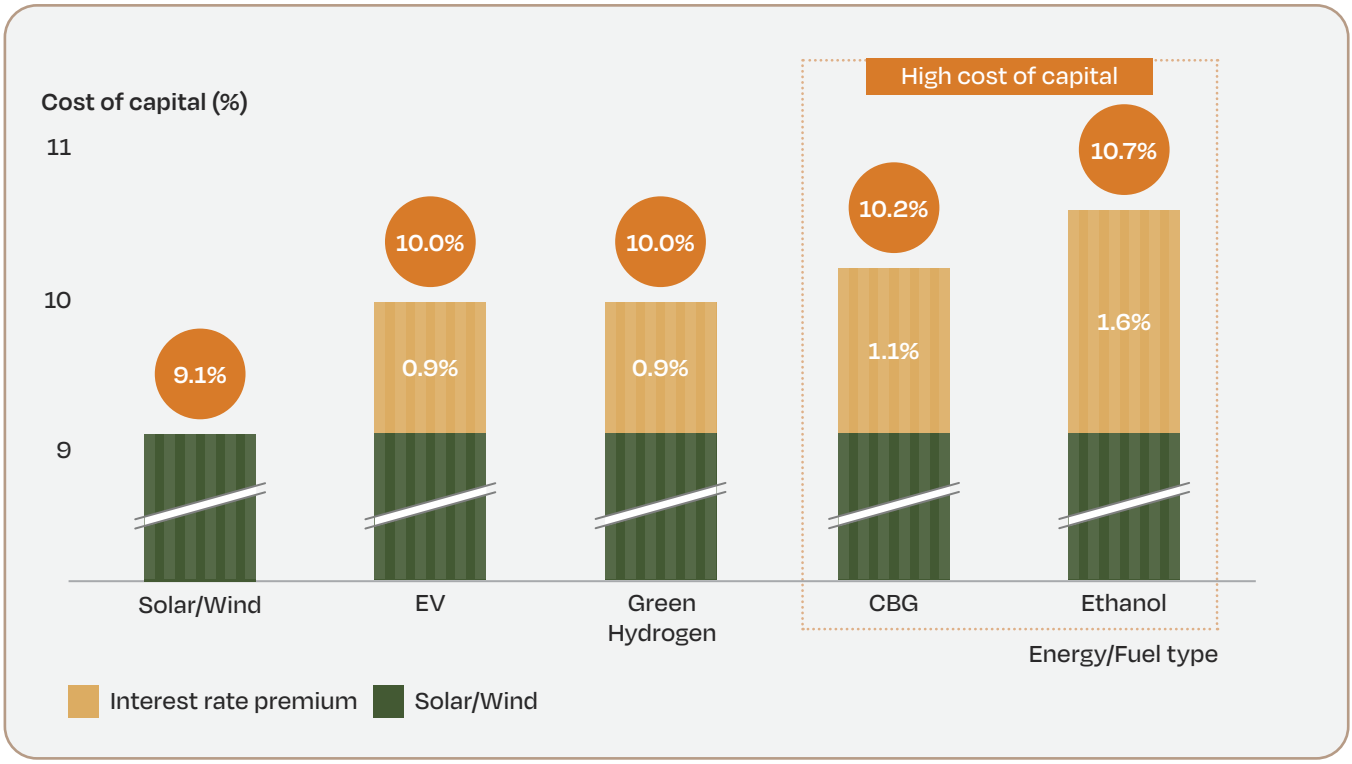
NGB biofuels production tends to be more costly than fossil fuels and conventional biofuels. In addition, the price differential between NGB biofuels and fossil fuels is also dependent on oil prices. While innovation can reduce the price differential between NGB biofuels and fossil fuels, as per IRENA NGB biofuels may not become consistently competitive without a price on carbon emissions. As IRENA's innovation outlook indicates, the production cost of advanced biofuels is likely to amount to USD 0.60-1.10 per litre by 2045. At oil prices below USD 80/ bbl, advanced biofuels would have difficulty competing with fossil-based gasoline and diesel. Hence there will be a need to recognize and reward the socio-economic benefits of NGB biofuels to improve their competitiveness.

Considering this need, India should carefully evaluate mechanisms to provide a premium for NGB biofuels. These mechanisms ranging from enabling carbon trading to offering price differential, should provide initial thrust to the industry while ensuring long term sustenance of the market. Simultaneously, there is a need to encourage global trade of NGB biofuels so that countries with access to NGB feedstock could leverage the price premium that exist in global markets compared to domestic market, supporting the development of global market for NGB biofuels.

Access to Financing

Currently, NGB biofuels projects face challenges in accessing financing compared to other low-carbon-pathways. For instance, the cost of capital for solar and wind projects is 100-170 bps lower than for biofuel projects, indicating the higher risks perceived by financial institutions for biofuels. As 2G ethanol and SAF plants often break even at a higher capacity, this elevated cost of capital exacerbates the already high initial capital expenditures, impacting project feasibility.

Exhibit 13[13] | Cost of Capital across sustainable and alternative fuels



Therefore, improving the availability of funding, including from the public sector, is crucial for balancing risk and enhancing the sector's attractiveness. Also, given the higher cost of capital in India for biofuels projects and premium prices available in global markets, India should explore mechanisms to tap into international capital to develop its biofuels ecosystem. Development of export-focused biorefineries (EOUs) could cater to markets with higher premium for NGB biofuels. For instance, establishing Special Economic Zones (SEZs) has enabled India to leverage lower cost of capital in international markets. These strategies would not only benefit the Indian biofuels sector but also set a global precedent for harnessing international capital to advance sustainable energy initiatives effectively

Policy and Regulatory Environment

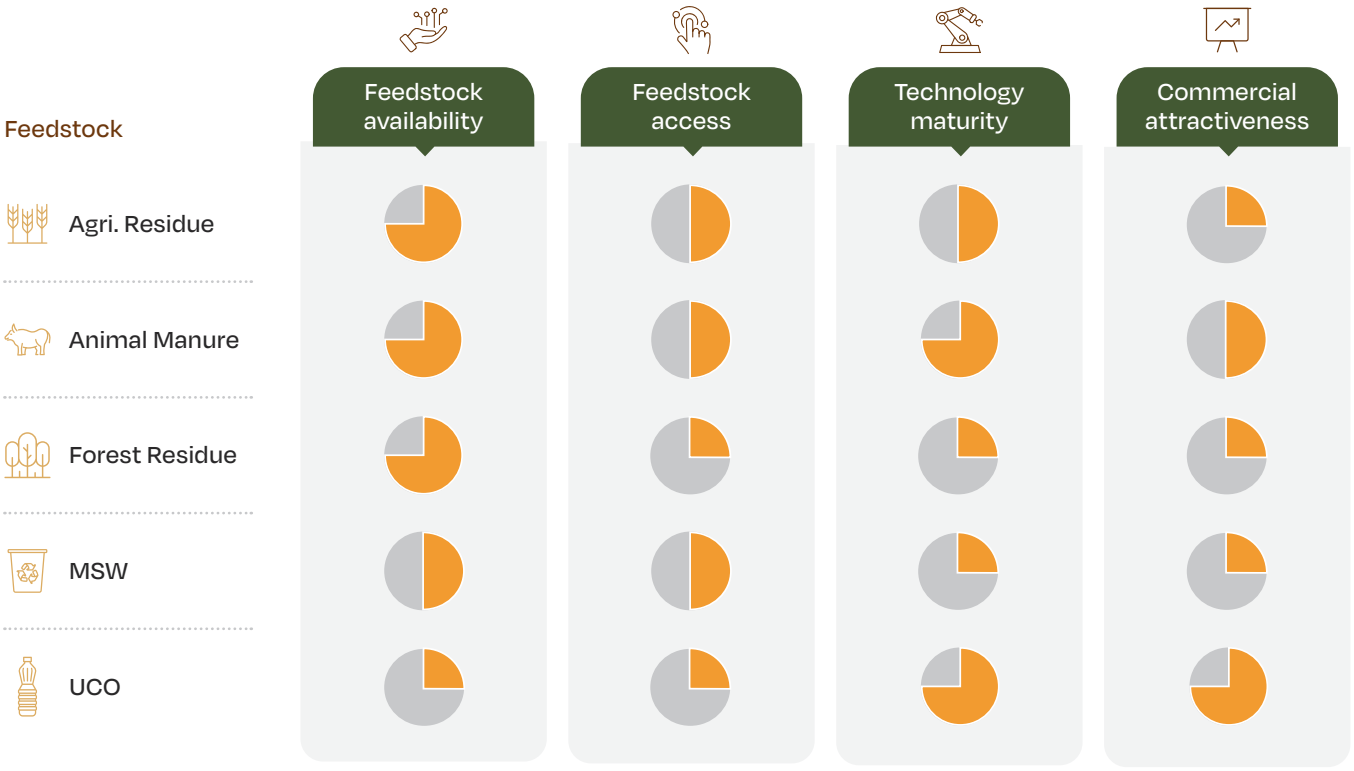
Biofuels industry is at its nascent stages with uncertainties associated around product demand, prices, and technology maturity. In this context, a stable policy and regulatory environment is crucial to develop investor confidence and support market growth. Hence, close coordination is required among stakeholders across multiple industries involved, to ensure clarity and consistency in the regulatory landscape impacts the ease of doing business. By ensuring stable policies, reliable market environment, and consistent trade policies the overall attractiveness of the sector can be increased.

Ecosystem

There is a need to develop a supporting ecosystem for NGB biofuels industry in India to thrive. For example, currently, there is little incentive for OEMs to produce flex-fuel engines due to low consumer demand, exacerbated by the higher costs of NGB biofuels compared to fossil fuels. Additionally, the lack of recognized GHG savings accounting and tracking mechanisms raises sustainability-related concerns with NGB biofuels. Also, how much of this premium will be absorbed by different stakeholders needs to be solved. If the entire increase in price is passed on to consumers without highlighting the environmental benefits, it can dampen the demand for the product. Conversely, if producers absorb these costs of sustainability, it could negatively impact their financial performance. Thus, without strategic incentives and clear benefits, the adoption of NGB biofuels faces considerable hurdles.

As we look at all the parameters, it can be safely said that there is no clear pathway and strategic choices made across pathways today will determine the future path of NGB biofuels industry of India

Exhibit 14 | Overall assessment of different feedstocks



Note: Select product based on maturity assumed for attractiveness calculation with Agri residue for ethanol, animal manure for Biogas, Forest residue for ethanol, MSW for ethanol and biogas and UCO for bio-diesel production

FEEDSTOCK SPECIFIC CHALLENGES LIMITING NGB BIOFUELS

While the previous section touches upon the strategic pillars that need to be evaluated, there is a need to recognize and address feedstock-specific nuances as these choices are being made. These nuances come from unique challenges across feedstock access and feedstock technology (primarily pre-processing). These feedstock-specific challenges encompass issues such as limited feedstock availability, challenges in collection, emerging technological maturity, limited commercial appeal, constraints in accessing financing, evolving policy and regulatory environment, and developing ecosystem.

1. **Feedstock availability:** As already highlighted in previous sections sustainable, consistent, low-cost and at-scale availability of feedstock is a key unlock to advance non-grain based (NGB) biofuels in India. While the overall feedstock potential is high, the on-ground feedstock availability can be limited by some feedstock related nuances as well. For example, agricultural residues are only available for a short period post-harvest, with feedstock like rice straw having an extremely short collection period of only 15-20 days. Also, variation in quality of feedstock can lead to operational inefficiencies, increased costs, and lower fuel quality, thus impacting viability of NGB biofuels.

2. **Collection efficiency:** Efficient collection ensures consistent supply, reduces cost, improves transportation efficiency, and enhances production scalability. However, certain feedstock necessitate a tailored approach to improve collection efficiency. Factors such as labor intensity in operations, geographical spread, traceability, physical properties and associated cultural practices must be considered to ensure development of the right collection pathway. While feedstock such as agricultural residues currently require labor intensive operations, animal manure and waste have stigma associated with their handling, hence requiring a tailored approach to improving collection efficiency. An effective example of improving collection efficiency via waste segregation can be seen in South Korea where awareness initiatives increased food waste recycling from 2% in 1995 to 95% in 2019.

3. **Tech maturity:** Technological maturity, including efficient and economical pre-processing is crucial to improving efficiency, and output, in the production pathway. Advanced technologies ensure the conversion process is cost-effective and sustainable and facilitate broader market adoption. However, several feedstock specific challenges such as composition of feedstock (silica content, lignin content, etc.), custom pre-processing requirement and energy intensity impede progress in this area. Hence, considering feedstock specific challenges is equally important for advancing the technological readiness of biofuels and ensuring feedstock potential translates to biofuels' share in energy mix.

4. **Commercial attractiveness:** To improve the cost competitive of NGB biofuels, commercials of the venture for all stakeholders in the biofuel production value chain must be attractive. This necessitates ensuring a consistent and attractive business case and price stability of NGB feedstock to ensure availability for NBG biofuels production. This will require a feedstock specific lens to ensure commercial attractiveness of wide variety of feedstocks.

5. **Access to financing:** Considering different production pathways will have different capex requirement and currently, there is a need to develop multiple pathways, access to accessible and low cost financing should be developed that could be tailored to widespread of feedstocks. For example, there are limited direct financing schemes supporting the production of biodiesel from UCO, which hampers the development of ecosystem around this feedstock.

6. **Policy and regulatory environment:** A supportive policy and regulatory environment that enabling NGB biofuels feedstock is crucial for growth of NGB biofuels in India. For example, although there are regulations governing the disposal of MSW and UCO, public awareness about these regulations is low, leading to non-

compliance and inefficiencies in feedstock utilization for biofuel production limiting NGB biodiesel production.

7. **Ecosystem:** Development of a robust ecosystem is essential for the success of NGB biofuels. An effective ecosystem encompasses specialized infrastructure, logistical networks, and technologies tailored to each type of feedstock and biofuel production pathway is crucial for unlocking NGB biofuels production. For instance, specific feedstocks like bagasse require special storage facilities to prevent spoilage due to high moisture content, which can foster bacterial growth. Additionally, collecting fragmented and geographically scattered feedstocks such as forest residues and animal manure demands the development of dedicated infrastructure. Developing these nuanced ecosystems is vital for ensuring that the biofuel sector can effectively contribute to India's energy security and environmental sustainability goals.

Structural Challenge	Challenges	Feedstock	Example
Feedstock availability	Seasonality		Agri. residues only available for collection post harvest
	Narrow collection window		Timeframe for collection of rice straw, only 15-20 days
	High Moisture Content		Over 30% water weight in bagasse
	High impurities		Fatty acid impurities in UCO
	Inconsistent physical properties		Water content in rice straw varies from 10-30%
	Health impact on consumers		Houshold air pollution from using agri. residues as cooking fuel
Collection efficiency	Labour intensive		Agri. residues require manual effort to collect/extract
	Geographically disaggregated		Forest residue spread out over a vast area
	Low traceability		60% UCO remains uncollected; goes back to small vendors
	Improper waste segregation		MSW not segregated at source prior to collection
	Low bulk density		High volume-to-weight ratio of crop residues
	Unique physical properties		Brittle cotton stalks make handling difficult
	Social taboo		Stigma associated with handling manure and waste
	Segregation		Low awareness on segregating MSW

Structural Challenge	Challenges	Feedstock	Example
Tech maturity	High silica and ash content		Silica in rice straw causes wear and tear of equipment
	High lignin content		Lignin in cotton stalks, is resistant to chemical breakdown
	Requires detoxification		Cassava stalks release toxic chemicals that pose safety risk
	Custom pre-processing required		Heterogenous forest residues lead to complex pre-processing requirements
	Energy-Intensive		High moisture content necessitates energy-intensive pre-processing
Commercial attractiveness	Alternate usage as feedstock		Diverted to uses such as animal fodder, cooking fuel, co-generation, etc.
	Fluctuation in feedstock prices		Seasonal supply impacts feedstock prices, esp. for agricultural residues
Access to financing	Financing available for alternate usage		Financing schemes encourage co-gen, electricity generation, etc.
	Lack of financing scheme		No direct financing scheme for UCO product - biodiesel
Policy and regulatory env	Government regulations on disposal		Low awareness re regulations, and implementation challenges impacting effectiveness
	Broader collaboration required		# of policymaking stakeholders in forest residue collection will be high; need to balance collection and ecological sustainability,
	Policy supporting alternate usage		Biomass policy mandates 5% co-firing of agri. residue in TPP
Ecosystem	Special storage facilities		Bacterial growth in bagasse due to high moisture content if not stored properly
	Infrastructure to enhance accessibility needed		Forest residue, animal manure, etc. are fragmented, in difficult to access areas
	Nuanced ecosystem development needed		Feedstock for CBG require pipe-line infrastructure, for SAF require blending facilities near airports, etc.

Legends: Rice, Wheat, Maize, Cotton, Bagasse, Others, Forest, UCO, Animal, MSW

GLOBAL BENCHMARKS INSPIRING AVENUES TO ADDRESS CHALLENGES

As the global energy landscape evolves, the NGB biofuels industry is emerging as a critical component of sustainable energy strategies worldwide. Recognizing the potential and benefits of NGB biofuels, countries such as the USA, Brazil, Sweden, and Germany have responded by taking different strategies that enhance the attractiveness of NGB biofuels across feedstock availability, feedstock access, advancing technology, streamlining financing, and ensuring robust regulatory compliance.

These practices can act as inspiration and provide valuable lessons for other countries. There is a significant opportunity to leverage this global knowledge to develop India's NGB biofuels sector. As India starts to see promising examples of success in this sector, there is potential to scale these efforts nationwide, tapping into the benefits of NGB biofuels.

Category	Practices observed globally (non-exhaustive)	Country (non-exhaustive)
Feedstock Availability	• Concentrated production of feedstock e.g. sugarcane, corn, leading to higher production of bagasse, corn stalk	 
	• Increasing awareness among farmers to boost production of feedstock e.g. bagasse	  
	• Financial assistance via programs like USDA's BCAP for feedstock suppliers to establish, produce and deliver biomass feedstock	 
	• Allowing imports of biofuels from specific regions to meet decarbonisation goals	
	• Prescribing non-grain-based feedstocks as acceptable for biofuel production	Multiple
Feedstock access	• Investing in agricultural technology to improve yield by 400% from 1975 to 2015, improving concentration of feedstock	
	• Integrated operations e.g refinery, to ensure consistency in quality and delivery of feedstock	 
	• Two-tiered system for efficient waste collection and management from households	
	• Behavioral nudges for improving waste segregation, along with penalties for non-conformance via redesigning containers, information flyers and distributing sorting bags etc.	

Feedstock access	• Strict penalties for illegal UCO sales to ensure compliance with regulation	
	• Financial support for the construction and renovation of forest roads	
	• Mechanization of forestry activities, improving economic feasibility of extracting forestry residues	
	• Established farmer co-operatives to develop new markets for crop residues used in biofuel production	
Technology Maturity	• Strategic collaboration between integrated oil players and global oil majors to facilitate technology transfer and incentivise R&D	
	• Offtake agreements with pilot bioethanol plant with Carbon dioxide removal	
	• Inflation Reduction Act Funding for Advanced Biofuels - Funding development of scaling up key process steps of biorefinery technologies	
	• US DoE BETO funds projects to support specific research efforts by industry, universities, laboratories and govt. agencies	
	• Government agencies like CanmetENERGY focusing on improving the commerciality of pyrolysis technology	
	• Investment subsidies for large demonstration projects focused on renewable fuels	
Commercial Attractive-ness	• Exports encouraged for realising premium prices	
	• Tradeable carbon credits awarded to recognise GHG emission savings, complimenting project revenue	
	• Blending mandate for ethanol and biodiesel	Multiple
	• Lower taxes for ethanol and biodiesel for 20 years	
	• Advanced biofuels volume obligation mandates established	
	• Quarterly payments basis advanced biofuel produced	
	• Annual incremental payment for producers who increase production over the previous fiscal year (excludes forest biomass advanced biofuel production)	

Commercial Attractiveness	• Biodiesel tax credit: Flat credit paid to producers and blenders of biodiesel & renewable diesel through IRS tax refund	
	• Incentives for using agricultural residues for biogas production	
	• Special tariffs to small plants to restrict usage of food crops for biogas production	
Access to financing	• BNDES RenovaBio program which reduces the cost of capital for projects based on their sustainability	
	• Section 9003 Program- Loan guarantees to eligible applicants to develop advanced biofuels manufacturing facilities to deliver new and innovative technologies	
	• Direct financing support to convert existing refineries to biorefineries	
	• Grants for biofuels research and infrastructure developed as per the national biofuels program	
	• Special banking scheme to fund first-of-a-kind demonstration projects in renewable energy	
Policy environment & Incentives	• Decade-long plan for role biofuels in decarbonization plan published every ten years	
	• Clear focus on waste from the sugar industry for the production of NGB biofuels	
	• SAF Grand Challenge lays out SAF targets till 2030 and 2050 providing longer-term certainty	
	• Established cap on input share of energy crops, and prohibited use of corn for biogas production	
	• Ordinance defining acceptable quality and requirements of digestate that can be used as fertilizers	
	• Automatic approval for co-processing biofuel feedstocks	
Ecosystem	• Carbon accounting and recognition mechanism implemented	
	• Liquid carbon credits market established on the national stock exchange	
	• Tax reduction of 1-3% on industrialized products for fuel-flex vehicles	

Ecosystem	• Accessible infrastructure, coupled with stringent policies and penalties, to motivate and guide effective waste management	
	• All public bus services in capital city moved to biofuels	
	• Integration with industrial clusters such as ports for easy transportation	
	• Prescribed tool by Clean Fuel Regulation to calculate the life cycle carbon intensity (CI) of fuels and energy sources to ensure sustainability	

While the table above provides a non-exhaustive list of global best practices, there are notable examples within India where local initiatives showcase advanced systems. For example, in urban waste management, Indore Municipal Corporation (IMC) has created a good case study to follow. The city faced significant challenges with waste management until 2016, including inadequate waste segregation and collection inefficiencies. In response, as part of the Swachh Bharat Campaign, IMC implemented robust measures mandating waste segregation at source, which significantly enhanced recycling rates. The introduction of waste-to-energy facilities while reducing landfill usage was also important in achieving the city's sustainability objectives.

Public engagement was intensified through widespread awareness campaigns, fostering a collective drive to establish Indore as the cleanest city in India—a title it has proudly held since 2017. The success of these initiatives is evident in the 90% household compliance in waste segregation, a remarkable 95% waste recovery rate, and a significant 60% reduction in vector-borne diseases, collectively improving the quality of life for its residents and establishment of one of Asia's largest biogas plants in the city. This model not only highlights the effective implementation of integrated waste management strategies but also serves as a scalable blueprint for other Indian cities. Encouraged by this success, cities like Mumbai and Delhi are also planning to convert their MSW into biogas.

In terms of financing, the Government of India launched the Pradhan Mantri JI-VAN Yojana[14] to provide financial assistance to set up 2G ethanol projects in India. The financial assistance can range from upto ~$ 1.8 Mn for demonstration projects to ~$ 18 Mn for commercial plants. Under this scheme, financial assistance of over $ 100 Mn has already been approved to private and public OMCs for multiple commercial 2G ethanol plants across the country. Other interventions and initiatives like additional excise duty on non-blended fuels, offtake assurances by OMCs to private stakeholders by Ethanol Purchase Agreements (EPA), differential pricing for 2G ethanol, etc. are also in place to help improve the commercial attractiveness of biofuel projects in India.

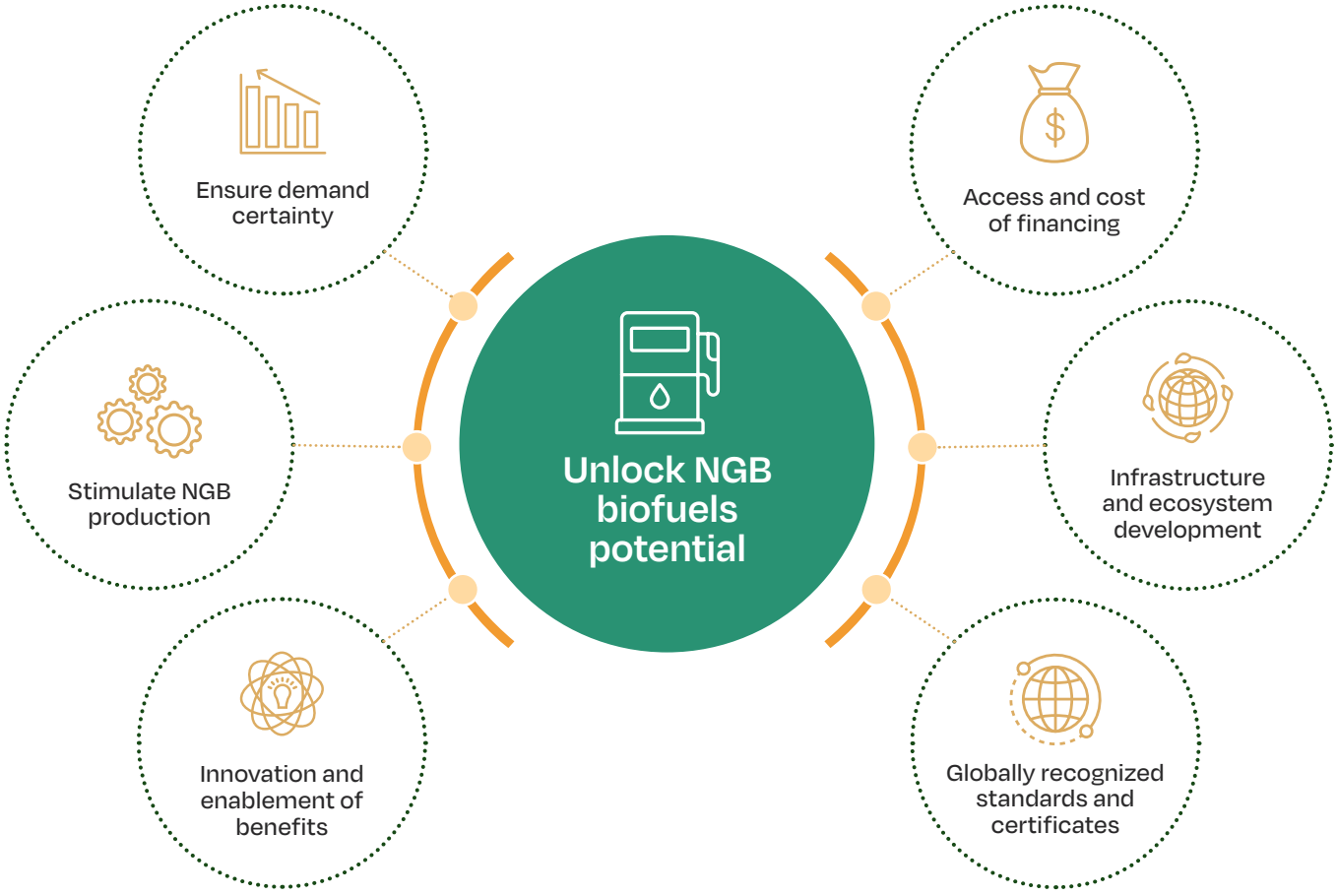
Some additional incentives underpinning the development of India's biofuels ecosystem include the Ministry of Heavy Industries' Production Linked Incentive (PLI) scheme which incentivizes Auto OEMs to accelerate the introduction of flex-fuel vehicles in India, aligning with national goals of increased biofuels usage. Furthermore, recommendations have been put forward to provide financial incentives to farmers to stop crop residue burning. This shall not only help increase feedstock availability for biofuel production, but also mitigate release of greenhouse gases, thereby supporting energy and environment objectives.

Learning from these best practices, India is well-positioned to expand and intensify its biofuel initiatives. International practices have laid a foundation of innovative strategies which could be leveraged to advance NGB biofuels sector. The following section outlines the specific actions required to catalyze a shift in India's NGB biofuels industry.

STRUCTURAL INTERVENTIONS REQUIRED TO UNLOCK NGB BIOFUELS POTENTIAL

Realizing the NGB biofuels potential will require significant commitments in technology, investment, feedstock supply, policy and awareness to support sector development and drive investments. Based on the assessment of challenges, action is needed across 7 categories of challenges. These actions span 6 strategic pillars, as shown in Exhibit 15, to create an inflexion point in the NGB biofuels industry of India.

Exhibit 15 | Pillars along which structural interventions are required



In the exhibit below, key actions across strategic pillars have been identified. Initiatives with higher impact and shorter implementation timelines or with a head start due to starting position have been highlighted as quick wins to unlock the true potential of the NGB biofuels industry in India.

Realizing the NGB biofuels potential will require significant commitments in technology, investment, feedstock supply, policy and awareness to support sector development and drive investments. This will require actions across 6 strategic pillars covered below. These actions span from ensuring demand uncertainty, stimulating production supporting innovation, enabling benefits of biofuels and ensuring access to capital to create a strong foundation for NGB biofuels industry. Finally, developing the overall ecosystem and ensuring globally recognized standards and certificates can ensure global adoption of NGB biofuels. While it is understandable that different countries can have different goals and stages in the energy transition, it is important to kickstart the integration of NGB biofuels in their energy mix to achieve globally set emission targets.

1. **Ensuring demand certainty:** Ensuring stable and long-term demand certainty for NGB biofuels is crucial, since it would encourage the ecosystem to commit resources to this sector - encouraging production, and increasing investors' confidence to mobilize capital towards biofuel projects. In addition, a predictable market shall drive technological advancements, scale up production, and reduce costs, making NGB biofuels more competitive. A policy framework ensuring long-term and stable mandates and encouraging industry to target markets with high-demand and premiums can help the industry secure consistent demand. Producers too can support a demand-led transition by improving customer awareness, developing necessary infrastructure, and providing necessary incentives to encourage NGB biofuels adoption.

2. **Stimulating NGB biofuels production:** Currently for many NGB biofuels such as SAF, demand is outpacing supply. To fully tap into the benefits of NGB biofuels it is crucial to ensure supply keeps up with the demand. Increase in supply will also bring additional benefits such as increasing investor confidence, scale benefits, efficiency improvement etc. further contributing to development of NGB biofuels sector. Policymakers can simulate biofuels production by identifying high feedstock potential regions via mapping initiatives, and setting standards for feedstock quality and usage. Producers need to focus on developing robust feedstock collection infrastructure and integrating advanced refinery operations to improve yield. At the same time, raising awareness about optimal feedstock use minimizes waste and enhances efficiency among stakeholders, which can also help increase biofuels production.

3. **Innovation and enablement of benefits:** Innovations in technology and operations will help lower costs, improve efficiency, and increase the scalability of biofuel production. Industry and academia need to work together to enhance pre-processing, implement feedstock agnostic technology, and reduce operational expenses for emerging technologies to make them viable. Financial institutions can contribute by enabling financing at favorable terms for industry to collaborate and developing lighthouse projects, thus helping drive innovation. At the same time, enablement of benefits of NGB biofuels is needed for their broader acceptance and integration into the market. Policymakers can enable these by developing avenues to recognize socio-economic benefits of NGB biofuels. Lastly, development and dissemination of best practices by all stakeholders across the biofuel value chain ensures continuous improvement and knowledge sharing, crucial for industry-wide advancement.

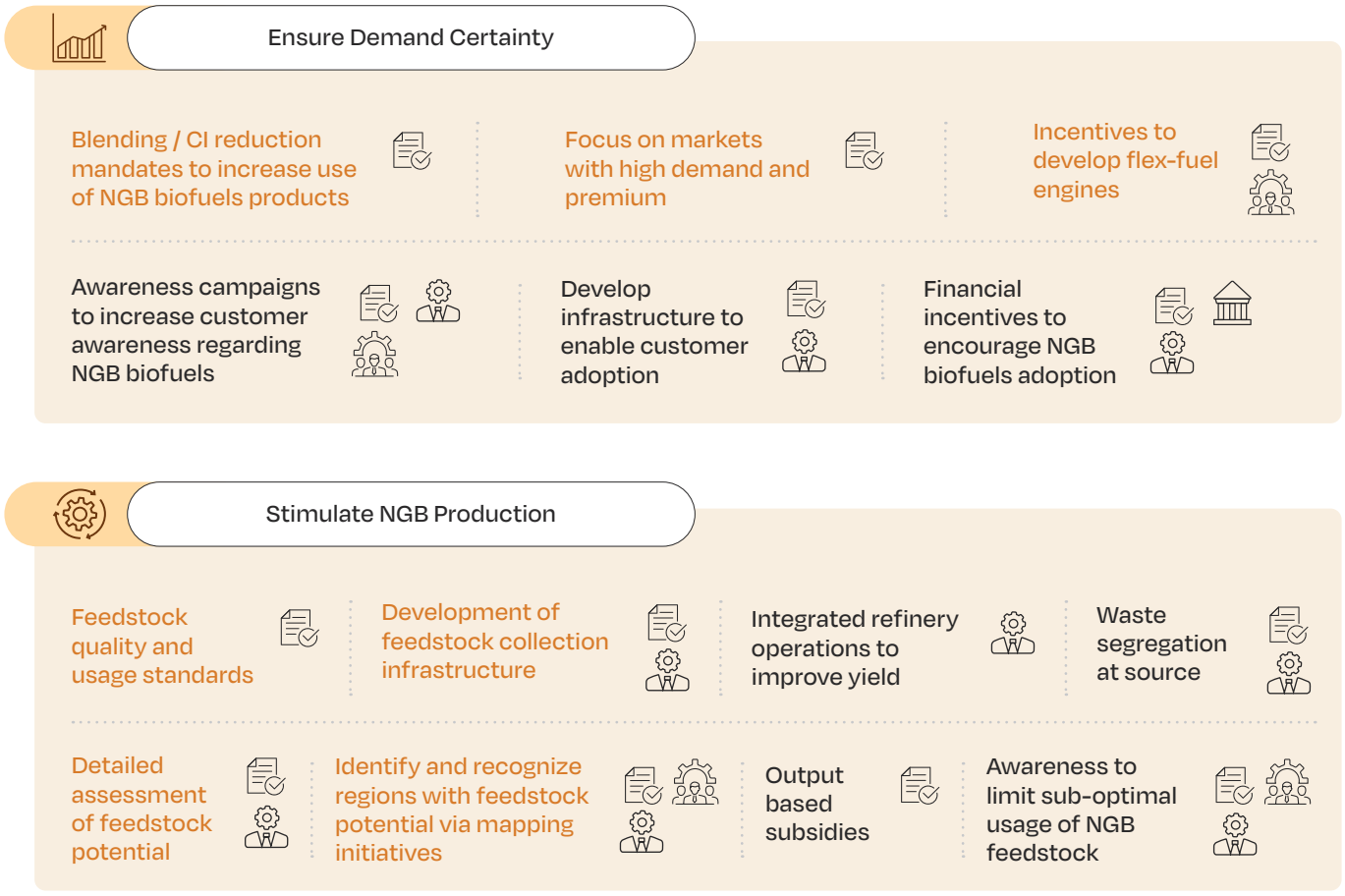
4. **Global standards and certificates:** Since non-grain based biofuels are relatively new and involve a diverse range of feedstock and conversion processes which are still evolving, there is a need to develop globally recognized and consistent standards and certificates. Adopting best practices for certifications and maintaining end-to-end product compliance standards across the biofuel production chain ensure consistency and reliability in product quality. These would facilitate international trade by ensuring compliance with global market expectations, and enhance consumer trust and investor confidence. Industry can collaborate with policymakers and international organizations to develop markets for tradeable carbon credits, explore models like book and claim, and streamline their mechanisms to global levels. Stakeholders

could even come together to implement a 'guarantee of origin' for feedstock and utilities to provide proof of sustainable sourcing of materials, by deploying blockchain technology to enhance traceability across the supply chain.

5. **Infrastructure and ecosystem development:** NGB biofuels adapt more readily to existing systems than several other clean energy technologies, offering a scalable, practical solution. However, unlocking their full potential requires dedicated infrastructure and ecosystem development tailored to their unique requirements. Support from policymakers and international organizations is required to foster international collaboration, launch capacity building programs, and develop market for by-products to develop the ecosystem, and enhance commercial attractiveness. Dedicated marketplace for feedstock aggregators, and storage solutions and last-mile infrastructure for the end products developed by the industry would help create a conducive ecosystem for NGB biofuels to thrive.

6. **Access and cost of financing:** There is lack of low-cost financing for NGB biofuels due to their high capital costs, coupled with perceived risks by investors who are unfamiliar with this nascent technology. Adequate and affordable financing will support R&D and help overcome high initial costs associated with these pioneering technologies. Industry associations and international organizations should come up with standard KPIs for appraisers to help improve evaluation of NGB biofuel projects. To lower the risk for investors, policymakers should offer investors first-loss guarantees, backstop credit agreements, etc. Viability gap funding is essential for supporting technologies that are promising but not yet mature, ensuring they progress to commercialization. Additionally, providing grants and funds specifically for R&D in novel feedstocks, new pathways, and demonstration projects can spur innovation and lead to breakthroughs in biofuel technologies.

Exhibit 16 | Focused action required across 6 areas to unleash the potential of biofuels



Innovation & enablement of benefits

- Develop avenues to recognize socio-economic benefits of NGB biofuels
- Improved pre-processing technologies and resilience
- Feedstock agnostic processing technologies
- Invest in reducing OpEx for upcoming technologies
- Collaborations to develop lighthouse projects for NGB biofuels
- Develop and share best practices across value chain
- Investing in agricultural technology to improve yield

Global standards & certificates

- Streamline current mechanisms to globally recognized mechanisms
- Best practices for certifications and standards
- End-to-end product compliance standards
- Tradeable carbon credits and book and claim
- Deploy blockchain for traceability across supply chain
- Guarantee of origin for feedstock and utilities

Infrastructure & ecosystem development

- Dedicated storage solutions and last-mile infrastructure
- Develop marketplace and support feedstock aggregators
- Better implementation of waste management policies
- Single window clearances for establishing NGB biofuels plants
- Foster international collaboration
- Develop markets for by-products
- Integrate with industrial clusters, eg: airports, for direct consumer access
- Indigenous equipment and consumables
- Launch comprehensive capacity building programs

Access & cost of financing

- Capability development and standard KPIs for appraisers
- Enable access to financing via low-interest rate loan, first loss guarantees, backstop credit agreements, etc.
- Single tax system for biofuels and blended fossil fuels
- Viability gap funding for less mature but promising technologies
- Grants/funds for R&D in novel feedstock, new pathways and demo projects
- Favorable debt-to-equity ratio
- Dedicated funds to support NGB biofuels projects

Legends

Priority actions | Policymakers | Producers, OEMs | Industry Associations, IOs, Academia | Financial Institutions

CONCLUSION AND NEXT STEPS TO REALIZE THE POTENTIAL OF NGB BIOFUELS

India's NGB biofuels sector is well established to be a fast-growing sector in India as well as globally, mirroring the nation's economic growth. This report has laid a foundation for evaluating India's NGB biofuels industry. However, the complexity of this task necessitates ongoing research and analysis. Further work is required in evaluating the feedstock potential at pan India level, deeper understanding of competing demand and excess available feedstock across various feedstocks to a more detailed level.

Additional analysis is required to assess technologies for producing NGB biofuels to understand technical readiness levels cost competitiveness, yields, CapEx, etc. to continue innovation in technology, and build India's leadership in this sector.

While keeping in mind these considerations, transforming this potential into reality requires commitment from all stakeholders: policymakers industry and research institutes. To scale the NGB biofuels following actions can be initiated

1. Establish a committee to chart the roadmap for NGB biofuels in India
2. Create a task force to identify high priority geographical regions/states and develop regional/ state level targets based on regional conditions such as feedstock availability and supply chain, infrastructure, awareness, etc.
3. Form an advisory council to identify, address and prioritise feedstock level challenges
4. Identify a body to lead and coordinate R&D efforts for pathway development for NGB biofuels
5. Constitute a coordination cell with relevant stakeholders (ministries, government agencies, municipal corporations to develop feedstock level supply chain. E.g. FSSAI for UCO, Ministry of Housing and Urban Affairs for MSW, etc.
6. Collaborate with other initiatives, eg: Mission LiFE, to drive awareness campaigns about biofuels
7. Develop innovative debt financing schemes and drive mandate with national funds to invest in NGB biofuels startups
8. Conduct stakeholder consultations to gather inputs on challenges in NGB biofuels in India and potential initiatives to advance them.

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