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Creating Innovative Solutions for a Sustainable Future

TOWARDS A GREENER TOMORROW

White Paper on Indo-Dutch Opportunities for the Biotransition

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FOREWORD

The Netherlands is working on a strategic partnership with India to increase our earning capacity, safety and innovation power. Within this partnership, cooperation on energy & climate goals is an important pillar and active efforts are being made on the biotransition.

The world is moving rapidly towards a future where sustainable, bio-based solutions will play a key role in tackling climate change and resource scarcity. In this context, the bio-transition is more than just a technological shift—it is an opportunity to rethink how we produce, consume, and grow in a way that is better for both people and the planet. One of the most exciting areas where this is happening is in the bioeconomy space—a shift towards using biological resources more sustainably to create energy, chemicals, fuels, materials, and more.

The Netherlands is proud to be at the forefront of this transition through our strategic investments in innovation, circularity, and green technology. From public-private partnerships in green chemistry and advanced biomanufacturing, to top-tier technical universities and applied research centres - we are home to pioneers in topics such as biorefinery design, enzymatic hydrolysis, and microbial bioprocessing.

We see India as a natural partner to bring these technologies to scale—whether it is in second-generation ethanol, sustainable aviation fuel, or value-added biochemicals. India, with its scale, ambition, and entrepreneurial energy, is quickly emerging as a global leader in this transformation. Between our two countries lies an opportunity: to come together and co-create solutions that can define the next era of clean growth.

This white paper, written by our partner TERI, helps by offering a comprehensive look at where we stand, what's possible, and how we can move forward together. I am therefore very grateful to all the contributors—researchers, government colleagues, and industry experts—for their invaluable insights. Their work reflects what this partnership can offer.

Dr Dhoya Snijders
Innovation Counsellor
Netherlands Embassy in India

PREFACE

Biotransition has immense potential to drive sustainable development, promote economic growth, while improving human well-being. Transition towards bioeconomy offers a promising opportunity to reduce reliance on fossil fuels, address climate change, and establish a sustainable circular economy. India's bioeconomy is projected to expand rapidly, reaching $300 billion by 2030 and $1 trillion by 2047, with an estimated $165.7 billion in 2024. Sustainable practices, policy advocacy, and biotechnology innovations are the main forces behind expansion of India's bioeconomy. These interventions helped India to expand bioethanol blending programmes and enhance fermentation-based fuel production, thereby leading to reduced dependence on fossil-based fuels. Further to promote bioeconomy growth, India has introduced the BioE3 (Biotechnology for Economy, Environment, and Employment) policy that aims at promoting biomanufacturing and bio-based industries.

The Netherlands is a leader in biotransition. By leveraging its strong agricultural sector, advanced biotechnology with a strong focus on research and development, The Netherlands has promoted its bioeconomy. The country is investing on bio-refineries for production of biofuels, biochemicals and biomaterials, and is leading the mission along with India under Mission Innovation platform.

Keeping in line with the nation's bioeconomy objective, TERI's bioeconomy research spans the domain of 'biofuels, biochemicals, and bio commodity' production, in a zero-waste approach.

Collaboration between India and the Netherlands is well-established in several areas, including agriculture and food security, water management, renewable energy. Indo-Dutch partnership in bioeconomy domain can contribute significantly to advance the biotransition goal through sharing best practices, exchanging technologies, and coordinating policies, for promotion of bio-based industries.

I hope, this study will be useful as a knowledge tool the organizations and industries in identifying Indo-Dutch collaboration opportunities through development of joint programmes and business ventures.

Dr Vibha Dhawan
Director General
The Energy and Resources Institute

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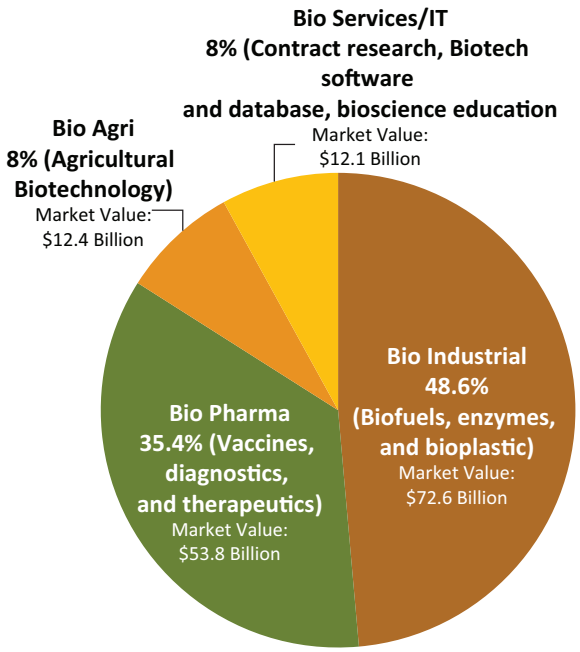
BIO
FUEL

EXECUTIVE SUMMARY

The shift to a sustainable and low-carbon future is imperative as global temperatures have risen above a critical point. Therefore, switching to alternative renewable energy sources is essential to address climate security concerns and meet the growing energy demand. Bio-based resources are renewable and have great potential for achieving the decarbonization goal. We call this the biotransition, which refers to the shift from a fossil-based economy to bio-based economy that places a strong emphasis on using biological resources. The term bioeconomy hereby refers to economic activities that leverage biological resources such as microbes, plants, and animals, as well as bioprocesses for the sustainable production of food, energy, chemicals, materials and contribute significantly to drive the economic growth of a nation.

India's emphasis on biotransition stems from its aspirational objectives for climate action and sustainable growth. To increase the nation's bioeconomy target, India has set an ambitious biotransition goal that calls for the use of bio-based resources to produce bioenergy, biochemicals, and bio-based products & commodities. India has a great volume of unused residues to reduce carbon emissions, promote energy independence, and boost rural economies. India's commitment to promote bioenergy, biochemicals, and bio-commodities is demonstrated by a number of policy frameworks, including the Bio-E3 policy and Bio-RIDE schemes, the National Biofuel Policy, Ethanol Blending Programme, the SATAT Scheme, and the Green Hydrogen Mission Programme. By 2050, the global bioeconomy is predicted to generate up to $30 trillion in economic growth worldwide. India is one of the driving forces behind the expansion of the global bioeconomy. By establishing a robust framework for collaboration in the bioeconomy space, India hopes to further develop bio-based solutions and industrial relationships around the world through the Global Biofuel Alliance.

Incorporating insights from the India-Netherlands joint Innovation Mission workshop and Indo-Dutch Tech Summit, which were held in India (New Delhi) in October, 2024 and February, 2025 (organized by TERI in collaboration with the Netherlands Innovation Network), this report outlines the current state of bioeconomy policy and growth projections for both India and the Netherlands. With an emphasis on bioenergy, biochemicals, and bio-based materials, this study examines the prospects and synergies between India and the Netherlands in the bioeconomy sector.



India's bioeconomy sectoral highlights (2023-2024)


H2

Recommendations

Recommendations and Roadmap for Advancing Indo-Dutch Collaboration in Bioeconomy

Key Focus Areas	Challenges	Recommended Actions	Stakeholders Involved
Strengthening Policy & Regulatory Frameworks	• Lack of harmonized biofuel standards • Need for policy alignment in bioeconomy sectors	• Align India-Netherlands bioenergy policies through facilitation of bilateral policy dialogue • Align bilateral trade & investment in biofuels, biochemicals, and biomaterials • Provide incentives & subsidies for bio-based startups and R&D • Consider joining the Global Biofuel Alliance for multilateral collaboration	Government of India, Dutch Government, GBA, Industry Associations
Advancing Technology & Innovation	• Lack of proactive collaboration between the Netherlands and India • Limited scale-up of advanced biofuels • High R&D costs & slow technology transfer	• Organize innovation missions, conferences and match-making initiatives • Increase Public-Private Partnerships (PPP) for biofuels & biorefineries • Foster joint research through Mission Innovation & Horizon Europe • Establish full-scale biorefineries & algae-based biochemicals and biofuel projects • Establish bilateral institute to institute links between leading stakeholders	Academic and research institutions from India and the Netherlands focusing on bioeconomy, along with biofuel companies
Capacity Building & Workforce Development	• Shortage of skilled workforce in bioeconomy • Lack of industry-academia integration	• Launch Indo-Dutch joint training programmes in bioengineering & biorefineries • Provide industry internships & research exchange programmes • Strengthen vocational training for SMEs in bio-based sectors	Academic Institutions, Vocational Training Centres, Industry Leaders
Market Integration & Commercialization	• Low consumer awareness of bio-based products • Weak biofuel & biochemical supply chain	• Promote Public-Private Partnerships (PPPs) for large-scale adoption • Support SMEs & startups in bio-based product commercialization • Develop sustainable biofuel supply chains • Public Procurement of biobased products	Large Corporations, SMEs, Startups, Biofuel Manufacturers, Logistics Companies
Improving International Cooperation & Knowledge Sharing	• Limited international engagement in bioeconomy expansion • Lack of regional biofuel trade mechanisms	• Strengthen Indo-Dutch engagement (R&D and demonstration) under bilateral and multilateral collaboration platform • Strengthen engagement under Mission Innovation partnerships to promote R&D collaboration and trade of biomass and its derived products • Leverage India's BioE3 policy and explore joint R&D opportunities to promote high performance biomanufacturing of bio-products	Netherlands Enterprise Agency (RVO), Indian & Dutch Governments, Global Bioeconomy Networks

INTRODUCTION

1. INTRODUCTION

Biotransition refers to the shift from a fossil-based economy to bio-based economy that places a strong emphasis on using biological resources. The term bioeconomy refers to economic activities that leverage biological resources such as microbes, plants, and animals, as well as bioprocesses for the sustainable production of food, energy, chemicals, materials and contribute significantly to drive the economic growth of a nation. India has set the ambitious target of having a net-zero economy by 2070 and wishes to be positioned as one of the global leaders in this transition. India intends to accomplish this by promoting greater use of renewable energy sources, particularly bio-based resources, through innovation-driven policy advocacy.

For the Netherlands, the exploration of international cooperation on innovation and the establishment of value chains in the bio-economy is of increasing importance. The National Energy System Plan (NPE) explains the vision of the Dutch government on the carbon chain. In 2050, there will still be a substantial carbon demand because there are no or very limited alternatives available in certain sectors. This applies, for example, to fuels in aviation and shipping and to the production of plastics, paint and coatings. This remaining carbon demand will have to be met permanently with renewable carbon carriers, in which biogenic carbon carriers from bio-based raw materials play an important role. Collaboration with a country like India is important to explore.

The Netherlands' National Technology Strategy (NTS) is a particularly important framework for innovation in the biotransition. This framework is meant to propel the country as a global leader in high-tech industries, bio-manufacturing, and sustainable innovations. NTS is in line with the country's circular economy agenda and focuses on:

- **Sustainable biomass utilization**: Promoting the use of agricultural residues, forestry byproducts and marine biomass for bio-refineries and biofuels.
- **Bio-based manufacturing**: Growing bio-based materials, bioplastics, and green chemicals to replace fossil-based products.
- **Advanced bio-refinery technologies**: Supporting lignocellulosic biomass conversion, enzymatic hydrolysis, and microbial fermentation to improve bioeconomy competitiveness.

India's biotransition is driven by the new BioE3 Policy framework (Biotechnology for Economy, Environment, and Employment), a strategic initiative launched by the Indian government to harness biotechnology for sustainable economic growth. BioE3 policy framework is expected to attract international collaborations, investments, and expertise in biotechnology. Country's focus especially on high-performance biomanufacturing and sustainable practices can serve as a model for other nations.

BioE3 policy aims to position India as a global leader in bioeconomy through:

Fostering innovation

Encouraging research and development in biotechnology, synthetic biology, and bio-based industries.

Promoting sustainability

Supporting regenerative bioeconomy models, circular practices, and sustainable agriculture.

Driving economic growth

Creating high-performance biomanufacturing capabilities, generating employment opportunities, and attracting investments.

The Netherlands' biotransition mission is to employ a circular bioeconomy approach to promote sustainable development, generate employment and create business opportunities for industries. With its thriving agricultural sector, state-of-the-art biotechnology, and logistical expertise, the Netherlands is a leader in the bioeconomy and fosters long-term growth.

The Netherlands' bioeconomy strategy is based on a national policy framework, industry incentives, and a research and innovation agenda.

Key focus areas of bio-based economy:

Bio-based industries

Developing biorefinery industries like biopharma, bioenergy, and climate-resilient agriculture.

Carbon Capture and Utilization

Promoting technologies that convert captured CO_2 into valuable products like biofuels and biochemicals.

Sustainable agriculture

Improving agricultural productivity and sustainability through biotechnology and precision farming.

Key initiatives under the Netherlands' bioeconomy strategy:

- **Bio-refineries**

The Netherlands is investing in bio-refineries, which convert biomass into biofuels, biochemicals, and other products.

- **Bioplastics**

The country is also exploring and realizing the production of bioplastics from renewable bioresources (e.g., Avantium-We believe in a fossil-free world. Let's go).

- **Public-Private Partnerships**

Collaboration between industry, research institutions, and government is driving innovation and growth in the bioeconomy.

The Netherlands and India are building on their existing relationship. For example, in September 2024, an MoU on strategic energy cooperation was renewed between the Ministry of KGG (Dutch Ministry of Climate Policy and Green Growth) and the Ministry of New and Renewable Energy (MNRE), Government of India. The intensive bilateral Knowledge and Innovation Agenda (so-called WAH! Agenda) makes various R&D programmes possible every year with the help of instruments from Indian and Dutch ministries and research funders. A Combitrack has been started on Waste Management, which focuses on better governance, knowledge exchange and technological development on the theme of bioenergy.

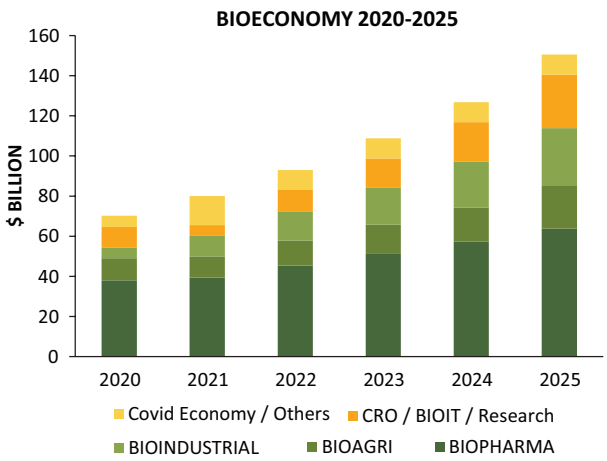
India and the Netherlands have similar biotransition objectives and can explore collaborations in the bioeconomy space by leveraging each other's strengths and expertise.

2. INDIA'S BIOECONOMY LANDSCAPE

Global bioeconomy is expected to contribute to the world economic growth up to $30 trillion by 2050. Among other nations, India is one of the key drivers for this growth. India's ambitious climate goal targets and policy advocacy for production and uptake of bio-based sustainable materials, contribute significantly to India's bioeconomy growth trajectory.

India has established itself as a global leader in sustainable bioeconomic transformation through its powerful R&D infrastructure and innovative industry sector. Since the last decade, India's bioeconomy sector has shown exponential growth by 16-fold, starting from $10 billion in 2014 to $165.7 billion in 2024, which is further projected to grow up to $300 billion by 2030. Over past four years, India's bioeconomy sector has contributed for about 4.25% GDP with a compound annual growth rate (CAGR) of 17.9%. Major segments contributing towards India's bioeconomy growth are—biopharma; bio-agri and bio-industrial (biofuels, biochemicals, bio-commodities), bio-IT and Covid economy (Figure 1).

The country stands among the top five global bio-economies (Table 1) with its leadership in vaccine production, ethanol blending, bioplastics and biomanufacturing. India aims to expand this sector further up to $300 billion



(Data: https://bmi.dbtindia.gov.in/biomanufacturing-initiative.php)

Figure 1: Major bioeconomy segments of India

Table 1: Global Bioeconomy: Current Status (Based on Indian Reports & Context)

Region / Country	Bioeconomy Value ($ billion)	Key Sectors	Sources
USA	~$1,000 billion (Estimated)	Biotech R&D, Genomics, Bio-manufacturing	Mentioned in comparison in IBER 2024 PDF
EU	~$800 billion	Bio-based industries, Sustainable agriculture, Bio-innovation	Referenced in Indian Express
China	~$700 billion (approx., 2023 Est.)	Synthetic biology, Biopharma, Bio-industrials	Cited in Entrepreneur
Brazil	~$400 billion (includes agri-bio)	Bioenergy, Agro-biotech, Forest bioeconomy	Contextual mention in IBER 2024 PDF
Global (Overall)	>$4 trillion (Est.)	Food systems, Renewable materials, Green energy	Highlighted as a global shift in ABLE India
India	$165.7 billion (2024)	Biotech, Bio-agri, Bioenergy, Biopharma, Startups	PIB - BioSarthi Launch

(Table 2) by 2030 (MNRE – Bioenergy Overview). Top seven states contributing for India's bioeconomy growth are: Maharashtra, Karnataka, Telangana, Gujarat, Andhra Pradesh, Tamil Nadu, Uttar Pradesh (Table 3).

India's bioeconomy sector is expected to generate 35 million green jobs by 2030 backed strongly by policy. Till date more than 8,500 biotech startups have been founded. The bio-industrial segment which includes biofuels and biogas together with enzymatic bioprocesses generated $72.6 billion in value during 2023 and contributed for 48% of India's total bioeconomic value of $151 billion. The biofuel sector is projected to generate $20 billion bioeconomy by 2025 (from $6 billion in 2021 (almost threefold).

Table 2: India's Bioeconomy Growth and Projections (2014–2030)

Year	Bioeconomy Value ($ billion)	Growth Highlights	Source
2014	10	Baseline estimate	ABLE India
2019	62	6x growth in 5 years	BIRAC
2020	70.2	Continued growth	IBER 2024 PDF
2021	80.1	Crossed $80 billion	Next IAS
2022	102.3	Crossed $100 billion mark	Indian Express
2023	150	~47% growth YoY	Entrepreneur India
2024	165.7	4.25% of India's GDP	PIB News - BioSarthi Launch
2025	N/A	Current year	PIB IBER Launch
2027	>200	Based on trajectory	Next IAS
2030	300	Target milestone	ABLE India

*YoY—Year-over-year; GDP—Gross domestic product

Table 3: Top states of India contributing for bioeconomy growth (2024)

State	Value (In $ billion)	Share of total value (%)
Maharashtra	35.45	21.4
Karnataka	32.4	19.5
Telangana	19.9	12
Gujarat	12.9	7.8
Andhra Pradesh	11.1	6.7
Tamil Nadu	9.9	6
Uttar Pradesh	7.7	4.6

Source: Indian Bioeconomy Report

In India, about 5 million tonnes of hydrogen is consumed annually, of which about 99% is used in petroleum refining and ammonia production.

India's ammonia production reached around 19 million tonnes in 2023 (95% dedicated to fertilizer production) and is expected to grow annually by 3.9% until 2034 to reach 28 million tonnes. Currently, all the ammonia produced is derived from reforming natural gas.

Led by the Ministry of New and Renewable Energy (MNRE), the National Green Hydrogen Mission (NGHM) focuses on the green hydrogen value chain and is expected to drive the growth of green hydrogen and ammonia in the country through government initiatives and industry demand. As of

2025, the main driver to ensure its success is to guarantee the demand, stimulated by large tenders from public corporations such as India Oil Corporation (IOCL) or various fertilizer companies.

Nevertheless, the focus of green hydrogen and ammonia is currently in heavy industries for the conventional use of hydrogen (chemical, refineries, steel) for energy purposes but has yet to take off.

India has a methanol production capacity of approximately 1-2 million tonnes. As of 2021, about 75-80% of methanol use in the country was met through imports. The Indian methanol market is expected to grow by 4.73% by 2030, driven by government initiatives to promote the chemical as a cleaner transportation fuel.

- The Methanol Economy Programme from NITI Aayog, which has yet to be formalized as an established policy equivalent to NGHM, focuses on production and utilization of methanol as a clean green fuel suggesting (i) blending 15% of methanol in gasoline and (ii) blending 20% DME (Di-Methyl Ether, a derivative of methanol) in liquefied petroleum gas (LPG).
- The bio-route for methanol production appears to be most likely due to the current biomass potential and limited availability of biogenic captured carbon dioxide for e-fuel production.

2.1. India: Biomass Generation Status

The annual biomass production in India reached 750 million tonnes. Country's annual surplus biomass amounts to 230 million (Figures 2 & 3, EAI). The Biomass Atlas of India, developed by the National Institute of Bio-Energy (NIBE) shows the complete spatial distribution of total and surplus biomass resources throughout the country. The total biomass resource distribution shows Uttar Pradesh with the highest amount at 124 million tonnes (MT) followed by Madhya Pradesh with 70 MT and Maharashtra with 52 MT and Rajasthan with 59 MT. The surplus biomass amount reaches 21 MT or more in Uttar Pradesh, Madhya Pradesh, Gujarat, Andhra Pradesh and Telangana. These numbers identify major states which possess substantial bioenergy potential for decentralized renewable energy and circular bioeconomy development. The Ministry of New and Renewable Energy (MNRE) identifies biomass as a vital material for decentralized energy systems and circular bioeconomic operations.

The main agricultural residues that create surplus include paddy straw, wheat straw, cotton stalks and sugarcane bagasse (Figure 4). According to Tata Consulting Engineers, the available biomass surplus amounts to 30% of the total while the remaining portion either decomposes or gets burned, thus, producing air pollution and GHG emissions. The biomass market in India will experience substantial growth because the biofuel and biogas value chains need sustainable feedstocks which will drive the biomass market to reach $3.9 billion by FY31 (ET EnergyWorld).

Figure 4 highlights the total and surplus biomass of 8 major rabi and kharif crops of India, which include wheat, mustard, sugarcane, bajra, maize, rice, groundnut, and arhar (tur). The total and surplus biomass of these major crops stands to be 526809.7 metric tonnes (0.526 MMT) and 110611.5 metric tonnes (0.111 MMT), respectively.

2.2. India's Bioenergy Sector: Status and Growth Projections

The bioenergy sector in India operates across multiple segments including biogas, compressed biogas (CBG), biomass power, bioethanol, biodiesel and advanced biofuels (Figure 5). India's bioenergy sector is witnessing a significant growth, driven by robust government policies and biomass generation potential. The total bioenergy capacity of India reached 9.8 GW in 2019 and expanded further to 11.35 GW in 2024 at a CAGR of 3.7%. The National Bioenergy Programme together with increasing biomass-based power generation projects, fuel this growth. The biogas market is projected to achieve $1.77 billion by 2025 and $3.49 billion by 2032. This was driven by advocating policies on compressed biogas (CBG) production.

The National Bioenergy Mission together with the SATAT scheme for compressed biogas and the Ethanol Blended Petrol Programme have together fast-tracked biofuel consumption while enhancing rural economic growth and fulfilling India's carbon reduction objectives. The biofuel innovation efforts are led by industry leaders and academia

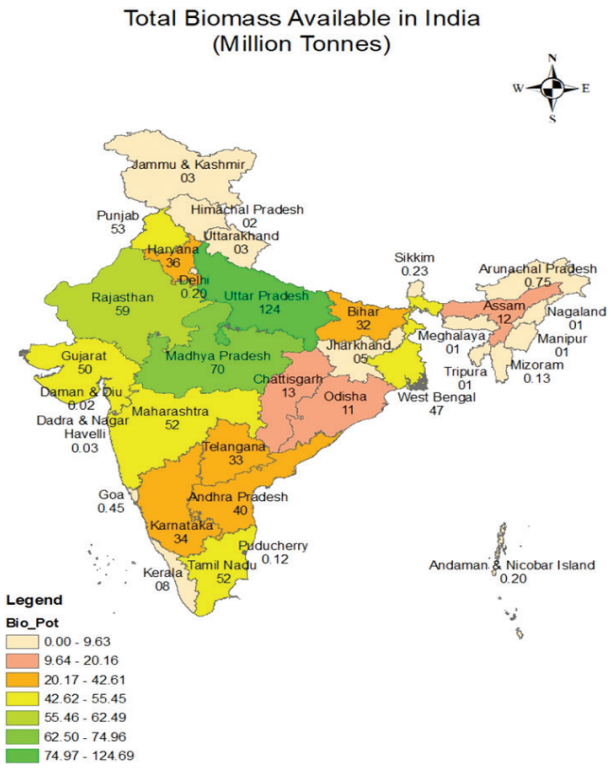


Figure 2: Total biomass available in India

Source: SSS NIBE, Biomass Atlas

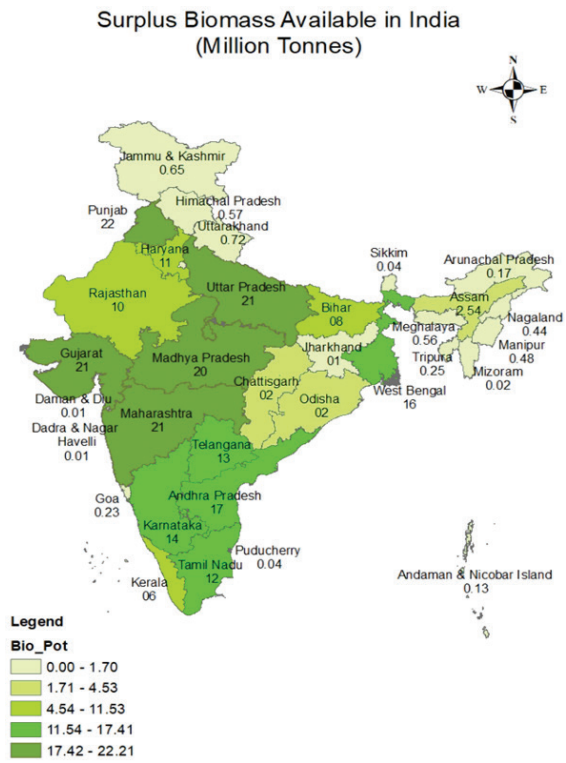


Figure 3: Surplus biomass available in India

Source: SSS NIBE, Biomass Atlas

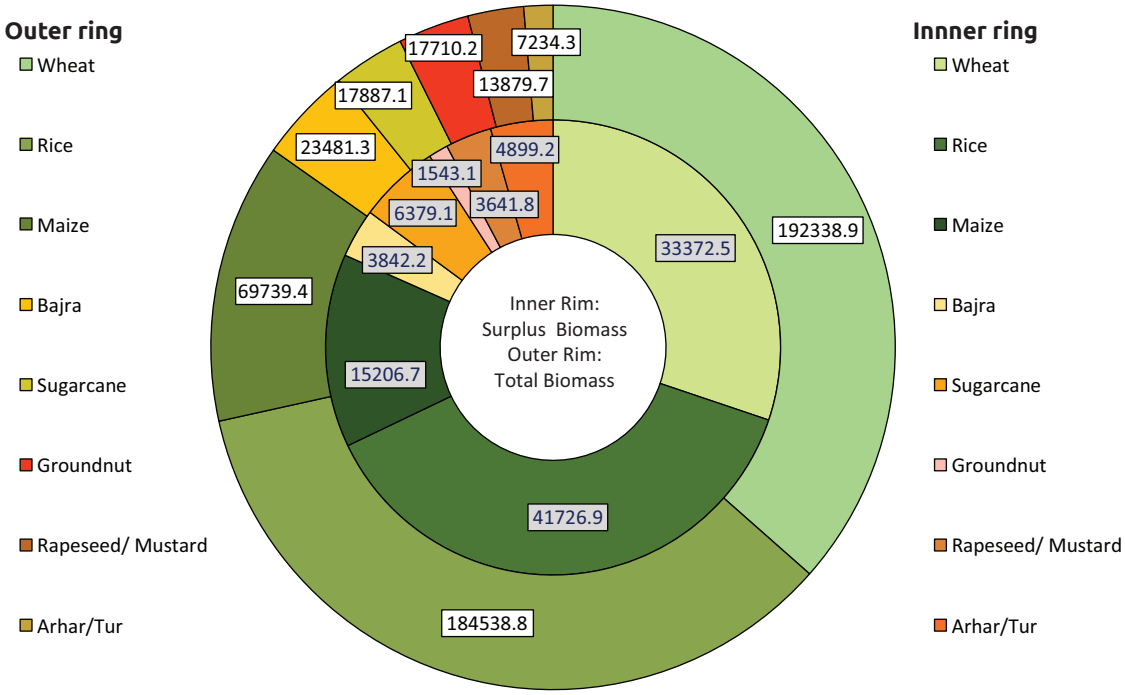


Figure 4: Total and surplus biomass (in metric tonnes) available in India

Source: SSS NIBE, Biomass Atlas

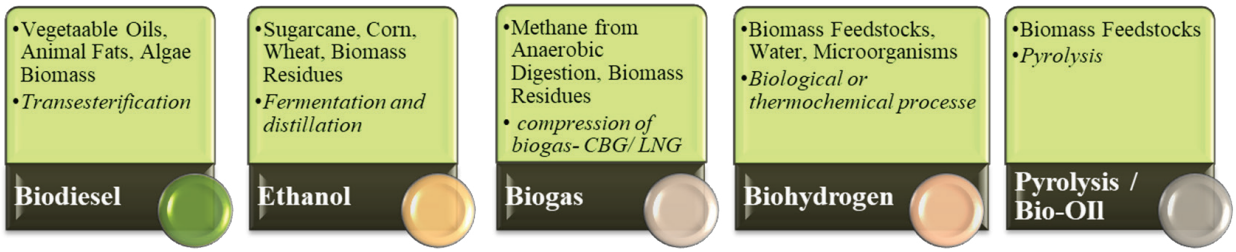


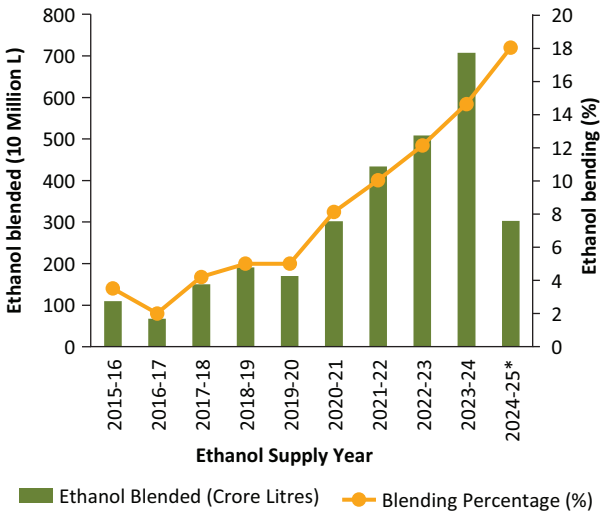
Figure 5: Different biofuel types: major feedstock used, and process involved

including The Energy and Resources Institute (TERI), Praj Industries, Godavari Biorefineries and Indian Oil Corporation that are developing second and third generation (2G & 3G) biofuels alongside sustainable aviation fuel (SAF) and waste-to-energy solutions. Bioenergy research collaborations between Indian Institute of Technologies (IITs), National Chemical Laboratory (NCL), TERI, Institute of Chemical Technologies (ICT), International Centre for Genetic Engineering and Biotechnology (ICGEB) and Department of Biotechnology (DBT) are advancing next-generation bioenergy solutions through employment of synthetic biology and integrated biorefineries and microbial bioprocessing. India can lead the global bioeconomy transition through future R&D (Research & Development) opportunities for scale up of algal biofuels and improve biomass conversion rates and cost-effective enzymatic hydrolysis technologies.

Among the core segments of India's bioenergy landscape, the biofuels sector has emerged as a dominant growth driver. Indian biofuels market demonstrated significant growth that is backed by the government's support for production and uptake of biofuels through various policies and programmes.

India is the third largest producer and consumer of ethanol in the globe and the second largest producer of sugar. The bioethanol industry has achieved 15% blending in 2024 and aims at achieving 20% blending (Figure 6) by 2025 (Devdiscourse). Under Ethanol Blending Program (EBP), Indian Oil marketing companies (OMCs) have paid sugar mills nearly €85,35,715 (Figure 7) for ethanol supplies in the last seven years, which has helped mills clear farmers' dues. B grade molasses, C grade molasses and sugar syrup, surplus food/rice grains and damaged food grains are the major feedstock used for bioethanol production (Figures 8–12). Bioethanol production from 2nd generation feedstock (lignocellulosic biomass) is in good progress (by OMCs).

The biodiesel production sector showed a 0.17 million tonne output in 2021 but analysts predict it will grow to 0.26 million tonne by 2030 with a 8.60% compound annual growth rate (EAI). The bioethanol market is projected to grow up to $406.64 million by 2030 owing to the increasing demand for sustainable fuels and policies supporting bioethanol production and uptake, feedstock diversification and improved production (EAI; MoPNG; Biofuels Overview MNRE).



(Data: NITI Aayog, https://iced.niti.gov.in, Copyright © 2025)

Figure 6: Bioethanol blending profile during 2015-2025

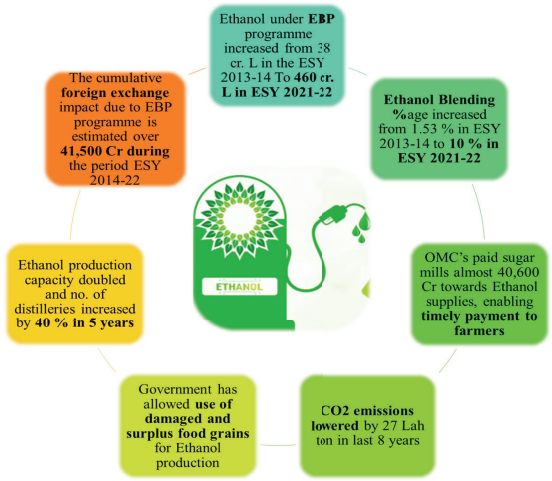
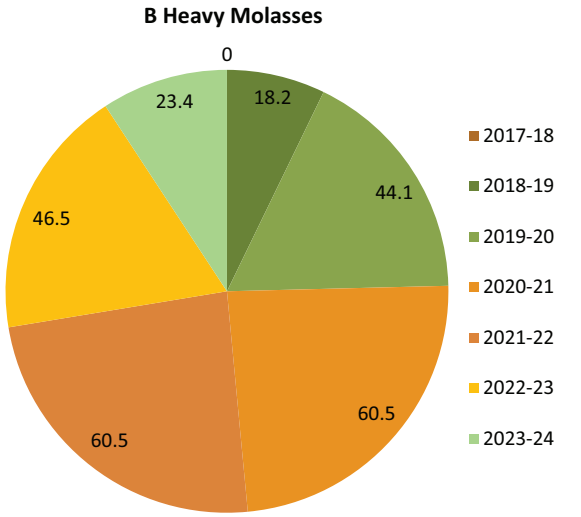


Figure 7: Advantage of Ethanol Blended Programme (Ethanol Blending Programme)



https://iced.niti.gov.in/energy/fuel-sources/others/bio-energy/bio-fuel

Figure 8: Ethanol contribution from B heavy molasses (%) over the years (2017–2024)

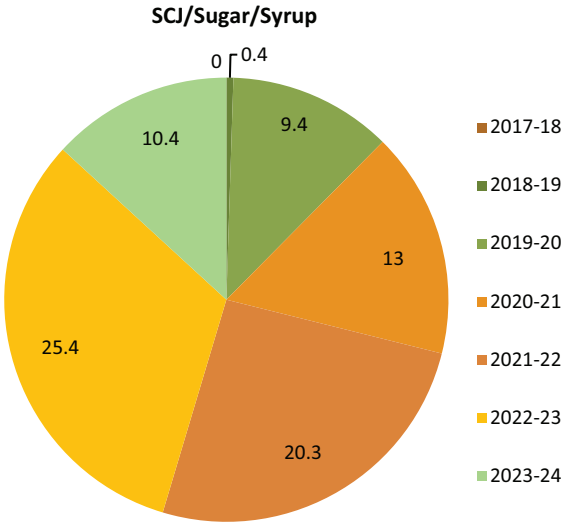


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Figure 9: Ethanol contribution from SCJ/sugar/syrup (%) over the years (2017–2024)

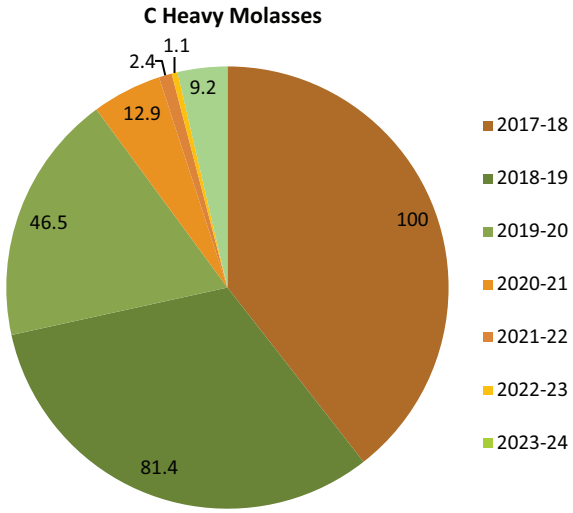

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Figure 10: Ethanol contribution from C heavy molasses (%) over the years (2017–2024)

2.3 Biogas Development in India and the Netherlands: A Comparative Overview

India has made substantial progress in biogas development through its abundant organic waste resources and effective policy support. The country installed 4.54 million biogas plants during 2012 and now operates more than 5,000 small-scale and 40+ large-scale facilities. The energy potential of biogas in India reaches approximately 17,000 MW while serving multiple uses including electricity production and cooking fuel and the developing market of Compressed

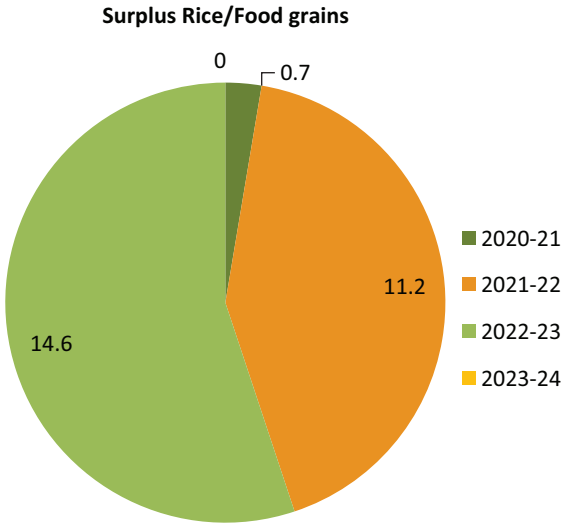


Figure 11: Ethanol contribution from surplus rice/food grains (%) (2020–2024)

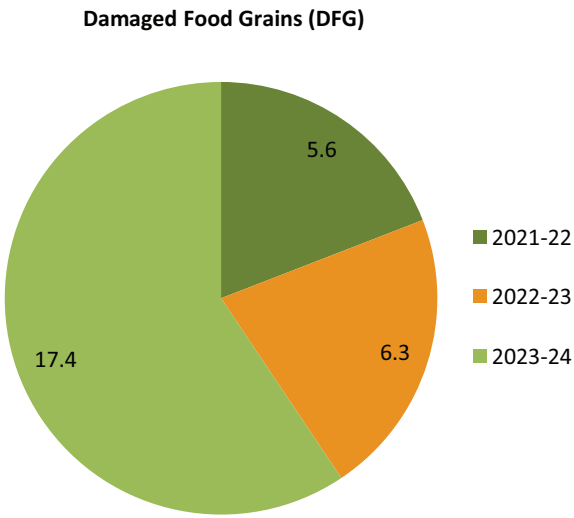


Figure 12: Ethanol contribution from damaged food grains (%) (2021–2024)

Table 4: Key Bioenergy Companies in India

Company Name	Introduction	Work/Products	Current Trajectory
praj	Pioneer in bioenergy technologies, especially ethanol and bio-CNG	Develops 1G & 2G ethanol plants, bio-CNG projects	Leading innovation in bio-refineries and exports globally
HPCL BioFuels Limited	Subsidiary of HPCL dedicated to ethanol production from sugarcane	Produces ethanol, power, and bio-compost from sugarcane	Expanding capacity for E20 ethanol blending
IndianOil	PSU working extensively on ethanol, CBG and 2G biofuels	Bioethanol, compressed biogas (CBG) and 2G ethanol plants	Running 500+ CBG plants; aiming to be net-zero by 2046
SHREE RENUKA SUGARS	Leading sugar producer, also large bioethanol player	Produces fuel ethanol from molasses	Growing focus on ethanol blending mandates
Bharat Petroleum	PSU implementing bioethanol and compressed biogas (CBG) projects	CBG and ethanol projects across India	Commissioning large-scale ethanol refineries
NRL	Govt refinery building 2G ethanol plant in Assam	Cellulosic ethanol from bamboo	First-of-its-kindin NE India, key to bamboo valourization
gps	Startup focused on bio-CNG and organic waste-to-energy	Bio-CNG from food/agri waste	Operates 100+ decentralized bio-CNG plants
GREENJOULES	Pune-based startup working on drop-in biofuels	Produces clean fuels from agri and municipal waste	Backed by BPCL and expanding B2B biofuel solutions
AGF AGREENERFUTURE	Focused on manufacturing biodiesel and biofuel blends	Biodiesel from used cooking oil and non-edible oils	Growing under RUCO initiative
EVER ENVIRO	Large private player in CBG production and MSW-to-fuel	Focus on compressed biogas (CBG) from waste	Scaling up across multiple Indian states
Godavari Biorefineries Ltd	One of India's oldest integrated biorefineries with operations in sugar, ethanol, and chemicals	Produces ethanol, bio-based chemicals, and power from biomass	Expanding bio-based chemicals and ethanol production capacities

Table 5: Key Bioenergy Industries in India

Bioenergy category	Introduction	Contribution	Current Trajectory
Ethanol Production (Sugar-based)	Utilizes sugarcane juice, syrup, and molasses for ethanol production	Supports India's ethanol blending programme, reducing oil imports and enhancing farmer incomes	Expansion due to government policies allowing ethanol production from cane juice and B-heavy molasses
Biodiesel from Used Cooking Oil (UCO)	Converts waste cooking oil into biodiesel	Promotes waste-to-energy initiatives, reducing environmental pollution	Growth driven by initiatives like RUCO, encouraging biodiesel production from UCO
Biogas and Bio-CNG Production	Processes organic waste into biogas and upgrades it to Bio-CNG	Provides renewable fuel alternatives, aiding in waste management	EverEnviro leads the way as companies increase the adoption of public transport and industry operations
Second-Generation (2G) Ethanol	Produces ethanol from agricultural residues like rice straw and bamboo	Enhances energy security and provides value addition to agricultural waste	Projects like NRL's bamboo-based ethanol plant in Assam exemplify this trajectory
Biomass Power Generation	Utilizes agricultural and forestry residues to generate electricity	Diversifies energy mix and provides rural employment	Abellon Clean Energy is among the companies that are increasing their biomass power project operations
Algae-based Biofuels	Develops biofuels from algae cultivation	Offers high-yield, sustainable biofuel options	Emerging sector with research institutions exploring commercial viability
Biofuel from Agricultural Waste	Converts crop residues into biofuels	Reduces stubble burning and associated air pollution	Government incentives are promoting technologies for crop residue utilization
Municipal Solid Waste (MSW) to Energy	Processes urban waste to generate bioenergy	Addresses urban waste management challenges while producing energy	Waste-to-energy plants have been adopted by cities and GPS Renewables is one of the companies operating in this field
Bioenergy Equipment Manufacturing	Produces equipment for bioenergy production, like digesters and reactors	Supports the bioenergy infrastructure development	Increasing need for domestic manufacturing capabilities to back bioenergy projects creates growing demand
Integrated Bioenergy Parks	Combines multiple bioenergy technologies in a single location	Maximizes resource utilization and energy output	Development of bioenergy parks receives encouragement to make optimal use of resources

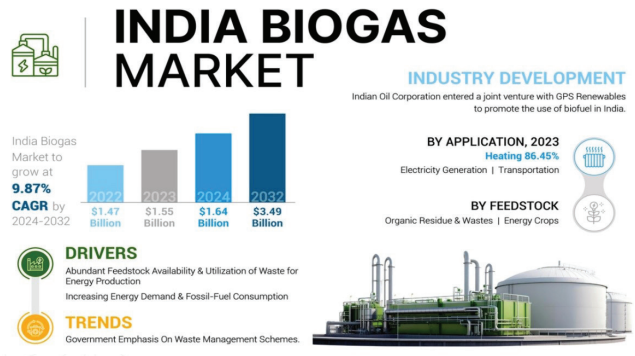
Table 6: Key Bioenergy Institutes in India

Institute/ Centre Name	Introduction	Research Contribution	Current Trajectory	Sector
DBT-IOC Centre for Advanced Bio-Energy Research	A collaborative centre between DBT and Indian Oil Corporation focusing on bioenergy research	Advanced biofuels and bioenergy technologies are developed to provide sustainable energy solutions	Lignocellulosic ethanol and other next-generation biofuels are being researched	Government funded
Advanced Biofuels and Biochemicals centre, The Energy and Resources Institute (TERI) DBT-TERI Centre of Excellence on Integrated Production of Advanced Biofuels and Bio-commodities	Research explorations focused on technology development for biofuel, biochemical and bio-commodity production and their deployment at precommercial scale A joint initiative by DBT and TERI to enhance integrated biofuel production (3rd generation biorefinery using marine algae as platform feed)	Sustainable biofuels and bio-commodities are being developed for integrated approaches	1G, 2G and 3G bio-refinery Research on algal biofuels and waste-to-energy technologies is being advanced	Not-for-profit research organization (Government funded)
Sardar Swaran Singh - National Institute of Bio-Energy (SSS-NIBE)	Autonomous institution under the Ministry of New and Renewable Energy (MNRE), Government of India, focusing on bioenergy research and development	Specializes in R&D on biomass, biogas, waste-to-energy, and biofuels including thermochemical and biochemical conversion technologies	Advancing clean energy technologies and capacity building for rural and industrial bioenergy applications	Government funded
DBT-ICT Centre for Energy Biosciences	Collaboration between DBT and Institute of Chemical Technology, Mumbai, which is specific to energy biosciences	Involves research on bioenergy, including production of bioethanol and biodiesel from different feedstocks	Technologies are being upscaled for use in industrial bioenergy applications	Government funded
DBT Pan IIT Centre for Bioenergy	Consortium of Indian Institutes of Technology that work on bioenergy solutions under the guidance of DBT	Interdisciplinary research on bioenergy, including biomass conversion and biofuel production is done	Efforts are being made to come up with new and improved ways of using bioenergy	Government funded
DBT-ICGEB Centre for Advanced Bio-Energy Research	Collaboration between DBT and International Centre for Genetic Engineering and Biotechnology, which is focused on bioenergy	Research has been done on advanced biofuels, including second generation ethanol and biodiesel production	Genetic engineering techniques are being used to improve biofuel production	Government funded
Indian Institute of Technology (IIT) Roorkee - Biofuel Research Lab	A biofuel research and development laboratory situated at IIT Roorkee	Involved in the production of biofuels from lignocellulosic biomass and other renewable energy sources	Cost effective and sustainable methods of biofuel production are being developed	Government funded

Institute/ Centre Name	Introduction	Research Contribution	Current Trajectory	Sector
Praj Industries Limited	A major private company that focuses on bioenergy and environmental technologies	Develops and markets technologies for bioethanol, biodiesel, and other bio-based products	Global market expansion with innovative bioenergy solutions	Private
Abellon Clean Energy	A private company that operates in the clean energy space with a focus on biomass power generation	Involved in the creation of biomass power projects to meet renewable energy targets	There is an expansion of biomass energy projects in different parts of India	Private
Orient Green Power Company Limited	One of the leading renewable energy-based power generation companies in India, which is focused on biomass	Operates biomass power plants on agricultural residues and energy crops	Company is expanding its renewable energy business to wind and solar energy	Private
Greenko Group	One of the leading renewable energy companies that has biomass, wind and solar power projects	Involved in biomass power projects for the promotion of sustainable energy	Applying advanced technologies to improve biomass power production	Private

Biogas (CBG) for transportation and industrial applications (Energy World). The SATAT (Sustainable Alternative Towards Affordable Transportation) programme under the government aims to establish 5,000 CBG plants which will annually produce 15 MMT of CBG for integration into the national gas distribution network. Feedstocks such as crop residues, livestock manure, municipal solid waste, and food waste offer substantial biogas yields (e.g., bakery waste yields up to 470 m³/tonne) (IBA, MNRE).

The National Bioenergy Programme (2021–2026) under the MNRE provides a complete policy structure to support India's biogas sector. The umbrella scheme includes three sub-programmes which are the Biogas Programme for small to medium digesters, the Waste to Energy Programme (supporting power, CBG, and syngas from waste) and the Biomass Programme (promoting biomass briquettes and cogeneration). The financial support for small units ranges from ₹9,800–₹70,400 per plant and for large power-generating systems it is ₹45,000/kW (MNRE Sansad). Incentives are also provided for projects in remote areas and for marginalized communities. The implementation process involves State Nodal Agencies, Khadi and Village Industries Commission (KVIC), Biogas Development and Training Centres (BDTCs), and National Dairy Development Board (NDDB) as stakeholders and the Biogas Application Portal is used for application processing (MNRE Biogas Prog 2021–26).



Source: https://www.fortunebusinessinsights.com/india-biogas-market-106563

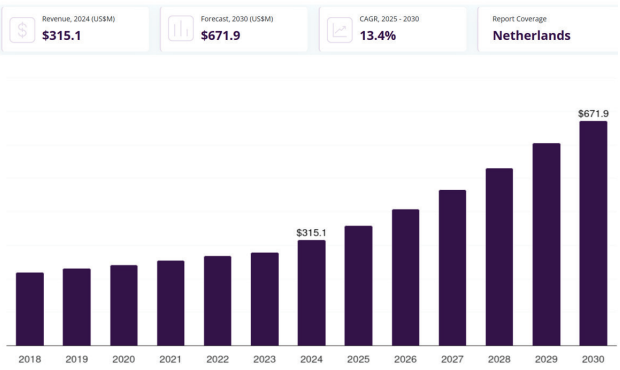
Despite progress, challenges persist due to high capital expenses and technical processing difficulties with lignocellulosic biomass and inadequate waste segregation system. The National Biofuel Policy (2018), GOBAR-DHAN Scheme and Green Hydrogen Mission together establish biogas as a fundamental component for India's transition to clean energy. The complete realization of this sustainable circular solution requires three key elements: expanding feedstock logistics operations, conducting research to decrease technology expenses and establishing stronger connections between transportation systems and energy distribution networks.

In contrast, the Netherlands has established itself as a European leader in biogas and biomethane production through strategic investments combined with technological innovation and strong policy support. The country established more than 250 anaerobic digesters since the early 2010s which now operate at 219 MW capacity and produce 11,905 Nm³/h of biomethane through the use of manure and sewage sludge and organic waste (Green Create). The total energy supply of the Netherlands reached 12.7% renewable energy in 2022 while biomass made up 45% of this renewable energy share (IEA Country report, 2024). The Netherlands maintains complete biogas self-sufficiency while expanding its capabilities through international partnerships, as reported by IEA Country report, 2024 and the World Biogas Association.

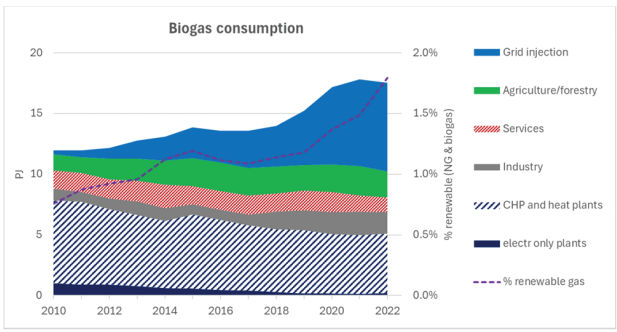
A key shift in recent years has been the transition from combined heat and power (CHP) to biomethane production, which allows grid connection. For example, the Groengas Jelsum plant - which is operational since 2006 produce over 2 million Nm³ of biomethane annually, and also supplying around 1,600 homes (HoSt Group). Further, the country's scaling capacity is illustrated by large-scale facilities like the Holwerd Plant (3.2 million m³/year) and the Wijster Campus (36.8 million m³/year from poultry manure) according to Green Create reports. Amsterdam's Waternet wastewater plant alone generates 11 million m³ of biogas yearly, supporting electricity generation, biomethane production (European Biogas Association).

Policy measures have been central to this growth. By 2030, the Dutch Climate Act mandates a 49% GHG reduction and by 2050 up to 95% (compared to 1990 levels), supported by biomethane blending obligations that target 150 million m³ by 2025 and 2 billion m³ (Dutch Law Biomethane). These mandates require that 20% of gaseous energy for the built environment come from biomethane by 2030. A noteworthy emphasis is placed on using domestic organic waste - particularly manure - for biomethane production, addressing both energy and agricultural sustainability challenges (EBA). The government has also phased out subsidies for forest biomass for heat, encouraging more sustainable biomass applications (Fern).

The Dutch biomethane market reached USD 315.1 million in 2024 and analysts predict it will grow to USD 671.9 million by 2030 at a compound annual growth rate of 13.4% (Grand View Research). The municipal waste sector leads the market as its fastest-growing feedstock segment while biogas compression and grid injection systems show promising development potential (Research Nester). The



Source: https://www.grandviewresearch.com/horizon/outlook/biomethane-market/netherlands



Source: IEA Country report, 2024

sector encounters three main bottlenecks which include permitting delays and feedstock logistics challenges and the requirement to integrate smaller producers as seen in the EU's Biogas Action initiative. The Netherlands' biogas systems demonstrate substantial GHG reduction potential yet lifecycle management of inputs and outputs requires careful attention according to sustainability assessments (MDPI).

In a nutshell, both India and the Netherlands are strategizing paths in biogas development, driven by diverse national priorities and strengths. India is operating its vast organic resource base and rural energy needs, while the Netherlands influences policy precision and upgrade of the technology to decarbonize its built environment. Together, their experiences offer collaborative models for advancing biogas as a foundation of the global clean energy transition.

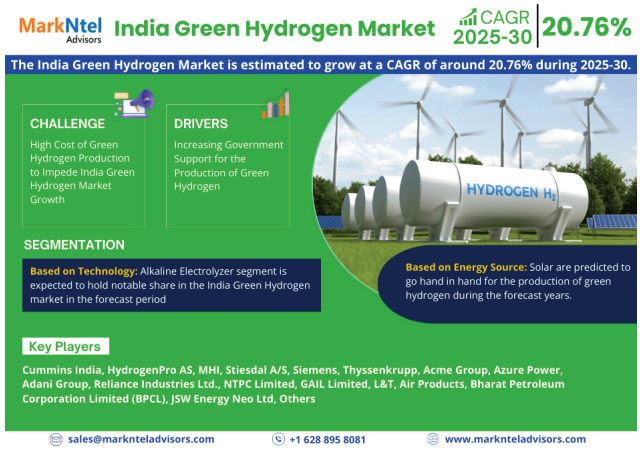
2.4. Green Hydrogen in India and the Netherlands: Status, Mission, and Biomass-Based Pathways

Biohydrogen is gaining traction as a promising clean energy vector which shows significant potential through biomass and organic waste conversion into a sustainable decentralized hydrogen production system. The MNRE – R&D roadmap for GH reports that India uses research and pilot-scale projects to convert its large agricultural residues and organic municipal waste into hydrogen through dark fermentation and photo fermentation and bio-electrochemical methods. The technologies apply microbial conversion at mild conditions which makes them ideal for decentralized applications in rural and semi-urban regions. The National Green Hydrogen Mission supports the Ministry of New and Renewable Energy (MNRE) in funding research and development and demonstration facilities and biomass valourization programs to advance innovation in this field. The round-the-clock biomass-fed hydrogen generation capability of biohydrogen systems enhances both resilience and flexibility in India's green hydrogen strategy according to PIB, 2023.

Green hydrogen is rapidly emerging as a foundation for clean energy transitions worldwide. The National Green Hydrogen Mission (NGHM) which India launched in 2023 serves as a pivotal initiative to cut carbon emissions in challenging sectors and boost national energy autonomy (MNRE NGHM). The Ministry of New and Renewable Energy (MNRE) directs the mission which plans to produce 5 million metric tonnes (MMT) of green hydrogen annually until 2030 while building 125 GW of renewable energy capacity. The 2.3 billion USD budget enables domestic electrolysers manufacturing growth and green hydrogen hub development and supports R&D activities and public-private partnerships (MNRE; PIB, 2023).

The NGHM's implementation strategy includes two core components: (1) SIGHT (Strategic Interventions for Green Hydrogen Transition) to provide financial incentives for electrolyser manufacturing and green hydrogen production, and (2) supportive regulatory measures such as steel and fertilizer and refining industry demand creation mandates (MNRE NGHM). India is also actively forming international alliances, notably with countries like the Netherlands, Japan, and the European Union, to co-develop hydrogen hubs together and obtain technology access and expand market integration (ET Energyworld, 2024).

India's green hydrogen potential will benefit both renewable energy-driven electrolysis and biomass-based production pathways. Electrolysis using from solar and wind-powered electrolysis results in zero-emission hydrogen while biomass conversion allows decentralized hydrogen production using agricultural residues. According to Lepage et al. (2020) and



Source: Markntel advisors GH2

Ringgswandl et al., (2022) biomass-to-hydrogen can occur via:

A. Biological routes:

- **Dark fermentation**: Anaerobic conversion of carbohydrates to hydrogen using mesophilic or thermophilic microbes.
- **Photo-fermentation**: Hydrogen production under light by non-sulphur photosynthetic bacteria.
- **Bio-photolysis**: Through direct use of solar energy or organic substrates, algae or cyanobacteria split water molecules to produce hydrogen.

B. Bio-electrochemical routes:

- **Microbial Electrolysis Cells (MECs)**: Electroactive bacteria convert organic materials into hydrogen through low-voltage processes.

C. Thermochemical methods:

- **Gasification and Pyrolysis**: Conversion of lignocellulosic biomass into hydrogen-rich syngas for large-scale centralized facilities (Lepage et al., 2020; Ringgswandl et al., 2022).

Meanwhile, the Netherlands is emerging as a European hydrogen hub, in order to achieve its carbon neutrality goal by 2050 while decarbonizing its industrial sector (GH2). In 2024, the Dutch government dedicated 2.37 billion USD for green hydrogen development, through electrolyser project subsidies along with the establishment of a 4% green hydrogen usage mandate for industry sectors including chemicals and steel (H2 View, 2024).

The Netherlands aims in establishing 3-4 GW of electrolysis capacity facilities through offshore wind power integration during the period by 2030 (Marouani et al., 2023). TNO (Netherlands Organisation for Applied Scientific Research) leads initiatives like HyScaling to decrease electrolyser expenses and create efficient supply networks for hydrogen utilization (TNO, 2024).

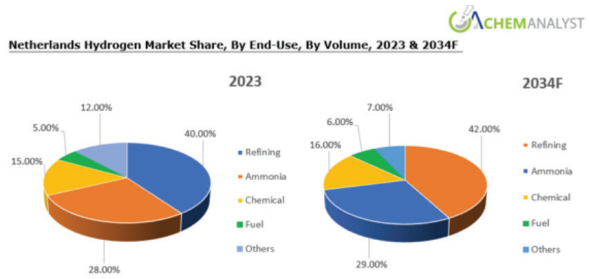
Key Dutch strategies includes: (H2 Europe)

- Construction of a hydrogen pipeline which links industrial areas to port facilities such as Rotterdam.
- Large-scale green hydrogen production from offshore wind farms in the North Sea.
- Hydrogen trade and standardization of infrastructure will occur through cross-border cooperation between the Netherlands and Germany and Belgium.
- Market-shaping policies like blending mandates, auctions, and guaranteed demand mechanisms.

Furthermore, according to ChemAnalyst together with other market intelligence reports indicate the Netherlands

A map of the planned Dutch national hydrogen network in 2030

Source: Energy transition NL



Source: ChemAnalyst, 2024

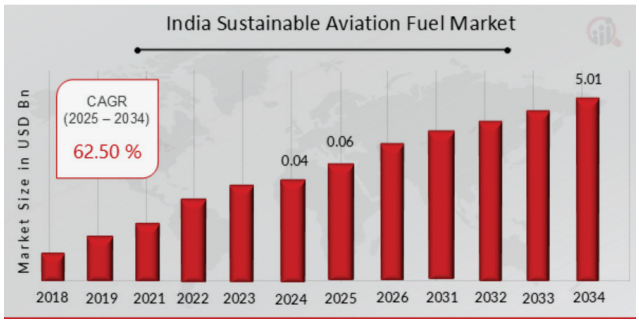
examines hydrogen imports from Norway and Middle Eastern countries while establishing itself as a future distribution and technology centre for Northern Europe.

In summary, India and the Netherlands are both moving forward with green hydrogen initiatives in their own national ways through missions and international cooperation. India's plan for green hydrogen production involves decentralized units which use renewable and biomass sources backed by large public funding and compulsory demand requirements. The Netherlands aims to expand its offshore wind-electrolysis capacity while building up industrial mandates and hydrogen trade infrastructure. These countries demonstrate the worldwide variations in hydrogen approaches by using their individual assets of renewable energy resources and innovative capabilities and industrial governance models.

2.5 Sustainable Aviation Fuel: India and the Netherlands - Status and Market Outlook

India is emerging as a major global player in the Sustainable Aviation Fuel (SAF) landscape, by forecasting 8-10 million tonnes (MT) annual production until 2040, as projected by a Deloitte India report. India will produce sufficient SAF to satisfy both its national demand for 4.5 MT under a 15% blending mandate while establishing itself as a major SAF export hub (SAF Deloitte press release). The transition will produce more than 70-85 billion USD in investments while creating up to 1.4 million green jobs that will reduce annual CO_2 emissions by 20-25 MT (SAF Vurdhaan).

India holds an advantage because it possesses a large feedstock supply that includes 230 million tonnes of agricultural residue and municipal solid waste and used cooking oil which makes decentralized Alcohol-to-Jet (AtJ) SAF production feasible (Deloitte SAF; Bioenergy Times). IATA along with global stakeholders endorse India's SAF development because the country possesses enough



India Sustainable Aviation Fuel Market by Platform, 2022 & 2032 (USD Billion)

Source: https://www.marketresearchfuture.com/reports/india-sustainable-aviation-fuel-market-13940

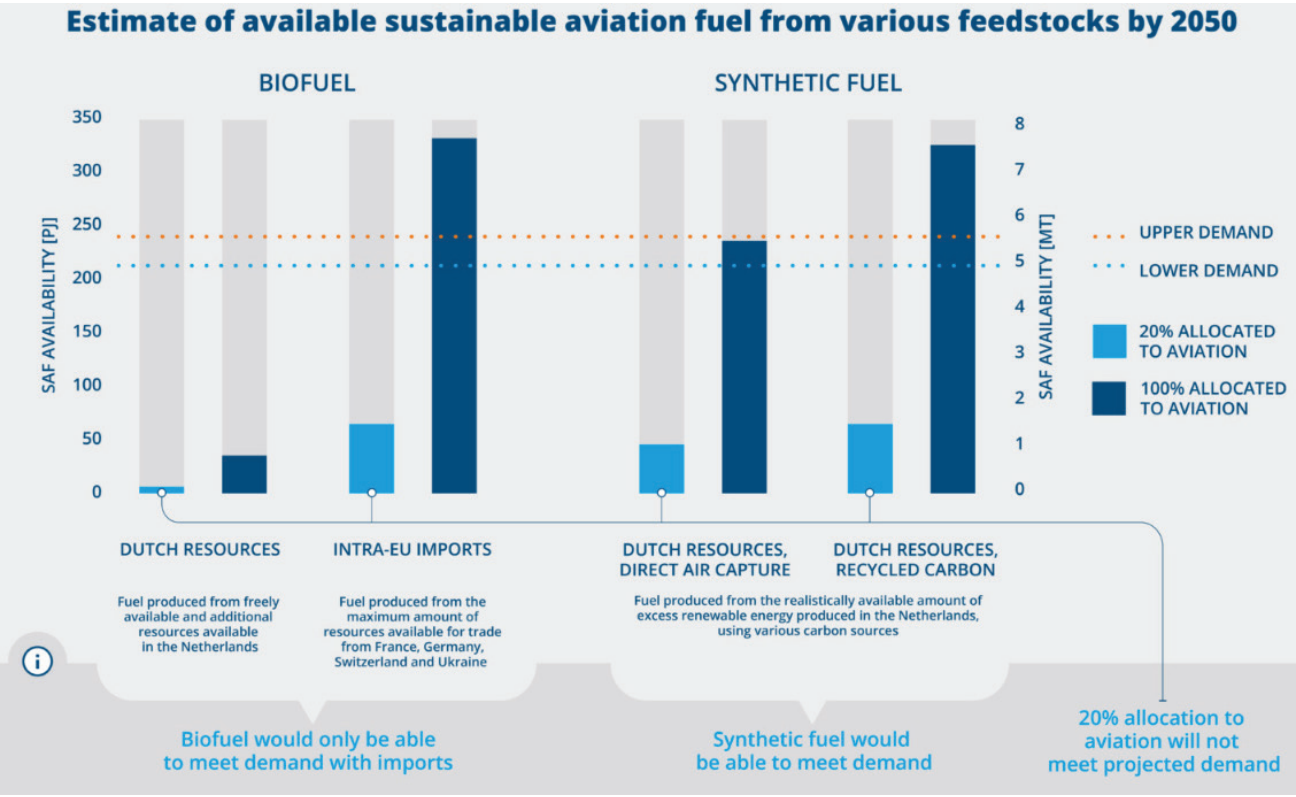
Feedstock and pathway	2024A production [million tonnes]	2040P availability for SAF [million tonnes]
Used cooking oil (HEFA)	~2.4	<0.5 Potential shortfall in future for biodiesel production as well
Maize (AtJ with 1G Ethanol)	~37	Limited availability after domestic consumption, potential exports of sugar and requirement for ethanol blending; Maize shortfall however can be met through imports
Sugar (AtJ with 1G Ethanol)	~33	
Agri-residue (AtJ with 2G Ethanol)	~230	80–90 (25-30% agri-residue is made available for biofuel production)
Municipal solid waste (FT)	~61	12–13 (~50% organic matter in MSW and 10-15% MSW is used for SAF)

Source: Deloitte India report

ethanol supplies and its lipid feedstocks from non-edible oils can scale up for production. The first SAF demonstration facility launched by Praj Industries marked a milestone in India's infrastructure development during 2023 (Biomass Magazine).

India is engaged in promoting SAF adoption, aligned with the IACO-CORSIA roadmap that aims to 1% SAF in jet fuel for international flights by 2027, doubling to 2% by 2028 and 5% by 2030. To achieve these targets, the country requires approximately 140 million liters of SAF annually.

Key players of SAF include Indian Oil Corporation, who aims to achieve at least 1% SAF blending in jet fuel by July-September 2025. Production capacities for SAF in India, however, remain limited for now.

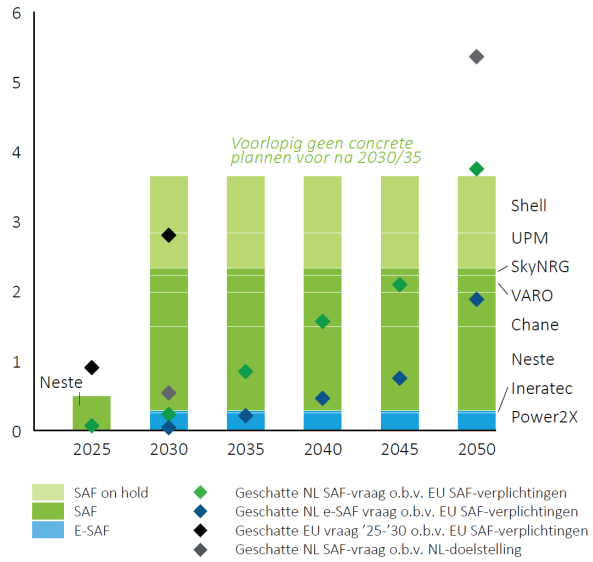


Biofuel feedstocks available in the Netherlands will not be able to meet the demand in 2050

Source: NLR.ORG

The Netherlands maintains its position as it stands as a global frontrunner in Sustainable Aviation Fuel (SAF) production because of its supportive laws and robust industrial network. The European aviation sector receives its SAF supplies from pioneering manufacturing facilities operated by Dutch companies including SkyNRG. However, a recent report suggests that the Netherlands may face a possible shortage of SAF production to satisfy future market needs so additional investment and feedstock mobilization efforts are necessary (NLR; GreenAirNews). Key players such as Neste together with other major players enhance their SAF production through improvements made at the Rotterdam refinery (World Bio Market Insights).

A Deloitte Netherlands roadmap outlines the country's SAF targets in line with EU mandates, supported by collaborations, innovation clusters, and access to feedstocks via global import chains. The strategic position of the Netherlands and its supportive policies together with



Roadmap for SAF production capacity in NL (MT) (2030-2050)

Source: Dutch aviation sector publishes SAF-roadmap

industrial partnerships keep it positioned as a central SAF hub (Invest in Holland; Global SAF 2025 Report).

Together, India and the Netherlands demonstrate different approaches to SAF production through India's focus on cost-effective large-scale production using local feedstocks while the Netherlands focuses on policy-backed innovation to meet EU climate requirements.

2.6. India: Biochemical Market

The fermentation chemicals market of India is growing at a faster pace owing to the growing demand of pharmaceuticals, food processing, biofuels, and agriculture industries. The market was valued at over $4.5 billion in 2023 and is expected to reach approximately $6.7 billion by 2030 at a CAGR of 5.5% (Figure 13, TechSci Research, BlueWeave Consulting).

The biochemicals include bioethanol, biodiesel, biopesticide, fermentation chemicals, ethanol, citric acid, lactic acid, acetic acid, enzymes and antibodies which are used in drug formulation, food additives and textile manufacturing. According to IMARC, the $50 billion pharmaceutical industry of India has a significant share (about 10% and may grow) of fermentation-based inputs as these chemicals are used to produce antibiotics, amino acids, and vitamins.

The India Bio-Economy Report 2024 reveals that fermentation-based Active Pharmaceutical Ingredients (APIs) and formulations contribute $6 billion to India's $53.8 billion biopharma segment, thus demonstrating their rising economic value (IBER 2024). The fermentation chemical sector of India is well placed to be a key pillar of bio-industrial economy with the increasing demand for sustainable production and alternative protein ingredients, thus, contributing to import substitution and export growth. The BioE3 policy's biomanufacturing hubs will be essential for upscaling domestic fermentation capacity for advanced bioeconomy products.

2.7. India: Bio-based Materials and Bioplastic Market

India's bio-based materials sector is rapidly gaining momentum because of innovative approaches combined with supportive policies and expanding market interest in sustainable alternatives. The market value of India's sustainable bio-based materials sector is projected to reach $388.9 million by 2025 with 11.7% CAGR and $844 million by 2032.

The Indian bioplastics accounted for $454.3 million in 2024 while maintaining a 20.3% annual growth rate (AGR) since 2019. The market growth results from escalating environmental consciousness and sustainable packaging and agricultural requirements with government regulations for prevention of single-use plastics. The bioplastic market is predicted to reach $761.9 million by 2030 (with a CAGR of 19.9%) owing to the material science progress and increased industrial use.

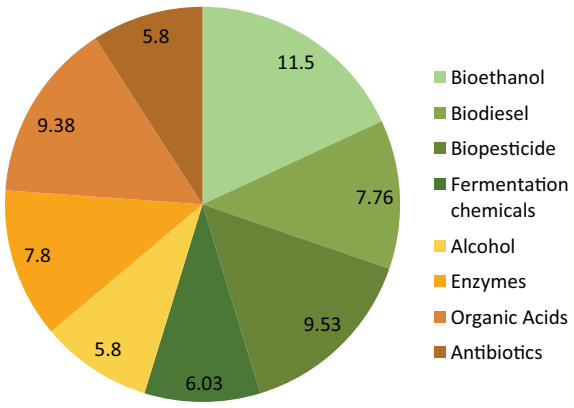


Figure 13: Biochemical market (%) growth projections in India (2023-24 to 2033-34)

2.8. India: Key Policy Frameworks and Mission Programme

India: Key Policy Frameworks

Ethanol Blending Programme (EBP): EBP sets a clear target of 20% ethanol blending in petrol (E20) by 2025, reducing crude oil imports and enhancing energy security.

National Policy on Biofuels (NBP): The 2022 amendment advanced the target of 20% ethanol blending in petrol from 2030 to 2025-2026, to speed up the adoption of biofuels. Going forward the Indian government is actively exploring options for setting future biofuel blending targets in different sectors.

SATAT (Sustainable Alternative towards Affordable Transportation): SATAT aims to establish a nationwide network of Compressed Bio Gas (CBG) production plants using organic waste, supporting cleaner and renewable transport fuel. SATAT programme set the target by setting up 5,000 CBG plants by 2025 with an expected CBG production of 15 million metric tonnes (MMT) per annum.

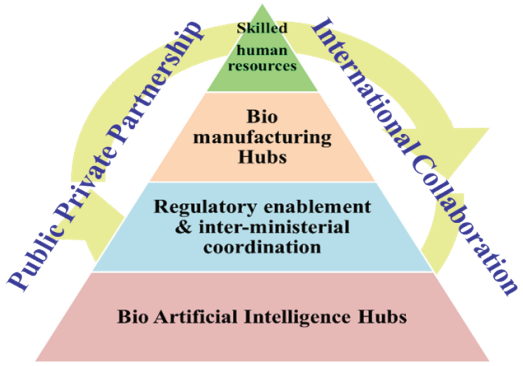
Sustainable Integrated Bio-refinery (India and the Netherlands lead Bio-refinery Mission): Under Mission Innovation, India co-leads the mission integrated bio-refinery initiative alongside the Netherlands. This mission fosters international cooperation in clean energy Research, Development and Demonstration(RD&D). This mission's target is replacing fossil resources by bio-based resources and securing a sustainable transition. The initiative focuses on developing efficient bio-refineries for the production of advanced biofuels, -chemicals and -materials. Under this umbrella, the EU has opened a Horizon EU research call with India for which Dutch researchers and companies have participated for submission of joint proposals.

Green Hydrogen Mission: The National Green Hydrogen Mission (NGHM) which India launched in 2023 serves as a pivotal initiative to cut carbon emissions in challenging sectors and boost national energy autonomy (MNRE NGHM). The Ministry of New and Renewable Energy (MNRE) directs the mission which plans to produce 5 Million Metric Tonnes (MMT) of green hydrogen annually until 2030 while building 125 GW of renewable energy capacity. The 2.3 billion USD budget enables domestic electrolysers manufacturing growth and green hydrogen hub development and supports R&D activities and public-private partnerships (MNRE; PIB, 2023). India's green hydrogen potential will benefit both renewable energy-driven electrolysis and biomass-based production pathways. Electrolysis using solar and wind-powered electrolysis results in zero-emission hydrogen while biomass conversion allows decentralized hydrogen production using agricultural residues. According to Lepage et al. (2020) and Ringgswandl et al., (2022). This mission aims at positioning India as a global hub for green hydrogen production and export, while decarbonizing key domestic sectors like refining, steel, and shipping.

Global Biofuel Alliance (GBA): An initiative that aims at promoting the development and uptake of biofuels through acceleration of biofuel adoption, improvement of sustainability and enhancement of energy security. GBA aims at facilitating international cooperation by supporting biotransition by knowledge, technologies and best practices.

Multilateral Platform for Collaboration Under GBA: Under the Global Biofuel Alliance (GBA), a multilateral platform that India launched during the G20 in 2023, India invited the Netherlands to become a member of this platform, that includes 24 member countries and 12 international organizations.

BioE3 Policy: In August 2024, the Indian government launched the BioE3 (Biotechnology for Economy, Environment, and Employment) policy, which is projected to position India as a global leader in the bioeconomy. The framework for biomanufacturing and bio-foundry initiative's implementation is established by this policy as it encourages green growth. This policy will serve as the blueprint for global sustainability. (https://bmi.dbtindia.gov.in/biomanufacturing-initiative.php)



Biomanufacturing Hub, Bio-foundries: Aims to open new avenues for international collaborations by serving as a focal point for global partnerships in biotechnology that can attract investments and expertise from around the world.

Government initiatives for boosting agricultural sector and farmer's income

1 Pradhan Mantri Fasal Bima Yojana (PMFBY)

A crop insurance scheme aimed at providing financial protection to farmers against crop failures.

2 Pradhan Mantri Krishi Sinchayee Yojana (PMKSY):

A scheme aimed at improving irrigation infrastructure and promoting efficient water management practices to ensure *'har khet ko pani'* (water for every field).

3 National Mission for Sustainable Agriculture (NMSA):

Focuses on promoting sustainable agricultural practices, such as soil health management and organic farming, while improving farmer livelihoods.

4 PM-KISAN Scheme (PM-KISAN Scheme):

Provides direct income support to small and marginal farmers, boosting rural spending and enhancing economic stability in agricultural communities.

5 Digital Agriculture Mission:

Encourages the adoption of digital technologies like AI, IoT and blockchain to increase productivity, reduce costs, and modernize Indian agriculture.

6 Agri Infrastructure Fund:

To strengthen agricultural infrastructure by building warehouses, cold storage facilities, and supply chain systems, enhancing market access for farmers.

STAKEHOLDER DELIBERATIONS AND STRATEGIC TAKEAWAYS

3. STAKEHOLDER DELIBERATIONS AND STRATEGIC TAKEAWAYS

TERI and the Netherlands Innovation Network have jointly organized two bilateral workshops; 1) The Indo-Dutch Innovation Mission Workshop on 15 October 2025 (held at TERI) and 2) the Indo-Dutch Tech Summit on 6 February 2025 (held at IIT Delhi), respectively.

The Indo-Dutch Innovation Mission Workshop

During the innovation mission workshop, The Dutch delegates have visited three locations. Workshop/ roundtable happened at TERI. Stakeholders from Dutch industries and academia including representatives from governments participated in this mission.

The workshop was hosted by TERI at TERI Gram, Gwal Pahari, India on October 15, 2024. This joint workshop served as a dynamic forum for multistakeholder dialogue and R&D collaboration and industrial matchmaking between the two countries. The mission built on the Integrated Bio-refineries Track of the Mission Innovation focused on advancing the global biotransition through joint action in SAF, 2G ethanol, bioplastics, and biochemical pathways. Subject experts from India and the Netherlands (from government, industries and academic institutions) took part in this forum. Indian stakeholders working in these domains are IFGE (Indian Federation of Green Energy), ISMA (Indian Sugar Mills Association), IBA (Indian Biogas Association), MRPL (Mangalore Refinery and Petrochemicals Limited), oil marketing companies (IOCL, BPCL, HPCL, MRPL), and PRESPL. Multiple challenges in the bioeconomy domain were critically discussed with the discussions focused on technology readiness level, challenges, feedstock logistics and supply chains. Joint discussions also focused on biomass supply dispersion and feedstock procurement uncertainty and technological limitations for expansion and

economic sustainability across all value chain stages. The ISMA advocated for enhanced sugarcane-based ethanol integration with the IBA highlighting the expanding potential of bio-CNG while demanding better biomass logistics systems and bankable business models. The oil marketing companies together with MRPL stressed that standardization along with clear policies and investment incentives will bring private sector participation to biofuels.

Indo-Dutch Tech Summit

High-level officials and industry representatives met through the Indo-Dutch Tech Summit 2025 (2nd round table/panel discussion) held in February 2025, to discuss about the opportunities and challenges of advancing bioeconomy in India and the Netherlands. The deliberations focused on the issues of technological advancements, biochemical innovations, supply chain efficiency, policy interventions, and international collaboration, that are key enablers for bio-refineries, bioenergy and biochemicals.

The joint discussions focused on 'integrated policy frameworks, cross-border partnerships and sustainable bio-based solutions' to foster the transition towards a low-carbon future.

A. Advancing Bioeconomy Growth through Technological Innovation

- CSIR-NCL and University of Groningen emphasized that biochemicals, enzymatic hydrolysis, and microbial bioprocessing will play a crucial role in advancing the bioeconomy. They highlighted the need for Indo-Dutch collaborations in process optimization, technology integration, and scaling up industrial applications.
- TNO and TERI underscored the potential of clean, energy-efficient bio-refineries, carbon capture technologies, and digital bioprocessing systems. Waste to energy vapourization and the development of biohydrogen pathways were identified as key areas of cooperation.
- Dutch and Indian bio-based industries pointed to bio-based platform chemicals and supply chain improvements as critical enablers for scaling up bioplastics and bio-based solvents. Strengthening the raw material value chain through logistics innovation and sustainable feedstock sourcing was also highlighted.

B. Addressing Key Challenges in Feedstock Supply and Scaling Biofuels

- Praj Industries and SHV Energy highlighted feedstock logistics and seasonal biomass variability as major challenges affecting biofuel production. They suggested long-term policy measures and financial incentives to stabilize feedstock availability.
- Indian and Dutch bio-refineries emphasized the importance of an integrated biomass value chain to support biofuel refinery operations. Dutch expertise in process efficiency and bio-refinery modelling can provide a pathway for cost-effective and scalable biofuel production.
- Mission Innovation (MI) and Horizon Europe experts noted that there is a lack of large-scale biofuel demonstration projects in India and it was suggested that pilot Indo-Dutch collaborations to validate and commercialize new bio-based technologies should be pursued. Stakeholders from the Netherlands suggested increasing biofuel consumption in hard-to-abate sectors, in line with their bioeconomy policy on sustainability, private investment, and renewable carbon markets. They highlighted the importance of proactive national and international policies to increase the sustainable carbon supply, to harmonize certification standards and accelerate innovation via global co-operation. The Indian Sugar Mills Association (ISMA) recommended that ethanol production should be expanded through

reliable feedstock supply of sugarcane molasses and surplus grains while addressing concerns about price stability and market demand certainty. The Indian Biogas Association (IBA) stressed the significance of decentralized bio-CNG plants which require strong logistics support and supply chain management and policy incentives to attract investments.

The Netherlands' commitment to sustainable development can be seen in important projects such as the €332 million Bio-Waste Circular Project which is dedicated to resource recovery, sustainable waste management and bio-based chemicals collaboration with India. Moreover, the €7 million Horizon Europe Biorefinery Initiative is designed to improve integrated bio-refineries, enable multi-feedstock processing and promote Indo-Dutch partnerships for enhancing the bio-refinery performance.

C. Strengthening Policy Frameworks and Market Integration

- The Netherlands' Bio-Waste Circular Project and India's SATAT Initiative were discussed as reference models for aligning policy frameworks and industry standards. Participants stressed the need for harmonizing sustainability criteria under the Global Biofuel Alliance (GBA) to facilitate trade and investment in bio-based industries.
- Godavari Biorefineries and Wageningen University emphasized joint research initiatives in low-cost enzyme development and microbial bioprocessing to drive down biofuel production costs. Strengthening academic-industry linkages was seen as essential for innovation-driven growth.
- Dutch and Indian policy experts proposed carbon credit incentives, tax benefits, and life-cycle assessment (LCA) frameworks to encourage private-sector investments in bio-based solutions. Regulatory support for waste-to-energy projects was identified as an area where Indo-Dutch cooperation can drive the impact.

D. Driving Sustainable Aviation Fuel (SAF) and Bioenergy Innovations

- TERI and DBT along with Mission Innovation received technical inputs on policy and research for integrated bio-refineries and SAF production from bioenergy and biotechnology experts. The expansion of SAF development was identified as an urgent priority to decarbonize the aviation sector.
- International bioenergy collaborators, including IEA Bioenergy, FAO, and the Global Bioenergy Partnership (GBEP), presented current pilot projects and partnerships to establish scalable SAF production. International expertise is used by the region to establish a global benchmark for renewable jet fuels.
- ICGEB, DBT-ICT Centre for Energy Biosciences and NREL Feedstock Research Groups worked towards the advancement of 2G, 3G and future 4G feedstocks to create high-yield and low-cost biofuel sources. The following advanced synthesis technologies and biomass transformation methods presented themselves as strong potential developments.

E. Strengthening International Collaboration for Bio-based Solutions

- Mission Innovation together with IEA Bioenergy and CII's Bioenergy Group under innovation networks and international research organizations underscored the requirement for more extensive global partnerships in biofuels, biochemicals and biomaterials. The strengthening of world-level partnerships was seen as a crucial factor for the scaling-up of bio-based technologies.
- DBT, DST and BMGF (Bill & Melinda Gates Foundation) research funding agencies decided to boost financial investments for large-scale bioenergy R&D projects to speed up tech improvements and market-based deployment.
- Policy and industry experts from the MNRE, NITI Aayog, ICAO and the European Commission underscored that regulatory alignment with cross-border partnerships helps industry engagement and scales up sustainable carbon applications beyond low-value uses.

CONCLUSION AND RECOMMENDATIONS

4. CONCLUSION AND RECOMMENDATIONS

Strategic Importance of Indo-Dutch Partnership

- For the Netherlands, the exploration of international cooperation on innovation and the establishment of value chains in the bio-economy is of increasing importance. The National Energy System Plan (NPE) lays this out and presents the vision of the Dutch government on the carbon chain. In 2050, there will still be a substantial carbon demand because there are no or very limited alternatives available in certain sectors. This applies, for example, to fuels in aviation and shipping and to the production of plastics, paint and coatings. This remaining carbon demand will have to be met permanently with renewable carbon carriers, in which biogenic carbon carriers from bio-based raw materials play an important role.
- In the short term, the relationship with India offers innovation opportunities in the bio-economy. There are concrete initiatives to set up collaborations under the Integrated Biorefineries Mission, under the Horizon EU call, and directly between knowledge institutions and knowledge-intensive companies.
- In the long term, India may be able to help meet the increasing biogenic carbon demand of the Netherlands. For this reason, it is important to build a relationship with Indian parties active in the (often complex) value chain. The G2G collaboration within the Integrated Biorefineries Mission helps with this and during the innovation mission valuable contacts with the private sector were made for this.
- Joining the Global Biofuel Alliance (GBA) can also help. Membership of the GBA may offer opportunities to further strengthen the relationship with IND and other countries in this area. The Strategic Energy Cooperation MoU renewal (September, 2024) and WAH! Knowledge & Innovation Agenda established fundamental partnerships for R&D at multiple levels as well as trade and policy collaboration. The Dutch National Plan for the Energy System (NPE) requires sustainable renewable carbon imports which India can meet through its bio-based surplus materials production. This report concludes with opportunities for three target groups of stakeholders: R&D-professionals, industry and government.

Opportunities for Indo-Dutch Joint R&D and Demonstration

- Consider providing incentives & subsidies for bio-based startups to strengthen the bilateral R&D ecosystem
- Leverage India's BioE3 policy and explore joint R&D opportunities to promote high performance biomanufacturing of bio-products
- Strengthen engagement under Mission Innovation partnerships to promote R&D collaboration and trade of biomass and its derived products
- Existing working groups and relations between the Dutch and Indian government, such as the Joint Working Group on Science, Technology and Innovation, the collaboration on Mission Innovation, the MoU with MNRE, and Horizon EU framework can be utilized to prioritize R&D and science on the biotransition by means of Bi-lateral and Multi-lateral programmes.

Topics that are of particularly relevance to launch R&D on are:

- 1st and next generation biorefineries for integrated production of biofuels, biochemicals (including bioplastics, enzymes, industry platform biochemicals) and biomaterials.
- Waste-to-energy such as biohydrogen production that can offer technology validation in large-scale markets. The EU-MNRE Horizon call on this topic (May 2025) is of interest here.
- Enzyme-based bioprocessing of bio-based chemicals, which may speed up commercial production.

Opportunities for Dutch Industries

The Netherlands as a leader in circular economy innovations and bio-based industries, has a strategic opportunity to expand its presence in India's rapidly growing bioeconomy sector.

An Indo-Dutch partnership can offer Dutch industries a strategic business opportunity to increase their presence in India's growing bioeconomy.

Key benefits of The Indo-Dutch partnership offers Dutch companies:

A. Increasing demand for Biofuels & Sustainable Energy

The growing economy, together with India's E20 policy together with the upcoming SAF mandates may create significant demand for renewable fuels.

Industry flags a shortage of skilled workforce in the bioeconomy. It is advised to look into launching Indo-Dutch joint training programmes in bioengineering & biorefineries, facilitate industry internships & research exchange programmes and strengthen vocational training for SMEs in bio-based sectors.

B. Bioplastics & Bio-based Packaging

- India's ban on single-use plastics is projected to create a $5 billion market for biodegradable packaging which Dutch innovation can effectively address.
- Dutch companies can produce biodegradable plastics and bio-based composites using the extensive lignocellulosic biomass resources available in India.

C. Biochemicals & Green Chemistry

- The Indian industrial sector is moving towards bio-based solvents and adhesives and coatings which match Dutch innovative developments.

Table 7: Opportunities for Dutch Industries in Indo-Dutch Bioeconomy Collaboration

Dutch Industry Sector	Opportunity in India (Indo-Dutch Collaboration)
Biofuels & SAF	Market expansion, biogas/SAF production
Bioplastics & Packaging	Biodegradable plastics & alternatives
Biochemicals	Enzyme-based bio-based chemicals
Circular Economy	Waste-to-value bio-products

D. Expanding Markets for Dutch Sustainable Solutions

- Opportunity for Dutch technology companies (such as advanced bio-refineries and enzymatic hydrolysis) to enhance biomass conversion.
- BioE3policy roll out by India in August 2024, offers business opportunities for Dutch firms in India for large scale production biofuels (including SAF and biofuel for maritime transport), biodegradable plastics and bio-based materials (Industry biochemical like high organic acids, speciality platform biochemicals). Dutch industry have expertise in this domains and thus they have good market potential in India.

Table 8: Value Proposition for Dutch Companies in Indo-Dutch Bioeconomy Collaboration

Opportunity	Benefit for Dutch Companies
Expanding bio-based market	Increased demand for SAF, bioplastics, and bio-chemicals
R&D collaboration	Joint research with India, EU funding access
Investment incentives	Subsidies, carbon credits, and market expansion

Recommendations for Dutch Policymakers

This report finds numeral opportunities for government to government collaboration between India and the Netherlands. For Dutch policymakers such collaboration could help achieve certain national and EU-wide targets in climate action, trade and circular economy leadership. We identify four domains:

A. Strengthening Netherlands' Position in Global Bioeconomy Leadership

- The Netherlands' global position as a leader in sustainable transitions can grow stronger through its collaboration with India in circular economy and bio-based innovation.
- Through its engagement with India's BioE3 and SATAT programmes, green hydrogen mission, the Netherlands may gain influence on international bioeconomy policies as well as develop standardized sustainability frameworks.

B. Supporting EU and Dutch Climate & Circular Economy Goals

- The EU Green Deal and Dutch Circular Economy Programme establish rigorous targets for removing fossil-based materials and Indo-Dutch partnerships may speed up this process.

- Biofuels and bioplastics produced in India create possibilities for both nations to align at the policy level and focus on sustainable trade practices and carbon emission reduction and waste recycling.
- Through joint carbon credit mechanisms Dutch policymakers can advocate for sustainability incentives that benefit bio-based industries.

C. Enhancing Sustainable Trade & Economic Growth

- There is a perceived lack of proactive collaboration between the Netherlands and India. It is recommended to organize innovation missions, conferences and match-making initiatives to overcome this.
- Consider joining the Global Biofuel Alliance for multilateral collaboration. The GBA could see Indian policymakers work closer with Dutch counterparts to work on unified biofuel standards and certification procedures which promote regulatory and trade-related alignment.
- The Global Biofuel Alliance (GBA) could have Indian policymakers work with Dutch and other counterparts to work on unified biofuel standards and certification procedures which promote regulatory and trade alignment.

Promoting Indo-Dutch Joint R&D and Knowledge Exchange

- Establish a bioeconomy researcher mobility programme between the Netherlands and India similar to the MSCA exchange calls and India's VAJRA faculty programme.
- Promote technology transfer and policy alignment through joint bilateral research programmes between Dutch and Indian institutions in the biorefinery domain. This can be facilitated through setting up of joint Indo-Dutch working groups on sustainable biorefineries.

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2G	Second Generation
3G	Third Generation
4G	Fourth Generation
ACRRES	National Centre for Applied Research on Renewable Energy and Green Resources
AI	Artificial Intelligence
APIs	Active Pharmaceutical Ingredients
Bio-E3	Bio-Economy for Energy, Environment and Economy
Bio-RIDE	Biofuels for Rural Integration, Development and Empowerment
BIRAC	Biotechnology Industry Research Assistance Council
BMGF	Bill & Melinda Gates Foundation
CAGR	Compound Annual Growth Rate
CBG	Compressed biogas
CII	Confederation of Indian Industry
CO_2	Carbon Dioxide
DBT	Department of Biotechnology
DME	Dimethyl Ether
DST	Department of Science and Technology
E20	Ethanol 20
ESG	Environmental, Social, and Governance
ESY	Ethanol Supply Year
EU Horizon	Horizon Europe
FAO	Food and Agriculture Organization
GBA	Global Biofuel Alliance
GBEP	Global Bioenergy Partnership
GDP	Gross domestic product
GHG	Green House Gas
GW	Giga Watt
H_2	Hydrogen
IBA	Indian Biogas Association
ICAO	International Civil Aviation Organization
ICGEB	International Centre for Genetic Engineering and Biotechnology
ICT	Institute of Chemical Technology
IISc	Indian Institute of Science
IIT	Indian Institute of Technology
IOCL	Indian Oil Corporation Ltd.
ISMA	Indian Sugar Mills Association
LCA	Life-cycle assessment
LNG	Liquefied Natural Gas
LOTUS HR	Local Treatment of Urban Sewage Streams for Healthy Reuse
LPG	Liquefied Petroleum Gas
m^2	Square metres

MI	Mission Innovation
MNRE	Ministry of New and Renewable Energy
MoPNG	Ministry of Petroleum and Natural Gas
MoU	Memorandum of Understanding
MRPL	Mangalore Refinery and Petrochemicals Limited
MMT	Million Metric Tonne
MSW	Municipal Solid Waste
NBP	National Bioenergy Programme
NCL	National Chemical Laboratory
NIOK	Netherlands Institute for Catalysis Research
NPB	National Policy on Biofuels
NPCE	National Circular Economy Programme
NPE	National Plan for the Energy System
NPE	National Policy on Education
NREL	National Renewable Energy Laboratory
NSBMB	Netherlands Society for Biochemistry and Molecular Biology
NTS	Netherlands' National Technology Strategy
OMC	Oil Marketing Companies
OTC	Over the Counter
PLA	Poly lactic Acid
PPPs	Public-Private Partnerships
PSU	Public Sector Undertaking
R&D	Research & Development
RDME	Renewable and Recycled Carbon Dimethyl Ether
SAF	Sustainable Aviation fuel
SATAT	Sustainable Alternative Towards Affordable Transportation
SMEs	Small and Medium-sized Enterprises
TERI	The Energy and Resources Institute
TKI-BBE	Top Consortium for Knowledge and Innovation Biobased Economy
TNO	Netherlands Organisation for Applied Scientific Research
TU Delft	Delft University of Technology
UCO	Used Cooking Oil
USD	United States dollar
WAH!	Water, Agriculture, and Health
WUR	Wageningen University & Research
YoY	Year-over-year