PROJECT FUNDED BY

European Union

INDIA

FEASIBILITY STUDY ON THE USE OF SUSTAINABLE AVIATION FUELS

Authors: **Susan van Dyk** and **Ajay Deshpande**

ICAO Technical Consultants on Sustainable Aviation Fuels

Project funded by:

European Union

Project developed in cooperation with:

The Republic of India (Bharat Ganarajya)

This document was produced under the ICAO ACT-SAF Assistance Project *Capacity Building for Sustainable Aviation Fuels (SAF) eligible under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)*, funded by a contribution of the European Union to the ICAO Environment Fund (Project Ref. Number: 2023/445-096).

FOREWORD

In June 2022, on the 50-year anniversary of the Stockholm Convention, the International Civil Aviation Organization (ICAO) launched the Assistance, Capacity-building, and Training for Sustainable Aviation Fuels (ACT-SAF) programme to aid developing states in their transition to cleaner energy for aviation.

Later in 2022, the 41st ICAO Assembly adopted a long-term global aspirational goal (LTAG) for international civil aviation: collectively targeting net-zero carbon emissions by 2050, as a contribution to global climate action in line with the objectives of the UNFCCC Paris Agreement. The ICAO Assembly, through Resolution A41-21, emphasized the need for targeted support to developing states, including enhanced access to financial resources, technology transfer, and capacity-building initiatives.

With the adoption at the 3rd ICAO Conference on Aviation Alternative Fuels (CAAF/3) in November 2023 of the ICAO Global Framework for Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other Aviation Cleaner Energies, ICAO and its Member States have agreed to strive to achieve a collective global aspirational Vision to reduce CO_2 emissions in international aviation by 5 per cent by 2030 through the use of SAF, LCAF and other aviation cleaner energies (compared to zero cleaner energy use).

The Vision has four building blocks, the third of which is implementation support. It expresses the importance of support for developing countries and states with particular needs, to be addressed through the ACT-SAF programme. This should be a robust and substantial capacity-building and implementation support programme designed to assist states, to foster partnerships and collaboration on SAF initiatives under ICAO's coordination and to serve as a global platform for knowledge exchange.

Since 2013, the European Union has funded successive capacity building efforts through the two phases of the ICAO Assistance Project. In total, 24 ICAO Member States in Africa and the Caribbean were assisted, including the development of seven feasibility studies on the use of SAF by 2023. In the margins of the 41st ICAO Assembly, the EU and ICAO signed a Declaration of Intent to fund a new EUR 1.6 million initiative to continue cooperation to address climate change and to reduce the environmental impact of international aviation through the promotion of SAF within the ICAO ACT-SAF Programme. The action is aimed at delivering SAF feasibility studies in ten selected ICAO Member States, in addition to assistance provided by the EU directly through EASA.

India is one of the ten selected ICAO Member States. This feasibility study assesses the potential for producing and utilizing sustainable drop-in Sustainable Aviation Fuel (SAF) in India, ensuring alignment with the environmental and socio-economic sustainability criteria in ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). It follows the guidelines set out in the ICAO *Template for Feasibility Studies on Sustainable Aviation Fuels* and *Guide for Feasibility Studies on Sustainable Aviation Fuels* (Version 1, July 2023).[1]

[1] https://www.icao.int/assistance-capacity-building-and-training-sustainable-aviation-fuels-icao-act-saf

ACKNOWLEDGEMENTS

This feasibility study would not have been possible without the invaluable engagement and leadership of the India Directorate General of Civil Aviation and, in particular, their appointed focal point for this ACT-SAF project, Ms Ekta Agrawal.

The authors also wish to acknowledge the instrumental role of the many national stakeholders who have contributed to the development of this work by providing valuable information and guidance to identify SAF potential in the country. The authors express their gratitude to all stakeholders (listed in the APPENDIX – STAKEHOLDER ENGAGEMENT) and particularly to the following, with whom valuable meetings were held:

- CSIR - Indian Institute of Petroleum and Engineers India Limited
- LanzaTech and LanzaJet
- Topsoe
- Axens, Gevo, and Praj Industries Ltd
- Boeing
- Airbus Industries
- Volpe Center
- Shell iH2 Technology
- M11 Industries
- Reliance Industries Ltd
- Praj Industries Ltd
- Indian Sugar & Bioenergy Manufacturers Association (ISMA)
- NABCB (National Accreditation Board for Certification Bodies)
- Federation of Indian Petroleum Institute (FIPI)
- IndianOil Corporation Limited (IOCL)
- Mangalore Refinery & Petrochemical Limited (MRPL)
- Bharat Petroleum Corporation Limited

EXECUTIVE SUMMARY

This feasibility study assesses the potential for developing sustainable aviation fuel (SAF) in India to reduce aviation-related greenhouse gas emissions and generate socio-economic benefits. Aligned with ICAO's ACT-SAF Template and Guide for Feasibility Studies on SAF, this assessment evaluates India's domestic feedstock potential, viable production pathways, infrastructure and policy readiness, and the enabling conditions needed to establish a domestic SAF market. It draws on international best practices, adapted to India's socio-economic and environmental context.

KEY FINDINGS

The Indian government and other stakeholders are committed to the development of a domestic SAF industry. The government has set targets of a 1% SAF blend by 2027, 2% by 2028, and 5% by 2030. Numerous stakeholders are actively involved in the development of a SAF sector, including petroleum refiners, SAF technology developers, feedstock suppliers, airlines, original equipment manufacturers, etc. The first volumes of SAF are expected to be produced in the latter half of 2025 through coprocessing of UCO in an existing refinery.

This study carried out a comprehensive assessment of feedstocks available in India and potential SAF technologies that could utilize them. India has vast resources of bio-based feedstocks that could potentially be used to produce SAF, with sugarcane bagasse, rice straw, and municipal solid waste forming the bulk of the biogenic feedstocks.

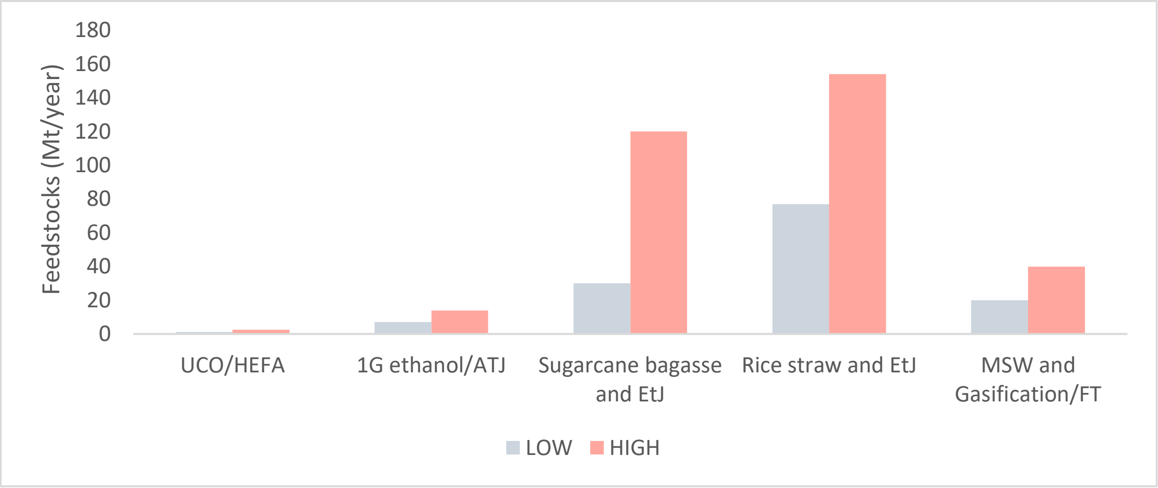


Figure ES1. Total feedstock availability for biofuel production, including SAF.

FEEDSTOCK AVAILABILITY FOR THE MAIN OPTIONS BASED ON LOW AND HIGH ESTIMATE

However, the SAF technologies that can use these feedstocks are still undergoing commercialization, including the production of 2G[2] ethanol from bagasse and rice straw and the alcohol-to-jet process. For municipal solid waste (MSW), the main technology route that has been pursued is gasification with Fischer-Tropsch synthesis. However, commercialization has been very challenging, with many technical obstacles remaining due to the

[2] 2G or second generation ethanol, also called cellulosic ethanol or advanced ethanol, is based on lignocellulose feedstocks such as rice straw or based on processes such as waste gas fermentation.

challenging nature and complexity of the feedstock. While these feedstocks can supply very significant volumes of SAF, the critical challenge is to reach commercial scale with first-of-a-kind facilities at a global level.

The production of SAF through the alcohol-to-jet (AtJ) process presents the largest opportunity for India as a route to SAF production. There are many different sources of ethanol based on different feedstocks and process routes, and the ethanol intermediate is chemically identical. The ethanol can be transported and aggregated for large-scale AtJ facilities, regardless of the source of ethanol.

The Indian-based multinational company Praj Industries Limited is currently demonstrating the small commercial-scale production of 2G ethanol from rice straw with a 30,000 m^3 per year facility, with the scale limited by feedstock and supply chain challenges. To utilize this feedstock for SAF production, hundreds of such 2G ethanol facilities will be required. Sugarcane bagasse is an "easier" feedstock for 2G ethanol production and has been successfully demonstrated in Brazil by the company Raizen. The bagasse supply chain and feedstock characteristics have fewer challenges than rice straw, and this feedstock should be a primary target for 2G ethanol to support SAF production.

Due to the challenges and expected slow pace of scale-up of 2G ethanol from residues, establishing alcohol-to-jet plants based only on 2G ethanol will result in avoidable delays in SAF production. It is therefore recommended that 1G ethanol be used for establishing commercial-scale AtJ facilities until 2G ethanol becomes more available. Sugarcane ethanol, in particular, can deliver very low carbon-intensive SAF, but policy considerations with respect to food security and ethanol blending in gasoline should be addressed. From a fuel blending perspective, broader climate goals should be considered, as the aviation sector has very limited options (mainly SAF), while road transportation has many other options.

Another source of 2G ethanol that is actively pursued by technology providers, such as Lanzatech, is the fermentation of waste gases (from industrial point sources) and from syngas (gasification of feedstocks such as MSW). Lanzatech's gas fermentation facility at IOCL will have a capacity of 33 kt/year. This has very significant potential due to the substantial emissions from sources such as steelmaking, cement production, refinery off-gases, etc.

The HEFA process using oils, fats, and greases is the only fully commercial technology for SAF production, both through stand-alone facilities and co-processing in existing conventional refineries. However, relatively low volumes of waste oils are available in India. As India is a net importer of vegetable oils, these feedstocks are not considered available for SAF production. Although the availability of used cooking oil (UCO) can potentially be increased, this will depend on improved collection, additional pre-treatment facilities, and prevention of unsafe reuse of UCO. Even if all the UCO can be collected and utilized, it can only supply limited volumes of SAF compared to other feedstocks. However, in the short term, SAF production in India will be based on UCO. In the medium to long term, expansion of inedible oil cultivation could increase the supply of HEFA feedstocks.

Although this study is concerned with SAF production, other fuel products, such as renewable diesel and renewable naphtha (for gasoline), are also produced. The graph in Figure ES2 below shows potential production volumes based on different feedstocks, illustrating the significant potential for SAF from key feedstocks.

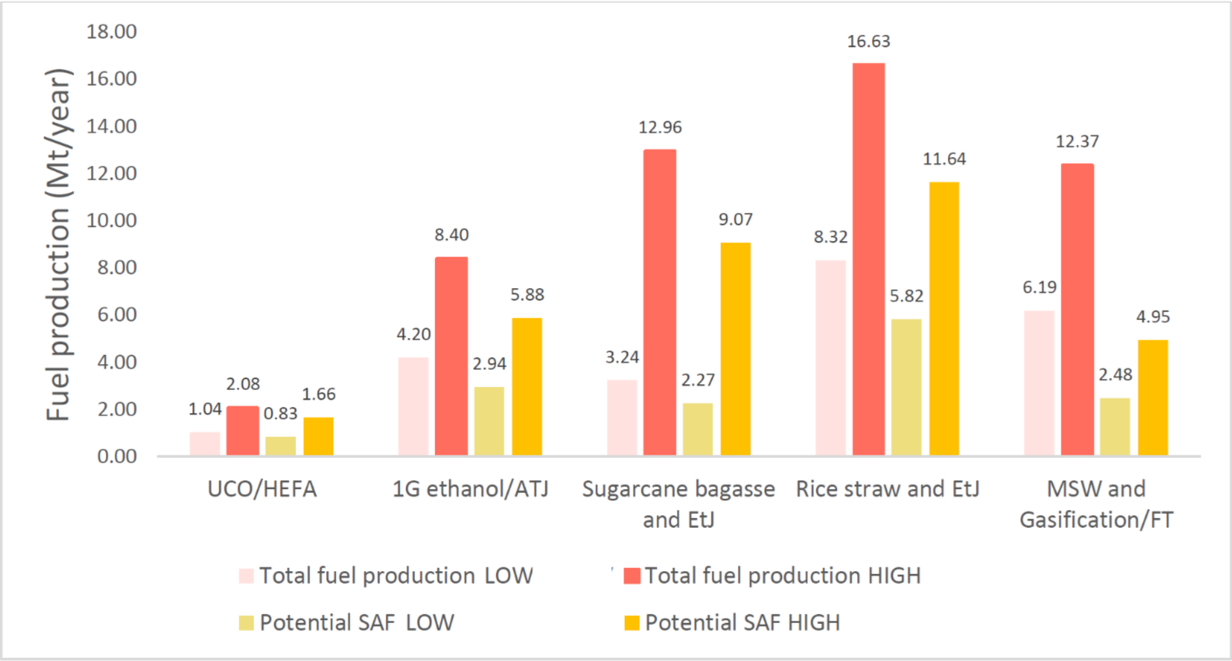


Figure ES2. Potential total biofuel and specific SAF production based on assessed feedstock availability.

At a low estimate, more than 14 million tonnes (Mt) per year of SAF can be produced from these feedstocks, with a high estimate of over 33 Mt/year. This does not include the potential SAF from waste gas fermentation or power-to-liquids based on point sources.

The potential low estimate of SAF volumes that can be produced in India is more than sufficient to supply up to 70% SAF blends into all jet fuel used in India (based on jet fuel forecasts to 2050), with additional SAF available for export. As shown in Figure ES3 below, this study indicates that India has enormous potential for establishing a substantial domestic SAF industry to supply its own needs as well as having excess SAF available for export.

POLICY IMPLICATIONS

The SAF industry faces many well-documented challenges, including lack of SAF availability, slow commercialization of technologies, high production costs, and others. At the same time, ICAO's LTAG analysis has shown that the majority of emissions reductions in the sector must come from SAF, with no other option for medium- and long-haul flights for decades to come. The production of hundreds of billions of litres of SAF will be essential for meeting the industry's net zero target by 2050. However, SAF production volumes are still less than 1% of total jet fuel demand, and commercialising new technologies and scaling up are critical, globally and in India.

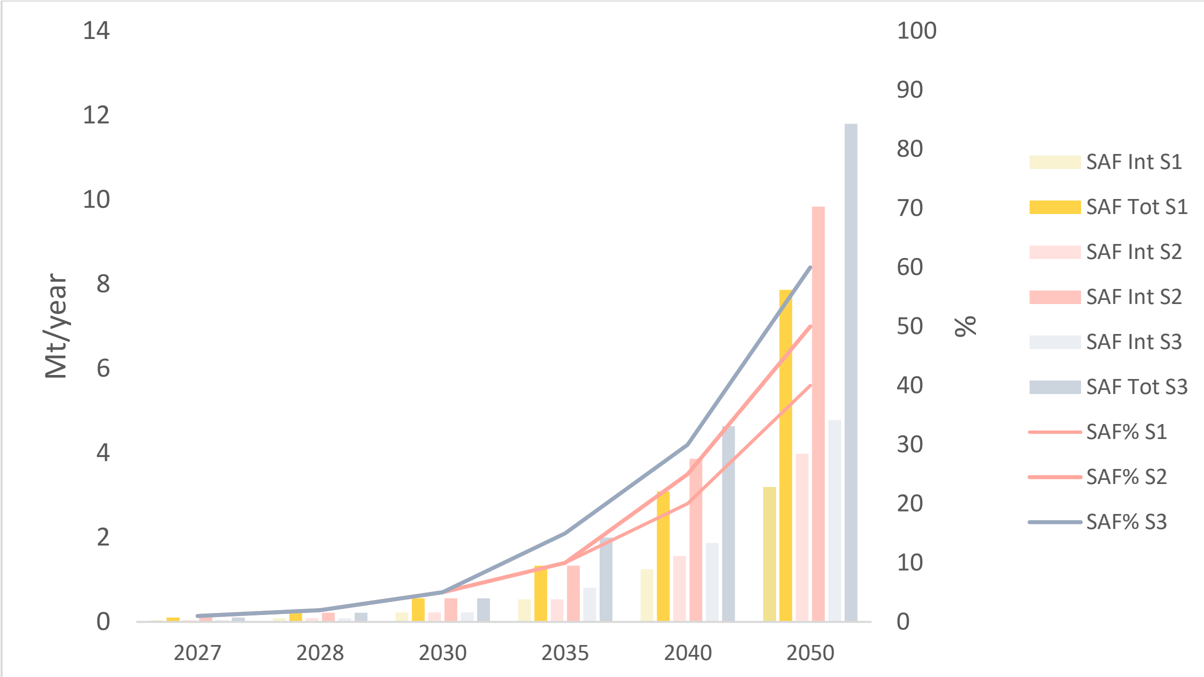


Figure ES3. SAF demand (as a % blend) for three scenarios based on jet fuel demand for international flights (Int) only or for total jet fuel demand (Tot). Scenario 1 (S1) is based on reaching a 40% blend by 2050; Scenario 2 (S2) is based on reaching a 50% blend by 2050; and Scenario 3 (S3) is based on reaching a 60% blend by 2050.

There is a consensus that policies supporting the production and consumption of SAF will be critical for the industry. Policies in Brazil, the USA, the EU, and the UK for SAF have been relatively comprehensive and can provide insights for India to develop domestic policies to facilitate SAF production and consumption. India has many existing policies for supporting biofuel production and blending and supporting the development of nascent industries through financing. These policy frameworks can serve as a scaffold for building SAF-specific policies. Extending existing regulations to SAF development but modifying them to take into account SAF-specific considerations could integrate the overall biofuel sector while targeting long-term climate goals. The National Biofuels Policy can incorporate and integrate SAF, while existing institutions such as IREDA, NABARD, SIDBI, and other PSBs (public sector banks) could be leveraged for the development of SAF production facilities. Support for feedstock development and improvement of feedstock-related challenges could be incorporated into an existing body such as ICAR (Indian Council of Agricultural Research). Furthermore, funding to develop technologies and support near-commercial projects could be leveraged through OIDB and CSIR.

Above all, the financing of SAF development, production, and consumption is a critical challenge. A basket of policies and pathways for achieving this is recommended, including grants and loan guarantees for the construction of first-of-a-kind facilities and other financial support mechanisms such as tax credits and incentives. Creating a long-term structural demand as an integral part of a long-term vision and strategy to 2050 will provide certainty and serve to derisk investment while also creating a level playing field between airlines.

Overall, the development of a long-term vision for a SAF sector in India will be critical to focus efforts from stakeholders and government. Therefore, the establishment of a SAF Council (similar to, as an illustrative example, the Jet Zero Council in the UK) is recommended with high-level representatives from government departments and CEOs from relevant stakeholders with decision-making power to ensure fast and effective development of a vision and strategy for the future of a domestic SAF sector. Urgent action is needed to establish a policy framework for SAF development in India. Multiple companies are engaged in SAF development and commercialization in India but are faced with high construction costs and high production costs. The right mixture of policies can facilitate the rapid development of a SAF industry in India.

India needs a strong sustainability framework for all biofuels that should be integrated with the globally recognized sustainability requirements for SAF established under the ICAO CORSIA standard to ensure maximum climate benefits.

OPPORTUNITIES AND CHALLENGES

Table ES1. Summary of opportunities and challenges facing SAF production in India.

Opportunities	• The Indian government, aviation industry, feedstock and SAF producers, and technology providers are committed to the establishment of a domestic SAF sector. • India has significant volumes of sustainable feedstocks available for SAF production. • Establishing a long-term SAF vision and strategy with a supporting policy framework can lead to a strong domestic SAF industry in India. • India can produce more than enough SAF to deliver high blending targets demand and also export SAF to other regions. • SAF development can address many external challenges facing India, such as air pollution as a result of burning rice straw and other wastes. • Development of SAF and construction of SAF plants provide jobs and income to farmers. • India's favourable geographic location positions it for export to Southeast Asia and Europe.
Challenges and barriers	• Most SAF technologies are not commercial yet and must still be demonstrated successfully. • SAF is perceived as a high-risk investment with high investment costs for the construction of SAF plants. • Policies that can reduce and bridge this price gap are necessary because SAF production costs are significantly higher than conventional jet fuel prices. • Competition between aviation and road transportation exists. • Lack of supportive and adequate policies in India makes investment in Indian SAF facilities uneconomical. • Effective utilization of feedstocks requires addressing challenges such as increased UCO collection and improvement of feedstock supply chains to maximize its use and reduce feedstock costs.

CONTENTS

ABBREVIATIONS AND ACRONYMS

1G ethanol	1st Generation ethanol based on crops such as grains or sugarcane
2G ethanol	2nd generation ethanol based on lignocellulose feedstocks such as rice straw or based on processes such as waste gas fermentation
AEP	Agriculture Export Policy
APEDA	Agriculture and Processed Food Products Export Development Authority
ATM	Air Traffic Management
ATAG	Air Transport Action Group
AtJ	Alcohol-to-Jet
AtJ-SPK	Alcohol to jet synthetic paraffinic kerosene
ASTM	American Society for Testing and Materials
AFQRJOS	Aviation Fuel Quality Requirements for Jointly Operated Systems
BAU	Business-As-Usual
BPCL	Bharat Petroleum Corporation Limited
BRPL	Bongaigaon Refinery & Petrochemical Ltd
BTC	Blender’s Tax Credit
CAAF	Conference on Aviation Alternative Fuels
CAEP	Committee on Aviation and Environmental Protection
CAPEX	Capital Cost (Expenditure)
CARB	California Air Resources Board
CDCC	Centralised Data Collection & Coordination
CEA	Central Electricity Authority
CFA	Central Financial Assistance
CHJ	Catalytic Hydrothermolysis jet fuel
CNG	Compressed Natural Gas
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CPCB	Central Pollution Control Board
CPCL	Chennai Petroleum Corporation Ltd
CFA	Central Financial Assistance
CHP	Combined Heat & Power
CRI	(Global) Climate Risk Index
CRMB	Crum Rubber Modified Bitumen
CSIR-IIP	Council of Scientific & Industrial Research – Indian Instt of Petroleum
DAC	Direct air capture (of CO2)
DGCA	Directorate General of Civil Aviation
DHT/DHDT	Diesel Hydrotreater
dLUC	Direct Land Use Change
EPR	Extended Producers Responsibility
EV	Electric Vehicle
EU	European Union
FAO	Food and Agricultural Organization
FAA	Federal Aviation Administration
FAME	Fatty acid methyl ester
FAS	Financial Assistance Scheme
FC-HCU	Full Conversion Hydrocracker Unit
FCC	Fluidized Catalytic Cracker Unit

FFP	Fit-for-purpose
FOG	Fats, Oil, Greases
FSSAI	Food Safety & Standards Authority of India
FT -SPK	Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene
FT-SKA	Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources
GDP	Gross Domestic Product
GeM	Government e-Marketplace
GHG	Greenhouse Gases
GFAAF	Global Framework for Aviation and Alternative Fuels
GFT	Gasification Fischer Tropsch
GMB	Grain Marketing Board
GMR	GMR Group – Airport Operator
GOBARDHAN	Galvanising Organic Bio-Agro Resources Dhan (Organic Waste to Value)
GREET	Greenhouse gases, Regulated Emissions and Energy use in Technologies)
GSE	Ground Support Equipment
HCU	Hydrocracker Unit
HDPE	High Density Polyethylene
HEFA	Hydroprocessed Esters and Fatty Acids
HC-HEFA-SPK	Synthesized paraffinic kerosene from hydrocarbons - hydroprocessed esters and fatty acids
HPCL	Hindustan Petroleum Corporation Limited
HTL	Hydrothermal Liquefaction
IATA	International Air Transport Association
ILUC	Indirect Land Use Change
ICAO	International Civil Aviation Organization
ICAR	Indian Council of Agricultural Research
IEA	International Energy Agency
IIT / NIT	Indian Institute of Technology / National Institute of Technology
INDIGO	Inter Global Aviation Limited (Airline company)
INR	Indian Rupee (Currency)
IOCL	IndianOil Corporation Limited
IRA	Inflation Reduction Act
IREDA	Indian Renewable Energy Development Agency
ISCC	The International Sustainability and Carbon Certification
JIVAN	Jaiva Indhan Vatavaran Anukool Fasal Scheme (2G Bioethanol)
kt	Thousand (metric) tonnes
LUC	Land Use Change
LCA	Life-Cycle Analysis
LCFS	Low Carbon Fuel Standard
LDPE	Low-Density Polyethylene
LLDPE	Linear Low-Density Polyethylene
LTAG-TG	Long-Term Aspirational Goal Task Group
METI	Japan's Ministry of Economy, Trade and Industry
MFSP/MSP	Minimum Fuel Selling Price
Mha	Million hectares
Mt	Million (metric) tonnes
MW	Megawatts
MoA	Ministry of Agriculture & Farmers Welfare

MoCA	Ministry of Civil Aviation
MoEFCC	Ministry of Environment, Forest & Climate Change
MNRE	Ministry of New & Renewable Energy
MoPNG	Ministry of Petroleum & Natural Gas
MIC	Ministry of Industry and Commerce
MoF	Ministry of Finance
MoRTH	Ministry of Road Transport & Highways
MPEDA	Marine Products Export Development Authority
MRPL	Mangalore Refinery & Petrochemical Limited
MSW	Municipal Solid Waste
Na	Sodium
NABARD	National Bank of Agriculture & Rural Development
NABCB	National Accreditation Board for Certification Bodies
NAPT	National Action Plan Team
NBP	National Biofuels Policy
NDC	Nationally Determined Contributions
NGHM	National Green Hydrogen Mission
NITI Aayog	National Institution for Transforming India
NIWE	National Institute of Wind Energy
NPF	National Policy for Farmers
NRL	Numaligarh Refinery Limited
NRRP	National Rehabilitation & Resettlement Policy
NSM	National Solar Mission
OECD	Organization for Economic Co-operation & Development
OIDB	Oil Industry Development Board
OMC	Oil Marketing Companies
OT-HCU	Once-through Hydrocracker Unit
PET	Polyethylene Terephthalate
PNGRB	Petroleum & Natural Gas Regulatory Board
PFAD	Palm Fatty Acid Distillate
POME	Palm Oil Mill Effluent
PtL	Power-to-liquid
PVC	Polyvinyl Chloride
RBI	Reserve Bank of India
RD	Renewable diesel
RDDO	Research, Development, Demonstration and Deployment
RDF	Refuse Derived Fuel
ReFuelEU	European Union Aviation Fuel Legislation
RFSP	Renewable Fuel Standard Program
RIL	Reliance Industries Limited
RIL-DTA	RIL Domestic Tariff Area (Refinery)
RIL-SEZ	RIL Special Economic Zone
RIN	Renewable Identification Numbers
RN	Renewable Naphtha
RTK	Revenue Tonne Kilometre
RUCO	Repurposed Used Cooking Oil
RSB	Roundtable of Sustainable Biomaterials
RVO	Renewable Volume Obligation
SARPs	Standards and Recommended Practices

SATAT	Sustainable Alternative Towards Affordable Transportation
SCS	Sustainability Certification Scheme
SAF	Sustainable Aviation Fuel
SAC	Scientific Advisory Committee
SDG	Sustainable Development Goals
SIDBI	Small Industries Development Bank of India
SIP	Synthesized iso-paraffins from hydroprocessed fermented sugar
TBO	Tree-Borne Oil
TCI	Total Capital Investment
TERI	The Energy Research Institute
TIES	Trade Infrastructure for Export Scheme
TPD	Tonnes per day
TRRAI	Tyre & Rubber Recyclers Association of India
UCO	Used Cooking Oil
UK	United Kingdom
USA	United States of America
USD	United States Dollar
USDA	United States Department of Agriculture
VGF	Viability Gap Funding
WEF	World Economic Forum
WPI	Wholesale Price Index
WtE	Waste-to-Energy

LIST OF FIGURES

LIST OF TABLES

SECTION 1. STATE-SPECIFIC INFORMATION

1.1 GEOGRAPHY & CLIMATE

1.1.1 Geography

India is the 7th largest country in the world, with an area of 3,287,263 km^2. The mainland comprises four regions with distinct geographical and climatic characteristics, namely the Great Mountain Zone, the plains of the Ganga and the Indus, the desert region, and the southern peninsula. India has 28 states and eight union territories.

1.1.2 Climate and rainfall

India's climate is tropical monsoon, with distinct wet and dry seasons. However, India's large size, diverse topography, and varying latitudes result in a variety of regional climatic conditions. According to the Köppen climate classification, there are seven different climatic regions: tropical semi-arid, subtropical arid desert, subtropical semi-arid, tropical rainforest, tropical savannah, subtropical humid, and alpine.

The main seasons and climate conditions in India are:

- Summer: The hot weather season is from March to May. Temperatures in low-lying areas can exceed 50 °C (122 °F) in May.
- Monsoon: The rainy season lasts from June to September, with annual rainfall averaging between 750 and 1,500 mm (30 and 59 inches) across the region.
- Winter: The cold weather season runs from mid-November until February. December and January are the coldest months.
- Retreating monsoon: October and November are the retreating monsoon season.
- Coastal: The influence of the Indian Ocean creates coastal climates.
- Desert: The climate in the northwest is characterized by aridity.
- Subtropical: The Himalayan region has a temperate climate.

The average rainfall in India is 118 cm, but rainfall varies dramatically across the country, with some areas experiencing very high rainfall, while others receive little to no rain. There is a well-defined rainy season over most of the country from about June to September.

Rainfall in India can be categorized as follows:

- Extreme precipitation areas: The northeastern regions and the windward side of the Western Ghats experience an average of 400 cm of annual rainfall. Areas such as Assam, Meghalaya, Arunachal Pradesh, and the hilly tracts of the Western Ghats are home to tropical rainforests. The highest rainfall in India and the world is recorded at Mawsynram village in Meghalaya.
- Heavy precipitation regions: These regions experience 200-300 cm of rainfall annually. Most of eastern India is covered under this zone. These regions are also home to tropical rainforests. States such as West Bengal, Tripura, Nagaland, Manipur, Odisha, and Bihar are included in this zone. Most of the areas in the sub-Himalayan belt also fall under this zone.

- Moderate precipitation regions: Areas that experience 100 to 200 cm of rainfall include parts of West Bengal, Bihar, Odisha, Madhya Pradesh, Andhra Pradesh, and the leeward side of the Western Ghats. The most common natural vegetation in these regions is wet deciduous forests.
- Low precipitation regions: Areas with 50 to 100 cm of rainfall are parts of Maharashtra, Gujarat, Karnataka, Tamil Nadu, Andhra Pradesh, Madhya Pradesh, Punjab, Haryana, and Western Uttar Pradesh. These areas commonly feature tropical grasslands, savannahs, and dry deciduous forests.
- Desert and semi-desert regions: These areas receive less than 50 cm of rainfall. The states of Rajasthan and Gujarat, along with their adjacent areas, are classified as desert or semi-desert based on the amount of rainfall they receive. Some parts of Jammu & Kashmir, such as the Ladakh plateau, are also included in this zone as cold deserts. The vegetation consists of hardy species that can withstand extended droughts. Some areas, like parts of Gujarat, have savanna vegetation in the wetter regions. The lowest rainfall in India has been recorded in Ruyli village, Rajasthan.

Monsoon winds are very important in the Indian climate and control the rainfall in the country. It is also significant for the country's economy, as a large part of Indian agriculture relies on monsoon rains for cultivation. Monsoon winds reverse their direction according to the change in season. The monsoons travel from the sea to the land in the summer and from the land to the sea during the winter; hence, they are a double system of seasonal winds.

In the summer, India experiences southwest monsoon winds, and during the winter, it receives northeast monsoons. The former arises because of the formation of an intense low-pressure system over the Tibetan Plateau. The latter occurs due to the high-pressure cells formed over the Siberian and Tibetan plateaus.

1.2 DEMOGRAPHICS

India is home to an estimated 1.4 billion people, more than twice the population of Europe. It surpassed China to become the world's most populous country in 2023. The population comprises over 2,000 ethnic groups and represents at least six religions with more than 122 spoken languages. India's population boom coincided with an economic transformation that significantly improved life expectancy, living standards, and food production.

The median age of the Indian population is 28.4 years. However, the role of this expanding population in India's GDP growth depends, among other factors, on the size of the working population in the total population. India's working-age population is expected to comprise over 65% of the total population by 2031, after which it is projected to decline.

A commercialized economy, the development of infrastructure, and family planning programs have led to significant changes in traditional Indian family structures. Large joint families of over eight members have disintegrated into smaller nuclear families over the decades. Economic considerations, such as the cost of raising children, increased education levels for women, and the resulting empowerment of women to make informed decisions about their reproductive choices, as well as changing societal norms, have contributed to reducing fertility rates and the desire for smaller family units.

Migration is a significant indicator of changing socio-economic and political conditions, as well as existing disparities. Various factors, such as employment, marriage, standard of living, calamities, or conflicts, influence the movement of people. Employment is the key reason for internal migration for men in India. However, marriage is a far larger driver of migration than jobs, especially for women who move to different villages within their states after getting married. According to government estimates, one in three urban Indians is a 'migrant,' but mostly intra-state.

1.3 LAND USE & AVAILABILITY OF MARGINAL LAND

Land is a crucial natural resource and a significant determinant of a country's socioeconomic and ecological well-being. The quality and quantity of land in India are under threat due to the rapid increase in population and development of urbanization. The expanding population has increased the demand for converting farmland to non-agricultural uses, which has implications for national food security, ecological security, and sustainable land resource use (*Profile - India At A Glance - Know India: National Portal of India*, n.d.).

Out of 329 million hectares (Mha), land use statistics are only available for 305-307 Mha, and 7% of the land is not covered or classifiable under the nine-fold classification. Population density (people per km^2) was 114.48 in 1950 and is 423.8 at present. The per capita availability of agricultural land was 0.48 ha in 1950, and it is now 0.12 ha.

Here are some features of land use patterns in India (*Land Resources And Land Use Patterns In India*, n.d.; Roy et al., 2015) (also see Table 1 for more detail):

- Cultivation: About 51% of India's land is cultivated (cropland). The amount of land used for agriculture depends on the climate, soil type, and the availability of irrigation facilities.
- Forests: About 22% of India's land is covered by forests. The forest area has not increased significantly since 1960-61 due to industrialization, urbanization, and population growth.
- Pasture: About 4% of India's land is used for pasture.
- Built-up areas and uncultivated land: About 12% of India's land consists of built-up areas and uncultivated land.
- Uncultivated wasteland: About 5% of India's land is uncultivated land, which can potentially be converted into agricultural land.

Table 1. Land use and land cover classes and areas covered.

Land use/land cover classes	Area in km^2 (2005)	Description of land cover classes
Built-up and Urban	47,239	Land covered by buildings and other man-made structures.
Agricultural land	1,914,617	
- Cropland	1,614,921	Temporary crops followed by harvest and a fallow period (e.g., single- and multi-cropping systems).
- Fallow land	221,136	Cultivated land temporarily allowed to remain uncultivated for one or more seasons.
- Plantations	78,560	Commercial horticulture plantations, orchards, and tree cash crops
Forest	729,262	
- Deciduous broad-leaf forest	224,101	
- Deciduous needle-leaf forest	56,583	
- Evergreen broad-leaf forest	178,646	
- Evergreen needle-leaf forest	19,346	
- Mixed forest	147,284	

- Mangrove	4,579	
- Savannah/Woodlands/Scattered trees	98,723	
Shrubland	192,873	Woody vegetation less than 2 m tall and with a shrub canopy cover. The shrub foliage can be either evergreen or deciduous
Grassland	61,595	Herbaceous types of cover. Tree and shrub cover is less than 10%
Barren land	69,855	Exposed soil, sand, rocks, or snow and never have more than 10% vegetated cover during any time of the year.
Wasteland	74,355	Sparsely vegetated with signs of erosion and land deformation.
Water bodies[3]	114,856	Reservoirs and rivers. Can be either fresh or salt-water bodies, including aquaculture
Others[4]	92,552	
TOTAL	**3,297,204**	

As per the latest published 'Land Use Statistics—at a Glance 2012-13 to 2021-22', the area under agricultural land in the country has marginally reduced from 180.62 Mha in 2018-19 to 180.11 Mha in 2021-22 (*Land Use Statistics – At a Glance*, n.d.). Land falls under the purview of state governments, which are responsible for monitoring the diversion of arable land for non-agricultural purposes.

The Government of India supplements the efforts of States through appropriate policy measures and budgetary support. Under the National Policy for Farmers-2007 (NPF-2007), state governments have been advised to earmark lands with low biological potential, such as uncultivable land, land affected by salinity, acidity, etc., for non-agricultural developmental activities, including industrial and construction activities.

The National Rehabilitation and Resettlement Policy–2007 (NRRP, 2007) has also recommended that, wherever possible, projects should be established on wasteland, degraded land, or unirrigated land. The acquisition of irrigated, multi-cropped agricultural land for non-agricultural uses should be kept to a minimum or avoided to the extent possible.

As a result of efforts made by the government under various schemes and programmes to enhance production and productivity in the agricultural sector, the total cropped area in the country (including the state of Maharashtra) has increased from 201.18 Mha to 219.16 Mha during the same period.

Similarly, according to advance estimates for the year 2023-24, food grain production in the country has also increased from 285.2 Mt during the year 2018-19 to 328.8 Mt in 2023-24. The state-wise details of agricultural land, cropped area, and food grain production are shown in Table 2

Table 2 below (Directorate of Economics and Statistics, n.d.).

[3] Includes aquaculture, water bodies, and permanent wetlands.
[4] Includes salt pans, snow, and ice.

Table 2. State-wise agricultural land, cropped area and corresponding production of food grains for the year 2021-22 and 2022-23, respectively.

States	Area in thousand ha (2021-22)		Quantity in Mt (2022-23)
	Agri-cultivable land	Total cropped land	State-wise production of food grains
Andhra Pradesh	8,987	7,328	12.15
Arunachal Pradesh	431	338	0.39
Assam	3,321	3,872	5.95
Bihar	6,542	7,329	18.34
Chhattisgarh	5,552	5,704	10.89
Goa	141	144	0.09
Gujarat	12,428	14,759	9.88
Haryana	3,847	6,566	17.39
Himachal Pradesh	831	890	1.48
Jammu & Kashmir	1,075	1,134	1.76
Jharkhand	4,324	1,845	3.17
Karnataka	12,836	14,748	14.18
Kerala	2,223	2,523	0.60
Madhya Pradesh	17,432	30,049	41.90
Maharashtra	20,466	25,730	16.72
Manipur	399	393	0.44
Meghalaya	1,015	325	0.34
Mizoram	367	206	0.06
Nagaland	672	319	0.50
Orissa	6,782	4,997	9.07
Punjab	4,225	7,916	30.20
Rajasthan	25,463	27,442	23.8
Sikkim	97	140	0.08
Tamil Nadu	8,105	6,348	11.68
Telangana	6,715	-	-
Tripura	270	487	0.84
Uttar Pradesh	18,264	28,200	57.50
Uttarakhand	1,541	969	1.77
West Bengal	5,595	10,259	18.77
Andaman & Nicobar	28	39	0.01
Dadra & Nagar Haveli; Daman-Diu	23	23	0.04
Delhi	53	58	0.10
Pondicherry	28	28	0.07
TOTAL	**180,112**	**219,158**	**329.68**

1.4 AGRICULTURE & CROPS

Agriculture, along with its allied sectors, is the largest provider of livelihoods in India, with roughly 55% of the population relying on it. It also contributes significantly to the Gross Domestic Product (GDP) (*Agriculture | National Portal of India*, n.d.). India has the world's largest cattle herd (buffaloes), the largest area planted for wheat, rice, and cotton, and is the largest producer of milk, pulses, and spices in the world. It is the second-largest producer of fruit, vegetables, tea, farmed fish, cotton, sugarcane, wheat, and rice.

India is one of the largest agricultural product exporters in the world, and rice exports contribute approximately 20% of the country's total agricultural exports. The Indian government has introduced a comprehensive Agriculture Export Policy (AEP) to promote exports of agricultural products with key objectives to diversify the export basket and destinations, boost high-value-added agricultural exports, promote indigenous, organic, traditional, and non-traditional agricultural product exports, provide an institutional mechanism for pursuing market access, and enable farmers to get the benefit of export opportunities in overseas markets (*India: Leading Agricultural Product Exporters*, n.d.).

To this end, the government introduced a Financial Assistance Scheme (FAS) under the Agriculture and Processed Food Products Export Development Authority (APEDA) to support businesses in their export development efforts. The Department of Commerce, under the Ministry of Commerce and Industry, has also initiated several schemes to promote exports, including the Trade Infrastructure for Export Scheme (TIES) and the Market Access Initiatives (MAI) Scheme.

In addition, assistance to exporters of agricultural products is also available under the Export Promotion Schemes of the APEDA, Marine Products Export Development Authority (MPEDA), Tobacco Board, Tea Board, Coffee Board, Rubber Board, and Spices Board. Furthermore, to boost honey exports, India has made NMR (nuclear magnetic resonance) testing mandatory for honey exported to the United States. Major crops and production volumes in India are shown in Table 3.

Table 3. Major crops in India and production volumes for 2023/24.

	Crop	Production (Mt)
Food grains	Rice	137.8
	Wheat	113.3
	Nutri/coarse cereals	56.9
	Maize	37.7
Pulses	Shree Anna	17.5
	Tur	3.4
	Gram	11.0
Oilseeds	Groundnut	10.1
	Soybean	13.0
	Rapeseed & mustard	13.2
Others	Sugarcane	453.2
	Cotton	5.5
	Jute & mesta	1.8

The agricultural crop cycle year in India runs from July to June. Factors that impact crop health and productivity include the timing, quantity, and duration of rainfall; soil conditions; and prices. India has three main cropping seasons:

- Kharif: This season spans from June to November, during which crops are cultivated from the onset of the monsoon season until the onset of winter. Crops grown during this season include rice, corn, millet, groundnut, moong, bajra, jowar, soybean, and urad. The timing and quantity of rainfall are important factors that determine the output of Kharif crops. Coffee and tea are Kharif crops. These crops require a lot of water (known as monsoon crops).
- Rabi: This season is from October to April, and crops are sown in the winter after the monsoon rains are over. Crops grown during this season include wheat, barley, mustard (also known as rapeseed), oats, gram, and linseed. These crops require less water and thrive in cold weather (known as winter crops).
- Zaid: This season is short, occurring between the Rabi and Kharif seasons during summer. Crops grown during this season include watermelon, muskmelon, cucumber, vegetables, and fodder crops. These require warm and dry weather for growth and a longer day length for flowering.

1.5 RIVER SYSTEMS & IRRIGATION

India's river system is a complex network of rivers and streams that support the country's ecosystems, geography, and daily life (*Know India: National Portal of India*, n.d.). The system consists of several major river systems, including:

- Indus River System: Originates in the Kailash range of Tibet and flows through Jammu and Kashmir into India. It has many tributaries in India and Pakistan.
- Brahmaputra River System: Originates in the Angsi glacier of Tibet and flows through Arunachal Pradesh into India. It has many tributaries, including the Dibang, Lohit, and Kenula.
- Ganga River System: Originates in the Gangotri glaciers.
- Godavari River System: Originates in Trimbak (Nashik-Maharashtra) and has the second-longest river course in India.
- Narmada River System: Originates in Amarkantak (Madhya Pradesh) and is a major west-flowing river in the Deccan region.
- Cauvery River System: Originates in Talkaveri in Coorg-Karnataka and is a major east-flowing river in the south that flows into the Bay of Bengal.
- Mahanadi River System: It originates in the Dandakaranya region in Chhattisgarh and has the third-largest river basin in India.

India's river systems provide irrigation, drinking water, transportation, power, and livelihoods for many people. They can be broadly divided into three types:

- Himalayan River Systems: Includes the Indus, Brahmaputra, and Ganga River Systems.
- Peninsular River Systems: Includes the Godavari, Krishna, Cauveri, and Mahanadi River Systems.
- West Flowing Peninsular River Systems: Includes the Narmada, Tapti, Sabarmati, Mahi, and Luni Rivers.

According to the classification of the Food and Agriculture Organization (FAO), the river systems are combined into 20 river units, comprising 14 major river systems and 99 smaller river basins grouped into six river units. The Ganges-Brahmaputra-Meghna basin is the largest, covering 34% of the land catchment area and contributing to nearly 59% of the available water resources.

Others include the Indus tributaries, Godavari, Krishna, and Narmada, which account for 10%, 9%, 8%, and 3% of the land catchment area, respectively.

Irrigation in India encompasses a network of major and minor canals from Indian rivers, groundwater well-based systems, tanks, and other rainwater harvesting projects, all of which support agricultural activities. Of these, the groundwater system is the largest. In 2013–14, only about 36.7% of India's total agricultural land was reliably irrigated, and the remaining cultivated land is dependent on monsoons. 65% of the irrigation in India is from groundwater. Currently, about 51% of food grain cultivation is under irrigation. The rest of the area depends on rainfall, which is usually unreliable and unpredictable.

The Indian government has launched a demand-side water management plan costing INR 6000 crore (around USD 680 million) across 8,350 water-stressed villages of 78 districts in seven states—Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, and Uttar Pradesh—over five years from 2021–22 to 2026–27, with the view to harvest rainwater, enhance the water table, and increase the water recharge rate with the village Panchayat water management plans.

Most of the canal irrigation is located within the canal network of the Ganges-Yamuna basin, mainly in the states of Punjab, Haryana, and Uttar Pradesh and, to a lesser extent, in Rajasthan and Bihar. At the same time, small local canal networks also exist in the south in Tamil Nadu, Karnataka, and Kerala. The largest canal in India is the Indira Gandhi Canal, about 650 km long. India has an ambitious river-linking national project to enhance the coverage of canal-irrigated areas and reduce floods and water shortages.

Irrigation in India helps improve food security, reduce dependence on monsoons, improve agricultural productivity, and create rural job opportunities. Dams used for irrigation projects produce electricity, provide transportation facilities, supply drinking water to a growing population, control floods, and prevent droughts.

1.6 TRADE & GOVERNANCE

India remains one of the world's fastest-growing major economies. However, it faces challenges common to many other countries, such as inflationary pressures, commodity price volatility, and supply chain disruptions in the aftermath of the COVID-19 pandemic and global conflicts. The Indian economy grew by 8.2% in the fiscal year 2023-24 (Reuters, n.d.) (Figure 1).

India's trade and governance are shaped by the government's role in determining what the country imports and exports, as well as its desire to protect employment. India's trade policy is also influenced by its concern that domestic industries may become uncompetitive in the face of more open trade. The key aspects of India's trade and governance are:

- India has trade agreements with over 50 countries, providing preferential market access and fostering economic cooperation.
- Trade Statistics: The Ministry of Commerce and Industry provides trade statistics, including export and import data, as well as a Foreign Trade Performance Analysis (FTPA) system.
- Trade facilitation: The Directorate General of Foreign Trade (DGFT) utilizes information technology to reduce the costs of imports and exports, including simplifying procedures, facilitating paperless filing, and promoting electronic communication.
- Government eMarketplace (GeM): The Department of Commerce and Industry's GeM provides information on products, services, bids, tenders, and more.
- India Trade Promotion Organisation (ITPO): ITPO ensures that trade and industry from different regions of India participate in its events in India and abroad.
- India's main exports are mineral fuels and gold.

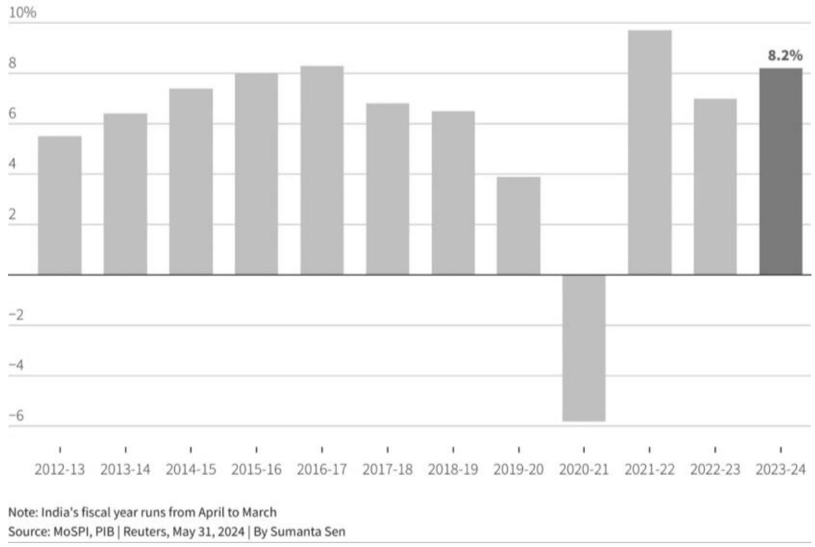


Figure 1. India's GDP growth from 2012 to now.

The salient features of India's current trade performance during the period April-December 2024 were:

- The cumulative exports (merchandise and services) for April-December 2024 are estimated at USD 602.64 billion, compared to USD 568.36 billion for April-December 2023, representing an estimated growth of 6.03%.
- The cumulative value of merchandise exports from April to December 2024 was USD 321.71 billion, compared to USD 316.65 billion during the same period in 2023, representing a positive growth of 1.6%.
- Non-petroleum exports in December 2024, valued at USD 33.09 billion, registered an increase of 5.05% compared to USD 31.50 billion in December 2023.
- India's net trade balance for the period, with imports higher than exports, was USD 6.78 billion.

The Indian government's foreign direct investment (FDI) initiatives are concentrated in sectors such as information technology services, software, business services, pharmaceuticals, and industrial equipment.

India is the United States' ninth-largest trading partner, with U.S. goods and services worth USD 73.1 billion sold to India in 2022. The United States maintained its position as India's largest trading partner, with USD 118.8 billion of imported goods and services. U.S. stock of FDI reached USD 103 billion during FY22-23, and the U.S. remained the largest single source of FDI in India for the second consecutive year.

The Indian government has a focus on "self-reliance" to bolster domestic businesses and create employment opportunities. Government procurement heavily favours domestically produced options. As part of its self-reliance initiative, India has introduced various market access barriers, including tariffs and taxes, localization requirements, indigenous standard mandates, labelling practices, price controls, and import restrictions.

1.7 ENERGY GENERATION

The two biggest sources of domestic energy production in India are coal (45.9%) and biofuels and waste (20.7%) (Figure 2). Most of the crude oil processed in India is imported, comprising 24.0% of the total energy supply.

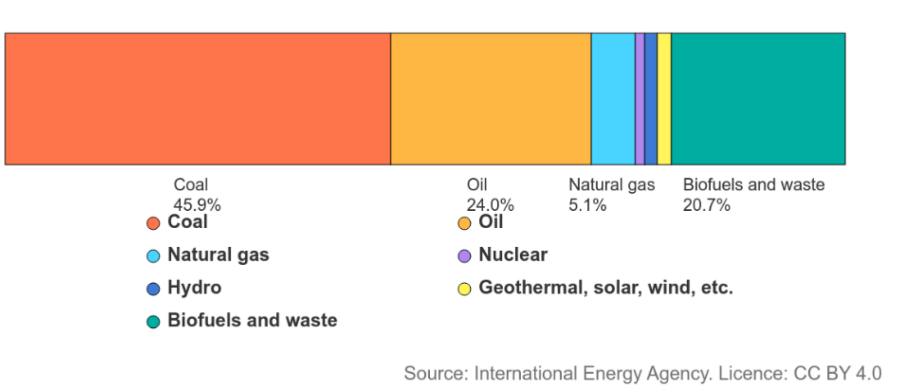


Figure 2. India's total energy supply (2022) (IEA, n.d.).

1.8 OVERALL ELECTRICITY GENERATION AND CONSUMPTION

India is the world's third-largest electricity producer, and its electricity sources are illustrated in Figure 3. During the fiscal year (FY) 2023–24, the total electricity generation in the country was 1,949 TWh, of which 1,734 TWh was generated by utilities.

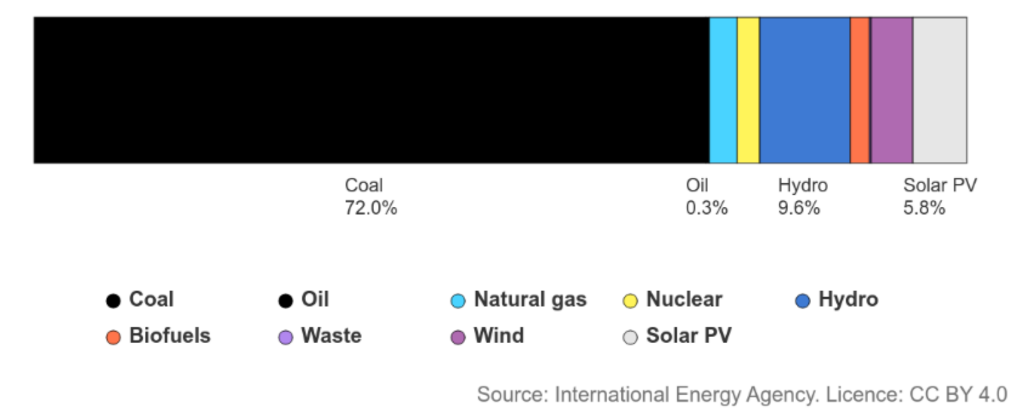


Figure 3. Electricity generation in India (2022) (IEA, n.d.).

The per capita electricity consumption is low compared to that of most other countries despite India having a relatively low electricity tariff. The Indian national electric grid had an installed capacity of 442.0 GW as of 31 March 2024. Renewable energy plants, including large hydroelectric power plants, constitute 43% of the total installed capacity (Ministry of Power, n.d.).

India's electricity generation is more carbon-intensive (713 gCO_2/kWh) than the global average (480 gCO_2/kWh), with coal accounting for three-quarters of its generation in 2023 (Central Electricity Authority, n.d.). The government targets increased investment in renewable energy. Under the government's 2023-2027 National Electricity Plan, India will not build any new fossil fuel power plants in the utility sector aside from those currently under construction. It is expected that the non-fossil fuel generation contribution will likely reach around 44.7% of the total gross electricity generation by 2029–30.

By the end of 2015, despite low hydroelectricity generation, India had a power surplus with substantial idle power generation capacity due to a lack of demand. In 2016, there was a sharp decline in the international price of energy commodities, including coal, diesel oil, naphtha, bunker fuel, and liquefied natural gas (LNG). As a result of the global glut in petroleum products, these fuels became cheap enough to compete with pithead coal-based power generators. Coal prices had decreased, and a low demand for coal led to coal stocks building up at power stations and coal mines. New installations of renewable energy in India surpassed installations of fossil fuel for the first time in 2016–17. On 29 March 2017, India's CEA stated that India became a net exporter of electricity with exports of 5,798 GWh to neighbouring countries, against a total import of 5,585 GWh.

Table 4. Breakdown of installed power generation capacity.[5]

Source	Capacity (MW)	Share in total (%)
Fossil fuels total (March 24)	237,269	52.4
- Coal	205,235	45.3
- Lignite	6,620	1.5
- Gas	24,824	5.5
- Diesel	589	0.1
Non-fossil fuels total (December 24)	216,103	47.6
- Hydro	46,850	10.3
- Wind	48,163	10.6
- Solar	97,864	21.6
- Biomass/cogeneration (bagasse)	9,806	2.2
- Biomass/cogeneration (non-bagasse)	921	0.2
- WTE (waste to energy) off-grid	370	0.1
- Waste to power	249	0.1
- Small hydro	5,100	1.1
- Nuclear	6,780	1.5
TOTAL	**453,372**	**100**

1.9 RENEWABLE ENERGY

India's energy security is critical to its economic growth and sustainability goals. The government has launched various schemes to promote renewable energy, enhance grid stability, and reduce carbon emissions. Key initiatives, such as the National Bioenergy Mission, National Green Hydrogen Mission, PM-KUSUM, and PM Surya Ghar Muft Bijli Yojana, reflect the nation's commitment to a cleaner and self-reliant energy future.

The Union Ministry of New and Renewable Energy (MNRE) has reported progress in India's renewable energy sector, highlighting significant achievements between December 2023 and December 2024. This growth

[5] (1) Hydroelectric power plants with $\leqslant$ 25 MW generation capacity are included in the renewable category (classified as SHP—small hydro project). (2) The installed captive power generation capacity (above 0.5 MW capacity) associated with industry-owned plants is 79,340 MW as of 31 March 2024, which generated 214,581 GWh in fiscal year 2023-24, with 84% coal, 10% NG, and 5% RE-based generation. (3) DG sets of 75,000 MW capacity (excluding sets of size above 1 MW and below 100 kVA) are also installed in the country. (4) In addition, there are a large number of DG sets of capacity less than 100 kVA to cater to emergency power needs during power outages in all sectors.

reflects India's commitment to achieving its clean energy targets and broader vision under the 'Panchamrit' goals announced by the government.

As of December 2024, India's total renewable energy installed capacity had reached 209.44 GW, representing a 15.84% increase from 180.80 GW in December 2023. The total capacity added during 2024 amounted to 28.64 GW, representing a year-on-year increase of 119.46% compared to the 13.05 GW added in 2023 (Ministry of Power, n.d.).

Table 5. India installed renewable energy capacity (in MW).

Sector	Achievements (1 April 2024-31 Dec 2024) FY 2024-25	Cumulative achievements (as of 31 Dec 2024)
Wind power	2,276.65	48,163.16
Solar power[6]	16,051.10	97,864.72
Small hydropower	97.30	5,100.55
Biomass (bagasse) cogeneration	372.86	9,806.42
Biomass (non-bagasse) cogeneration	0.00	921.79
Waste to power	0.00	249.74
Waste to energy (off-grid)	34.13	370.20
Total	**18,832.04**	**162,476.58**

In 2024, solar power spearheaded this growth with the addition of 24.54 GW, reflecting a 33.47% rise in its cumulative installed capacity from 73.32 GW in 2023 to 97.86 GW in 2024. The country's installed and in-pipeline solar projects' combined capacity stands at 261.15 GW (November 24). Wind energy also contributed to this expansion, with an additional 3.42 GW installed in 2024, increasing the total wind capacity to 48.16 GW, a growth of 7.64% from 2023. The country's installed and in-pipeline wind projects' combined capacity stands at 74.44 GW (as of November 2024), driving continued progress in the sector.

Bioenergy has shown substantial growth, with its installed capacity increasing from 10.84 GW in December 2023 to 11.35 GW in December 2024, representing a 4.70% rise. Small hydropower projects saw incremental growth, with installed capacity increasing from 4.99 GW in 2023 to 5.10 GW in 2024, representing a 2.20% rise. The MNRE has been undertaking various key initiatives to achieve the government's vision of 500 GW of renewable energy by 2030. The following initiatives are driving the growth of renewable energy in India:

<u>CCDC Wind Initiative</u>: Launched in June 2020, the Centralized Data Collection and Coordination (CCDC) Wind Initiative aims to advance India's wind energy development by improving wind resource assessment through accurate data collection and research. The initiative offers valuable insights for project developers, enabling them to identify the most promising locations for wind energy projects. It supports the efficient implementation of large-scale wind energy projects and encourages investments in the wind sector. Through the National Institute of Wind Energy (NIWE), the government has installed over 800 wind-monitoring stations nationwide and issued wind potential maps at 50 m, 80 m, and 100 m above ground level. In 2024,

[6] Solar Power (Cumulative): 97.86 GW; Ground-Mounted Solar Plant: 75.19 GW; Grid-Connected Solar Rooftop: 15.67 GW; Hybrid Projects (Solar Component): 2.77 GW; Off-Grid Solar: 4.23 GW

the Union Cabinet approved an INR 7,453 crore (around USD 850 million) Viability Gap Funding (VGF) scheme to set up India's first offshore wind energy projects. The scheme includes INR 6,853 crores (around USD 780 million) for 1 GW of offshore wind capacity (500 MW each off the coasts of Gujarat and Tamil Nadu) and INR 600 crores (around USD 68 million) for port upgrades to support logistics for these projects.

NGHM (National Green Hydrogen Mission): Launched in January 2023, the National Green Hydrogen Mission is an ambitious initiative to transition India towards a hydrogen-based economy. The scheme focuses on developing indigenous technology for green hydrogen production infrastructure, including storage, transportation, and utilization. By promoting hydrogen as a clean energy source, the mission aims to position India as a global leader in green hydrogen production and export, thereby driving sustainability and reducing dependence on fossil fuels. With over INR 8 lakh crores (around USD 91 billion) in total investments, green hydrogen capacity is expected to reach 5 Mt by 2030. This is expected to create 600,000 jobs by 2030. INR 19,744 crore (around USD 2.25 billion) is allocated for the mission's implementation, focusing on infrastructure development and technology innovation. The Mission has an outlay of INR 600 crore (around USD 68 million) for FY 2024-25. Three hydrogen production hubs were established in key locations across the country, and tenders were awarded to companies for 412,000 tonnes per year of green hydrogen production. Development of key policies and financial incentives, with a 50% subsidy on electrolyser manufacturing and hydrogen production. The selection of manufacturers for a 1,500 MW electrolyser capacity was also conducted in 2024.

NSM (National Solar Mission): Launched in January 2010, the NSM is a major initiative aimed at promoting ecologically sustainable growth while addressing India's energy security challenges. It also contributes to the global effort to meet the challenges of climate change. To achieve the above target, the Government of India has launched various schemes to encourage the generation of solar power in the country, including the Solar Park Scheme, VGF Schemes, CPSU Scheme, Defence Scheme, Canal Bank and Canal Top Scheme, Bundling Scheme, and Grid Connected Solar Rooftop Scheme. It intends to achieve the Nationally Determined Contributions (NDCs) target of 50% cumulative electric power installed capacity from non-fossil fuel-based energy resources and to reduce the emission intensity of its GDP by 45% from the 2005 level by 2030.

PM-KUSUM Scheme: Launched in March 2019, the PM-KUSUM Scheme provides financial assistance to farmers for installing solar-powered irrigation systems, including solar pumps and grid-connected solar power plants. By shifting to solar energy, the scheme also helps to reduce carbon emissions and improve energy access in rural agricultural areas. Under the scheme, a central government subsidy of up to 30% or 50% of the total cost is given for the installation of standalone solar pumps and the solarization of existing grid-connected agricultural pumps. Over 610,000 solar pumps were installed nationwide by December 2024, and 350,000 grid-connected agricultural pumps were solarized. As of June 2024, more than 400,000 farmers nationwide have benefited from the PM-KUSUM scheme. Under Components B and C of PM-KUSUM, 30% of the Cost of Financial Assistance (CFA) was provided (or 50% for North-Eastern, hilly regions, and islands) for installing standalone agricultural pumps and solarizing grid-connected pumps.

1.10 ENERGY FOR TRANSPORT – PETROLEUM PRODUCTS AND REFINING CAPACITY

The total oil supply in India used in 2022 amounted to 11,345,640 TJ, with domestic production of oil amounting to 1,406,004 TJ (IEA, n.d.). Petroleum refineries in India produce a range of products (Table 6). India has the fourth-largest refinery capacity in the world and the second-largest in Asia after China. It has emerged as a refining hub with refining capacity exceeding demand. As of March 31, 2024, India's oil refining capacity stood at 256.82 Mt per year, with 261.5 Mt of oil being processed at a utilization rate of 103%. The refining capacity is sufficient for domestic consumption, and a substantial surplus remains for the export of petroleum products. Since 2001-02, India has been a net exporter of petroleum products. According to the International Energy Agency (IEA), approximately 8.1% of Indian refinery products are exported (IEA, n.d.).

Table 7 gives the state-wise capacity of refineries in MT/Y and indicates the presence of distillate hydrotreater (DHDT), hydrocracker, and fluid catalytic cracker (FCC) units in these refineries. Further classification is provided in terms of once-through (OT) or full conversion (FC) types for hydrocrackers, gasoline (FCCU), or petrochemical (PFCCU) units for an FCCU. These units could potentially be used for co-processing.

Table 6. Petroleum products production / consumption / surplus / shortfall (2023-24).

Major products	Production (Mt/year)	%	Consumption (Mt/year)[7]	Shortfall (Mt/year)	Surplus (Mt/year)
LPG	12.78	4.63	29.66	16.89	-
Naphtha	18.27	6.62	13.81	-	4.46
Petrol (motor spirit (MS))	45.08	16.33	37.22	-	7.86
Jet fuel (Aviation turbine fuel (ATF))	17.12	6.20	8.25	-	8.88
SKO (superior kerosene oil)	0.98	0.35	0.48	-	0.50
HSD (high-speed diesel)	115.94	42.00	89.63	-	26.32
LDO (light diesel oil)	0.66	0.24	0.78	0.13	-
Lubes	1.35	0.49	4.09	2.734	-
FO (Fuel oil)	9.70	3.51	6.52	-	-
LSHS (low sulphur heavy stock)	0.74	0.27	-	-	3.92
Bitumen	5.24	1.90	8.81	-	3.57
RPC (refinery petcoke)	15.05	5.45	20.32	5.27	-
Others[8]	33.13	12.00	14.70	-	18.43
TOTAL	**276.06**	**100**	**234.26**	**25.01**	**73.94**

Table 7. State-wise existing & proposed (by 2030) refining capacity.[9]

State	Refinery	Existing capacity (Mt/year)	Proposed capacity (Mt/year)	Units present in the refinery configuration
Andhra Pradesh	HPCL Vizag	13.7	13.7	DHDT, OT-HCU, FCCU
Assam	NRL	3	9	DHDT, OT-HCU, FCCU
Assam	IOCL Guwahati	1.2	1.2	DHDT, Petro-FCCU

[7] The consumption represents market demand and is the aggregate of (a) actual sales by oil companies in the domestic market, (b) consumption through direct imports by private parties, and (c) sales by SEZ (Special Economic Zone) units in Domestic Tariff Area (DTA).
[8] Others include products like propylene, solvents (hexane, benzene, toluene, xylene, and specialty solvents), reformate, mineral turpentine oil, carbon black feedstock, waxes, sulphur, and petcoke.
[9] (DHDT-Diesel Hydrotreatment Unit), (OT-HCU: Once-through Hydrocracker); (FC-HCU: Full conversion Hydrocracker); (FCCU: High Gasoline yield FCCU); (Petro-FCCU: High Olefin yield FCCU)

Assam	BRPL Bongaigaon	3	3	DHDT
Assam	AOD Digboi	0.7	0.7	DHDT
Bihar	IOCL Barauni	6	9	DHDT, OT-HCU, Petro-FCCU
Gujarat	IOCL JR Vadodara	13.7	18	DHDT, Petro- FCCU
Gujarat	RIL DTA	33	33	DHDT, OT-HCU, Petro-FCCU
Gujarat	RIL SEZ	35.2	35.2	DHDT, OT-HCU, FCCU
Gujarat	Nayara	20	20	DHDT, OT-HCU, Petro-FCCU
Haryana	IOCL Panipat	15	25	DHDT, OT-HCU, FCCU, Petro-FCCU
Karnataka	MRPL Mangalore	15	15	DHDT, OT-HCU, FCCU
Kerala	BPCL Kochi	15.5	15.5	DHDT, FCCU, Petro-FCCU
Madhya Pradesh	BPCL Bina	7.8	12	DHDT, FC-HCU to OT-HCU
Maharashtra	BPCL Mumbai	12	12	DHDT, OT-HCU, Petro-FCCU
Maharashtra	HPCL Mumbai	9.5	9.5	DHDT, FCCU
Orissa	IOCL Paradeep	15	25	DHDT, Petro-FCCU
Punjab	HMEL Bathinda	11.3	11.3	DHDT, OT-HCU, Petro-FCCU
Rajasthan	HRRL Barmer		9	DHDT, Petro-FCCU
Tamil Nadu	CPCL Manali	10.5	10.5	DHDT, OT-HCU, FCCU
Tamil Nadu	CPCL Nagapattinam		9	
Uttar Pradesh	IOCL Mathura	8	8	DHDT, Petro- FCCU
West Bengal	IOCL Haldia	8	8	DHDT, OT-HCU, FCCU
TOTAL		**257**	**312.5**	

1.11 VULNERABILITY TO CLIMATE CHANGE

India is very vulnerable to the impacts of climate change. More than 50% of Indians work in agriculture and other sectors sensitive to climate change. Some of the effects that can be observed are the changes in growing season, an increase in average temperature, and more frequent wet and dry conditions (Yale Program on Climate Change Communication, 2023). Long-term, these impacts could cause lower yields of crops and affect food security. Many Indians live in areas called "hotspots" where changes in climate can negatively affect living standards (Mani et al., 2018).

India's updated National Action Plan on Climate Change committed to reducing emissions intensity by 45% by 2030 compared with 2005 and achieving net zero by 2070. India aims to achieve 50% electric power from non-fossil sources by 2030 and has increased its solar capacity with plans to expand to 450 GW renewable energy capacity by 2030 (Yale Program on Climate Change Communication, 2023). To meet its climate targets, it is estimated that India will need about USD 10.1 trillion in investments (Yale Program on Climate Change Communication, 2023).

1.12 BIOFUEL PRODUCTION

The Indian government supports the production and use of multiple biofuels through various policies and financial support. Climate mitigation, in the form of GHG emissions reductions, is not the primary goal of these policies; many other objectives lie behind them, including reduced import dependency in the oil and gas industry, rural development, and job creation. A key rationale for utilizing domestic feedstocks and wastes is the broader environmental benefits of reducing the burning of residues (e.g., rice straw) and other wastes, which cause widespread pollution and associated health issues.

The carbon intensity (CI) of biofuels and their benefits in reducing greenhouse gas (GHG) emissions are not currently included in India's policies, and there is no value associated with a reduction in CI. Bioethanol and biodiesel use are based solely on volumetric blending requirements.

The unlimited use of feedstocks for biofuel production is not permitted. The Essential Commodities Act, 1955, allows the Indian government to control the production, supply, distribution, and trade of essential commodities to ensure public interest. This Act plays an important role in regulating commodities related to food security. The use of essential commodities, such as grains or sugar, for biofuels is only permitted after food security has been satisfied. Thus, limits may be placed on the use of crops for biofuel production, and these may be adjusted on an annual basis or as needed, based on factors such as projected harvests, drought conditions, and others. This could result in annual fluctuations in ethanol production.

Vegetable oils, as may be used for biodiesel production, are not included under the Essential Commodities Act. Under the Act, the government of India also exercises price control over feedstocks and can implement a minimum support price for commodities. Thus, a minimum selling price of sugar was set at INR 29 per kg in 2018 and INR 31 in 2019 to ensure that sugar prices didn't fall below the cost of production. Current discussions are underway to increase this minimum price (Chinimandi, n.d.).

Similarly, the Indian government regulates prices for ethanol. Currently, ethanol produced from cane juice is priced at INR 65.61 per litre, while the rates for ethanol from B-heavy and C-heavy molasses stand at INR 60.73 and INR 57.97 per litre (from 1/11/2024), respectively. A price revision is under consideration. Similar price controls are not used in the case of biodiesel.

Another important government control mechanism that influences the biofuel industry is the imposition of trade restrictions and tariffs. The import of biofuels for fuel blending, including both ethanol and biodiesel, is not currently permitted, although various import duties are in place for the import of ethanol and biodiesel blends. When permitted, ethanol supplied to OMCs for blending with gasoline will incur a 5% Integrated Goods and Service Tax (USDA, 2024). The current restriction on imports of biofuels has been highlighted by the US as an unfair trade practice, and this may affect policy in the future. The Indian government clarified in March 2023 that biodiesel produced from imported feedstocks and exported from special economic zones would not be subject to tariff restrictions (USDA, 2024).

Further restrictions are in place for the export of some biofuel feedstocks. On January 17, 2024, the Indian government levied a 50% export duty on two key biofuel feedstocks, B- and C-heavy molasses. The purpose of the increase from zero to 50% is to ensure the availability of feedstock for domestically supplied ethanol (USDA, 2024).

National biofuels policy

In 2018, India released its National Policy on Biofuels (Ministry of Petroleum and Natural Gas, n.d.), which set blending targets for ethanol (20% blending by 2030) and biodiesel (5% by 2030), feedstock requirements for different fuels, and laid out the responsibilities of 11 ministries to coordinate government actions (USDA, 2024). Beyond blending targets, India established guaranteed pricing, long-term ethanol contracts, and technical standards and codes. Financial support for building new facilities and upgrading existing ones was also provided. In 2022, due to the success of the ethanol sector, the government moved the 20% volume blending target for ethanol forward by 5 years to 2025-26 (USDA, 2024).

Sugarcane provides most ethanol production, with the remainder from food grains such as maize and surplus rice stocks determined by the Food Corporation of India. The Indian government gives separate pricing to maize-based ethanol. A further emphasis is placed on the development of cellulosic ethanol, with one plant in operation and three others under development.

The NBP also includes advanced biofuels, which are produced from lignocellulosic feedstocks (i.e., agricultural and forestry residues, such as rice and wheat straw, corn cobs and stover, and bagasse) or non-food crops (i.e., grasses and algae), as well as industrial waste gas/ off gases (Steel plant, Ferro-Alloy plant, RFG, biomass/ MSW/CO_2). These advanced biofuels must have low CO_2 emissions or high GHG reduction and not compete with food crops for land use. Fuels such as second-generation (2G) ethanol, drop-in fuels, algae-based 3G biofuels, bio-CNG, bio-methanol, dimethyl ether (DME) derived from bio-methanol, biohydrogen, and drop-in fuels with municipal solid waste (MSW) as the feedstock material will qualify as advanced biofuels.

The PM-JIVAN scheme envisages setting up about 12 commercial-scale Advanced Biofuel Projects and about 10 demonstration-scale Advanced Biofuel Projects based on non-food biomass feedstocks and other renewable feedstocks. This will be supported with a financial contribution of INR 1969.5 crore (around USD 220 million) from the government. For commercial projects, financial assistance is subject to a maximum of 20% of the project cost, or INR 5 crore (around USD 570,000) for every million litres (or 1000 m^3), summed to a biorefinery's annual nameplate capacity, whichever is lesser, will be provided to make the projects commercially viable. The maximum financial outlay per project has been capped at INR 150 crore (around USD 17 million).

For demonstration projects, the milestones against the financial assistance payment will be decided by the Scientific Advisory Committee (SAC). The scheme will be implemented from 2018-19 to 2028-29. To promote multiple technologies and feedstocks, the SAC may give preference to project proposals based on new technologies that encourage innovation in the sector. Both "bolt-on" plants and "brownfield projects" are eligible under the scheme.

Biodiesel

Conventional diesel accounts for approximately 87% of the total road transport fuel demand. Blending biofuel into transportation fuel enables India to reduce its dependence on foreign oil imports. Table 8 shows the production of biodiesel (fatty acid methyl esters, FAME) in India, the number of biorefineries, and the current blend rate in the diesel pool (USDA, 2024).

Table 8. Biodiesel production and use in India (USDA, 2024).

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024[10]
Production (million litres)	152	158	170	185	230	200	180	185	200	226
No. of biorefineries	6	6	6	6	6	6	6	7	10	12
Nameplate capacity (million litres)	500	550	600	650	670	580	520	577	600	820
Biodiesel on-road use (million litres)	41	48	72	83	100	50	10	40	40	105
Diesel on-road use (billion litres)	52	55	56	59	60	44	53	57	62	66
Blend rate (%)	0.08	0.09	0.13	0.14	0.17	0.11	0.02	0.07	0.06	0.16

Figure 4 shows the main feedstocks used for biodiesel production in India. The Indian government implemented policies to support the development of jatropha for biodiesel production. However, many argue that this has not been successful (Down to Earth, 2018). Current biodiesel production mainly depends on feedstocks such as animal fats, non-edible oils, used cooking oil (UCO), and imported palm oil and palm stearin. Many producers utilized palm acid oil (PAO) in 2021 due to a limited supply of animal tallow (USDA, 2024). Only about 32% of the total installed biodiesel production capacity is currently used. Figure 5 illustrates the difference between the nameplate capacity and actual biodiesel production in India over the past few years.

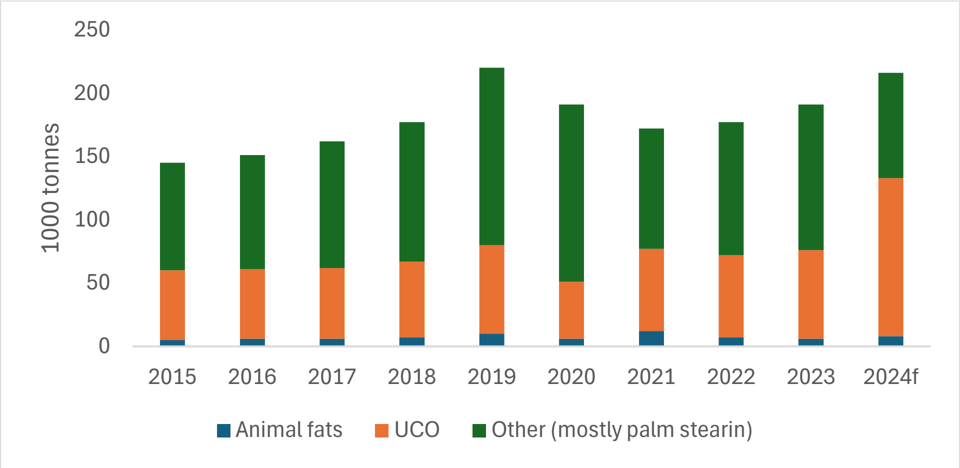


Figure 4. Feedstocks used for biodiesel production in India (USDA, 2024).[10]

[10] 2024 numbers projected.

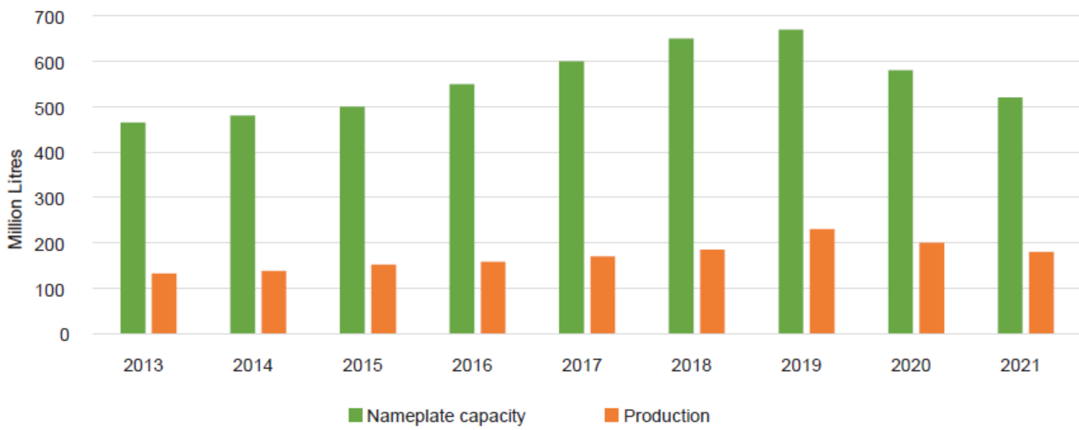


Figure 5. Nameplate capacity versus actual production of biodiesel in India.

India's biodiesel industry is struggling with the availability of feedstocks (Jamal, 2023). Low yields of jatropha and other inedible oilseeds on non-arable lands make cultivation uneconomical. Non-edible sources are some of the country's most promising sources of biodiesel production. The major barriers to the supply of feedstocks such as UCO include a poor collection mechanism, a disrupted supply chain network, and a lack of proper regulation mechanisms.

Following a business-as-usual trend rate of diesel consumption growth over the past decade, India is expected to consume approximately 92.85 Mt of conventional diesel by 2030. A 5% blending requirement will require about 4.64 Mt of biodiesel annually. As shown in Figure 4, current production is about 200 kt of biodiesel.

The high cost of biodiesel, compared to conventional diesel, is a barrier to its widespread commercialization. Biodiesel also does not have the same level of policy support as ethanol. A recent tender by the OMCs in India has awarded biodiesel a flat rate of INR 106.86 per litre, excluding transportation costs and taxes. Keeping the current rate as the base year and considering the average WPI rate for the last five years to be 6%, biodiesel prices are expected to rise to INR 170 per litre under the business-as-usual scenario.

Bioethanol

With ethanol blending, India has a promising opportunity to reduce its dependence on imported oil while addressing environmental concerns. Production volumes of bioethanol are shown in Table 9. Over 6 billion litres of ethanol are produced in 270 biorefineries with close to 20% blending rate expected for 2025.

Table 9. Production of ethanol in India (US Department of Agriculture, 2025).

	2018	2019	2020	2021	2022	2023	2024	2025 (est)
Production (million litres)	2,692	2,552	2,981	3,280	5,300	6,500	7,197	10,500
No. or biorefineries	166	170	220	231	252	263	270	1212
Nameplate capacity (million litres)	2,300	3,000	3,500	4,300	5,700	10,820	16,150	20,000
Bioethanol on-road use (million litres)	1,500	1,890	2,100	3,695	5,140	5,200	6,400	9,650

Petrol/gasoline (on-road use)	40,367	42,496	40,741	37,926	41,831	45,427	48,400	50,100
Blend rate (%)	3.7	4.4	5.2	8.	8.8	11.4	13.2	19.3

As shown in Figure 6, several feedstocks are used for ethanol production, with sugarcane syrup and B-heavy molasses predominant.

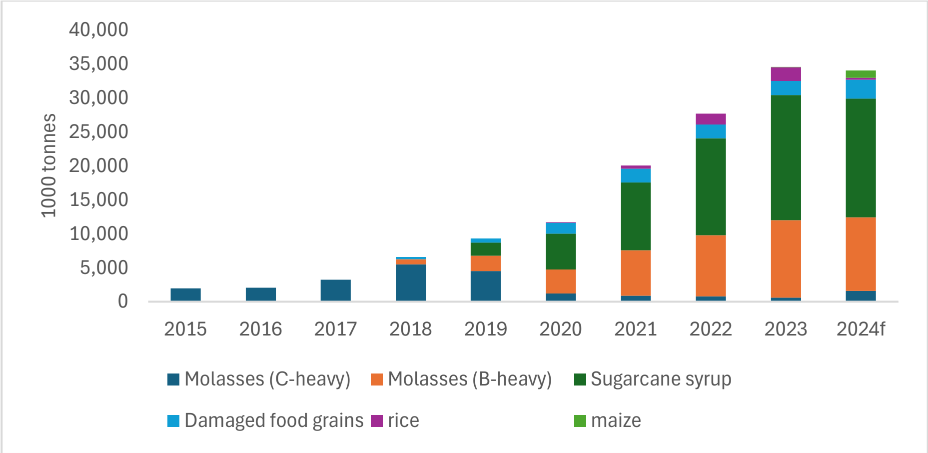


Figure 6. Feedstocks used for bioethanol production in India (USDA, 2024).[10]

Blending ethanol with petrol began in 2001 as a pilot project. The ethanol industry has since expanded significantly, and an initial target of 20% ethanol blending by 2030 was modified to a 20% target by 2025.

In India, ethanol is primarily produced as a by-product of sugar manufacturing, and large sugar companies are among the leading ethanol producers in the country (Table 10). Major sugarcane-producing states, such as Uttar Pradesh, Maharashtra, Tamil Nadu, Karnataka, Andhra Pradesh, and Bihar account for most sugar mills. The major producers of ethanol are all sugar companies.

Table 10. Major ethanol producers in India.

Sugar company	State	Cane crushing capacity (t/day)	Ethanol capacity (m^3/day)
BHSL (Bajaj Hindustan Ltd)	Uttar Pradesh	136,000	800
BCML (Balrampur Chinni Mills)	Uttar Pradesh	76,500	520
Dalmia Bharat Sugar & Ind Ltd	Uttar Pradesh, Maharashtra	35,000	305
Shri Renuka Sugars Ltd	Karnataka, Maharashtra	46,000	930
Triveni Engg & Sugar Industry	Uttar Pradesh	-	660

To accommodate the use of 20% ethanol blends, the Indian government is actively promoting the domestic manufacturing of flex-fuel vehicles that can use high blends of ethanol, offering greater flexibility. Additionally, domestic production and use of electric vehicles are promoted, which will ultimately lead to a reduction in gasoline demand.

Ethanol production capacity more than doubled in the last four years to reach 16.23 billion litres as of September 18, 2024. In the Ethanol Supply Year (ESY), which runs from November to October, the blending of ethanol with petrol stood at 3.8 billion litres compared with a blending percentage of 1.53% in ESY 2013-14.

Given the shortfall expected to meet the 20% ethanol blending target, the Indian government has taken various steps to increase the production and utilization of ethanol. The government has announced an Ethanol Interest Subvention Scheme(s), extending financial assistance in the form of interest subvention at 6% per annum or 50% of the rate of interest charged by banks/financial institutions, whichever is lower, for five years, including a one-year moratorium.

Biogas

Biogas is an energy-rich gas produced by anaerobic decomposition or thermochemical conversion of biomass. Biogas is mostly comprised of methane (CH_4) and carbon dioxide (CO_2). The methane content of raw (untreated) biogas typically ranges from 40% to 60%, with CO_2 accounting for the majority of the remainder, along with small amounts of water vapour and other gases. Biogas can be burnt directly as a fuel or treated to remove the CO_2 and other gases for use, just like natural gas. Treated biogas may be called renewable natural gas or biomethane. There are technology pathways that can utilize biogas or renewable natural gas for the production of sustainable aviation fuel. However, it is mostly used for power production in India.

Compressed biogas (CBG) can be produced from waste, including municipal solid waste, sludge from wastewater treatment plants, market residues, agricultural residues, cattle dung, sugarcane press mud, sago waste, etc. (*Overview and Status of CBG in India*, n.d.)

The Indian government launched the Sustainable Alternative to Affordable Transport (SATAT) in October 2018 to promote the technology (Satat: Home, n.d.). The scheme aimed to produce 15 Mt of CBG from 5,000 plants by 2023. Public sector undertakings, oil marketing companies (OMCs), including IndianOil, BPCL, HPCL, GAIL, and IGL, have partnered with potential entrepreneurs under this initiative to set up plants and supply CBG for sale as automotive and industrial fuels.

The SATAT initiative has the potential to increase the availability of more affordable transport fuels, enhance the utilization of agricultural residue, cattle dung, and municipal solid waste, and provide additional revenue streams for farmers (Satat: Home, n.d.). It will also benefit vehicle users as well as farmers and entrepreneurs. Besides retailing from OMC fuel stations, CBG can be injected into CGD pipelines later for efficient distribution and optimized access to cleaner and more affordable fuel.

The Ministry of New and Renewable Energy (MNRE) launched the programme “Energy from urban, industrial, agricultural wastes/residues and municipal solid waste” with the objectives to promote: (a) projects for recovery of energy in the form of biogas/bioCNG/power from urban, industrial, and agricultural waste, and captive power and thermal use through gasification in industries; (b) projects for recovery of energy from municipal solid waste (MSW) for feeding power into the grid and for meeting captive power, thermal, and vehicular fuel requirements; and biomass gasifiers for feeding power into the grid or meeting captive power and thermal needs of rice mills/other industries and villages. To support these objectives, the programme offers central financial assistance (CFA) in the form of capital subsidies and grants-in-aid. A total of 56 CBG plants have been commissioned, with 46 implemented under the SATAT scheme. Table 11 lists the CBG plants by state.

Table 11. India's commissioned CBG plants by state.

State	No. of CBG plants	State	No. of CBG plants
Andhra Pradesh	3	Punjab	3
Chhattisgarh	1	Rajasthan	2
Gujarat	13	Tamil Nadu	4
Haryana	5	Telangana	3
Karnataka	4	Uttar Pradesh	5
Madhya Pradesh	3	Uttarakhand	2
Maharashtra	7	West Bengal	1
TOTAL	**56**		

1.13 JET FUEL SUPPLY TO INDIA'S AIRPORTS

Optimized jet fuel supply chains have been well established for decades. The introduction of sustainable aviation fuel is expected to have an impact on the downstream supply chain, as SAF can only be supplied as a blend, with very strict compliance with specifications. SAF cannot be supplied in pure form into an airport tank farm, and blending must take place outside the airport, as detailed in a later section. This may require specific blending infrastructure near airports or at fuel suppliers. In addition, SAF will, in most cases, be produced close to the source of feedstocks, which may be at remote locations and distant from existing petroleum refineries and supply chains. Thus, it is important to understand the existing jet fuel supply chains to airports in India and the standards applicable to SAF transport and blending to ensure specifications and safety are maintained across the supply chain.

New supply chains may have to be established for SAF and SAF blends, and optimization will be important to ensure the most economical methods are used. While pipeline transport is the lowest-cost method of transport, this may not be available for the supply of SAF and SAF blends. Supply chain challenges will likely only become apparent when production technologies other than HEFA become available. In India, petroleum refineries are playing a significant role in SAF development, which may help overcome some of the supply chain challenges.

Jet fuel is supplied to airports in India through a combination of interstate multiproduct pipelines, third-party and off-airport terminals, and dedicated local pipelines. While the fuel market is open, airplanes at the country's busiest airports are supplied by pipelines built by Public Sector Undertakings (PSU) oil firms — IOCL, BPCL, and HPCL — over the course of decades. These pipelines are not common carrier pipelines, and third parties do not have automatic access under current regulations. To ensure unencumbered access to SAF from independent producers at all airports, fuel supply to every airport must be evaluated to identify obstacles and suitable infrastructure for storage and blending of SAF.

1.14 MAIN JET FUEL SUPPLY COMPANIES

HPCL Aviation fuelling

Presently, HPCL provides fuelling services to domestic and international customers at 35 airports across India. ATF is supplied to both civil and defence aircraft. HPCL network covers all the major airports in India, and it plans to expand it further.

BPCL Aviation fuelling

Bharat Petroleum Corporation Limited (BPCL) provides fuelling services across 62 airports in India. BPCL provides into-plane services to domestic and international airlines, fuelling more than 45% of the international volume in India. BPCL is also associated with defence services in India and operates and maintains aviation facilities at multiple locations across the country that cater to defence aircraft.

IndianOil Aviation fuelling

IndianOil Aviation Service refuels over 2,200 flights in a 24-hour day and supplies jet fuel to 142 airports. IndianOil Aviation also caters to the fuel requirements of the Indian Defence Services, in addition to refuelling flights at all airports and remote helipads/heli-bases across the Indian subcontinent.

Shell MRPL Aviation fuelling

Shell MRPL Aviation Fuels & Services Limited is a 50:50 joint venture company formed in 2008 between Shell, a global leader in marketing aviation fuel and operating airport fuelling facilities and Mangalore Refinery and Petrochemicals Limited (MRPL), a subsidiary of Oil and Natural Gas Corporation Limited, India's largest national oil company. It supplies Aviation Turbine Fuel (Jet A-1) at 14 of India's airports.

1.15 APPLICABLE INTERNATIONAL STANDARDS FOR AIRPORT STORAGE AND FUELLING WITH SAF BLENDS

Sustainable aviation fuel is approved under ASTM International standards or an equivalent standard, as applicable in different countries. ASTM standards focus on the quality of jet fuel itself, ensuring it is fit for purpose and safe for use in jet engines.

In addition, standards are globally in place for the transport, storage, and uploading of conventional jet fuel and SAF blends into aircraft. These are operational standards to ensure the maintenance of quality and safety in conventional jet fuel and/or SAF blends throughout the supply chain. The primary global standards for this purpose are the Joint Inspection Group (JIG) standards. The Joint Inspection Group is the world-leading organization for the development of aviation fuel supply standards covering the entire aviation fuel supply chain, from refinery to wingtip (*Joint Inspection Group. JIG - Aviation Fuel Supply Standards*, n.d.).

ASTM standards

SAF has been approved under ASTM D1655, where co-processing is used, and the SAF and jet fuel mixture is certified according to ASTM D1655 specifications for conventional jet fuel.

Production of neat (unblended) SAF is approved under ASTM D7566 for various technology pathways as described in the annexes in ASTM D7566. The neat SAF undergoes testing according to the specifications in each annex. Once the neat SAF is approved, it must be blended with conventional jet fuel according to ASTM D7566, with most pathways allowing blends of up to 50%. The SAF blend is then tested and must meet the specifications listed in Table 1 of ASTM D7566. Once the SAF blend conforms to the specifications outlined in Table 1 of ASTM D7566, it is automatically certified under ASTM D1655 and is deemed equivalent to conventional jet fuel (Figure 7). What we refer to as SAF in this study is termed the "synthetic blending component" in ASTM D7566.

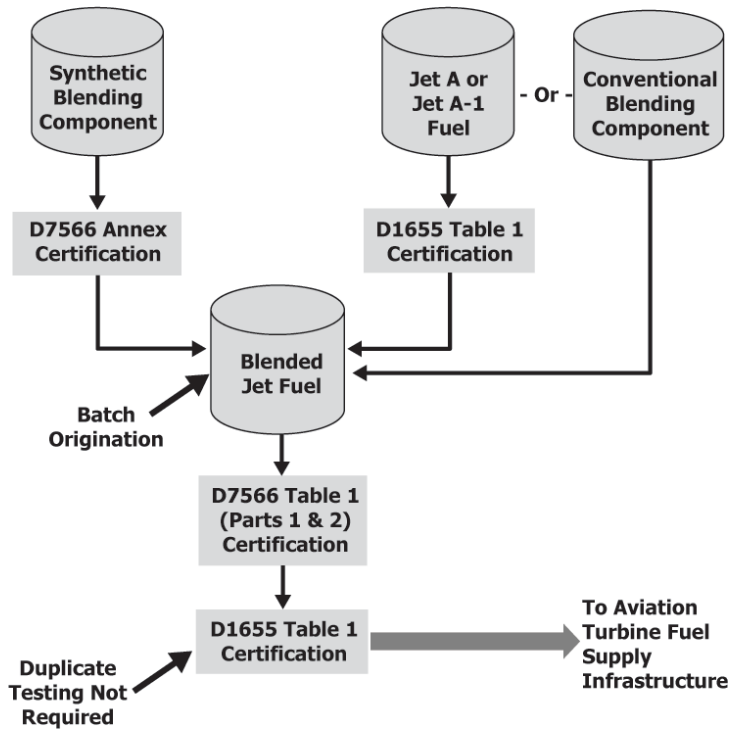


Figure 7. Diagram to illustrate the process of blending and certification of alternative jet fuels (ASTM D7566-23a Appendix X2).

A certificate of quality is generated after testing to show compliance with the relevant ASTM standards. Retesting may be required along the supply chain after transporting the SAF or SAF blend to ensure that the integrity of the jet fuel, SAF, or SAF blend is maintained.

Joint Inspection Group (JIG) standards

JIG 1 (standard for into-plane fuelling operations) is concerned with refuelling operations, i.e., the transport of fuel from the airport storage to its distribution to the aircraft wing.

JIG 2 (Standard for on-airport storage and hydrant operations) concerns the storage of fuel at an airport, including required documentation before discharging the product, design of the tanks (floating suction, cone shape to aid decantation of water, etc.), rules for filtering and drainage, etc. JIG 4 is a variation of JIG 2 applicable to smaller airports.

SAF blending location and certification

Where neat SAF is produced, the blending must take place in accordance with ASTM D7566 specifications for each type of SAF as listed in the annexes to the standard. The blending may take place at the SAF refinery, provided sufficient conventional jet fuel is available at that location.

Blending may also take place along the supply chain to the airport. Where long transport distances are involved, it may not be economical to transport a blend, and the neat SAF may be transported and blended further along the supply chain (and closer to the airport). Only fully certified SAF blends (complying with ASTM D1655) may enter the hydrant system at an airport. Where neat SAF is transported, blending has to take place at a location outside the airport tank farm. Depending on the location of SAF production and the blending location, new supply chains may have to be developed for delivery of SAF to an airport, and this may include SAF blending locations near an airport. Depending on the specific supply chain, this may require additional blending infrastructure to be put in place near an airport.

1.16 JET FUEL DEMAND & SUPPLY IN INDIA

Out of the 17.12 Mt of jet fuel produced by all public sector undertakings (PSU) and private refineries in 2022-23, 8.2 million tonnes were consumed within the country, and the rest was exported. RIL's twin refineries at Jamnagar produce close to 5 million tonnes of jet fuel, a large part of which is exported. Jet fuel demand in India is growing by double digits and rose by 11.8% in the fiscal year ended March 31, 2024. The following are the jet fuel demand and production volumes in India over the last 10 years (Source: Statista) (Figure 8). The production volumes are far above the country's requirements, and the surplus is exported. After that Figure 9 shows the split in jet fuel volumes for domestic and international flights up to 2030, respectively. ICAO only deals with international civil aviation, and the indicative SAF blending mandate in India is only applicable to international flights at this stage. However, it is possible that long-term SAF blending ambitions may extend to the total jet fuel demand in India.

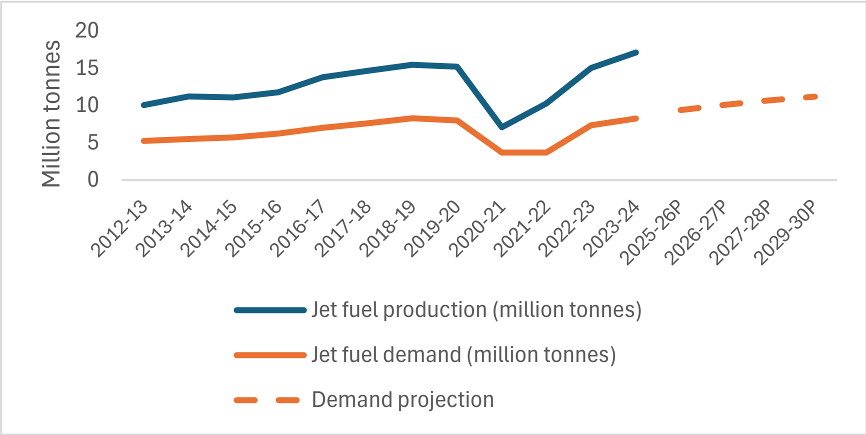


Figure 8. Jet fuel production, demand and projections to 2030.

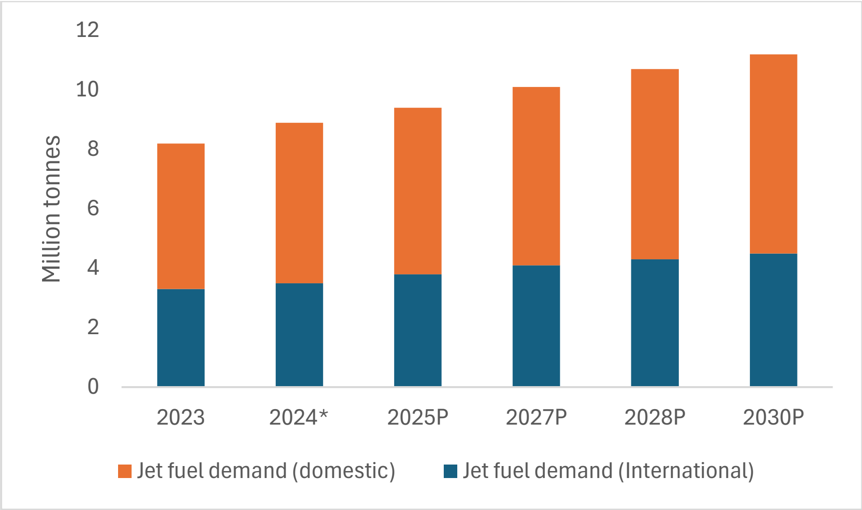


Figure 9. Jet fuel for international and domestic flights (data from DGCA).[11]

[11] *=estimated, P=projected.

Jet fuel demand projections for international flights up to 2050, as well as total jet fuel demand (for both domestic and international flights), are shown in Figure 10. Currently, the indicative sustainable aviation fuels mandate is a 1% blend of SAF in jet fuel for international flights by 2027, with a target of 2% by 2028, and 5% by 2030.

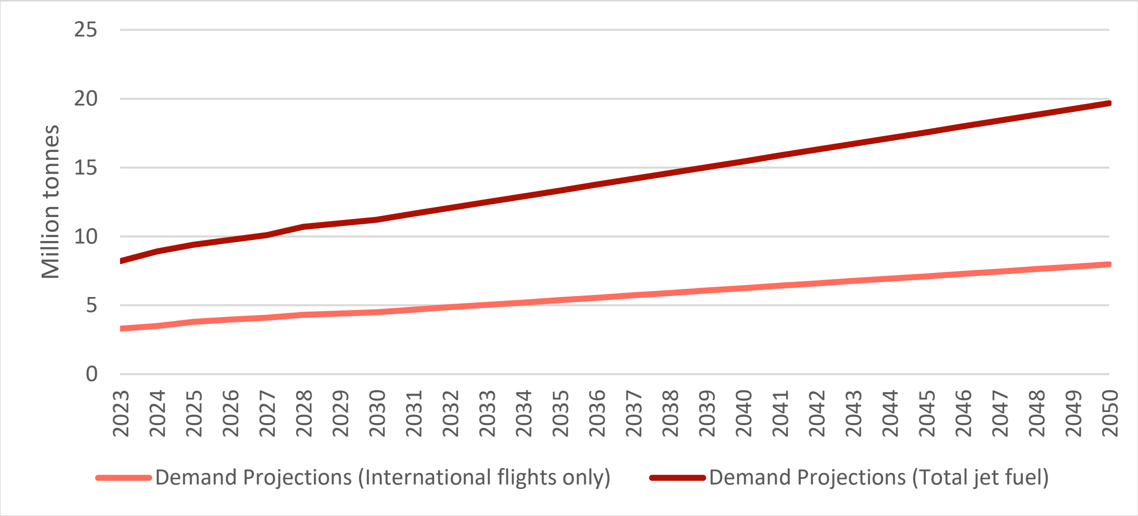


Figure 10. Jet fuel demand projections up to 2050.

1.17 SAF DEVELOPMENTS

Several companies are planning to produce SAF in India. IOCL and BPCL will initially pursue SAF production through co-processing of 5% oils and fats in existing refineries. IOCL will be co-processing 5% UCO in a kerosene hydrotreater at Panipat Refinery, with production starting in 2025. Co-processing 5% in a kerosene hydrotreater can potentially give an 80% recovery of the biogenic carbon in the jet fraction under certain conditions. Co-processing in a diesel hydrotreater will likely only yield 10-15% of the biogenic carbon in the jet fraction unless further hydrocracking takes place. Co-processing has been limited to 5% oils and fats based on ASTM D1655. However, this percentage was increased to 30% by Def Stan 91-091 (GreenAir News, 2025) and efforts are underway to increase it under ASTM D1655.

It is expected that the country's targets of meeting a 1% blend for international flights by 2027, a 2% blend by 2028 and 5% by 2030 will likely be met through the co-processing of oils and fats. In the near future, SAF production is planned at a number of facilities (Table 12).

Table 12. Planned SAF facilities in India.

Company	Location	Technology	Total capacity
IOCL	Panipat	HEFA co-processing	35 kt/year
MRPL	Mangalore	HEFA proprietary technology (IIP) pending ASTM approval	20 m^3/day
IOCL	Panipat	AtJ (Lanzajet process)	90 kt/year
BPCL	Mumbai	HEFA Co-processing	15 kt/year
BPCL	Kochi	Standalone HEFA	20 kt/year
BPCL	Bina	Alcohol-to-jet	

SECTION 2. EVALUATION OF FEEDSTOCKS AND PATHWAYS FOR SAF PRODUCTION

2.1 TECHNOLOGY PATHWAYS FOR SAF PRODUCTION

Figure 11 illustrates some of the potential feedstock/technology pathways for SAF production, including intermediates and process steps. Many other potential routes can be used to produce SAF, and it is impossible to cover all possibilities, so the figure reflects the most relevant ones today.

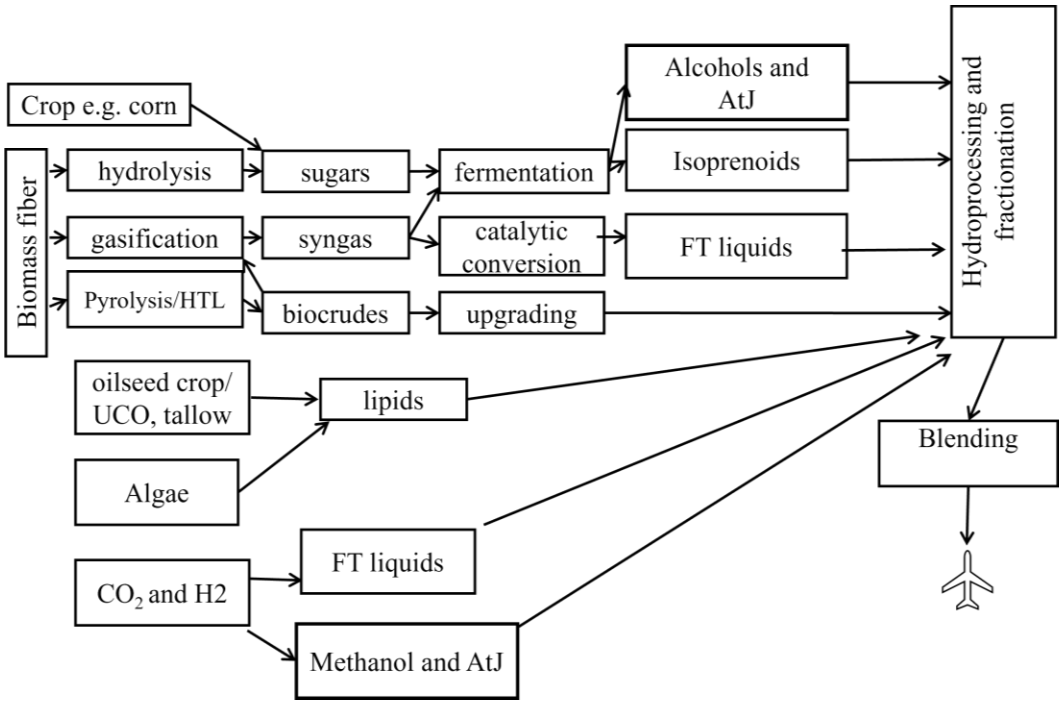


Figure 11. Diagram showing multiple feedstock and technology pathways for producing SAF.

2.1.1 ASTM-approved pathways

Before SAF can be used in commercial aircraft, it must be tested and approved as fit for purpose by a standards body such as ASTM International or Def Stan 91-091. Two ASTM standards apply: ASTM D7566 for neat SAF[12] and its blending requirements and ASTM D1655 for conventional jet fuel that includes co-processing pathways.

[12] ASTM does not use the term "sustainable aviation fuel" and refers to alternative jet fuel. ASTM approval is not concerned with sustainability and only evaluates whether an alternative jet fuel blend is fit for purpose.

Table 13. ASTM-approved pathways.

ASTM D7566	Blend level
Fischer-Tropsch Hydroprocessed Synthesized Paraffinic Kerosene (FT SPK)	50%
Synthesized Paraffinic Kerosene from Hydroprocessed Esters and Fatty Acids (HEFA SPK)	50%
Synthesized iso-paraffins (SIP)	10%
Fischer-Tropsch Synthesized Kerosene with Aromatics (FT SPK/A)	50%
Alcohol-to-Jet synthetic paraffinic kerosene (AtJ-SPK) (Ethanol-to-Jet)	50%
Alcohol-to-Jet synthetic paraffinic kerosene (AtJ-SPK) (Isobutanol-to-Jet)	50%
Catalytic Hydrothermolysis jet (CHJ)	50%
HC-HEFA	10%
Alcohol to Jet Synthetic Kerosene with Aromatics (AtJ-SKA)	50%
ASTM D1655	
Co-processing (lipids, Fischer-Tropsch liquids)	5%
Co-processing hydrotreated lipids or FT liquids	Max 24% insertion, max 10% in final fuel

In addition to these pathways, numerous other pathways are undergoing evaluation, such as the production of SAF from waste tires. Pyrolysis and hydrothermal liquefaction are two processes that hold substantial promise for SAF production; however, the ASTM approval process has not yet been initiated. Therefore, discussions in this study are not limited to ASTM-approved technologies.

For the approval of new alternative jet fuels, ASTM D4054 ("Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives") (ASTM, n.d.) was developed to provide producers of alternative jet fuel with guidance regarding testing and property targets necessary to evaluate such candidate fuels. New fuels must be tested to measure properties, composition, and performance. The testing encompasses basic specification properties, expanded properties known as fit-for-purpose (FFP) properties, engine rig and component testing, and, if necessary, full-scale engine testing. This is a rigorous process, and stakeholders such as engine and airplane manufacturers are involved in the approval process. The approval process can take many years to complete. Some of the processes that are currently under evaluation include an application from Indian CSIR-IIP for single-reactor HEFA (ICAO, n.d.-a).

2.1.2 Technology readiness of SAF production pathways at a global level

Development of new SAF technology pathways can take a long time, and the CAAFI Fuel Readiness Level tool describes the different stages of readiness levels (CAAFI | Commercial Aviation Alternative Fuels Initiative, n.d.) (Table 14). In Figure 12, a few of the main SAF technology pathways are shown based on different stages of commercialization on a global basis (with Level 9 representing one or more fully operational large-scale facilities based on the same process). HEFA and co-processing of fats and oils are fully commercial, with other technologies at lower levels. Progression from one level to the next can take 2-3 years, and from the announcement of a commercial-scale facility through funding, construction, commissioning, to ramp-up can take up to five years. Evaluating the potential production volumes of SAF for different time frames based on company announcements should take into account the pace of scale-up.

Table 14. CAAFI Fuel Readiness Level Tool.

FRL	Description	Toll gate
1	Basic principles observed and reported	Feedstock/process principles identified
2	Technology concept formulated	Feedstock/complete process identified
3	Proof of concept	Lab-scale fuel sample produced from realistic production feedstock. Energy balance analysis executed for initial environmental assessment. Basic fuel properties validated
4.1 **4.2**	Preliminary technical Evaluation	System performance and integration studies entry criteria/specification properties evaluated
5	Process validation	Sequential scaling from laboratory to pilot plant
6.	Full-scale technical evaluation	Fitness, fuel properties, rig testing, and engine testing
7	Fuel approval	Fuel class/type listed in international standards
8	Commercialization validated	Business model validated for production
9	Production capability established	Full-scale plant operational

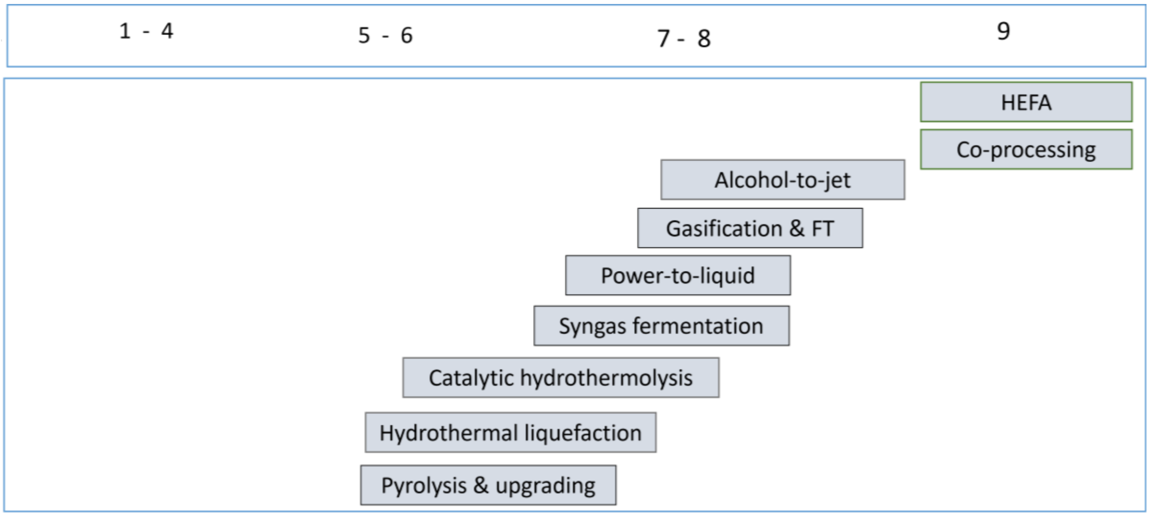


Figure 12. Estimated readiness level of some SAF technology pathways at a global level.

2.1.3 Relevance of SAF co-products for decarbonizing road transportation

Although we refer to SAF technologies and SAF production facilities, it is important to note that most technologies produce multiple products, while SAF is only one of them. Therefore, the production of SAF also produces road transportation (and even marine) fuels that can be used to decarbonize those other sectors. The further benefit is that these fuel products are drop-in fuels that can be blended in almost any concentration (even 100%). Unlike bioethanol and biodiesel, which can only be used in low blends, drop-in biofuels offer more flexibility than these first-generation biofuels. From a policy perspective, these transportation sectors should not be viewed as in competition with each other for feedstocks. Policies that promote SAF will also produce fuels that can decarbonize the gasoline and diesel pool. As shown in further sections of this report, there is competition for feedstocks between road transportation and SAF, specifically for the HEFA pathway (oils and fats used to meet biodiesel mandates) and the alcohol-to-jet pathway (ethanol used to meet the road transportation mandate for 20% ethanol blending). Restricting these feedstocks to road transportation biofuels will pose an obstacle to SAF development in India, as SAF production will require the use of advanced feedstocks and more expensive, not yet commercially demonstrated, technologies.

The potential fractions for different technologies are shown in Figure 13 below. Note that biorefineries can change the distribution of these products, depending on market demand and economics.

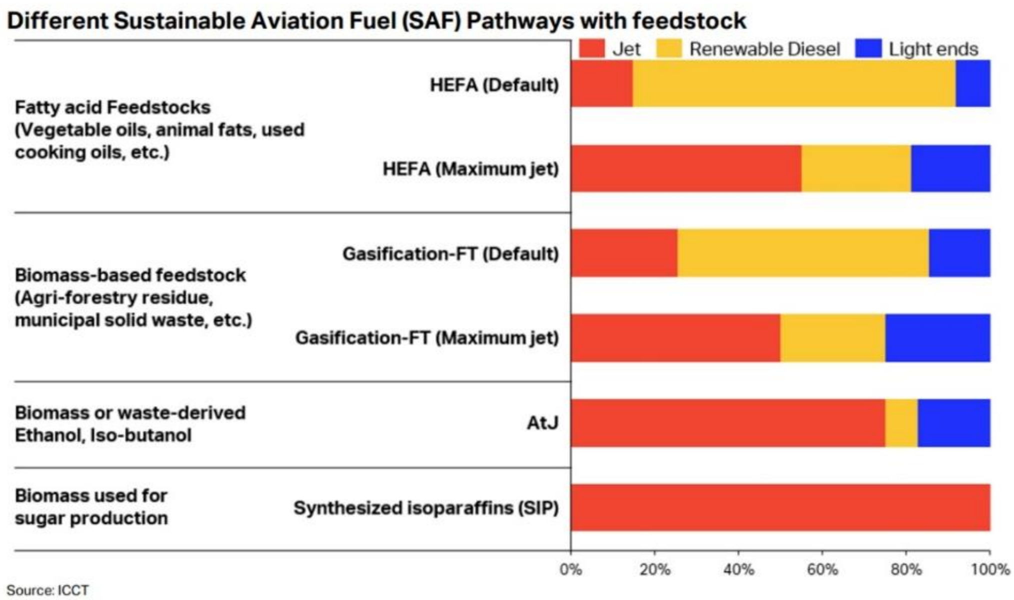


Figure 13. Product distribution for various SAF technology pathways (source: ICCT).

An important impact of the flexible product slate that can be produced is how refineries can be "persuaded" to produce maximum SAF fractions (or any SAF at all). This decision is driven by economic considerations and the SAF policies in place. For example, where a SAF mandate is in place or where policy incentives for SAF are more favourable than for other biofuel products.

2.1.4 Specific technologies with relevance for India

Multiple companies are pursuing the development and commercialization of SAF in India. The most relevant SAF production pathways for India are based on available feedstocks and suitable technologies, as further discussed in the sections below.

Initially, SAF will likely be produced through the co-processing of fats and oils, carried out in existing petroleum refineries that are currently implementing co-processing to meet the 1% SAF blend by 2027. Here, we take a more detailed look at co-processing as a pathway and its potential for SAF production in India.

The HEFA process, either as standalone facilities or through coprocessing, is the only fully commercial pathway and, as such, will be able to deliver SAF by 2027 in accordance with the indicative 1% mandate. Other pathways are under development that would see commercial facilities operational in the short to medium term.

The second SAF technology pathway category with enormous potential in India is the alcohol-to-jet pathway based on multiple routes for producing the starting alcohol (ethanol is the main focus in this study, but isobutanol as a starting alcohol is also pursued). With a large, thriving sugarcane industry, ethanol produced from sugar and byproducts such as molasses is a cost-effective first-generation ethanol that can support SAF through alcohol-to-jet production. Building on this, advanced ethanol production from rice straw is being commercialized in India by Praj, as well as advanced ethanol based on the fermentation of syngas or point-source CO_2 emissions by Lanzatech. Here, we take a more in-depth look at different routes for ethanol production that can support a thriving alcohol-to-jet industry in the future.

Focus on co-processing technologies

Co-processing involves the insertion of biogenic feedstocks into existing petroleum refinery processing units to simultaneously process them with fossil feeds to create lower carbon intensity fuels. Under ASTM D1655, lipids (oils and fats) and Fischer-Tropsch liquids can be inserted into refinery units at a 5% ratio. Note that amendments to the co-processing sections have recently been agreed to increase the percentage of renewable feed that can be inserted.

Petroleum refineries are taking a leading role in this process, with IOCL currently preparing for SAF production in the kerosene hydrotreater based on lipid feedstocks. A brief deep dive on co-processing is included here to highlight the potential for SAF production through co-processing in India.

Potential insertion points of biogenic feedstocks in a refinery are shown in Figure 14 and include the kerosene hydrotreater, the diesel hydrotreater, the hydrocracker, or the fluid catalytic cracker (FCC). The FCC is generally used for producing petrol (gasoline) but can be used for SAF production. However, insertion at a hydrotreater or hydrocracker is more suitable for SAF production.

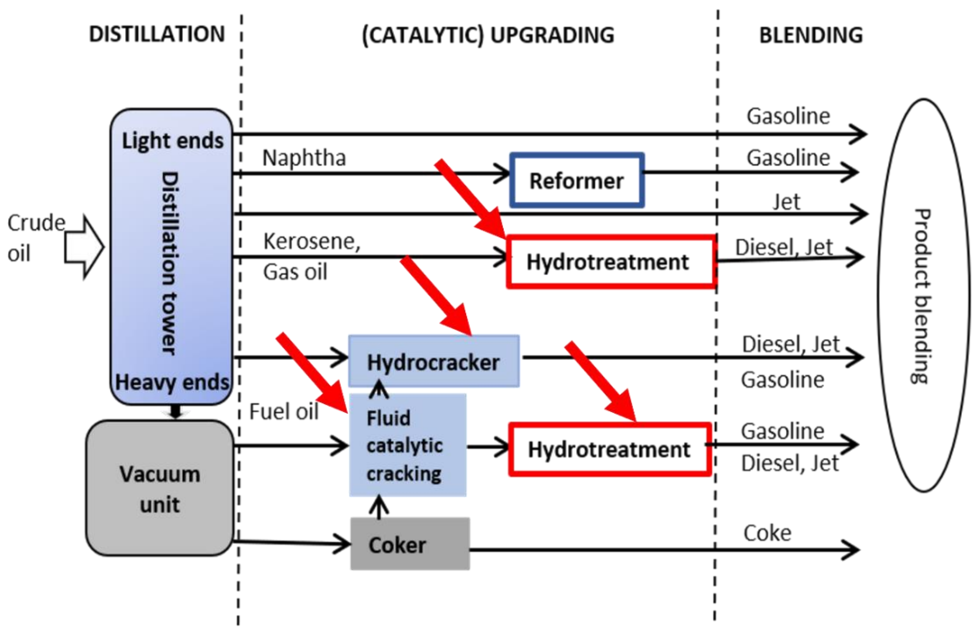


Figure 14. Basic refinery configuration, showing potential refinery units where biogenic feedstocks can be inserted for co-processing.

The specific insertion point is dictated by the desired product but also the characteristics of the biogenic feedstock. For example, the low-temperature Fischer-Tropsch process produces a large fraction of hydrocarbons with 20 to 40 carbons, which require cracking to produce jet-range molecules (between 8 and 16 carbons). Therefore, the hydrocracker would be the most likely insertion point for FT liquids co-processing. Oils and fats have mostly been co-processed in the diesel hydrotreater. Without additional hydrocracking, co-processing in the diesel hydrotreater would only produce 15% of the original biogenic molecules in the jet range. With hydrocracking, the volume of SAF can be increased to 55% or higher, depending on the extent of cracking taking place. The severity of the hydrocracker operating conditions will determine the extent of cracking and the SAF product fraction. Co-processing in the kerosene hydrotreater using specialized catalysts can potentially result in 80% of the biogenic carbon in the jet fraction under certain conditions.[13]

It should be noted that the CORSIA Default Lifecycle Emissions and the CORSIA Methodology for Calculating Actual Life Cycle Emissions describe the method for determining the renewable content of co-processed SAF. Biogenic carbon from the feed can potentially become distributed across multiple products, and Carbon-14 (C-14) analysis must be used to determine the final amount of biogenic carbon in the SAF fraction.

Currently, it is mainly fats and oils that are used for co-processing to produce mostly renewable diesel and some SAF. This will remain the main feedstock used for co-processing in the near term, as Fischer-Tropsch technologies are not commercial yet.

In the medium to long term, fast pyrolysis bio-oils and hydrothermal liquefaction biocrudes can potentially be co-processed, but using these feedstocks still has many technical challenges that must be resolved. In the near term, pyrolysis bio-oils based on waste plastics and waste tires are being explored for the production of SAF. These production pathways are under evaluation at ASTM but could also potentially be used in co-processing in the future.

Table 7 showed a list of all petroleum refineries in India and the presence of potential units for co-processing. Every refinery has a diesel hydrotreater (DHDT), while a number of other refineries also have a hydrocracker and/or an FCC. It is not clear what the total hydrotreater capacity is.

As of March, 31, 2024, India's oil refining capacity stood at about 257 Mt/year. As we don't have a detailed breakdown of hydrotreater capacity, total refining capacity will be used to illustrate the volumes of feedstocks needed to co-process 5% fats and oils. If all Indian petroleum refiners co-processed 5% fats and oils, a total theoretical volume of 12.8 Mt of fats and oils (~14 billion litres) would be required. The availability of fats and oils will, therefore, be the limiting factor in co-processing.

Conversion of fats and oils results in an 83% yield (wt/wt) of liquid product, which may vary for different refineries. Regardless of whether a freestanding refinery or co-processing is used, the following potential fuels, including HEFA SAF, can be produced based on a refinery's desired product slate and economics. Options include:

- 100% of the liquid product is sold as renewable diesel.
- Fractionation is carried out after hydrotreatment, and 15% of the renewable carbon (liquid product) is in the jet fraction and can be sold as SAF, with 85% sold as renewable diesel.

Fats and oils are inserted into the hydrocracker (likely after hydrotreatment), and cracking increases the jet fraction to produce maximum SAF (up to 70% of renewable carbon as SAF). This results in a lower liquid yield as more gases are produced.

Under certain specific circumstances, co-processing of fats and oils in a kerosene hydrotreater can potentially result in 80% of the biogenic carbon in the jet fraction[13] where the unit operates in sour mode, and the fossil kerosene has a low freeze point.

[13] Based on Topsoe catalyst TK-930 and under specific conditions.

Alcohol production for use in the alcohol-to-jet process

The alcohol-to-jet process for SAF production is likely to play a prominent role in the SAF industry in India. There are many types of alcohols that are targeted for SAF production, including ethanol, isobutanol, n-butanol, and methanol, although any type of alcohol could potentially be used[14]. Currently, only ethanol and isobutanol are ASTM-approved for SAF production, but n-butanol and methanol are in the pipeline for approval. The most common method for the production of ethanol is biochemical fermentation using glucose or other sugars as a feedstock, and *Saccharomyces cerevisiae*, common brewer's yeast, has been used for centuries to produce beer and wine. Other types of microorganisms can also produce ethanol through different methods. For example, LanzaTech uses a proprietary microorganism to produce ethanol from syngas (CO+CO2 +H2). Isobutanol production, as developed by Gevo, also uses a proprietary microorganism to produce a biobased alcohol. Isobutanol can also be produced in a chemical process from fossil fuels.

Methanol has also been commonly produced from fossil fuels; however, biomethanol can be produced from syngas (CO and H_2) either through the gasification process or the power-to-liquid technology pathway. The alcohol-to-jet technology is ASTM-approved for ethanol, isobutanol, and mixed alcohols (C2 – C5). Other alcohols in the ASTM pipeline are n-butanol and methanol. The Methanol-to-Jet pathway is still under review and expected to be approved at the ASTM level in the near future.

Table 15. Types of alcohol from different feedstocks – potential and challenges.

Types of alcohols	Potential	Challenges
First-generation ethanol		
Ethanol from sugarcane and sugar production byproducts (molasses) **Biochemical fermentation**	Fully commercial; Feedstocks available; Low carbon intensity	Competition with food; competition with ethanol for road transportation
Ethanol from corn and biochemical fermentation	Fully commercial	Sustainability challenges and competition with food Very little or no emissions reductions
Advanced (second generation) ethanol		
Ethanol from bagasse and biochemical fermentation	Aggregated, size-reduced, homogenous feedstock Co-location with ethanol production with shared utilities and downstream supply chain	Competition with bioenergy production
Ethanol from agricultural residues and biochemical fermentation	Very significant feedstock volumes available in India Utilization will address air pollution problems	Feedstock distributed across large areas. Short harvest period

[14] The Swedish biofuels process can use any alcohol with 2, 3, 4 or 5 carbon atoms.

		Quality Transport cost
Ethanol production from syngas fermentation	Can use waste gases Low carbon intensity	Proprietary microorganism Syngas cleanup required Yield of ethanol
Other alcohols		
Isobutanol and biochemical fermentation	Simpler and cheaper conversion to SAF through the AtJ process as starting with a 4-carbon molecule	More expensive to produce the isobutanol compared to ethanol

Advanced ethanol production from feedstocks such as agricultural residues is more complex with a higher production cost than conventional (1G) ethanol. SAF production costs through the AtJ process will be significantly higher when using advanced ethanol compared to conventional ethanol (Deloitte, 2024). While agricultural residues as a feedstock are much cheaper than molasses or maize, the capital costs for advanced ethanol production are much higher.

Using conventional ethanol for SAF production can result in better economics compared to advanced ethanol. This would be the low-hanging fruit for the AtJ pathway as advanced ethanol production is commercialized.

2.2 FATS, OILS AND GREASES

The hydrotreated esters and fatty acids (HEFA) pathway is the main technology using these feedstocks. HEFA facilities can be freestanding based on brownfield or greenfield construction, or SAF can be produced through co-processing in existing refineries. The catalytic hydrothermolysis jet process can also utilize these feedstocks, but, to our knowledge, a commercial facility is not currently planned.

Any type of vegetable oil can be used in the HEFA process but wastes and residues are preferred due to their excellent sustainability characteristics and low carbon intensity. Wastes and residues do not incur any emissions during production, and there are no induced land use change values associated with using wastes and residues.

Table 16. Challenges and opportunities of fats and oils feedstocks.

Challenges	Opportunities
Feedstock availability Sustainability of crop-based feedstocks Competition with road transportation (renewable diesel and biodiesel)	Improved UCO collection can expand feedstocks Non-edible oilseed cultivation can expand feedstock availability Fully commercial technology

2.2.1 Waste oils and fats

India uses approximately 27 billion litres of cooking oil annually. While substantial volumes of used cooking oils are produced, estimates vary between reports. A report from the World Economic Forum estimates between 2 and 5 million tonnes of UCO are available (WorldEconomic Forum, 2021), while a recent report suggested a theoretical availability of 3.2 Mt in 2022, increasing to 4.1 Mt by 2028 (Capgemini, 2025). Only a fraction of this potential volume is currently collected and used for biodiesel production. Various challenges have been identified for expanding the availability of UCO. Unsafe reuse of UCO and illegal disposal limit the availability of UCO, but the general consensus is that the collection of UCO is inadequate. It is critical to identify the specific challenges and shortcomings of the UCO supply system and take steps to increase the availability of UCO for SAF production. The HEFA process is fully commercial and optimized around the world. As such, it presents the opportunity for India to meet all its SAF production targets over the next few years based on this feedstock. This will allow room for the development of further commercial technologies and initiatives to increase SAF production.

UCO collection in India is inadequate due to fragmented supply chains, lack of awareness, weak enforcement, and limited city-wise coverage. Many small food business operators (FBOs) sell UCO informally to unauthorized vendors or dispose of it improperly, while formal collectors face competition from cash-based buyers. Enforcement of RUCO ("Repurpose Used Cooking Oil") guidelines is weak, and many Tier-2 and Tier-3 cities lack organized collection networks.

According to the WEF report (World Economic Forum, 2021), the Food Safety and Standards Authority of India (FSSAI) and the Biodiesel Association of India (BDAI) run a "Repurpose Used Cooking Oil" web portal to trace and collect UCO-based biodiesel to supply public-sector oil marketing companies (OMCs) under a national program that is already carried out in eight states and union territories and could be expanded to a national UCO system (The Economic Times, n.d.-b). FSSAI has issued guidance on the safe handling of UCO, including regulations that require business operators whose consumption of edible oils for frying is more than 50 kg or litre per day to maintain detailed records (FSSAI, n.d.). Records must include details like the date, name of the oil, quantity of oil used in frying, quantity consumed at the end of the day, quantity discarded at the end of the day, mode and date of disposal of UCO, and UCO collected by (the name of authorized agency). Potential ways in which UCO collection can be improved include expanding to all metro cities and untapped cities, incentivizing small FBOs, and collaborating with channel UCO collection to integrate UCO collection into biofuels. In addition, ensuring complete traceability through a digital app can provide FBOs with compliance records and enable real-time monitoring of UCO collection.

Tallow is used extensively for biofuel production in many regions. Production of tallow in India is quite low and estimated at about 142-144 kt (*Tallow Production in India*, n.d.). However, most of the tallow is used for the production of soaps and oleochemicals or exported. Therefore, very limited volumes of tallow are available for SAF production. In 2022, about 9 kt of animal fat and tallow were used as feedstock for biodiesel production in India (*Tallow Production in India*, n.d.).

Favourable initiatives such as tax rebates, subsidies, and financial incentives to encourage the collection and recycling of used cooking oil should result in an increase in the supply of used cooking oil for conversion into biofuels. Other types of waste fats and oils (classified as residues, waste, or byproducts under CORSIA) that can be used for SAF production include palm fatty acid distillates (PFAD), palm oil mill effluent (POME), corn oil, crude tall oil, and tall oil pitch. There is limited information available regarding these feedstocks in India.

Globally, waste fats and oils are limited and estimated to be about 40 Mt. Some of these feedstocks are used for biodiesel production, but the number of facilities that produce renewable diesel and SAF has rapidly expanded over the last few years. The potential biofuel that can be produced from these feedstocks is therefore limited. This has created a high demand for these waste feedstocks, particularly in regions such as the EU, where these feedstocks are the only fats and oils permitted for SAF production under the ReFuelEU Aviation mandate. Exports of these feedstocks to the EU have increased substantially, and the price of UCO has approached that of pure vegetable oils. This situation presents a risk for the use of Indian feedstocks, as UCO collectors may prefer to export the UCO to areas where they can get a higher price.

The cost of pretreated UCO in India, based on stakeholder input, varies based on location, quality, and market conditions. The landed cost is about INR 84,000 to INR 86,000 per tonne (around USD 1,000)[15].

2.2.2 Vegetable oils

Vegetable oil production in India is about 9 Mt per year. To meet domestic demand for oils, about 14 Mt per year must be imported (USDA, 2022). Therefore, edible oils were not considered available for SAF production.

2.2.3 Alternative oilseeds

Due to concerns over food security, there has been increasing interest in non-edible oilseeds for biofuel production. There are two categories, perennials such as jatropha and oilseed-bearing trees, and annuals such as camelina, carinata, pennycress, and more, which can be planted as cover crops. Many oilseed-bearing trees (as discussed below) produce edible oilseeds. While they may be used for oil production and SAF, the sustainability of these sources will be similar to other vegetable oil crops.

The limited global availability of waste fats and oils places a limit on the volume of HEFA SAF that can be produced from waste. As the HEFA pathway is fully commercialized and optimized, increasing the availability of sustainable feedstocks, such as non-edible oilseeds, can significantly contribute to future SAF supply.

Many of these emerging non-edible feedstocks can potentially be cultivated on unused lands[16]. Under CORSIA, cultivation on marginal lands or cover crops does not incur induced land use change when calculating the carbon intensity of SAF, and, therefore, they have a low carbon intensity score.

Cover crops, also called intermediate crops, can be grown on fallow land in between cultivation of main crops. The three main cover crops with considerable potential are camelina (Camelina sativa), carinata (Brassica carinata), and pennycress (Thlaspi arvense).

Camelina has beneficial characteristics such as a short growing season (90–110 days) and tolerance to saline, frost, drought, and semi-arid conditions (Agarwal et al., 2021). In India, studies were conducted at DIBER research stations spread over different agroclimatic regions, which include Haldwani (Uttarakhand, 246 m above mean sea level (msl)), Pithoragarh (5500 m above msl; Uttarakhand), Auli (9000 m above msl; Uttarakhand), Secunderabad (Telangana), Ahmednagar (Maharashtra), and Mhow (Madhya Pradesh) for assessing the feasibility of camelina cultivation as a sole crop as well as intercropped with Jatropha (Agarwal et al., 2021).

The National Biofuels Policy of India made it mandatory that non-edible oil crops for biofuel must only be grown on 'wastelands[17]'. It is estimated that about 13.4 Mha of such lands are available for feedstock cultivation in India (Agarwal et al., 2021). To support these efforts, government policies provide a package of economic and regulatory incentives (for example, tax reductions, credit provision through national banks, and facilitated access to land) to private companies willing to develop industrial plantations or to engage in

[15] Information provided by stakeholder

[16] Under CORSIA, eligible lands for the unused land approach could include, among others, marginal lands, underused lands, unused lands, degraded pasture lands, and lands in need of remediation.

[17] In 1985, wastelands were defined as "degraded land, which can be brought under vegetative cover with reasonable effort, and which is currently underutilized and (that) land which is deteriorating for lack of appropriate water and soil management or on account of natural causes".

contract farming schemes with smallholders. These non-edible feedstocks are also eligible for the National Rural Employment Guarantee scheme, which provides up to 100 government-paid days of manual rural labour per year.

Challenges remain for implementing extensive cultivation of non-edible oilseed crops under this policy. Wastelands have been poorly demarcated and are unfit for cultivation; government intervention to determine their use is imperative (Agarwal et al., 2021). The National Oilseeds and Vegetable Oils Development (NOVOD) Board has also launched research and development programs on Jatropha and Karanja for biodiesel production, involving a network of 25 institutions across the country (Kumar Vijay, 2024).

In Karnataka, there are existing plantations of Pongamia[18], Simarouba , Amora, Surahonne, etc. (oil content 30-50%), but their commercial use for biofuels is still in the early stages. Across Karnataka, more than 90 million trees were planted between 2002 and 2008. Existing plantations are found in regions like Tumkur, Chitradurga, Hassan, Mysore, Mangalore, Hubli, and Belgaum. Current usage in biofuels production is limited, and these are mostly used for shading, soil restoration, and small-scale oil extraction (for traditional uses like soap making and medicinal applications). However, these trees may have the potential for biofuel production. Challenges include limited awareness among farmers, a lack of organized collection centres, and the need for policy support to incentivize cultivation for biofuels. Steps to address these challenges could include a detailed assessment of existing plantations, as well as further research and development for optimization of seed varieties.

India also has significant potential for tree-based oilseed cultivation, with species such as Mahua, Neem, Simarouba, Karanja, Ratanjyot, Jojoba, Cheura, Kokum, Wild Apricot, Wild Walnut, Kusum, and Tung. However, most of these species are cultivated to increase volumes of edible oils rather than non-edible oils for biofuel production. However, India has significant potential, with over 100 tree species capable of producing seed oil suitable for biodiesel (Kumar Vijay, 2024). The mission objective is to increase TBO seed collection from 0.9 to 1.4 Mt and supply elite planting materials to expand cultivation in wastelands across 28 states. A summary of the tree species with their potential for seed oil is shown in Table 17.

Jatropha (Jatropha curcas) is a non-edible oilseed crop that can be grown on marginal lands. In December 2009, the Indian government's National Biodiesel Mission identified Jatropha as the most suitable tree-borne oilseed for biodiesel production, aiming to achieve a proposed biodiesel blend of 20 % with conventional diesel by 2017. Biodiesel procurement started in 2014, and a pilot program was started in August 2015.

However, the government's ambitious plan did not materialize for various reasons, such as the availability of jatropha seeds for planting, poor yields, and high plantation costs. Large-scale cultivation has been difficult, one reason being the long gestation period (3-5 years) before farmers can earn an income from jatropha (Down to Earth, 2018).

It is reported that Jatropha occupies only around 0.5 Mha of low-quality wastelands across the country, of which 65-70% are new plantations of less than three years. While about 0.5 Mha have been planted with Jatropha, obstacles remain, including "slow progress in planting, sub-optimal processing and marketing infrastructure, and underdeveloped distribution channels"(Down to Earth, 2018).

---

[18] Jatropha curcas (called Jangli arandi in Hindi and Kattukkotai in Tamil) and Pongamia pinnata (The Indian Beech called Karanj in Hindi and Pungai in Tamil)

Table 17. Various oilseed-bearing trees, oil content of seed and yields[19].

Name of the plant	Common name	Fruiting season	Oil content	Yield at 10th year
Pongamia pinnata	Karanj	Jan – Mar	28 – 40 %	30 – 50 kg/tree
Simarouba glauca	Paradise tree	Mar – Apr	55 – 60 %	30 – 50 kg/tree
Jatropha curcas	Jatropha	April & October	30 – 35 %	1 – 3 kg/plant
Bassia latifolia	Mahua	Aug – Sept	30 – 40 %	> 50 kg/tree
Aphanamyxis polystachya	Amoora	Oct – May	35 – 40 %	> 35 kg/tree
Calophyllum inophyllum	Surahonne	Oct – Dec	50 – 60 %	> 40 kg/tree
Sterculia sp	Sterculia	Dec – Jan	35 – 45 %	20 – 30 kg/tree
Mesua ferrea	Naga champa	Sept – Oct	50 – 55 %	> 50 kg/tree

2.2.4 Pretreatment of oils and fats

Typically, biobased feedstocks contain contaminants, such as alkali metals (Mg, Na, K), phospholipids, chloride, etc., that will deactivate and inhibit catalysts in downstream catalytic processes. Waste oils and fats can contain higher concentrations and different types of these contaminants. These contaminants are generally removed in a pretreatment step that could involve processes such as acid washing (degumming to remove phosphorus from phospholipids), bleaching (filtration using active clay), centrifugation, filtration, and enzymatic treatment.

UCO, animal fats, and other wastes have poor quality and can even contain polyethylene (from plastics), which is typically not found in vegetable oils (Biobased Diesel Daily, n.d.). Every biorefinery will set its own specifications for acceptable levels of contaminants, and the specifications for different companies will depend on the specific refinery configuration and other factors that would allow the handling of different contaminants.

Pretreatment can be carried out by the feedstock supplier, for example, the UCO collector, or at the biorefinery itself. Until a few years ago, biorefineries generally did not carry out their own pretreatment. However, as there is an ongoing shift to poor-quality waste feedstocks, more biorefineries are investing in their own pretreatment units. This can provide greater flexibility in feedstock sourcing and ensure high-quality standards are maintained. Pretreatment will require an investment in additional infrastructure.

UCO collectors in India generally carry out pretreatment to supply pretreated feedstocks to biofuel producers. However, the expansion of UCO collection in India will require capital investment into pretreatment infrastructure. If this presents a barrier to increased access to UCO feedstocks, refineries could consider establishing their own pretreatment facilities. This will also ensure suitable quality and greater flexibility in purchasing feedstocks.

2.2.5 Summary

Table 18 below shows the summary of SAF potential from fats, oils and greases.

[19] Input from stakeholders

Table 18. Summary of fats, oils and greases potential.

Feedstock	Waste oils and fats	Crop-based oils	Other oilseeds
Feedstock availability	Yes	No	Yes, limited
Existing uses and competition	Biodiesel production		
Potential for expansion	Yes	No	Yes
Suitable technology pathways for SAF	HEFA CHJ		HEFA CHJ
Feedstock readiness	Yes		No
Main challenges for using this feedstock	Availability		Commercial cultivation at scale
Potential opportunities	Increased UCO collection can increase availability		Can expand feedstock volumes
Sustainability	Yes	Maybe	Non-edible is sustainable. Edible oilseeds may be sustainable but must be assessed
Default carbon intensity CORSIA (incl ILUC)	13.9 – 22.5 gCO_2eq/MJ		Camelina, carinata, jatropha (India-specific) -1.3 – 28.6 gCO_2eq/MJ
Economic/market-related considerations (cost of feedstock, high demand)	High demand in other regions, which also drives costs		Not known
Key stakeholders	UCO collectors		Farmers

2.3 SUGARS AND STARCHES

Several technologies can use sugars and starch as a starting feedstock for biofuel production. Ethanol production from sugars and starches is the main technology considered here, with the ethanol currently used for blending with petrol but potentially converted to SAF through the alcohol-to-jet process. These sugar and starch feedstocks can also be used for the production of other alcohols, such as isobutanol, or hydrocarbons, such as farnesene (the Synthesized Isoparaffins (SIP) pathway).

Globally, the main sugars and starches used for ethanol production are crops such as sugarcane (in Brazil) and corn (in the USA). Other potential feedstocks could include rice, sugar beet, wheat, sorghum, cassava, and many more. The use of food crops for biofuel production raises the food-versus-fuel debate, and regions such as the EU do not permit these crops to be used for SAF production.

India has not banned the use of these crops for biofuel production, and these crops are currently used as feedstocks for ethanol production. However, India strictly regulates the use of crops to protect food security. The Essential Commodities Act of 1955 allows the Indian government to control the production, supply, distribution, and trade of essential commodities to ensure public interest. This Act plays an important role in regulating commodities related to food security. The use of essential commodities, such as grains or sugar, for biofuels is only permitted after food security has been satisfied. Thus, limits may be placed on the use of crops for biofuel production, and this may be changed on an annual basis or as needed based on projected harvests, etc. Under the Act, the government of India can also implement a minimum support price for commodities. The Indian government set a minimum selling price of sugar at INR 29 per kg in 2018 and INR31 in 2019 to ensure that sugar prices didn't fall below the cost of production (The Economic Times, n.d.-a). Current discussions are underway to increase this minimum price (ChiniMandi, 2025).

Similarly, the Indian government regulates prices for ethanol. Currently, ethanol produced from cane juice is priced at INR 65.61 per litre (about USD 0.74), while the rates for ethanol from B-Heavy and C-Heavy molasses stand at INR 60.73 and INR 56.28 per litre, respectively. A price revision is under consideration.

In India, sugarcane juice, "B" and "C" molasses are used for ethanol production.[20] Where "B" molasses are used for ethanol production, in addition to sugar production, about 21.75 litres of ethanol and 95 kg of sugar are produced from one tonne of sugarcane. Where "C" molasses are used, 10.8 litres of ethanol and 115 kg of sugar are produced from one tonne of sugarcane (*Indian Sugar Mills Association*, n.d.).

According to the Indian Sugar Mills Association, 14.9 Mt of molasses was produced in 2020-21 (Table 19) (*Indian Sugar Mills Association Statistics*, n.d.). This includes B-molasses used for ethanol production.

Table 19. Sugarcane production in India.

	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21
No. of factories in operation	526	493	525	532	461	506
Cane acreage (000 Ha)	5284	4945	5042	5502	4841	5288
Sugarcane production (Mt)	337	304	411	414	344	402
Molasses production (kt)	10873	9026	14063	13788	11526[21]	14906[22]

In 2023-2024, the estimated Indian cane sugar production was 34 Mt. Expected sugar exports in 2024-2025 are 3.7 Mt due to government export restrictions (USDA Foreign Agricultural Service, 2024). This restriction will be effective for an indefinite period (USDA, 2024).

Under the Indian Ethanol Blending Program (EBP), ethanol can be produced from sugarcane, broken rice, damaged grains, and maize. In 2023-2024, the government permitted the diversion of only 2.1 Mt of sugar for ethanol, although this allowance was increased in August 2024, also allowing excess rice to be used for ethanol production. In 2024, the government limited the use of sugarcane and its derivatives for ethanol production to 2.37 Mt. The Indian government is taking steps to increase the maize/corn production in India for fuel ethanol.

From a carbon intensity perspective, the ethanol production and blending policy in India does not take the carbon intensity of ethanol into account. This has implications for SAF production, where sustainability and carbon intensity are determined under ICAO's CORSIA, specifying default carbon intensities for feedstocks and technology pathways. Under CORSIA, the default carbon intensity values (CORE plus ILUC) of SAF from corn/maize ethanol are higher than the default carbon intensity of conventional jet fuel (ICAO, n.d.-b).

[20] The first boiling yields "A" molasses (or first syrup), which is the highest in sugar content. "B" molasses is produced during a second boiling and further sugar is extracted. "B" molasses is about 7.25% of the cane. The third boiling yields blackstrap molasses ("C" molasses), which is dark and viscous. "C" molasses is about 4.5% of the cane. Further sugar cannot be extracted from "C" molasses.

[21] Estimate.

[22] Includes B-heavy molasses used for ethanol production.

Therefore, SAF based on corn/maize ethanol in India would probably not meet CORSIA sustainability criteria that require at least a 10% reduction. This can be compared to SAF based on sugarcane ethanol, which can give emissions reductions of over 60%. Using sugarcane ethanol in India is a more suitable proposition for SAF production than using maize ethanol.

The main challenge for using these first-generation feedstocks for ethanol production, with a conversion to SAF through the AtJ pathway, is the government's prioritizing of ethanol for blending into petrol. Allowing these feedstocks to be used for SAF production would reduce the potential ethanol available for blending with petrol. However, as explained earlier, SAF technologies produce multiple products, including naphtha or drop-in blend stocks for petrol. Therefore, SAF production can reduce emissions in all transportation sectors, but this would require a change in policy or a more integrated approach to biofuel policy that incorporates all transportation sectors within one overall policy.

Conversion of first-generation sugars and starches to ethanol is fully commercial and can be done at high yields at a reasonable production cost. Limiting SAF to second- or third-generation feedstocks, e.g., advanced ethanol from agricultural residues or CO_2 fermentation, would result in very high SAF production costs. Simple sugars and starches are the low-hanging fruit for the AtJ process and should be considered for SAF production. The production of advanced ethanol (2nd and 3rd generation) is discussed in the next section.

Estimated ethanol production in India for 2025 is about 9.7 billion litres/year, with an estimated capacity for 2025 at about 20 billion litres/year (US Department of Agriculture, 2025). If all the production is utilized towards SAF production, about 5.6 billion litres/year (4.5 Mt/year) of SAF can potentially be produced[23].

Table 20 below provides a summary of SAF potential from sugars and starches.

Table 20. Summary of sugars and starches.

Feedstock	Co-product sugars (B and C molasses)	Sugarcane	Corn or other starches
Feedstock availability	Yes	Yes	Yes
Existing uses and competition	Ethanol for road transport	Food and ethanol for road transport	Food and ethanol for road transport
Potential for expansion	Yes	Yes	Yes
Suitable technology pathways for SAF	Alcohol-to-jet	Alcohol-to-jet	Alcohol-to-jet
Feedstock readiness	Yes	Yes	Yes
Main challenges for using this feedstock	Competition with ethanol blending in petrol	Competition with ethanol blending in petrol	Sustainability Competition with ethanol blending in petrol
Potential opportunities		Expansion	Reduction in actual carbon intensity to meet CORSIA standard
Sustainability	Yes	Yes	Maybe

[23] Based on a yield of 60%

Default carbon intensity CORSIA	No specific default	Isobutanol (33 gCO2eq/MJ) Ethanol (32.6 gCO_2eq/MJ) Actual CI of sugarcane ethanol in India can be lower than current defaults	Isobutanol (85.5 gCO2eq/MJ) Ethanol (100.6 gCO2eq/MJ)
Economic/market-related considerations (cost of feedstock, high demand)	Restricted use under the Essential Commodities Act SAF may be a higher value proposition	Restricted use under the Essential Commodities Act SAF may be a higher value proposition	Restricted use under the Essential Commodities Act
Key stakeholders	Sugarcane farmers, sugar mills, ethanol producers, maize producers		

2.4 AGRICULTURAL RESIDUES

Agricultural residues can be used in various SAF technology pathways, but their main application is likely to be the production of advanced ethanol (also termed cellulosic ethanol) or other alcohols such as isobutanol through biochemical fermentation processes followed by the AtJ pathway. Other potential technologies that can use this feedstock include gasification and pyrolysis.

Globally, agricultural residues are one of the most abundant feedstocks for SAF production, and the mobilization of this feedstock is critical for the production of high SAF volumes. Competing uses for agricultural residues include animal feed, animal bedding, biogas production, and power generation. Availability of residues in this study was assessed after excluding competing uses.

While many crops produce residues, the yield of residues per area will impact their economic suitability for SAF production, as low yield volumes will mean longer transport distances to a facility and higher costs of transport. These supply chain characteristics and associated challenges are discussed in more detail below.

2.4.1 Availability of agricultural residues in India

Crop residues consist of plant materials left behind after harvesting and threshing of crops. These residues have different uses; for example, many farmers utilize wheat straw as animal feed. Rice straw, however, is not used for animal feed due to its high silica content. As a result, farmers resort to burning rice straw residues in order to prepare fields for planting the next crop, creating widespread air pollution. The utilization of rice straw to reduce burning is, therefore, a priority in India.

Different varieties of crops yield different amounts of residue, and the total potential for all crops in India is shown in Table 21. Cereals (rice, wheat, maize, pearl millet, barley, minor millets, and sorghum) account for the majority of crop residues, accounting for 368 Mt (54%), followed by sugarcane (111 Mt) (16%). When it comes to individual crops, rice generates the most gross residues (154 Mt), followed by wheat (131 Mt).

Based on the surplus residues available from the selected crops, the yearly national potential is around 230 Mt per year, i.e., about 34% of the gross residue generated in India.

Table 21. Gross & surplus crop residues biomass potential in India.

Crop	Gross residue potential (Mt/year)	Surplus residue potential (Mt/year)
Cereals (rice, wheat, barley, jowar, ragi, small millets)	367.7	90.1
Oilseeds (Rapeseed-mustard, sesame, linseed, niger, safflower, soybean, groundnut, sunflower)	48.8	13.7
Pulses (pigeon pea, guar, chickpea, lentil)	17.9	5.1
Sugarcane	110.6	55.7
Horticulture crops (banana, coconut arecanut)	61.4	22.5
Others (cotton, jute)	79.8	47.3
TOTAL	**686.2**	**234.4**

The sugarcane industry generates two types of residues that are relevant for the purpose of SAF production. Sugarcane trash is the leaves and tops produced during sugarcane harvesting (8-10% of the sugarcane plant). Sugarcane bagasse is a dry residue produced during sugarcane crushing and juice extraction (30% of the sugarcane plant) (Konde et al., 2021). Bagasse is a very attractive feedstock for advanced ethanol production, as it does not encounter the supply chain challenges that occur with residues that have to be collected from the fields. Residues produced on-field have to be collected, baled, transported, stored, dried, and size-reduced. This is a complex supply chain and contributes to the cost of feedstock, but it also presents a challenge from a quantity and quality perspective. Supply chain challenges are probably one of the biggest challenges for the commercialization of technologies using on-field residues, regardless of the production technology used.

On the other hand, residues that are generated at a processing facility, such as sugarcane bagasse, do not face the same challenges. Bagasse does not incur costs for transport from the fields and is already size-reduced and aggregated as a result of sugar production.

From a SAF production perspective, sugarcane bagasse is considered a "low-hanging fruit" feedstock and is preferred above on-field feedstocks for a technology such as advanced ethanol production. About 100 Mt of sugarcane bagasse are produced annually in India (Konde et al., 2021). The bagasse is widely used for cogeneration of power, which provides an additional income for sugar mills. Many sugar mills have installed co-generation plants over the last twenty years, and the current installed capacity of cogeneration plants in India is about 9200 MW (Konde et al., 2021). However, about 30 Mt of bagasse are still available for the production of advanced ethanol and SAF after taking into account competing uses24. The cost of electricity from bagasse (INR6-7) is more expensive than other sources of electricity (INR2-3), and sugar mills are actively investigating other lucrative applications for bagasse, of which SAF is considered a very attractive proposition.

On-field residue, specifically from rice straw, is the most abundant and unused residue feedstock in India. Its disposal through crop residue burning contributes significantly to air pollution, and using these residues for

[24] Based on stakeholder information

value-added applications such as SAF production can address pollution while contributing to biofuel production. However, its use for advanced ethanol production is challenging from a supply chain and logistics perspective and, arguably, presents the biggest obstacle to its valorization. This is further discussed in the following sections.

2.4.2 Advanced ethanol production from agricultural residues

Biochemical production of advanced ethanol (or isobutanol) is a complex process with multiple steps, as illustrated in Figure 15.

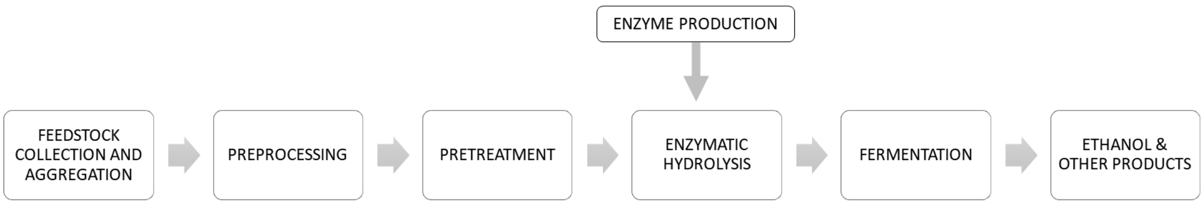


Figure 15. Process flow chart of key steps in cellulosic ethanol production.

The main steps are:

a. Feedstock collection at farms and aggregation, e.g., baling and storage at intermediate locations.

b. Preprocessing includes removing twine from bales and chopping or grinding the straw.

c. Pretreatment can be done in many ways and functions to break open the structure of the plant cells to provide access to the enzymes that break down the structure of the cellulose and hemicellulose components into simple sugars, such as glucose and xylose, which can then be fermented into ethanol. Various types of pretreatments can be used, including acid pretreatment, steam explosion, alkali pretreatment, deacetyl mechanical refining, etc. Praj uses a steam explosion with mild acid pretreatment. The selected pretreatment has an important impact on the rest of the process and the final yields of fermentable sugars that are obtained.

d. Enzyme production and enzyme hydrolysis—Due to the complexity of the plant structure, multiple enzymes are necessary to work in synergy to produce simple sugars. The enzymes have to be produced on-site or purchased from an enzyme supplier. Enzymes are generally a costly part of the process, but they are critical for achieving high sugar yields from the plant material. The specific enzyme mixture has an important impact on the yield of fermentable sugars and the final ethanol yield.

e. Fermentation of simple sugars is carried out by microorganisms, the most common one being the yeast *Saccharomyces cerevisiae*, the common brewer's yeast. While *S. cerevisiae* is very effective at producing ethanol, it can only produce ethanol from 6-carbon sugars such as glucose. Glucose is obtained from the cellulose component of the rice straw. Other sugars are found in the hemicellulose, but these are generally 5-carbon sugars, which require special fermentation organisms. Alternatively, genetically modified yeasts are used that can co-ferment 6- and 5-carbon sugars.

The remainder of the plant consists of lignin, which cannot be used to produce ethanol. Lignin is a by-product and is mostly burned to generate energy, although ongoing research and development are investigating higher-value products from lignin. The composition of a few residue types is shown in Table 22. The higher the lignin and ash content, the lower the fermentable sugars and the final potential yield of ethanol.

Table 22. Composition of various types of biomass feedstocks that can be used for advanced (cellulosic) ethanol production (ash content is not included).

Biomass	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Sugarcane bagasse	42-48	19-25	20-42
Rice straw	28-36	23-28	12-14
Corn stover	38-40	24-26	7-19
Wheat straw	33-38	26-32	17-19

The commercialization of advanced (cellulosic) ethanol production from agricultural residues has been ongoing for decades, but many obstacles were encountered along the way. Many commercial-scale facilities in Europe and the US were closed as they could not achieve capacity and were not economically viable.

The first commercial cellulosic ethanol facility, pioneered by Beta Renewables in Crescentino, Italy, was officially opened in 2013, with several other facilities commissioned over the next few years, including Abengoa, DuPont, and POET/DSM in the US and Raizen and GranBio in Brazil. Despite strong policy support (such as the US Renewable Fuel Standard), all facilities in the US have since closed down, as well as the plant in Italy. Raizen, based in Brazil, continued to produce cellulosic ethanol from sugarcane bagasse. Raizen has two operating facilities in Brazil, with others under construction, and plans for a total of nine facilities (Agribusiness Valorinternational, 2024).

Most recently, the Clariant facility in Romania started production of advanced ethanol in 2022 but closed in December 2023, having suffered significant losses (Clariant, 2023). In India, IndianOil operates a commercial-scale advanced ethanol facility based on agricultural residues. This 100 m^3/day capacity advanced ethanol biorefinery can process 200 kt of rice straw to produce 30,000 m^3 of ethanol annually.

One of the major challenges of previous commercial cellulosic ethanol production efforts was feedstock harvesting, collection, storage, and handling, and these challenges are extensively documented in the literature (DOE, 2016). The material handling problems that were encountered led to lengthy startups and a failure to achieve expected capacity. Establishing an effective biomass supply chain that can ensure consistent quality and sufficient quantity of feedstocks delivered to the ethanol producer is critical to the success of a facility.

From a cost perspective, all residues are different. Aggregated residues such as sugarcane bagasse are ideal for cellulosic ethanol production from a cost perspective, and supply chain challenges, as found with crop residues, are not encountered. Corn fibre from corn milling processes, similarly to bagasse, does not have the cost of transport and other associated supply chain challenges. Corn fibre has been effectively used for advanced ethanol production through bolt-on cellulosic ethanol production units next to conventional ethanol mills[25](Li et al., 2023). While these “low-hanging fruit” feedstocks may not be available in large volumes, their use as a feedstock for advanced ethanol production could be economically favourable. Advanced (2G) ethanol is a more expensive process than conventional (1G) ethanol, and using “low-hanging fruit” feedstocks can reduce production costs.

[25] Sometimes referred to as 1.5 generation ethanol.

2.4.3 Feedstock supply chain and logistics challenges with agricultural residues

Using agricultural residues as a feedstock presents challenges related to feedstock harvesting, collection, storage, and handling. The mobilization of commercial quantities of biomass resources from production sites to the gate of biorefineries requires an optimized, cost-efficient, and effective biomass supply chain.

Cost, quality, and quantity parameters are equally important. While this can be achieved at a small scale, it becomes problematic when operating a large-scale commercial facility. Achieving economies of scale requires larger commercial facilities, but the biomass supply chain may be the limiting factor. As facilities become larger, the unit cost of production will decrease (up to a certain point). One study demonstrated that the CAPEX per litre of ethanol would be 10% lower for a 70,000 m^3/year facility compared to a 36,500 m^3/year facility (Zhou et al., 2021). Arguably, the biggest obstacle to achieving high-capacity advanced ethanol facilities would be feedstock supply and logistics.

Table 23. Important parameters of an effective supply chain.

Parameter	Comments
Feedstock cost	Feedstock cost has an important impact on the economics and final production cost of ethanol and SAF, and transport cost is the major contributor. As agricultural residues have a low energy density, it is uneconomical to transport them over great distances. The moisture content of the residues will also impact feedstock cost. Cost is also linked to the quality of the feedstock, as this will impact the yield of ethanol per unit of feedstock. Poor-quality feedstocks will lead to lower yields.
Feedstock quality	Feedstock characteristics such as moisture levels and ash content will impact the economics. Apart from the inherent ash content of a specific feedstock, ash content is also affected by the harvesting, aggregating, and baling methods. If residues are covered in mud or stones and sand are picked up during raking and baling, the quality of the feedstock will be poor and could lead to lower yields, higher feedstock costs, and damage to equipment. Moisture content is an important quality parameter, and yields are calculated on a dry basis. High moisture in feedstocks will increase feedstock cost as it makes the feedstock heavier and transport more expensive. Drying of feedstocks can be costly from an energy perspective, but this is not usually done for agricultural residues. Maintaining quality from harvesting to final delivery to the biorefinery is important. When storage is inadequate, rain damage may lead to microbial degradation with a resulting yield loss in the final ethanol production. Quality also refers to the homogeneity of the feedstock particle sizes at the refinery gate. Consistent size will ensure efficient pretreatment and maximum yields.
Feedstock quantity	Achieving economies of scale will impact the final production cost of SAF, but the required volume of feedstock can become a logistics problem for large facilities. For example, a SAF production facility of 80,000 m^3 per year will require 130,000 m^3 of ethanol produced from 554 kt of rice straw (on a bone-dry basis) per annum [26]. This amounts to more than 27 million bales of rice straw (20 kg per bale) that must be harvested during a 20-25 day period and stored for use during the year.

The main steps in the current supply chain for rice straw collection in India are relatively similar, although differences may occur across India as some states have higher levels of mechanization. As farms are small (about 1 acre per farmer), straw collection and baling are done through intermediaries such as biomass

[26] Typical rice straw to ethanol yield is around 230-240 L/t of bone-dry rice straw, with an average yield of 235 L/t

aggregators. The use of intermediate biomass aggregators is common in India, and there are about 600 balers in Punjab and 300 in Haryana (Food and Agricultural Organization, 2022). Major biomass suppliers own raking and baling equipment and operate privately. In other cases, state government agencies are involved, and state-owned equipment is rented to aggregators. Raking and baling are not standardized, leading to inconsistent quality of bales. Bale sizes can vary from 18 to 25 kg, but the maximum size is restricted as bales are manually handled and loaded for transport. Bales are stored at depots, usually common land leased by the government for storage. About 23,000-25,000 farmers supply bales to one depot. Bales are stacked at a maximum height of 20 bales, and 1,200 – 1,300 tonnes of baled biomass occupies about 1 acre of land. Stacks are spaced apart with barriers between stacks to prevent fires from spreading, and stacks are covered with tarpaulins to prevent water from entering the stacks and degrading the biomass. Bales are transported from the depots to the biorefinery, where separate storage facilities keep 2-7 days' worth of feedstock. Unbaling and twine removal are done manually at the biorefinery, and residues are washed to remove mud before shredding and pretreatment take place.

Overall, the supply chain is complex, and it remains challenging to get sufficient feedstock to a biorefinery at high quality and low cost. The main challenges are self-evident. The collection of rice straw must take place within a period of three weeks, which is challenging. Storage of bales at depots occupies large areas, and quality has to be maintained over several months, with rain damage and fires being two challenges. Overall, transport distances must be less than 30 km to the biorefinery to remain cost-effective. Addressing supply chain and logistics challenges is critical for the successful use of agricultural residues for advanced ethanol production. Some of the areas that have been identified by stakeholders include improved standardization of collection and baling and quality verification at the farm level. Standardization of bale sizes and moisture content and increased mechanization can all contribute to improving the supply chains. Companies such as Praj are actively engaged in exploring all avenues for improvement and contributed substantially to this report.

Collection distance contributes substantially to transport costs, and this will likely remain a limiting factor in the quantity of feedstock that can be collected within a 30 km radius of the biorefinery. Harvesting, collection, storage, and transportation make up a substantial fraction of the cost of pre-processed feedstock, estimated at about 48% according to (Lin et al., 2020) and 35-50% according to (Food and Agricultural Organization, 2022). Based on current information from stakeholders, the price of rice straw can range from INR 1500 to 3500 (USD 17 to USD 40).

Unless intermediate densification steps in the supply chain can be implemented, the supply distance limitations will restrict the size of the biorefinery and maximum capacity. However, pelletization of rice straw is not a viable option due to factors such as binding agents used in the pellets, which cause problems at the biorefinery.

Similar to previous cellulosic ethanol production facilities, the supply chain challenges are critical for the success of the technology. However, the conditions in India differ vastly from areas such as the US, and unique solutions must be explored in the country. Some approaches adopted in the US and other regions could, however, be implemented. For example, carrying out a detailed GIS-based evaluation to determine the spatial distribution, availability, and suitability of biomass resources for bioenergy production, considering factors such as infrastructure, transportation, and environmental constraints. This type of mapping was done as part of the US Billion Ton study (US Department of Energy - BETO, 2023). The US Department of Transport Volpe Center has also developed the Freight and Fuel Transportation Optimization Tool, which is a flexible scenario-testing tool to optimize supply chains and compare costs of different options. This tool is freely available for use, and the model is publicly available (Volpe National Transportation Systems Center, n.d.). A more detailed analysis of various supply chain models would be required to determine the optimal model.

2.4.4 Summary

Table 24 below shows a summary of the potential for SAF from agricultural residues.

Table 24. Summary of agricultural residue potential.

Feedstock	Bagasse	Rice straw
Feedstock availability	Yes (about 30 million tonnes)	Yes
Existing uses and competition	Yes (cogeneration of electricity	No
Potential for expansion	Yes	
Suitable technology pathways for SAF	Alcohol to jet	Alcohol to jet
Feedstock readiness	high	Low (supply chain challenges)
Main challenges for using this feedstock	Complexity of the feedstock and the process	Supply chain Complexity of the feedstock and the process
Potential opportunities	Low-hanging fruit for advanced ethanol	Significant availability if supply chain issues resolved
Sustainability	Yes	Yes
Default carbon intensity CORSIA (incl ILUC)	Only default for general agricultural residues – 24-39 gCO2/MJ	Only default for general agricultural residues
Economic/market-related considerations (cost of feedstock, high demand)	High production cost of advanced ethanol compared to conventional ethanol	Cost of feedstock linked to supply chain challenges High production cost of advanced ethanol compared to conventional ethanol
Key stakeholders	Sugarcane farmers, sugar and ethanol producers	Farmers, biomass suppliers, biorefineries

2.5 FOREST BIOMASS

Forest biomass is considered one of the major feedstocks for SAF production around the world. The majority of the available forest biomass is produced as a byproduct of the lumber and pulp and paper industries. Feedstocks include forest residues that are the tops and branches left behind in the forest after logging. Other types of residues include sawdust and bark generated at sawmills, tall oil, and black liquor from kraft pulping. Residues generated at sawmills or pulp mills are considered the low-hanging fruit, as they are produced at a central location in an aggregate form, with feedstocks such as sawdust already size-reduced. This category of forest biomass is the most economical feedstock, as it does not incur transport costs (from locations in the forest)[27].

Two main types of SAF production technologies can be used based on this type of feedstock: gasification with Fischer-Tropsch or thermochemical liquefaction (pyrolysis or hydrothermal liquefaction).

---

[27] Transport costs may be incurred if sawdust is transported from smaller sawmills to a large-scale biorefinery. This is likely to be the situation in India due to the small size of the sawmills.

India has extensive forest areas, comprising 80.9 Mha, 25% of the total geographical area. The major timber species include Shorea robusta (*sal*), Tectona grandis (*teak*), Pinus roxburghii (*longleaf Indian pine*), Terminalia tomentosa (*saj*), Mangifera indica (*mango*), Cocos nucifera (*coconut*), and Areca catechu (*areca palm*). However, there is a limited stock of domestic species favoured for furniture production, for example, acacia arabica (*gum tree*) and dalbergia sissoo (*rosewood*). As India is the fifth-largest producer of furniture globally, there is a high volume of lumber imported into the country.

The logging sector in India is very limited, so no in-forest residues are considered for this study. However, sawmill residues are still produced from imported logs and were therefore included. There are 6,457 sawmills in India as of January 2025, of which 99.61% are single-owner operated. Twenty-five sawmills are part of larger companies. Three states have the most sawmills: West Bengal with 761 sawmills, Tamil Nadu with 699, and Kerala with 638 sawmills (*List of Sawmills in India*, n.d.).

It is estimated that India could be generating 8-10 Mt of sawdust every year, although some estimates suggest a higher number, about 18 Mt per annum (BioBiz, n.d.). Small sawmills may only generate one tonne of sawdust and residues, with large mills up to ten tonnes per day. However, sawmills occur in clusters, with some clusters including hundreds of sawmill units in one location. The availability of sawdust and mill residues should be assessed based on an entire cluster, which could amount to sufficient volumes to support a large-scale biorefinery. At an average of five tonnes per day, 500 units could produce 2,500 tonnes of residues per day.

Sawdust, mill residues and other biomass are used extensively for making briquettes and pellets, which can be used for industrial boilers and household heating. Other applications may also include incense stick manufacturing, animal bedding, mulch, and mushroom cultivation. The pulp and paper sector also uses biomass for steam generation.

The exact volumes of sawmill residues used, and therefore available, are not entirely clear, as other types of biomass are also used, but estimates suggest 10-12 Mt of biomass are used for industrial heating and 1.5 Mt in the pulp and paper sector. The availability of sawdust should be further investigated to quantify volumes available within central locations to support biorefineries. Sawdust and other sawmill residues offer a significant opportunity as a low cost and low-carbon-intensity feedstock that can readily meet size and quality specifications for both gasification and pyrolysis technologies.

2.6 MUNICIPAL SOLID WASTE

Municipal solid waste (MSW) is considered a prime target feedstock for SAF production as it is abundantly available in all urban areas. General MSW is mainly considered suitable for gasification and Fischer-Tropsch technology. However, for specific categories of MSW, such as waste tires, and non-recyclable plastics, other technologies are being commercialized, for example, pyrolysis or hydrothermal liquefaction, to produce a biocrude that can be further upgraded. The last two feedstocks are specifically discussed here because companies are actively pursuing ASTM approval for SAF production based on these feedstocks.

Landfills can also be capped to capture biogas, which can be converted into biomethane. While biomethane is generally used for heat and power, some companies are exploring different ways to convert the biomethane to SAF. The CO2 from biogas can also be used for SAF production, and this is discussed in the section below.

From a technical perspective, the heterogeneous nature and complexity of MSW is still a significant obstacle to the commercialization of SAF production. The closure of Fulcrum Bioenergy, the first small commercial-scale MSW gasification facility, was a setback for this technology, although several companies are still pursuing commercial production of SAF from this feedstock.

From a sustainability perspective, MSW feedstock is generally considered very attractive. However, the actual carbon intensity of SAF from this feedstock is based on the non-biogenic content28. The higher the non-biogenic content, the higher the carbon intensity. Therefore, MSW with low biogenic content is not an attractive feedstock for SAF production under CORSIA's LCA methodology.

Waste plastic doesn't qualify under CORSIA at present, and the following is written in the *CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels* (October 2024): "As of the current version of this document, plastics are not included in the list of wastes, residues, or by-products approved by ICAO to produce SAF and claim emissions reductions under CORSIA. Under MSW, plastics will be considered as non-biogenic content."

2.6.1 General MSW

The total quantity of solid waste generated in India (2020/2021) was 160,038.9 tonnes per day, of which 152,749.5 tonnes (95.4%) per day was collected. A total of 79,956 tonnes per day (50%) is treated, and 29,427 tonnes per day (18.4%) is landfilled (Central Pollution Control Board, 2021). The balance of 50,655 tonnes per day (31.7%) of the total waste generated is unaccounted for (disposed of in unregulated dumpsites).

The 5-year trend shows an increase in the treatment of waste and a reduction in the volume that is landfilled. The per capita amount of waste generated has remained relatively steady at about 120 grams per day (Central Pollution Control Board, 2021). Table 25 shows the breakdown by state.

Table 25. State-wise generation, collection, treatment and landfill details (in tonnes per day) (SW=solid waste; RDF=refuse-derived fuel) (Central Pollution Control Board, 2021).

State	SW Generated	SW Collected	SW Treated	SW Landfilled	Treatment types[29]
Andhra P	6,898	6,829	1,133	205	C,V,B,R/P,W
Arunachal P	237	202	0	27.5	C,V,M
Assam	1,199	1,091	41.4	0	C,V,B,R/P
Bihar	4,281	4,013	0	0	C
Chhattisgarh	1,650	1,650	1,650	0	C,R/P
Goa	227	219	197	22	C,W
Gujarat	10,373	10,332	6,946	3,385	C,V,B,R/P
Haryana	5,352	5,291	3,123	2,167	C,V,B,R/P,W
Himachal P	346	332	221	111	C
J&K	1,463	1,437	547	376	C,V,B,R/P
Jharkhand	2,226	1,651	758	1,086	C,V,B,R/P
Karnataka	11,085	10,198	6,817	1,250	C,V,B,R/P
Kerala	3,543	2,965	2,550	0	C,V,B,W
Madhya P	8,022	7,235	6,472	763	C,V,B,R/P,W
Maharashtra	22,632	22,584	15,056	1,355	C,V,B,R/P,W

[28] According to CORSIA. This may differ under the EU Renewable Energy Directive, for example, the policy on renewable fuels of non-biological origin (RFNBOs).
[29] Treatment types: (C) Composting; (V) Vermicomposting; (B) Biogas; (R/P) RDF/Pelletization; (W) WTE (Waste-to-Energy); (M) Sorting at a material recovery facility (MRF).

Manipur	282	190	108	82	C,W
Meghalaya	107	93	9.6	83.4	C,V,B
Mizoram	345	276	270	0	C,V,B
Nagaland	330	285	122	8	C
Odisha	2,133	2,097	1,038	1,034	C,V
Punjab	4,338	4,278	1,894	2,384	C,V,B
Rajasthan	6,897	6,720	1,210	5,082	C,V,B,R/P,W
Sikkim	72	72	20	51	C
Tamil Nadu	13,422	12,844	9,430	2,301	C,V,B
Telangana	9,965	9,965	7,530	991	C,V,B,W
Tripura	334	318	214	13	C,V
Uttarakhand	1,458	1,378	779	0	C
Uttar Pradesh	14,710	14,292	5,520	0	C,W
West Bengal	13,709	13,356	668	202	C,B
A&N Islands	89	82	75	7	C,B
Chandigarh	513	513	69	444	C,V,B
DDNH	267	267	237	15	C
Delhi	10,990	10,990	5,193	5,533	C,V,B,W
Lakshadweep	35	17	17	0	C,B
Puducherry	504	482	36	446	C,V,B
TOTAL	**160,039**	**152,749**	**79,956**	**29,427**	

According to a report from the Central Pollution Control Board in Delhi, there were eleven waste-to-energy (WtE) plants operational in India (three in Delhi; two in Andhra Pradesh; two in Uttar Pradesh; one in Goa; one in Haryana; one in Madhya Pradesh; one in Maharashtra) (Central Pollution Control Board, 2021). Many other waste-to-energy facilities are in the planning and construction stages (Statista, 2024). While WtE is successfully used in some regions such as Europe, it is argued by some that it is not an effective method for waste disposal in India (IDR Online, 2024).

According to the Central Pollution Control Board in Delhi, 1924 sites for landfills have been identified, 305 landfills have been constructed, 126 are under construction, 341 are in operation, 17 are exhausted, and 11 landfills have been capped. Five States (Lakshadweep, Manipur, Meghalaya, Tamil Nadu & West Bengal) did not have landfills at the time of publication of that report (Central Pollution Control Board, 2021). In the absence of landfills, waste is disposed of in unregulated dumpsites. There are 3,184 dumpsites in the country, of which 234 have been reclaimed, and the remaining 1,950 have been converted to landfills (CentralPollution Control Board, 2021).

Solid waste disposal in India is a significant problem from an environmental perspective that needs to be addressed (Chand Malav et al., 2020). This presents an opportunity for the production of SAF and other biofuels, provided that technical challenges can be addressed. The predominant technology considered for MSW feedstocks is gasification with Fischer-Tropsch synthesis. However, two challenges, similar to those encountered with WtE facilities, are the high moisture content of the MSW and its low calorific value. High moisture content requires high energy inputs and makes gasification inefficient. Wet waste may be more suitable for composting or anaerobic digestion (for biogas production), but where the target is liquid fuel production, it should be considered whether a technology such as hydrothermal liquefaction (HTL) with upgrading could be suitable for SAF production. Several projects and companies in other regions of the world are developing and commercializing biofuel production through hydrothermal liquefaction of wet wastes such as sewage sludge. The benefit of a technology such as HTL is that a biocrude can be produced in a very short period (minutes).

Another critical element is the composition of MSW in India, specifically the biogenic content. From a SAF production perspective, it has been discussed that CORSIA calculates the carbon intensity of MSW SAF based on the non-biogenic content of the MSW. No public information on the biogenic content of MSW in India was found, but the general composition of MSW in India is approximately 40%–60% compostable, 30%–50% inert, and 10%–30% recyclable content (Sharma & Jain, 2019). The World Bank gives a more detailed breakdown of MSW composition in South Asia (Figure 16). Paper, cardboard, rubber, and wood will likely be mostly biogenic, but specific information would be required by a potential SAF facility to ensure that any SAF will meet CORSIA criteria and provide substantial emissions reductions to airlines that purchase the SAF.

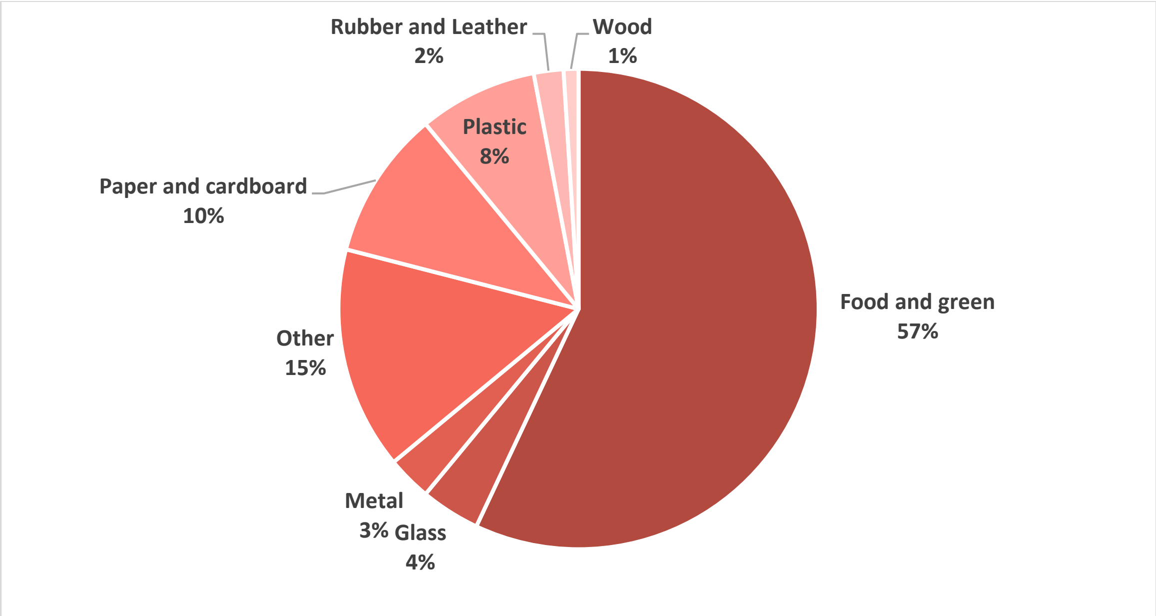


Figure 16. Composition of MSW in South Asia (World Bank Group, 2018).

As solid waste management is an important issue in India, policies are in place to improve the collection and processing of waste. These policies can potentially be extended to include applications such as SAF production, as the incentives and subsidies for broader waste management could also increase the potential economic viability of a SAF facility. In the case of WtE facilities, they enter into contracts with municipalities and receive a tipping fee per tonne of solid waste, which can range from INR 1,080 (around USD 12) n Indore to INR 2,000-2,700 (around USD 22-30) in Delhi (IDR Online, 2024). Tipping fees are a source of revenue for a WtE facility and could similarly improve the economics of a SAF facility based on MSW.

Financial assistance is also available to project developers under the Ministry of New and Renewable Energy's Waste to Energy Programme (Ministry of New and Renewable Energy, n.d.). The program provides "Central Financial Assistance (CFA) to project developers and service charges to implementing/inspection agencies in respect of successful commissioning of Waste to Energy plants for generation of Biogas, Bio-CNG/enriched Biogas/Compressed Biogas, Power/generation of producer or syngas." Financial incentives are provided to urban local bodies for supplying garbage free of cost at the project site and for providing land on long-term lease at nominal rates (30 years and above). There are also incentives for preparing feasibility reports and for promotion, coordination, and monitoring of projects. These subsidies and incentives can cover approximately 40 % of the project cost (IDR Online, 2024). Extending these policies to SAF production facilities can facilitate the establishment of commercial facilities in India, which would simultaneously achieve many environmental benefits outside the aviation sector.

2.6.2 Waste tires

About 2 Mt of tires per year are discarded as waste in India. Another 0.8 Mt of scrap tires are imported into India annually from countries such as the United Kingdom (BBC, 2025), Australia, and the UAE (The Hindu BusinessLine, 2024). Waste tires constitute about 1% by weight of the total municipal solid waste in India (Mongabay, 2024). However, tires are not biodegradable and occupy significant space in waste dumping areas. Waste tires also create broader environmental issues, and burning tires release toxic fumes and contribute to air pollution.

To encourage recycling, India's Ministry of Environment, Forests, and Climate Change (MoEFCC) introduced an extended producer responsibility (EPR) for waste tires in 2022 (Ministry of Environment, n.d.). The EPR places the responsibility for the safe disposal of tires on the producer or importer, who must purchase EPR certificates from recyclers, who are then responsible for converting waste tires into environmentally safe products. The basis of EPR is to fund tire recycling in India and allow recyclers to invest in environmentally safe technologies. Tire producers, importers (including those importing scrap tires), recyclers, and retreaters are supposed to register on the Central Pollution Control Board's (CPCB) EPR portal. Producers and importers can fulfil their EPR obligation by buying EPR certificates online from recyclers via this portal. Based on the quantity of tire recycled by them, the recyclers generate these certificates on the portal. Each recycling method carries weightage points, and recyclers are given credits accordingly. In 2022-23, more than 400,000 credits were generated by recyclers, while more than 91,000 credits were generated in 2023-24. Non-compliance with the EPR would invite a refundable fine. In 2022-23, when the notification came, producers were required to fulfil the EPR obligation of up to 35% of the tires, about 800,000 credits produced by weight. For 2023-24, it was supposed to be 70%, or 1.8 million credits. In the year 2024-25 and after that, it will be 100%. However, data from the Central Pollution Control Board (CPCB) shows that currently, less than 1% of the recycling of tires is paid for by tire producers.

There are about 800 registered recyclers in India, which constitutes about 70-80% of the entire tire recycling sector. Most plants are located in Uttar Pradesh and Haryana, with 250 and 150 units, respectively (Mongabay, 2024). The Tyre & Rubber Recyclers Association of India (TRRAI), a registered association representing scrap tire and rubber recycling companies in India, has 400 members. Of the total 800 recyclers in India, 650 produce Tire Pyrolysis Oil (TPO). Tire and rubber recycling today is a INR 35 billion (around USD 400 million) industry, set to grow ten times due to the increasing size of the domestic automobile industry and the value-addition in the recycling industry in the same period.

Multiple products are recoverable from waste tires, including reclaimed rubber, crumb rubber, crumb rubber modified bitumen (CRMB), recovered carbon black (RCB), and tire pyrolysis oil (TPO) and its char. Reclaim and crumb rubber are used to make conveyor belts, doormats, floor tiles for gymnasiums, play and walking areas, bicycle pedals, shoe soles, pots, rubber sheets, hosepipes, and battery containers. CRMB is used as an additive to bitumen in making roads, and over 125,000 km of road had been laid using CRMB until 2017. About

600,000 – 800,000 tonnes of bitumen is being imported annually in India, and imports of bitumen can be reduced by 12-14% by adding crumb rubber to bitumen.

The tire pyrolysis process generates 40% oil, 33% carbon char, and 15-20% steel wire. Out of 2.8 Mt of waste tires handled in India, and considering 30% of it (840,000 TPA) gets recycled, it translates to yields of 336,000 TPA of oil (TPO), 276,000 TPA of carbon char, and 126,000 to 168,000 TPA of steel wire. TPO is used as an alternative fuel for furnaces, while the carbon char generated is used as filler material for black polymer products like water tanks and also in paints and dyes.

TPO can potentially be a suitable feedstock for SAF production through upgrading the TPO or through gasification of the TPO and Fischer-Tropsch synthesis. TPO can potentially also be used as a coprocessing feedstock, for example, through insertion in the fluid catalytic cracker or hydrocracker for the production of liquid hydrocarbon fuels. Upgrading pyrolysis oil still has many technical obstacles due to the chemical characteristics of the pyrolysis oil and catalyst inactivation during upgrading. In general, the production of pyrolysis oil is at a commercial scale, but upgrading is only at a pilot scale.

From a sustainability and carbon intensity perspective, the biogenic content of waste tire pyrolysis oil will be important. Based on the CORSIA LCA methodology, the non-biogenic content determines the carbon intensity of the SAF. Tires contain about 47% natural and synthetic rubber, with natural rubber contributing to the biogenic content, with truck tires containing higher levels of natural rubber. A more detailed analysis would be needed to determine the potential CI of waste tire-based SAF.

2.6.3 Waste plastics

Plastic waste constitutes a significant global environmental problem. According to the Organization for Economic Co-operation and Development (OECD), plastics consumption is projected to rise from 460 Mt in 2019 to 1,231 Mt in 2060 unless appropriate policies are implemented (OECD, 2022). Due to inadequate recycling and disposal, plastic leakage to the environment will be 44 Mt by 2060. The buildup of plastics in lakes, rivers, and oceans is expected to more than triple from 353 Mt in 2019 to over 1,000 Mt in 2060.

Waste plastic can broadly be divided into recyclable and non-recyclable plastics. While many plastics can be recycled, some plastics may be more challenging to recycle than others. Generally, polyethylene terephthalate (PET – e.g. water bottles) and high-density polyethylene (HDPE – e.g. shampoo bottles) are most widely recycled, while polyvinyl chloride (PVC – e.g. piping), low-density polyethylene (LDPE – food bags), polypropylene (PP), and polystyrene (PS – disposable cups) often have limited or no recycling options.

Examples of non-recyclable plastics include bioplastics, composite plastic, plastic-coated wrapping paper, and polycarbonate. Well-known non-recyclable plastics include cling film. Thermoset plastics, which cannot be remelted and reformed, are also typically non-recyclable. Other factors that may affect recyclability include contamination (e.g., food residues, labels), the availability of recycling facilities and processing equipment, and the cost of sorting and processing different types of plastics.

Waste plastics are explored for SAF production through two main technologies: gasification with Fischer-Tropsch and thermochemical liquefaction (pyrolysis or hydrothermal liquefaction (HTL)) with upgrading. OMV and ReOil are currently engaged in the process for ASTM approval of non-recyclable plastics to SAF conversion (ICAO, n.d.-b). Pyrolysis bio-oils or HTL biocrudes could potentially be used in a co-processing strategy and make use of existing refinery infrastructure. However, it should be noted that plastics as a feedstock for SAF are not currently approved by ICAO under CORSIA. Plastics will be treated as MSW, and the carbon intensity will be determined according to the specified methodology for MSW. Where the plastics are all fossil-derived, the SAF based on plastics will not be able to meet the minimum sustainability requirements under CORSIA, as the carbon intensity is calculated based on the non-biogenic content.

India has a population of more than 1.4 billion and generates 26 kt of plastic waste daily, or 3.46 Mt per year (CSIRO, 2023). India recycles only 8% of its plastic waste, and under a business-as-usual scenario, this would only increase to 11% by 2035, with India's plastic use expected to rise to 70.5 million tonnes by then from the current 24.1 Mt (Dhodapkar R et al., 2023).

Three-quarters of this waste consists of three polymers: polypropylene (PP), polyethylene (PE), and polyvinyl chloride (PVC), with PVC accounting for 45%, low density polyethylene (LDPE) for 25%, high-density polyethylene (HDPE) for 20%, PP for 7.6%, and polystyrene (PS) with other polymers for 2.4% (Dhodapkar R et al., 2023). The chemical composition of plastic is important when considering its application for fuel production, with plastics containing chlorine (e.g., PVC) less desirable, as chlorine will have downstream impacts on catalysts involved in processing, and additional processing is required to remove chlorine with additional cost implications. However, based on the low levels of recycling in India, plastic waste will likely be a mixture of all types.

In addition to the composition of the plastic itself, contaminants will be present depending on the use of the plastics for chemicals, food, etc., and metals and other compounds may be present that could interfere with the potential valorization of the plastics into fuels and other products. Depending on the types of contaminants, additional process steps will likely be needed that would increase the cost of production.

Similar to other types of feedstocks available in India, waste plastics have substantial environmental implications that fall outside the scope of this study. The production of SAF using such feedstocks can address broader concerns, which must be taken into account from a policy perspective, as SAF is only one aspect of the valorization of these feedstocks. Improved collection and segregation of waste would contribute significantly to the potential for valorization of plastic waste. Some of the potential policies that could be implemented are discussed in further sections of this study.

Potential conversion technologies for converting plastic waste into SAF include gasification and pyrolysis or HTL. However, the main technology that is currently pursued is pyrolysis or hydrothermal liquefaction. HTL can produce a biocrude with a lower oxygen content than bio-oil produced through fast pyrolysis technology, which will reduce technical upgrading challenges presented by high oxygen-containing biocrudes. The biggest obstacle to using plastic waste for SAF is that it is considered MSW with 100% non-biogenic content under CORSIA. As such, it is unlikely to provide sufficient carbon intensity reduction to meet the CORSIA minimum standards.

2.6.4 Summary

Table 26 below shows the summary of SAF potential from MSW.

Table 26. Summary of MSW, waste tires and waste plastic potential.

Feedstock	General MSW	Waste tires	Non-recyclable plastics
Feedstock availability	yes	yes	yes
Existing uses and competition	none	Some recycling	Some recycling
Potential for expansion	Undesirable	Undesirable	Undesirable
Suitable technology pathways for SAF	Gasification and FT	Pyrolysis oil and upgrading (co-processing)	Gasification and FT Pyrolysis oil and upgrading (co-processing)
Feedstock readiness	No	No	No
Main challenges for using this feedstock	Quality	quality	Quality segregation sustainability
Potential opportunities	Potential for producing substantial SAF volumes	Potential for producing substantial SAF volumes	Potential for producing substantial SAF volumes
Sustainability	yes	yes	no
Default carbon intensity CORSIA	Calculated based on non-biogenic content	Calculated based on non-biogenic content	Calculated based on non-biogenic content
Economic/market-related considerations (cost of feedstock, high demand)	Low cost High availability	Low cost High availability	Low cost High availability
Key stakeholders	Waste collection; landfill operators; recyclers		

2.7 CARBON DIOXIDE AND CARBON MONOXIDE FROM INDUSTRIAL SOURCES AND BIOGENIC SOURCES

Carbon dioxide (CO_2) and carbon monoxide (CO) can be used directly to produce SAF through two main processes: power to liquids (PtL) and gas fermentation. In PtL, carbon dioxide (CO_2) is converted to carbon monoxide (CO) and combined with hydrogen to produce hydrocarbon fuels through a technology such as Fischer-Tropsch. Ideally, the hydrogen is sourced from the electrolysis of water using renewable electricity to achieve the greatest emissions reductions.

Another prominent technology for utilising CO_2 gases is syngas fermentation, which is being commercialized by LanzaTech. This technology produces ethanol, which, combined with LanzaJet's Ethanol-to-Jet technology, can be used to produce SAF. LanzaTech and LanzaJet are currently engaged in establishing production facilities in India for ethanol and SAF production. The first such facility is in India under construction at IOCL and NTPC. Lanzatech operates five gas fermentation globally, whereas the first ethanol-to-jet plant based on Lanzajet's technology (at Freedom Pines in Georgia, USA) was mechanically completed in 2024 and under commissioning at present.

India has substantial volumes of biogenic CO_2 from ethanol facilities, pulp and paper mills, and biogas facilities. Concentrated CO_2 is also available from multiple industrial sources. In addition, CO_2 can be directly captured from the air.

A wide range of waste gases can be utilized in both the PtL and gas fermentation technologies, and these will differ in the concentration of CO_2, CO, and other contaminants. Depending on the specific technology, extensive gas cleanup may be required before it can be used. Where Fischer-Tropsch is carried out based on the syngas, the purity of the syngas (CO and H_2) is essential, as the catalysts in the FT process are sensitive to inhibitors. The PtL process uses syngas exclusively. Therefore, CO_2 must be converted into CO through a reverse water-gas-shift reaction before it can be used for FT synthesis. The reverse water gas shift technology is still under development.

In the case of gas fermentation, microbes can use both CO and CO_2, although CO is preferred. Microbes can use CO_2 if there is sufficient hydrogen present. Alternatively, a reverse water gas shift reaction can be carried out to convert the CO_2 into CO before fermentation.

One advantage of gas fermentation versus PtL is the fact that gas fermentation produces an intermediate, ethanol, which can be transported to large-scale AtJ facilities to benefit from economies of scale. Thus, smaller quantities of waste gases could potentially be utilized. In the case of PtL, all process steps take place in one location. This could impact economies of scale, and smaller volumes of waste gases may not be economical to utilize.

Waste gases are included as feedstock under CORSIA, but default carbon intensity values are currently only available for fermentation of waste gases into ethanol. Some of the key sources of CO_2 are shown in Table 27 below (WSS Energy Consulting, n.d.).

Two key considerations for using CO_2 from various sources are CO_2 concentration and cost of capture. Capturing CO_2 that is present at low concentrations at point sources is more costly. Biogenic CO_2 from fermentation during bioethanol production is the lowest-cost capture application as it is at a high concentration. For CO_2 from biogas, large-scale facilities present an opportunity for economies of scale to reduce the cost of CO_2 capture.

Table 27. Key sources of CO_2 for SAF production and biogenic content.

Industry/source	Percentage biogenic CO_2	CO_2 concentration (mol %)	Typical quantity
Bioethanol production	100% from fermentation About 67% if energy from fossil[30]	Fermentation ~99%	1 mol of CO_2 for every mol of ethanol produced
Biogas	100%	>98%	2 tonnes of CO_2 per tonne of biomethane
Biomass to energy	1-100%[31] for biomass combustion 20-50% for co-firing with non-biogenic feedstocks	100% biomass combustion – 8-15% Coal/biomass mix – 12-15%	Co-firing power stations range from 50-700Mwe, releasing between 0.3 – 3.8 Mt per annum
Pulp and paper	Recovery boiler: 100% Power generator boiler: 100% Lime kiln[32] In total 75-100%	Recovery boiler: 12-16% Power generator boiler: 5-8% Lime kiln: 20-22%	~0.9 tonnes of CO_2 per tonne of paper product[33]
Waste-to-Energy	Typically 50-70%	8-12%	0.7 - 1.7 tonnes CO_2 per tonne of MSW

2.7.1 Biogenic CO_2 emissions – pulp and paper industry

Biogenic CO_2 is produced in the pulp and paper industry during the combustion of black liquor in the recovery boiler. At Kraft mills, biogenic CO_2 is produced in the recovery boiler (70-75%) and in the power generator boiler (15-20%). The remaining CO_2 emissions (5-15%) are emitted from the lime kiln and are a combination

[30] Most facilities use fossil fuel sources for some or all of the power and heat requirements. Some facilities use integrated on-site combined heat and power (CHP) for some energy demands.
[31] Dependent on the ratio of biomass to fossil feedstock.
[32] As classified by the EU, although 50% of the energy used in limekiln comes from the boiler, resulting in a mix of biogenic and anthropogenic CO_2 emissions.
[33] Calculated as a weighted average. Emissions vary by pulp and paper grade.

of biogenic and anthropogenic CO_2. GHG emissions vary by pulp and paper grade, ranging from 608 to 1,978 CO_2-eq per tonne of product (WSS Energy Consulting, n.d.).

The Indian paper industry is highly fragmented, with varying sizes ranging from 10 to 1500 tonnes per day, and 75-80% of paper production is from medium and small category mills. India has 900 paper mills with a total installed capacity of 27.43 Mt (operating installed capacity of 22.73 million tonnes). About 18.91 Mt of paper, paperboard, and newsprint are produced annually (Ananth et al., 2023). The CO_2 emissions from the Indian pulp & paper sector were around 30.5 Mt in 2019, all biogenic, with an average of 1.58 tonnes of CO_2-eq per tonne of paper (Ananth et al., 2023).

The paper industry is likely to continue growing at a rate of 6-8% per annum in the medium to long term. In a business-as-usual scenario, GHG emissions from the sector are expected to increase to around 70 Mt by 2040 unless the industry implements deep decarbonization strategies. Under a deep decarbonization scenario, the emissions from the sector can be restricted to 35 Mt by 2040 (Ananth et al., 2023). SAF production from pulp and paper CO_2 emissions could potentially be significant, but a further evaluation needs to be carried out.

2.7.2 Biogenic CO_2 emissions from ethanol plants

Biogenic CO_2 from bioethanol is a commercially attractive source for the valorization of CO_2, as it is present at high concentrations, which reduces capturing costs (WSS Energy Consulting, n.d.). In the case of small ethanol plants, the total volume of CO_2 may be too small to support a commercial facility based on CO_2 utilization unless CO_2 can be transported and aggregated at a larger scale through, e.g. CO_2 pipelines.

There are 413 ethanol production facilities in India, 261 based on sugar/molasses and 152 based on grain (All India Distillers Association, n.d.). Ethanol production in 2023 amounted to 6.5 million m^3 (USDA, 2024). Theoretically, based on total ethanol production, about 4.7 Mt of CO_2 can be available[34].

2.7.3 Current status of biogas production in India as a potential source of biogenic CO_2

Biogas facilities, based on anaerobic digestion, produce high concentrations of biogenic CO_2. Biogas consists of ~50-80 (mol)% CH_4 and ~20-50 (mol)% CO_2 – the exact ratio dependent on feedstock – and a digestate (WSS Energy Consulting, n.d.). Biogas can then be directly combusted in combined heat and power plants or upgraded into biomethane with the production of biogenic CO_2 as a by-product.

The Indian government launched the Sustainable Alternative to Affordable Transport (SATAT) in October 2018 to promote the technology. The scheme targeted the production of 15 million tonnes of compressed CBG by 2023. There are currently 56 biogas facilities in India, with many more in the pipeline.

Biogas facilities are generally relatively small, and this will limit the potential utilization of CO_2 for SAF production unless biogas can be aggregated through pipelines or other types of transport. The state-wise number of commissioned biogas plants are shown in Table 28 (Ministry of New and Renewable Energy, n.d.).

Table 28. Number of biogas plants in India by state.

State	No. of commissioned biogas plants
Andhra Pradesh	5
Chhattisgarh	1

[34] Based on 8 kg per 11 litres of ethanol.

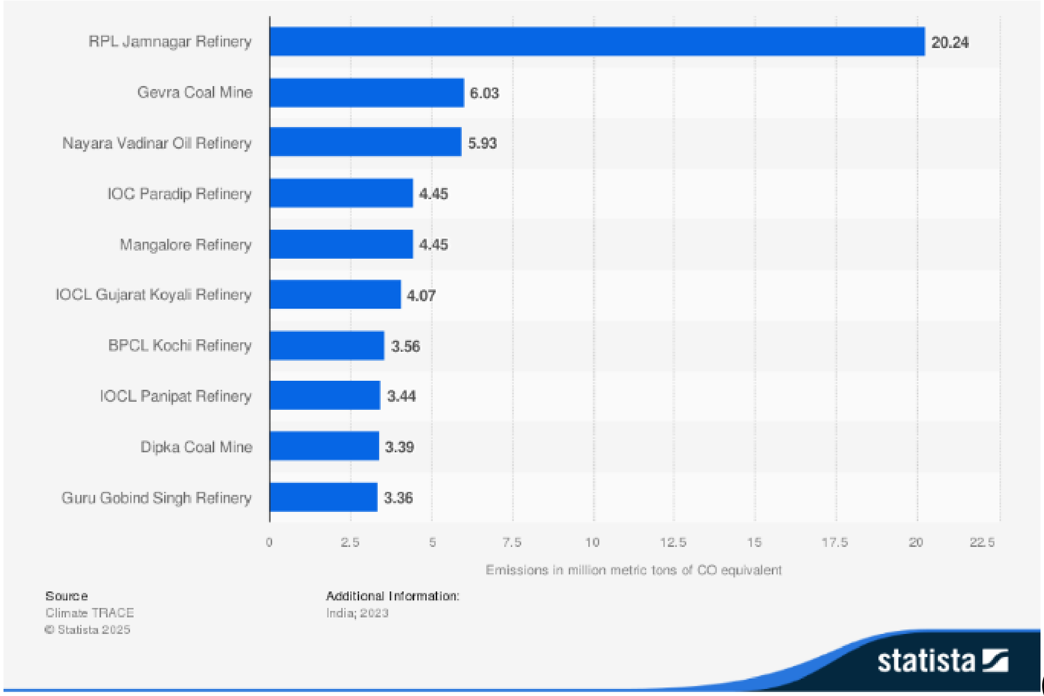
Gujarat	13
Haryana	5
Karnataka	4
Madhya Pradesh	3
Maharashtra	7
Punjab	3
Rajasthan	2
Tamil Nadu	4
Telangana	3
Uttar Pradesh	5
Uttarakhand	2
West Bengal	1
TOTAL	**58**

2.7.4 Industrial sources of CO_2

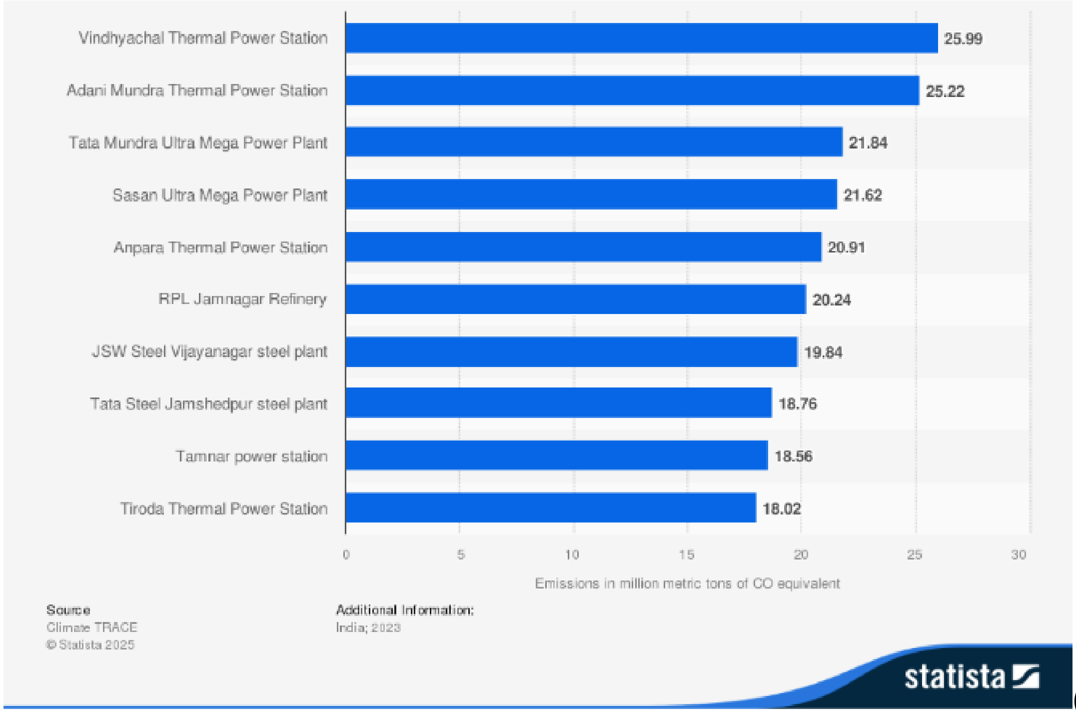
Waste gases are produced by industrial sources, and these can potentially be utilized for CO_2 utilization through power-to-liquids or gas fermentation technologies. Many of these industrial point sources produce large amounts of CO_2 that could readily support SAF production. However, these sources of CO_2 are often derived from fossil fuel combustion, unlike biogenic sources of CO_2.

Biomass-to-energy facilities burn biomass to generate electricity. Where the feedstock is 100% plant-derived, the CO_2 formed during combustion will be biogenic. However, co-firing is sometimes used where biomass is burned in combination with coal. A mixture of gases is present in flue gas, including CO_2, CO, N_2O, SO_2, and others. For SAF production, the main interest is in CO_2 and CO, and the concentration of these components will depend on the specific feedstock and the operating conditions in a facility. In biomass-to-energy plants, CO_2 concentration can range between 8% and 15%.

Flue gases from waste-to-energy plants can also be utilized for SAF production in cases where MSW is burned to generate power. In 2022, India had 12 operational and eight non-operational WtE plants (IDR Online, 2024). Figure 17 below shows the biggest industrial sources of GHG emissions in India, with (A) showing the largest petroleum refineries and (B) showing power plants and steel production facilities.



(A)



(B)

Figure 17. Greenhouse gas emissions (in million tonnes of CO2 equivalent) from various industrial source in India. (A) Major refineries; (B) Power stations and steel plants (Source: Statista).

2.7.5 Summary

Table 29 below provides a summary of SAF potential from CO and CO_2.

Table 29. Summary of potential for SAF based on captured CO and CO_2.

CO/CO_2 source	Ethanol plants, pulp mills	Industrial sources
Feedstock availability	yes	yes
Existing uses and competition	no	no
Potential for expansion	no	no
Suitable technology pathways for SAF	PtL and gas fermentation	PtL and gas fermentation
Feedstock readiness	Not commercial	Small commercial-scale gas fermentation for steel mill offgas
Main challenges for using this feedstock	Technology maturity Scale may be too small	Technology maturity
Potential opportunities	biogenic	Large point sources
Sustainability	Yes	Yes
Default carbon intensity CORSIA	Waste gas fermentation: 29.4 gCO2eq/MJ (integrated) 42.4 (standalone) PtL not determined yet	Waste gas fermentation: 29.4 gCO2eq/MJ (integrated) 42.4 (standalone) PtL not determined yet
Economic/market-related considerations (cost of feedstock, high demand)	PtL very high production cost Gas fermentation production cost unknown	PtL very high production cost Gas fermentation production cost unknown
Key stakeholders	Ethanol producers, pulp and paper companies	Petroleum refineries, steel mills, cement manufacturers

2.8 FEEDSTOCK SUSTAINABILITY AND CORSIA CERTIFICATION

2.8.1 General

The basic principles of sustainability and the determination of the carbon intensity of SAF are provided here as a background to guide stakeholders in India as to the certification of CORSIA Eligible Fuels based on feedstocks and production in India.

CORSIA sustainable aviation fuel is defined as a "renewable or waste-derived aviation fuel that meets the CORSIA Sustainability Criteria" as defined in the ICAO document *CORSIA Sustainability Criteria for CORSIA Eligible Fuels*. According to these criteria, CORSIA SAF will achieve net greenhouse gas emissions reductions of at least 10% compared to the baseline life cycle emissions values for aviation fuel on a life cycle basis.

A life cycle emissions value (L_{CEF}) is calculated from the following equation:

$$L_{CEF} = \text{core LCA value} + \text{ILUC} - \text{emission credits;}$$

The core LCA value can be obtained in two ways:

1) a default core LCA value obtained from Section 4 of the ICAO document *CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels*, or

2) an actual core LCA value calculated with the use of the methodologies described in the ICAO document *CORSIA Methodology For Calculating Actual Life Cycle Emissions Values.*

The ILUC value can be obtained in two ways:

1) Default ILUC values obtained from Section 5 of the ICAO document *CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels*, or

2) ILUC = 0 with the use of the low Land use change (LUC) risk practices (LLRP) provided in Section 5 of the ICAO document *ICAO document - CORSIA Methodology For Calculating Actual Life Cycle Emissions Values*

CORSIA-eligible fuels must be certified by a Sustainability Certification Scheme (SCS) approved by the ICAO Council. As of 2025, there are only three approved SCS: the International Sustainability and Carbon Certification (ISCC), the Roundtable on Sustainable Biomaterials (RSB), and ClassNK.

2.8.2 CORSIA default Carbon Intensity values

Figure 18 shows a comparison of default carbon intensities (CIs) for various feedstock/technology pathways under CORSIA as listed in the ICAO SAF Rules of Thumb(ICAO, n.d.-e). ILUC is included where crops are used. The CORSIA default values are updated on a regular basis, and the latest version of the default value document should be used [35]. Power-to-Liquid pathways and pyrolysis are not yet included under the default values, and values shown in Figure 18 were based on literature. The most recently released default values are not included in this study and can be accessed on the ICAO website. The updated values include waste gas fermentation pathways for the first time.

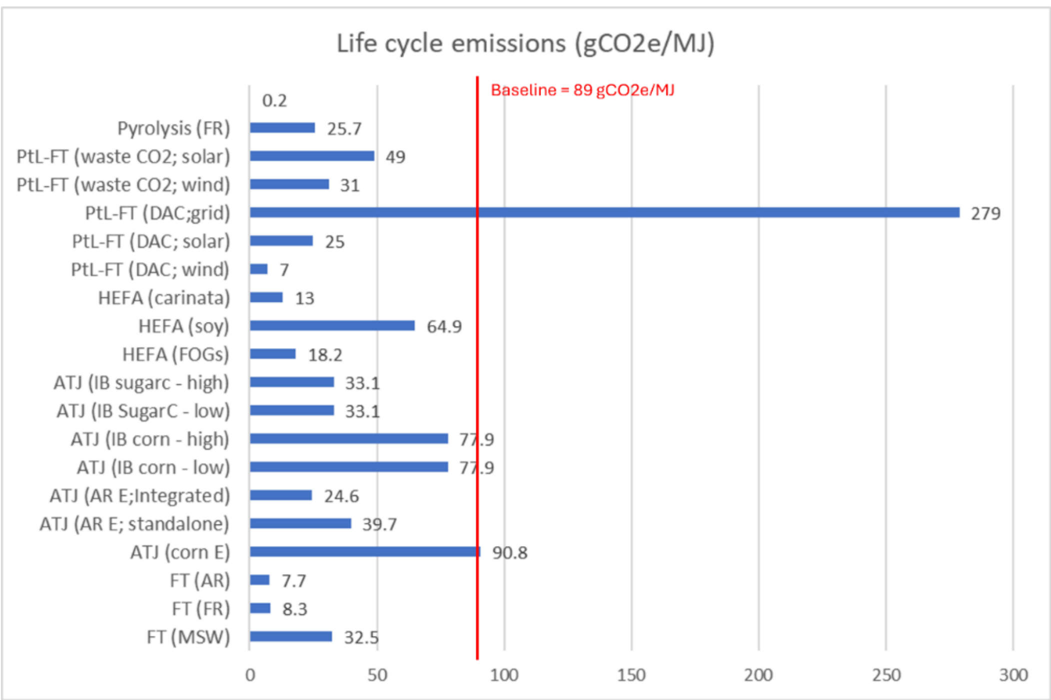


Figure 18. Default LCA values of SAF production pathways approved by ICAO.[36]

[35] https://www.icao.int/sites/default/files/environmental-protection/CORSIA/Documents/CORSIA%20Eligible%20Fuels/ICAO-document-06-Default-Life-Cycle-Emissions-June-2025.pdf

[36] FR=forest residues; AR=agricultural residues; E=ethanol; IB=isobutanol.

Figure 19 shows only default core LCA values under CORSIA (ILUC not included), but the contributions of various parts of the life cycle are shown separately (Prussi et al., 2021). Some of the pathways have been updated since then.

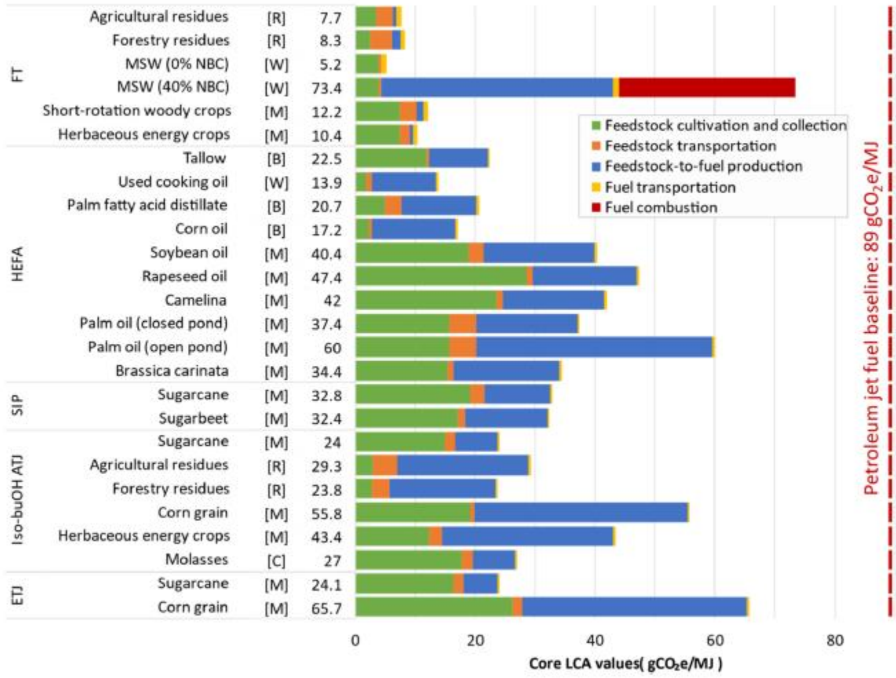


Figure 19. Default core LCA values of SAF production pathways approved by CORSIA as of 2021 to illustrate the contribution of different parts of the life cycles (Prussi et al., 2021).

2.8.3 CO_2 abatement cost

Table 30 (next page) shows the CO_2 abatement costs based on the ICAO SAF Rules of Thumb and the default CI values under CORSIA (ICAO, n.d.-e).

Table 30. CO_2 abatement costs for nth and pioneer facilities for each pathway (compared with the CORSIA baseline of 89 gCO_2e/MJ) .

Processing technology	Feedstock	Life cycle emissions (gCO_2e/MJ)	Abatement cost (USD/tCO_2e)	
			nth	Pioneer
FT	MSW	32.5	210	840
FT	Forestry residues	8.3	420	990
FT	Agricultural residues	7.7	520	1170
AtJ	Corn ethanol	90.8 [37]	No CO_2 abatement	No CO_2 abatement
AtJ	Agricultural residues ethanol, stand-alone	39.7	1020	1190
AtJ	Agricultural residues ethanol, integrated	24.6	780	910
AtJ	Isobutanol - low, corn	77.9 [37]	2100	2510
AtJ	Isobutanol - high, corn	77.9 [37]	3220	3680
AtJ	Isobutanol - low, sugarcane	33.1 [37]	420	500
AtJ	Isobutanol - high, sugarcane	33.1 [37]	640	730
HEFA	Fogs	18.2	130	-
HEFA	Soybean oil	64.9	640	-
HEFA	Brassica carinata	13.0	160	-
FT	DAC CO_2, green H_2, wind electricity	7 [38]	1390	-
FT	DAC CO_2, green H_2, solar electricity	25 [38]	1780	-
FT	DAC CO_2, green H_2, grid electricity	279 [38]	No CO_2 abatement	-
FT	Waste CO_2, green H_2, wind electricity	31 [38]	1510	-
FT	Waste CO_2, green H_2, solar electricity	49 [38]	2190	-
Pyrolysis [39]	Forest residues	25.7 [38]	370	750
Pyrolysis	Agricultural residue	0.2 [38]	270	550

[37] Includes ILUC values, which can be subtracted with the use of low LUC risk practices as defined in the ICAO document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values".
[38] Life cycle emissions obtained from external references; not a CORSIA value.
[39] Pyrolysis ASTM approval is pending.

2.9 CURRENT FRAMEWORK OR STRUCTURE IN INDIA FOR SAF SUSTAINABILITY CERTIFICATION

Potential SAF producers in India must use one of the above referred ICAO-approved SCS bodies to certify their SAF as sustainable. India's National Accreditation Board for Certification Bodies (NABCB) is responsible for accrediting certification, inspection, validation, and verification bodies operating in India. In February 2025, ISCC signed a Memorandum of Understanding (MoU) with India's NABCB. The purpose of this MoU is for NABCB to provide accreditation to Indian Certification Bodies for compliance with ISO/IEC 17065 while extending the scope to include ISCC CORSIA certification. This will enable Indian Certification Bodies (CBs) to demonstrate their product and process certification competence under the ISCC CORSIA certification scheme. NABCB-accredited Indian CBs will be able to certify SAF in accordance with ICAO requirements using ISCC CORSIA certification.

Currently, a number of CBs in India are in the process of accreditation. After NABCB grants accreditation to the CB, ISCC and the accredited CB will sign an agreement/contract for CORSIA certification. Two CBs are likely to be accredited by Q3 2025, and SAF feedstock suppliers and SAF producers can use these CBs to obtain CORSIA certification. According to NABCB, it is expected that the process of CORSIA certification of SAF in India will be in place for IOCL to meet their target date for the launch of SAF for the Indian aviation market. On July 22nd 2025, Cotecna India became the first certification body accredited by NABCB in India under the ISCC CORSIA scheme.

2.9.1 Approved feedstocks and process for registering new feedstocks

ICAO maintains a list of feedstocks used for CORSIA SAF, but new feedstocks can be added to this list upon application. Requests relating to feedstocks, described in detail below, can only be submitted by ICAO Member States, international organizations, or an approved Sustainability Certification Scheme (SCS). There are three types of feedstock "requests" that can be sent to ICAO, as detailed in *CORSIA supporting document — Life cycle assessment methodology* (version 6, July 2024):

i. A request may be made for the classification of a feedstock as a waste, residue, or by-product (which will incur a zero ILUC value) (see PART I, Section 4 of the supporting document). Table 31 contains the positive list of feedstocks that are currently recognized as a waste, residue, or by-product. The flowchart in Figure 20 can be used as a guideline to determine the classification of feedstocks.

ii. Request for a new default core LCA value (see PART I, Section 2.2 of the supporting document). Core LCA values for specific technologies and feedstocks are included in the document. For new feedstocks, ICAO can be requested to determine a default core LCA value for a feedstock/technology pathway. Alternatively, an actual value can be calculated for the specific SAF.

iii. Request for a new ILUC value (see PART I, Section 2.3 of the supporting document). ILUC values are based on two approved models and cannot be calculated by individual SAF producers/suppliers. Values can be global or for specific regions like USA, Brazil when the data demonstrate at least a 10% variation from the global value (Prussi et al., 2021). Four India-specific ILUC values are currently listed, all related to HEFA using Jatropha.

Feedstocks that are classified as a residue, waste, or by-product do not incur ILUC when calculating the carbon intensity of the final fuel product. If a new feedstock is not considered a residue, waste, or by-product but a product or co-product, it will incur ILUC when calculating the carbon intensity over the life cycle. This will require a determination of an ILUC value, which can be done upon application to ICAO. ILUC values cannot be provided by the feedstock or fuel producer. The process is illustrated below in Figure 20.

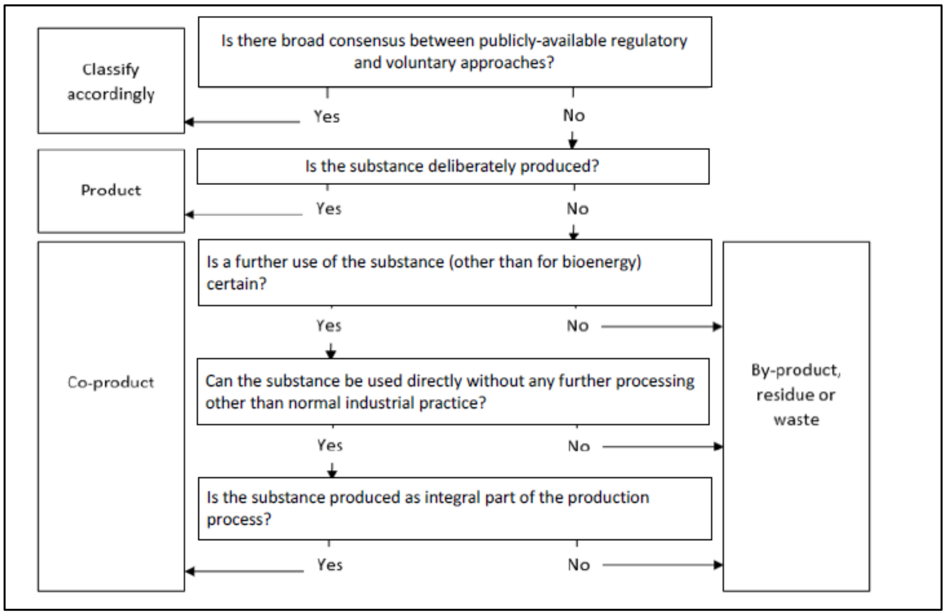


Figure 20. Process guidelines for inclusion of new feedstocks under CORSIA and identification of by-products, residues or wastes.

2.9.2 By-products, wastes and residues

By-products are classified as secondary products with inelastic supply and economic value. Wastes are materials with inelastic supply and no economic value. Waste is any substance or object that the holder discards or intends or is required to discard. Raw materials or substances that have been intentionally modified or contaminated to meet this definition are not covered by this definition. Residues are secondary materials with inelastic supply and little economic value. Residues include:

a) Agricultural, aquaculture, fisheries, and forestry residues: Residues directly deriving from or generated by agriculture, aquaculture, fisheries, and forestry.

b) Processing residues: A substance that is not the final product that a production process directly seeks to produce; the production of the residue or substance is not the primary aim of the production process, and the process has not been deliberately modified to produce it.

Feedstocks that are classified as waste, residue, or by-products are listed in Table 31, which is frequently updated.

Table 31. Positive list of materials classified as waste, residue to by-product (*CORSIA methodology for calculating actual life cycle emission values – October 2024*).

Residues	Wastes	By-products	Co-products
Agricultural residues:	Municipal solid waste	Palm Fatty Acid Distillate	Molasses
Bagasse	Used cooking oil	Beef tallow	
Cobs	Waste gases	Technical corn oil	
Stover		Non-standard coconuts	
Husks		Poultry fat	
Manure		Lard fat	

Nut shells Stalks Straw *Forestry residues:* Bark Branches Cutter shavings Leaves Needles Pre- commercial thinnings Slash Tree tops *Processing residues:* Crude glycerine Cobs Forestry processing residues Empty palm fruit bunches Palm oil mill effluent Sewage sludge Crude tall oil Tall oil pitch Wheat starch slurry		Mixed Animals Fat	

2.9.3 Potential feedstocks in India that are not currently included under CORSIA

Based on engagement with stakeholders, there are some feedstocks being considered for SAF production that are not currently included, and an application would have to be submitted for including such feedstocks. Feedstocks that are not currently included under CORSIA (list documents), are used for biofuel production and could potentially be used for SAF production in India:

- Pongamia and other oilseed trees and alternative crops (only camelina, carinata, and jatropha are currently listed).
- Cashew nut shell liquid (cardanol)
- Sweet sorghum.
- Waste tires as a feedstock are not specifically mentioned, although they will presumably be treated similarly to MSW (but only the Fischer-Tropsch process is currently included in CORSIA, not the pyrolysis route).

Stakeholders in the sugarcane industry have also indicated that India should advocate for a specific default LCA value for sugarcane ethanol from Indian feedstocks, as data has shown that it would be lower than the current global value. While molasses is listed as a feedstock in the CORSIA LCA methodology, only default values for isobutanol-to-jet is currently provided. A default value for ethanol-to-jet based on molasses should be addressed.

2.9.4 Chain of custody and traceability

An important part of the sustainability certification process is a demonstration of the origin of feedstocks through chain of custody verification and traceability. Figure 21 illustrates the step-by-step traceability through every part of the supply chain. At each step, a sustainability declaration demonstrates the sustainability characteristics.

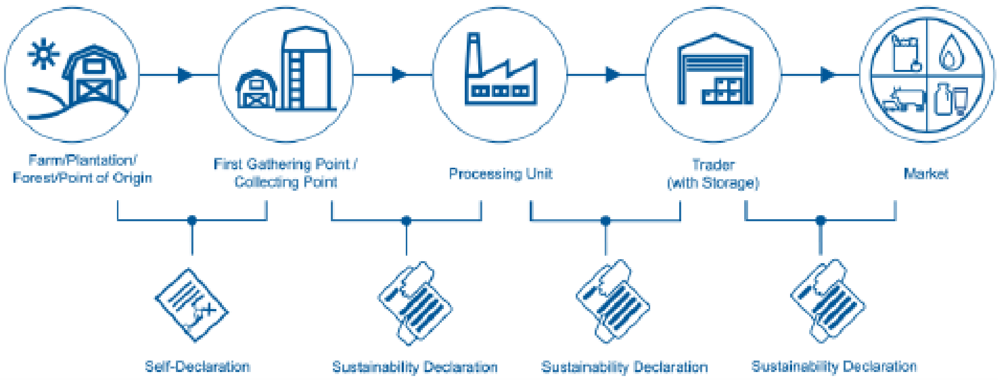


Figure 21. Process diagram showing the step-by-step chain of custody and traceability requirements for a simplified supply chain (ISCC).

In India, the feedstock supply chain is composed of thousands of small feedstock producers, whether in UCO collection, rice straw, or sugarcane. Therefore, it is important to note the potential for using self-declarations from a feedstock provider.

In the case of UCO, individual suppliers can submit signed self-declarations that would be accessible to an auditor. Under ISCC, there is no limit on the volume of UCO that can be supplied through self-declaration. Similarly, for agricultural residues, self-declarations stipulating the feedstock source can be used when providing material to the certified collecting point. Guidance on the requirements for traceability and chain of custody can be found on the ISCC website. Farms, plantations, and forest management units can be certified individually; however, this is not mandatory.

According to ISCC requirements, private households do not need to issue self-declarations to a collecting point, and they are not subject to on-site verification. However, the certified collecting point responsible for the collection of waste and residues from private households must be able to demonstrate to the CB the type of material collected, and the plausibility of the amounts collected (e.g., by showing collection routes, frequency of collection, and historical data of collected amounts).

2.10 PROPOSED TIMELINE FOR SAF DEVELOPMENT IN INDIA BASED ON TECHNOLOGY AND FEEDSTOCK MATURITY

Table 32. Overview of challenges and opportunities per technology and timeframe.

	Technology	Challenges	Opportunities
Short-term (2025-2028)	Co-processing of fats and oils based on UCO available in India	UCO volumes are limited Competition with biodiesel	Improved collection Expansion of lipids from other oilseeds
Medium-term (2028-2035)	Alcohol-to-jet based on sugarcane and starch	Competition with ethanol for petrol blending	Sugarcane ethanol is fully commercial, cost effective and has a very low carbon intensity
	Some AtJ from advanced ethanol (cellulosic ethanol from ag residues and waste gas fermentation)	Advanced ethanol still being commercialized and volumes limited initially	
	Co-processing of waste tire and plastic pyrolysis oil	Not ASTM approved Poor quality Upgrading has not been demonstrated	Large feedstock volumes available
Long- term (2035-2050)	AtJ from advanced ethanol expands (cellulosic ethanol)	Ag residues supply chain challenges and cost of cellulosic ethanol must be resolved	Large feedstock volumes available
	AtJ from advanced ethanol expands (waste gas fermentation)	Process must be demonstrated for all types of waste gases	Biogenic CO_2 utilization opportunities provides very low CI SAF
	Gasification based on MSW	Technology must be demonstrated at commercial scale	
	PtL from biogenic CO_2 sources	High cost Technology must reach commercial scale	Very low CI

2.10.1 HEFA as the key short-term opportunity

Most SAF technologies are not at a commercial scale, and this is delaying the scale-up of SAF production worldwide. Only the HEFA pathway is fully commercial and based on the hydrotreatment of fats and oils. SAF can be produced through both freestanding facilities and co-processing of these feedstocks. In the near term, this is the immediately available technology for SAF production. There are no immediate plans for the construction of a freestanding facility, but IOCL is planning to start producing SAF later in 2025 through co-processing in a kerosene hydrotreater.

India has available used cooking oil feedstocks, but improvement of UCO collection and enforcement of existing regulations to prevent unsafe use of UCO can increase the volumes available for SAF production. Competition with biodiesel production impacts the availability for SAF production. Biodiesel policies should be amended to allow feedstocks to be used for SAF as well. The HEFA process produces a major fraction of renewable diesel (up to 85%), which can be used in blends with diesel for road transportation. Renewable diesel is a drop-in solution and will not present challenges encountered with biodiesel, e.g., high NO_x emissions.

2.10.2 Alcohol-to-Jet as a medium-term route

After HEFA, the next SAF pathway expected to become commercial is the alcohol-to-jet technology based on ethanol (and then isobutanol). The AtJ pathway is expected to be the most prominent SAF pathway in India based on feedstock availability. Reports place an emphasis on the production of ethanol from rice straw, as it is an abundant feedstock that causes other environmental problems due to the burning of residues. However, cellulosic or advanced ethanol production from residues has significant challenges. Praj is currently operating a cellulosic ethanol facility, but cellulosic ethanol production is very complex, with existing supply chain challenges and much higher production costs than conventional ethanol production. The immediate opportunity for establishing commercial AtJ SAF production is in the utilization of first-generation sugar and starch feedstocks. Ethanol production is already established in India based on feedstocks such as sugarcane and maize. Sugarcane (specifically molasses) can form the basis of very low CI SAF. Sugarcane ethanol will likely be the lowest-cost ethanol to support AtJ facilities. This can support the establishment of commercial AtJ facilities in India while cellulosic ethanol production challenges are addressed. Other advanced ethanol production technologies, such as waste gas fermentation, have substantial opportunity in India, and a current facility is under development. This could supply low CI ethanol for AtJ facilities in the medium to long term.

While food security is a priority in India, excess sugarcane and maize are available for significant ethanol production. India has a very aggressive target for 20% ethanol blending into petrol. Restricting the use of this ethanol to road transportation applications will be a significant barrier to the development of SAF in India. The challenges with cellulosic ethanol and its high production cost will delay the commercialization of the AtJ pathway for SAF production. Extending existing biofuel policies to SAF and allowing feedstocks for ethanol to be used for SAF production will create significant opportunities for AtJ SAF development in India.

While first-generation sugars and starches will pave the way for AtJ production, mobilising rice straw and optimising supply chains for cellulosic ethanol production presents a critical challenge for a long-term supply of high ethanol volumes for SAF production. In addition, ethanol production through waste gas fermentation has substantial opportunities with the first facility at IOCL completed.

2.10.3 Long-term opportunities for SAF

The utilization of feedstocks such as MSW will likely proceed through gasification combined with Fischer-Tropsch, but this technology still has technical challenges while requiring very high capital costs. HEFA and AtJ opportunities are the low-hanging fruit, and production of SAF through gasification is seen as a longer-term solution as SAF volume requirements increase.

Thermochemical liquefaction technologies such as pyrolysis and HTL are still under development, and upgrading of bio-oils presents significant technical challenges. This pathway has not been ASTM approved, and the ASTM approval process can take a significant amount of time.

Production of eSAF through the PtL process can present significant opportunities, specifically based on biogenic CO_2. However, apart from the fact that this technology is not at a commercial scale, it has very high production costs. Unless policy drivers are implemented (such as in the EU, where a specific eSAF mandate is in place), the high production costs of this pathway will limit its utilization in India, as many other cheaper pathways can be explored.

SECTION 3. IMPLEMENTATION SUPPORT AND FINANCING

3.1 TECHNO-ECONOMICS OF SAF FEEDSTOCK/TECHNOLOGY PATHWAYS BASED ON THE ICAO SAF RULES OF THUMB

Techno-economic analyses can provide valuable information for comparing different feedstock and technology pathways. This can aid in decision-making and inform potential policies that could support SAF development. However, limited information is publicly available. Numerous techno-economic analyses have been conducted and published in the academic literature. However, these are based on different assumptions, making comparisons challenging.

Under the auspices of ICAO's Committee on Aviation Environmental Protection (CAEP), experts from Washington State University and Hasselt University carried out techno-economic analyses, called "Rules of Thumb", for multiple SAF production pathways that could be utilized to make order-of-magnitude estimations related to SAF costs, investment needs, and production potential that could inform policymakers and project developers. The analysis was based on US costs and financial assumptions. Four SAF manufacturing technologies were assessed: gasification Fischer-Tropsch (GFT), alcohol to jet (AtJ), hydro-processed esters and fatty acids (HEFA), and pyrolysis. For each of the technologies, multiple feedstocks and two levels of technology maturity were assessed: nth plant and pioneer plant. The Rules of Thumb provide information on the impact of feedstock cost, fuel yield, facility scale (total distillate and SAF), total capital investment (TCI), and minimum selling price (MSP) for nth plant and pioneer facility scales. Note that the analysis is based on specific-size facilities, which will allow for greater economies of scale. Smaller facilities may have a higher CAPEX and MSP.

Regional differences could have a substantial impact on the analyses and should ideally be carried out for specific geographical regions based on local assumptions. In the absence of specific analyses in India across this range of pathways, the ICAO SAF Rules of Thumb are shown here as a comparison of the listed pathways. Table 33 gives a detailed breakdown of each pathway for pioneer and nth facilities. Note that the analysis was carried out for the scale indicated, and smaller or larger facilities may differ. Figure 22 and Figure 23 show the capital cost in USD/L and the minimum fuel selling price (MSP) in USD/L for the different pathways.

It is recommended that any follow-up study include techno-economic analyses for the most relevant pathways based on specific Indian conditions. Based on our engagement with stakeholders, some feedstock costs are much lower, while others are much higher. There are also other technologies under development in India that are not included in the Rules of Thumb, e.g., syngas fermentation.

Table 33. Techno-economic analysis of the various technologies and feedstocks based on pioneer and nth facilities. Feedstock costs are for pre-processed feedstocks except for HEFA. As HEFA-based processes are considered already commercial, data for pioneer facilities were excluded. (Brandt et al., 2023; Brandt, Geleynse, et al., 2021; Brandt, Tanzil, et al., 2021b, 2021a; Brandt & Wolcott, 2021)

Processing technology	Feedstock	Feedstock cost (USD/t)	Yield[40]	Product slate (%) (jet:diesel:gasoline:other)	TCI (million USD) [total distillate (million L per year)]		MSP SAF (USD/L)	
					nth	Pioneer	nth	Pioneer
FT	MSW	30	0.31	40:40:20:0	1427.6 [500]	2944 [500]	0.9	1.63
FT	Forest residues	125	0.18		1207.2 [300]	2488.7 [300]	1.69	3.3
FT	Agricultural residues	110	0.14		1123.8 [220]	2316.8 [220]	2.0	3.8
AtJ	Ethanol (based on corn)	456	0.60	70:0:30:0	316.4 [1000]	662 [1000]	0.79	0.87
AtJ	Isobutanol	1110	0.75		649.5 [1000]	1349.8 [1258]	2.35	2.49
HEFA	FOGs	580	0.83	55:26:19:0	447.7 [1000]		0.8	
HEFA	Vegetable oil	810	0.83		456.4 [1000]		1.1	
Pyrolysis	Forest residues	125	0.28	44:28:16:12	384.4 [134]	794.7 [134]	1.3	2.04
Pyrolysis	Agricultural residues	110	0.27		384.4 [134]	794.7 [134]	1.33	2.08
PtL	DAC CO_2	300	0.24	40:40:20:0	1313.2 [400]	2266.1 [400]	3.60	4.02
PtL	Flue gas CO_2	50	0.24		1248.7 [400]	2155.9 [400]	2.70	3.14

[40] In wt/wt total distillate over wt dry feedstock, except in the case of pyrolysis, which is L/kg.

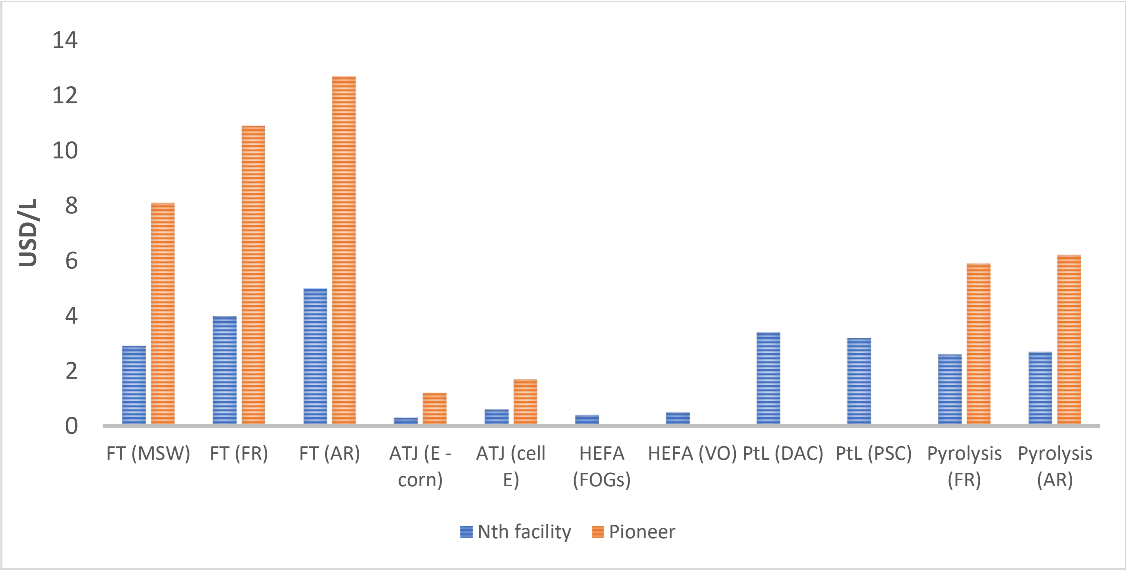


Figure 22. Capital cost comparisons for various SAF pathways based on the ICAO SAF Rules of Thumb.

Some of the broad takeaways on capital costs from Figure 22 are as follows:

- The HEFA pathway has the lowest capital costs of the evaluated technologies.
- The AtJ pathway can also achieve very low capital costs once the technology is fully commercialized with multiple facilities in operation (nth facility)
- Capital costs for all the gasification and FT pathways are high for pioneer facilities, but capital costs are substantially reduced for nth facilities.
- The Rules of Thumb do not currently provide capital costs for pioneer PtL facilities.

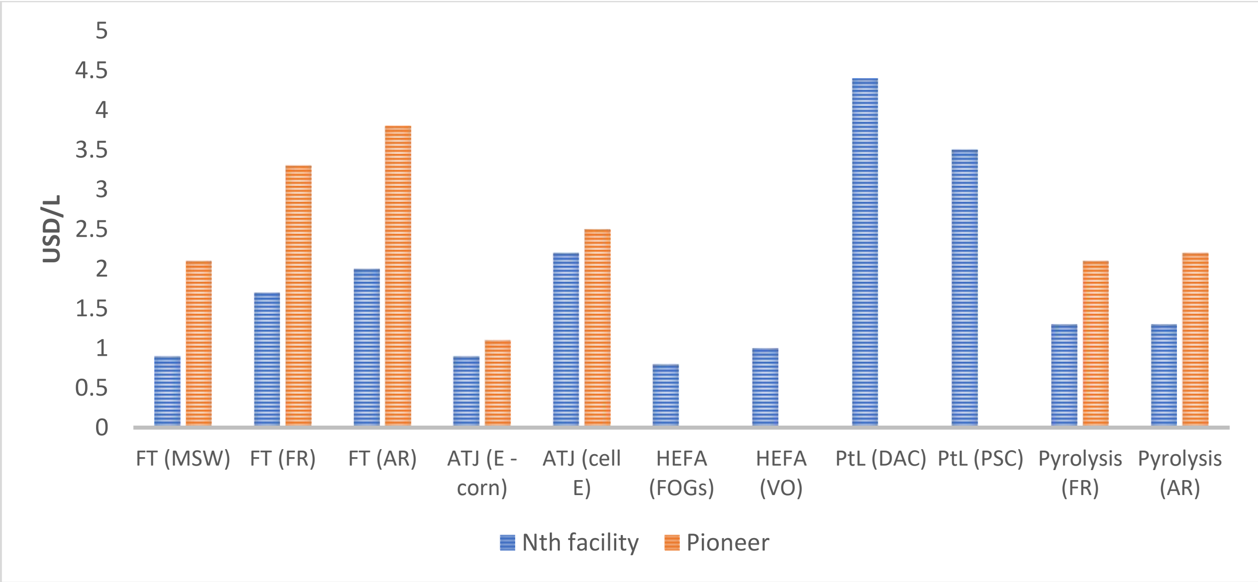


Figure 23. Minimum fuel selling price (MSP) (based on a net present value of zero) based on the ICAO SAF Rules of Thumb (jet fuel price in India in May 2025 was USD$0.543/L).

The MSP of the various technologies shows that the HEFA pathway has the cheapest production cost, but the AtJ pathway using 1G ethanol and the gasification FT pathway using MSW can both become very competitive for nth facilities. For HEFA facilities, the MSP will depend heavily on the feedstock cost, which contributes about 80% of the production cost.

It is likely that the production cost of SAF will remain higher than conventional jet fuel for the foreseeable future. Therefore, there is a consensus that dedicated policies will be essential to support the development and consumption of SAF.

3.2 THE ESSENTIAL ROLE OF POLICY FOR SAF DEVELOPMENT

ICAO has developed a document for guidance on policy measures for SAF development and deployment(ICAO, 2024). This provides valuable insights into the essential role of policy and guidance on the development and implementation of SAF policies. The International Air Transport Association (IATA) also developed a policy guide that can be used (IATA, 2023). The challenges to further development and deployment of SAF are summarized in the ICAO guidance document as follows:

- “the cost differential with conventional kerosene and the current higher costs of production for SAF;
- limited availability of cost-effective and sustainable SAF feedstocks (e.g., biomass, waste, or residue) and feedstock conversion infrastructure;
- limited investment and high costs of financing of SAF fuel production infrastructure; and,
- acceptability and competition for resources, as well as incentives with other sectors (e.g., road transport, renewable power).”

3.2.1 The characteristics of effective SAF policies

A few of the key characteristics of effective SAF-specific policies is that they:

- are stable, predictable, and consistent in implementation;
- are of a sufficient duration to reflect project development timelines (e.g., 10 years or longer);
- are “stackable” with other incentives – i.e., allow credits from multiple incentives at the same time;
- are technology-neutral – not picking “winners”;
- link incentives to GHG emission reduction performance;
- allow access to a compliance credit market to mediate prices between renewable fuels and fossil fuels by ascribing a compliance value, e.g., a low carbon fuel standard-type policy;
- allow clear access to non-dilutive capital via grants and loans.

A policy should also provide clear criteria on SAF targets, sustainability criteria, commercial parameters, and timeframe. This should be supported by a set of legal instruments. Lower SAF deployment is likely if no quantitative target is specified and if targets are not supported by a legal framework. Policies that incentivize greater verified GHG reduction achievement relative to conventional fuels may be more effective.

3.2.2 Policies used in other jurisdictions

Over the last few years, SAF-specific policies have been implemented in a number of jurisdictions, and more and more policies are being introduced. This has been a key driver for SAF development. These can be used as examples for developing SAF policies for India. Policies in the USA and the EU have been the most prominent examples, demonstrating two very different approaches to policy, often described as a carrot (USA) versus a stick (EU) approach.

The ReFuelEU Aviation policy set aggressive blending mandates up to 2050, with a dedicated sub-mandate for the PtL pathway. The obligation on fuel suppliers is supported by high penalties for non-compliance.

In contrast to the EU's demand-side policy approach, the US has taken a supply-side approach to policy. In the USA, there is no obligatory blending mandate, but various incentives are available. While the Inflation Reduction Act has attracted the most attention, other policies also provide incentives on a "stackable" basis. SAF can earn incentives under the Renewable Fuel Standard in the form of RINs (renewable identification numbers), which can be bought and sold in a RIN credit market. Under California's Low Carbon Fuel Standard, SAF has been able to earn credits that can be sold in the credit market. Other SAF-specific policies have also been agreed upon in a number of other states, such as Illinois, Minnesota, Washington State, etc., and these are all stackable with federal policy incentives.

The United Kingdom has also implemented strong SAF policies, similar to the EU. British Columbia has included jet fuel as part of its low carbon fuel standard and combined this with a SAF mandate. A number of countries have also introduced SAF policies, including mandates, for example, Brazil, Japan, etc.

3.2.3 USA federal policies

The USA has several policies that promote biofuels at the federal and state level, including the long-standing Renewable Fuel Standard (RFS2) and various blender tax credits for diesel and gasoline. States can also create additional policies and incentives that are stackable with federal policies. The most prominent state policy is the California Low Carbon Fuel Standard (LCFS), which has been copied in other jurisdictions such as Oregon and Washington States (and British Columbia).

Until recently, aviation and jet fuel were not regulated under this legislation. However, the RFS2 and the California LCFS now include aviation in their policies. More recently (in 2022), the Inflation Reduction Act (IRA) was adopted, and it includes significant incentives for SAF through a blender and producer tax credit.

The IRA was passed in August 2022 and includes widespread policy measures to support renewables and biofuel production and includes a new SAF Blenders Tax Credit (BTC) to support the sale and use of SAF. The BTC provides an economic incentive that helps bridge the price gap between conventional/fossil-derived jet fuel and SAF. To qualify, SAF must be blended in the US and uploaded to an aircraft in the US. The BTC results in USD$1.25 per gallon over a period of two years (2023-2024). Eligible SAF must obtain a minimum of a 50% CI reduction (compared with conventional jet fuel), with an additional one cent per gallon (capped at USD$1.75) for each additional % reduction in CI. In response, several US SAF producers have announced efforts to reduce the carbon intensity of their fuels by additional investment in renewable electricity, green hydrogen, and carbon capture and storage. Thus, linking incentives with increased carbon intensity reduction should support the higher investment costs resulting from the need for additional infrastructure.

After December 31, 2024, the sustainable aviation fuel, biodiesel, renewable fuels, and alternative fuels credits transitioned to the clean fuel production credit. However, this terminates on December 31, 2027. The producer tax credit is 20 cents per gallon if emission reduction limits are not met and USD 1/gallon where emissions reductions are above a certain limit. In the case of SAF, the production credit will amount to 35 cents per gallon if CI reduction limits are not met or USD 1.75 per gallon where the CI reduction minimum is achieved.

The IRA also established a competitive grant program in support of alternative aviation and fuels. Grants will be available for projects located in the U.S. that produce, transport, blend, or store SAF and will support additional infrastructure needed in the downstream supply of SAF to airports. Nearly USD 250 million in funding will be available to support SAF projects under the program.

The IRA has allocated USD 500 million to support the development of biofuel infrastructure (e.g., infrastructure improvements for blending, storing, supplying, or distributing biofuels) and includes an estimated USD 18 billion in support of climate-smart agriculture. A claimant who qualifies for the SAF credit may either: (1) claim an excise tax credit or a refundable income tax credit, or (2) claim a non-refundable general business income tax credit. The US also launched the Sustainable Aviation Fuel Grand Challenge as a government-wide commitment and comprehensive strategy to produce 35 billion gallons of SAF by 2050 (enough to meet all jet fuel demand in the US), with an interim target of 3 billion gallons by 2030.

The challenge is a collaborative effort of the U.S. Department of Energy (DOE), the U.S. Department of Transportation (DOT), the U.S. Department of Agriculture (USDA), and various other federal government agencies. The strategy's goals include scaling up new technologies to produce SAF at a commercial scale and expanding the production and use of SAF. A major focus is reducing the cost of SAF and enhancing its sustainability. The SAF Grand Challenge roadmap outlines an integrated government approach, describing coordinated policies and specific activities that should be undertaken by the federal agencies to support achieving both the 2030 and 2050 goals. It ensures alignment of government and industry actions and coordinates government policies so that the goals of the SAF Grand Challenge can be met. This includes coordination of research, development, demonstration, and deployment (RDD&D). In addition, modelling and analysis will be shared, including tools, assumptions, and insights across the various agencies' research centres. This includes the Department of Energy (DOE) National Laboratories, the Federal Aviation Administration's (FAA) Center of Excellence for Alternative Jet Fuels and Environment (ASCENT), and the US Department of Agriculture's (USDA) Agricultural Research Service, Forest Service, and National Institute of Food and Agriculture.

The roadmap describes six action areas. These span all activities that might impact the SAF Grand Challenge objectives of expanding SAF supply and end use, reducing the cost of SAF while enhancing the sustainability of SAF. The action areas include:

- Feedstock Innovation
- Conversion Technology Innovation
- Building Supply Chains
- Policy and Valuation Analysis
- Enabling End Use

The Renewable Fuel Standard (RFS2) is an existing policy that has been in place for biofuels for two decades. It requires any transportation fuel sold in the U.S. to contain a minimum volume of renewable fuels, termed Renewable Volume Obligations (RVOs), with the RVOs imposed on fuel refiners, blenders and importers. Renewable Identification Numbers (RINs) are used to track the compliance of obligated parties and serve as proof that they met their RVO. RINs are the system's credits and act as an incentive for fuel producers.

The RFS was amended to include renewable jet fuel as an "opt-in" option to earn RIN credits without establishing an RVO for aviation. Minimum emission reduction criteria apply to different RINs – D4 (50% reduction in CI), D5 (50% reduction in CI), and D7 (60% reduction in CI). In 2022, D4 RINs peaked on April 28 at USD 1.91 per gallon[41] (USD 0.50 per litre). The incentives under the RFS and IRA are stackable in nature on a federal basis but can also be combined with any state-specific incentives.

3.2.4 Principles of the Low Carbon Fuel Standard

The LCFS sets annual carbon intensity (CI) standards, or benchmarks, which are reduced over time for gasoline, diesel, and the fuels that replace them. The principle of an LCFS program is illustrated in Figure 24, showing the declining carbon intensity curve for designated fuel pools based on set targets. A fuel supplier who does not meet the target generates deficits, while a supplier who exceeds the target generates credits. Credits are sold in a credit market. Suppliers who have a deficit can purchase credits on the market to comply with targets or pay a penalty.

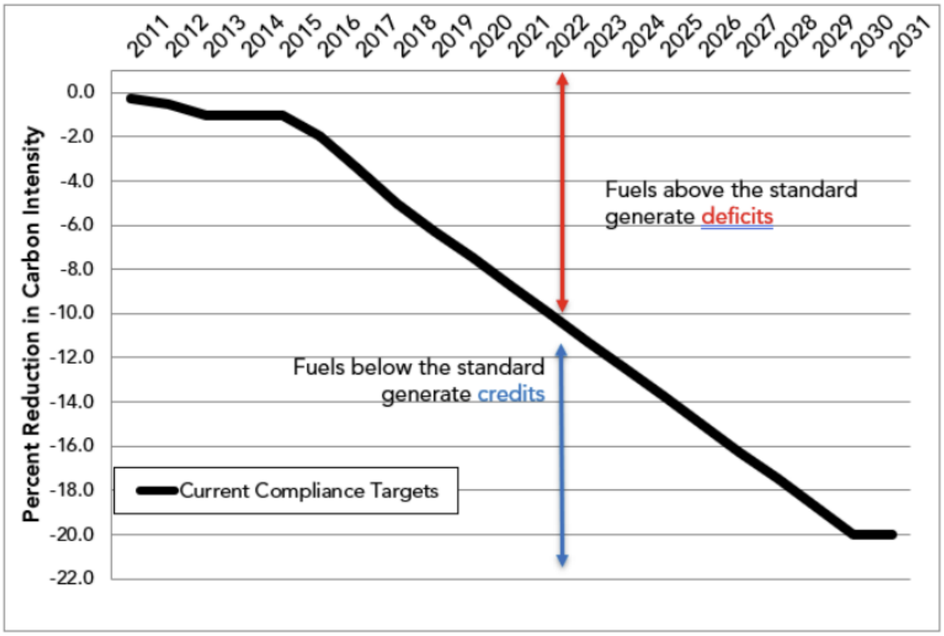


Figure 24. Illustration of how the California Low Carbon Fuel Standard works (California Air Resources Board).

The LCFS is technology agnostic and does not dictate which biofuels must be blended but allows fuel suppliers to determine which mix of fuels will be used to reach the program targets. Fuel suppliers/producers must carry out an LCA in accordance with the LCFS regulations, and the associated pathways must be approved with a specific CI assigned to a producer for every feedstock. Only fuels that have an approved pathway can be blended into the fuel pool, and there are no default values. The incentives, derived through the credit value of fuels, are stackable with any incentives that are also obtained via the RFS and the IRA.

Low-carbon fuel standards have been operating in California and British Columbia for more than a decade and have subsequently been introduced in Washington State, Oregon, New Mexico, and Canada. Other states are also considering LCFS programs. The value of credits varies between different programs. California has a maximum price ceiling on credits. This amounted to USD 239.18 in 2021 but is adjusted annually for inflation.

Jet fuel has not been an obligated fuel under the California LCFS, meaning there is no obligation to reduce the carbon intensity of jet fuel through blending with SAF. However, in 2018, the California Air Resources

[41] Different types of RINs have different prices in the credit market

Board (CARB) included alternative aviation fuels as an "opt-in", allowing these fuels to earn compliance credits in the fuel pool without incurring any debits.

The British Columbia LCFS program includes jet fuel as an obligated fuel. Under the BC LCFS, jet fuel will be subject to CI reduction requirements from 1 January 2024. This will require suppliers of jet fuels to meet increasingly stringent annual carbon intensity reduction targets as follows:

Table 34. Overview of British Columbia LCFS program targets.

Compliance period	Percent reduction for fuel in jet fuel category	Target carbon intensity for jet fuel category (gCO_2e/MJ)
2024	0%	88.83
2025	0%	88.83
2026	2%	87.05
2027	4%	85.28
2028	6%	83.50
2029	8%	81.72
2030 and subsequent compliance periods	10%	79.95

3.2.5 The ReFuelEU Aviation mandate

In July 2021, the European Commission developed climate, energy, land use, transport, and taxation policies aimed at reducing the EU’s net greenhouse gas emissions by at least 55% by 2030, compared with 1990 levels (the “fit for 55” package) (Think Tank, 2022). The ReFuelEU Aviation Regulation, adopted in October 2023 sets minimum obligations for all fuel suppliers to gradually increase the share of sustainable aviation fuels in the fuels supplied to EU airports. The minimum share of SAF supplied at each EU airport should be 2% in 2025 and 6% in 2030, increasing to 20% in 2035, 34% in 2040, 42% in 2045, and 70% in 2050. Within the SAF supply obligation, a sub-obligation is envisaged for synthetic aviation fuels (e-fuels), increasing from 0.7% in 2030 to 5% in 2035, 10% in 2040, 15% in 2045, and 35% in 2050.

The regulation includes a transition period until the end of 2034, during which fuel suppliers will have supplied the minimum share of SAF as an average over all the aviation fuel they supplied to EU airports (i.e., they don’t have to supply it at every single airport). The enforcement of the ReFuelEU mandate will take place through fines. Member States must determine fines, but fines may not be less than double the price difference between conventional fuel and the applicable SAF type, multiplied by any shortfall quantity. In addition, the volumes that were not supplied under the mandate are added to the obligation for the following year. Revenues generated from fines must be used by EU member states to support research and development of SAF or to bridge the price difference between SAF and conventional jet fuel.

In March 2025, EASA published reference prices for SAF and eSAF, which will be used to calculate the penalties for non-compliance(EASA, 2024). Average prices for SAF from biofuels, advanced biofuels, and recycled carbon biofuels in 2024 were calculated at EUR 2,085/t (around USD 2,150/t). The reference price for synthetic aviation fuels (eSAF) was estimated at EUR 7,695/t (around USD 8,000/t), while conventional aviation fuel was determined as EUR 734/t (around USD 760/t). Based on a price differential of EUR 1,351/t (USD 1,406/t) for SAF and EUR 6,961/t (USD 7,244/t) for eSAF compared with conventional fuel, SAF non-compliance penalties would be around EUR 2,700/t (USD 2,809/t), and eSAF penalties would be EUR 13,992/t (USD 14,560/t).

3.2.6 SAF-related policies in other countries

SAF mandates have also been introduced in individual countries. These mandates have been established ensuring a "level playing field" as all airlines operating in those jurisdictions are equally supplied with the SAF blends (at a higher price) avoiding competitive distortions. In contrast, in jurisdictions without blending mandates, airlines that wish to purchase SAF may be placed at a competitive disadvantage as their fuel costs are higher than other airlines that don't purchase SAF.

The United Kingdom launched a Jet Zero strategy, which commits UK domestic aviation to achieve net zero emissions by 2040 with a 10% SAF penetration by 2030. The strategy outlines a goal of all UK airports emitting zero emissions by 2040. The SAF mandate will operate as a greenhouse gas emission reduction scheme with tradeable certificates. The SAF must deliver at least a 40% reduction in GHG emissions and meet strict sustainability criteria. Any SAF made via the HEFA route will be capped, and power-to-liquid derived SAF will be supported through a sub-target. An Advanced Fuels Fund was established to support technology development. The goal is to have five commercial SAF facilities under construction by 2025. The mandate also includes a buy-out price, which is a cost penalty for jet fuel providers who cannot supply SAF in terms of the mandate. The buy-out mechanism for the main SAF obligation is GBP 4.70 per litre, and for the PtL obligation it is GBP 5.00 per litre. The government is also developing a revenue certainty mechanism, which will provide price support for SAF, but the specific format has not been finalized(Norton Rose Fulbright, 2024).

Brazil implemented a national SAF program, ProBioQAV (*Programa Nacional de Combustível Sustentável de Aviação*), that aims to "encourage research, production, commercialization and use" of SAF. From 2027, aircraft operators will be required to decrease well-to-wake CO_2 emissions 1% annually on domestic flights until reaching 10% by 2037 (Argus Media, 2025).

Japan's Ministry of Economy, Trade and Industry (METI) plans to introduce a SAF mandate for 10% SAF use by 2030, as well as tax exemptions and subsidies as investment promotion measures (JPY337 billion (USD22.4 billion equivalent) for 5 years 2024-2028)(Argus Media, 2024).

China announced a SAF policy in China aiming to produce at least 10 Mt of SAF annually by 2030. This will be achieved with a phased blending mandate, starting with a 2% SAF blend requirement by 2025 and gradually increasing to 15% by 2030. This mandate applies to both domestic and international flights operated by Chinese airlines. Non-compliance with the blending mandate may result in penalties, including fines and restrictions on flight operations. Financial incentives, including tax breaks, subsidies, and low-interest loans for the construction of SAF production facilities, will be provided. The government has also established a dedicated SAF fund to finance R&D projects and pilot programs (Modern Diplomacy, 2024).

3.3 POTENTIAL SAF DEMAND IN INDIA

Three different scenarios for SAF demand to 2050 were developed based on the forecast for international flights only and for international and domestic flights combined (Figure 25). While the ambition for SAF blends is currently only for 2027, 2028 and 2030, these scenarios give an idea of the SAF volumes that may be required based on reaching a 40% (S1), 50% (S2), and 60% (S3) blend by 2050 (Figure 26; Table 35).

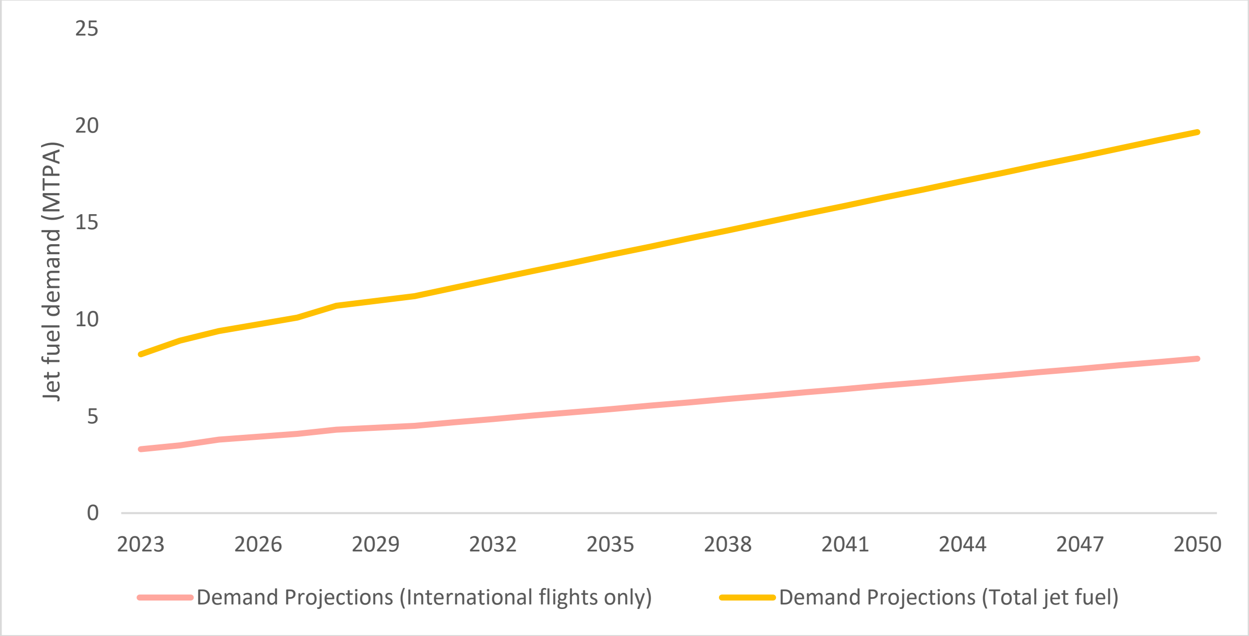


Figure 25. Forecast for jet fuel demand to 2050 for total jet fuel (international and domestic flights) and jet fuel demand for international flights only.

Table 35 shows the data for Figure 26 for the three scenarios and the estimated volumes of SAF that will be required to meet these demands.

Table 35. SAF demand (as a % blend) for three scenarios based on jet fuel demand for international (intl) flights only or for total jet fuel demand.

Year	SAF% S1	Intl (Mt)	Total (Mt)	SAF% S2	Intl (Mt)	Total (Mt)	SAF% S3	Intl (Mt)	Total (Mt)
2027	1	0.041	0.101	1	0.041	0.101	1	0.041	0.101
2028	2	0.086	0.214	2	0.086	0.214	2	0.086	0.214
2030	5	0.225	0.56	5	0.225	0.56	5	0.225	0.56
2035	10	0.54	1.33	10	0.54	1.33	15	0.81	2.00
2040	20	1.25	3.09	25	1.56	3.86	30	1.87	4.63
2050	40	3.19	7.87	50	3.99	9.84	60	4.78	11.80

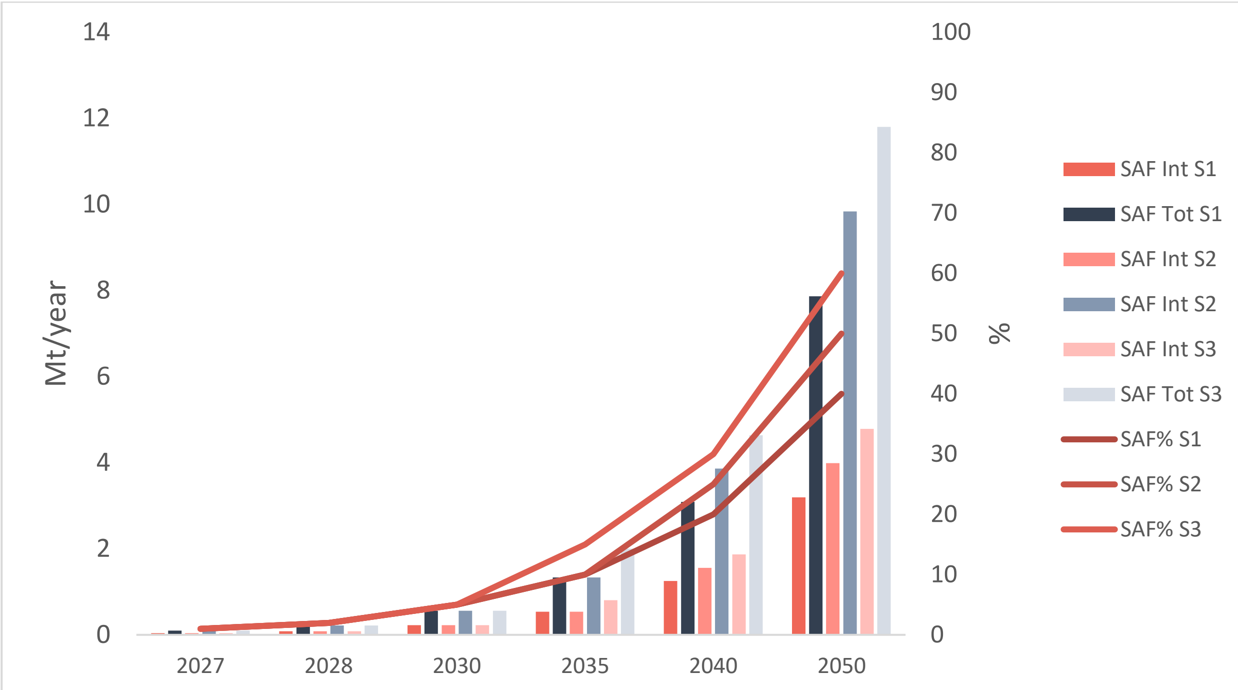


Figure 26. SAF demand (as a % blend) for three scenarios based on jet fuel demand for international flights only or for total jet fuel demand.

3.4 POTENTIAL PRODUCTION VOLUMES IN INDIA BASED ON AVAILABLE FEEDSTOCKS

Table 36 shows feedstock volumes in India based on a low and a high estimate. The high estimate is the total feedstock volume, while the low estimate is 50% of the total feedstock volume, except in the case of sugarcane bagasse, where the low estimate is based on current excess volumes after bioenergy applications were excluded. In the case of 1G ethanol, the sugarcane and grain feedstocks were not considered, but the ethanol capacity of all the existing facilities (high estimate), while the low estimate for 1G ethanol is 50% of the current ethanol plant capacity. As shown in SECTION 2, 1G ethanol production fluctuates based on limits placed on feedstock use, while none of the plants operate at full capacity. Currently, 1G ethanol is used for blending with petrol to meet the government target of 20% blends. However, it is assumed that initial AtJ facilities will be able to use 1G ethanol while 2G ethanol is being developed.

Table 36. Availability of key feedstocks in India based on a low and a high estimate.

Feedstock/technology	Feedstock volume (Mt/year)		Comment
Scenario	LOW	HIGH	
UCO/HEFA	1.25	2.5	Low- 50% of UCO goes to biodiesel. High - all UCO is diverted to HEFA
1G ethanol/AtJ	7	14	High is the total capacity of current ethanol facilities in India. Low is 50% ethanol going for petrol blending and the remainder being available for SAF production
Sugarcane bagasse and EtJ	30	120	High is total bagasse volumes. Low is surplus bagasse after bioenergy. Conversion: 0.18 tonnes ethanol per tonne of bagasse
Rice straw and EtJ	77	154	High is the total rice straw used for 2G ethanol and SAF. Low is 50% of rice straw used. Conversion: 0.18 tonnes ethanol per tonne of bagasse
MSW and Gasification/FT	19.96	39.9	Treated and landfilled MSW

Figure 27 shows a comparison of feedstock availability for the main biogenic feedstocks.

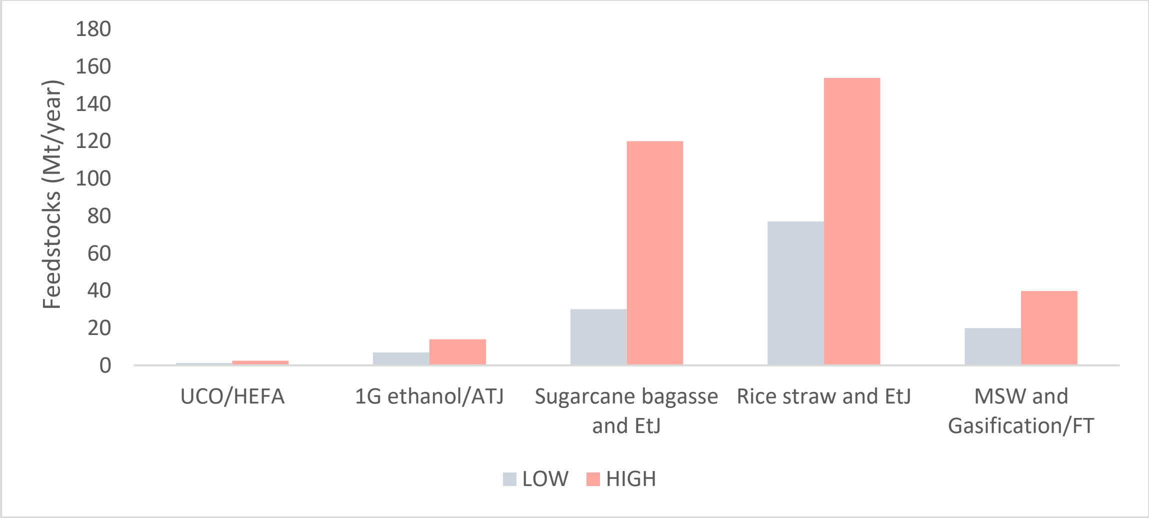


Figure 27. Feedstock availability based on low and high estimates for the main biogenic feedstocks only.

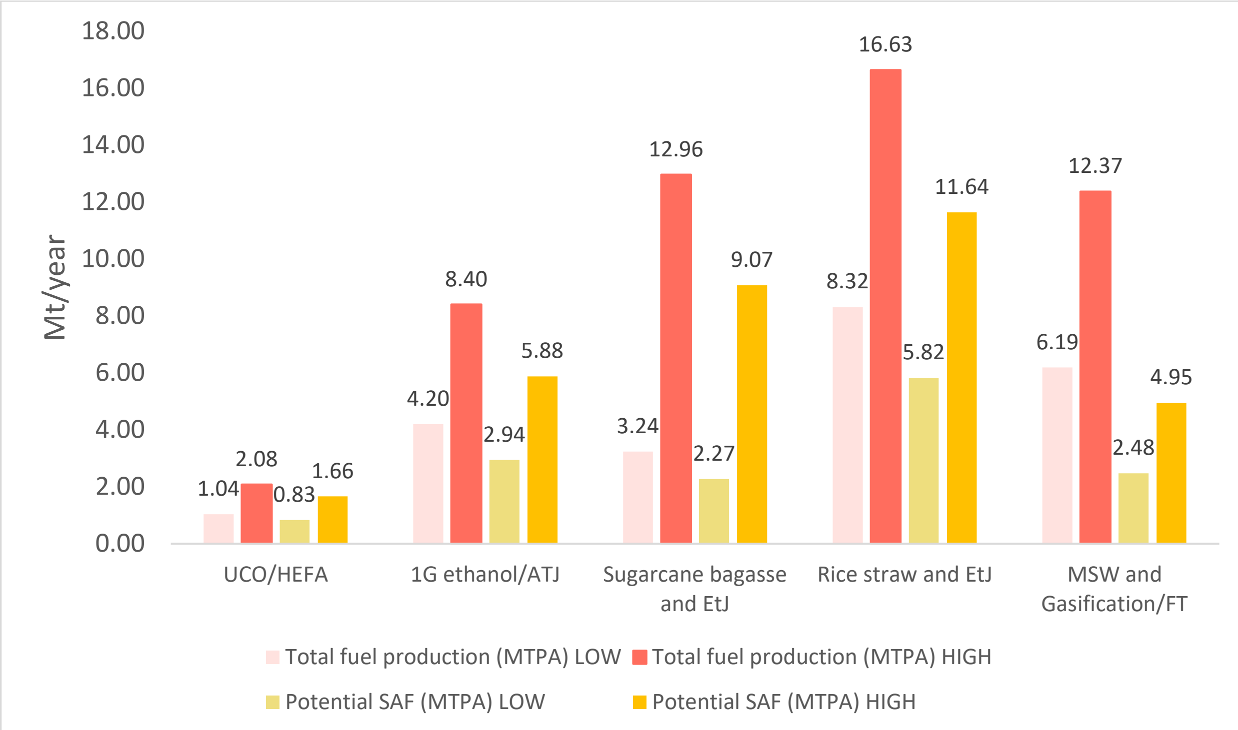


Figure 28. Potential total biofuel and SAF volumes based on assessed feedstock availability.

As shown in Table 37, SAF production volumes could range between 14.33 Mt/year and 33.2 Mt/year based on biogenic feedstocks alone. This would be more than enough SAF to meet demand for 2050, even at 60% blends (Figure 26).

Table 37. Potential production volumes of total fuels and SAF based on different feedstocks.

Feedstock / Technology	Total fuel production (Mt/year)		Potential SAF (Mt/year)		SAF in billion litres per year	
Scenario	LOW	HIGH	LOW	HIGH	LOW	HIGH
UCO/HEFA	1.04	2.08	0.83	1.66	1.04	2.08
1G ethanol/AtJ	4.20	8.40	2.94	5.88	3.68	7.35
Sugarcane bagasse and EtJ	3.24	12.96	2.27	9.07	2.84	11.34
Rice straw and EtJ	8.32	16.63	5.82	11.64	7.28	14.55
MSW and Gasification/FT	6.19	12.37	2.48	4.95	3.09	6.18
TOTAL	**22.98**	**52.44**	**14.33**	**33.20**	**17.92**	**41.50**

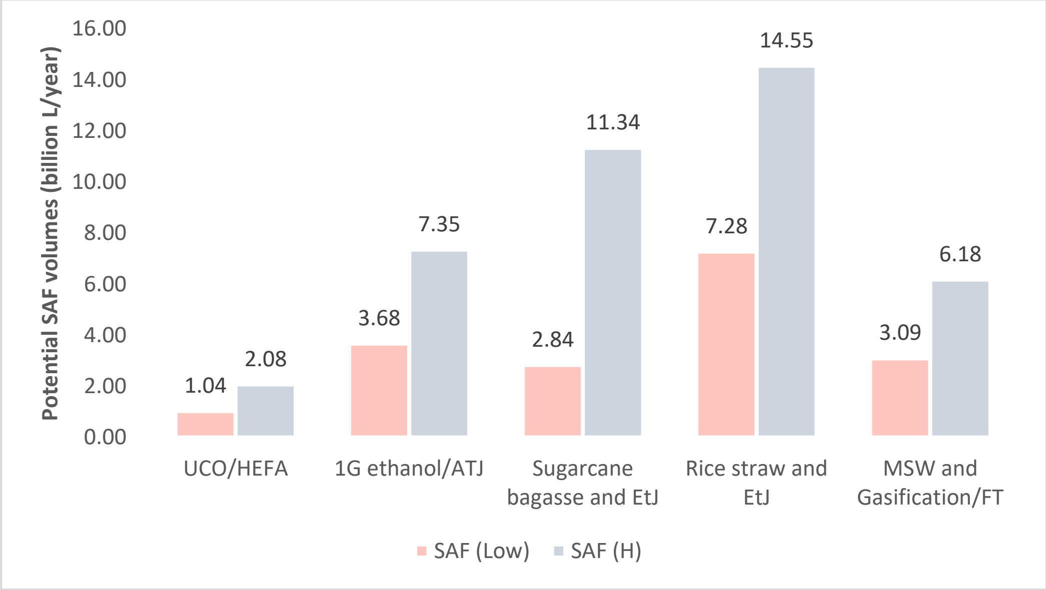


Figure 29. Breakdown of low and high SAF volumes potential from different feedstocks.

The preceding assessment of potential SAF production from the main feedstocks did not consider estimates for additional SAF production through technology pathways such as power-to-liquids and waste gas (or syngas) fermentation. However, utilization of these gases can produce significant volumes of SAF in excess of the estimates based on biobased feedstocks.

Biogenic CO_2 from current ethanol production can be utilized through PtL technology. However, this will also require hydrogen produced through electrolysis using renewable energy. Availability of sufficient renewable electricity will be a key enabler for PtL technologies. The utilization of biogenic CO_2 may be limited by the scale of ethanol facilities unless CO_2 can be aggregated. 2G ethanol plants are expected to be much smaller in scale due to supply chain challenges. Based on stakeholder engagement, 2G ethanol plants based on rice straw will likely be limited to 30,000 m^3 in total capacity.

Other sources of waste CO_2 and other gases include steel production, cement manufacture, refinery off-gases, and CO_2 from coal power plants. LanzaTech has successfully demonstrated the production of ethanol from steel mill off-gases and is actively pursuing commercial production in India at the IndianOil plant in Panipat. CO_2 emissions from steel mills and cement production amount to more than 410 Mt/year. Depending on the specific technology and yields, SAF production can be more than doubled if CO_2 sources are used as well, provided that sufficient renewable electricity can be produced for renewable hydrogen production.

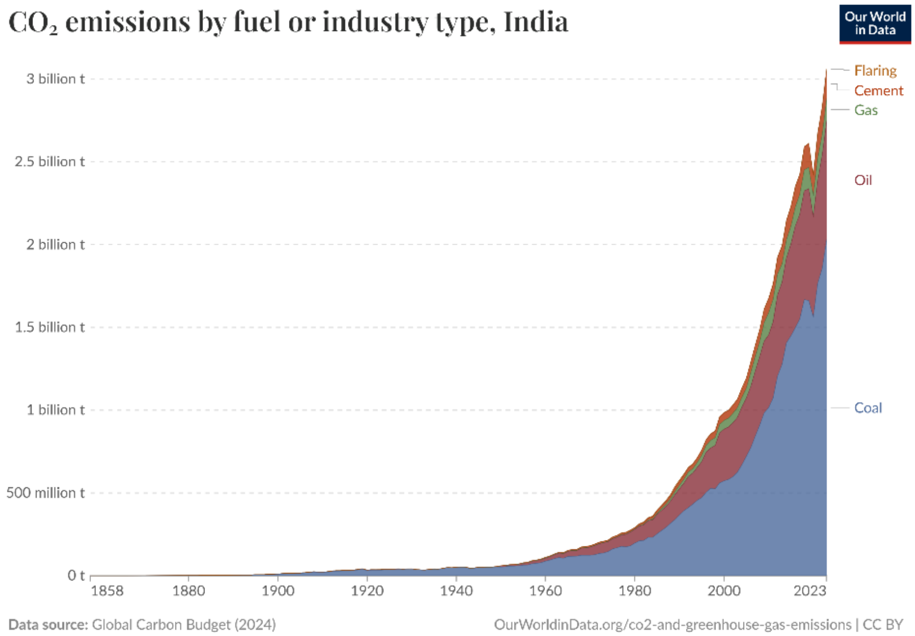


Figure 30. CO_2 emissions by fuel or industry type in India (*India: CO2 Country Profile - Our World in Data*, n.d.).

3.5 IMPLEMENTATION SUPPORT

3.5.1 Government-wide approach to develop a coordinated, long-term vision and strategy

In the US, the vision and long-term strategy for SAF production and use were developed as a coordinated effort between multiple government departments, including the US Department of Energy, the US Department of Agriculture, and the Department of Transport, with further input from multiple agencies. This led to the development of the Sustainable Aviation Fuel (SAF) Grand Challenge(US Dept of Energy, n.d.) "to work with industry to reduce cost, enhance sustainability, and expand production to achieve 3 billion gallons per year of domestic sustainable aviation fuel production that achieves a minimum of a 50% reduction in life cycle greenhouse gas emissions (GHG) compared to conventional fuel by 2030 and 100% of projected aviation jet fuel use, or 35 billion gallons of annual production, by 2050." The key characteristic of the SAF Grand Challenge is a clear vision with quantifiable goals. It also identifies challenges and creates the framework for addressing these challenges.

In the UK, a similar type of approach was followed. A Jet Zero Council was established as "a partnership between industry, academia, and government to bring together ministers and chief executive officer-level stakeholders, with the aim of delivering at least 10% sustainable aviation fuel (SAF) in the UK fuel mix by 2030 and zero-emission transatlantic flight within a generation, driving the ambitious delivery of new technologies and innovative ways to cut aviation emissions."(*Jet Zero Council - GOV.UK*, n.d.) The objectives of the JZC were defined as follows:

- "Provide ministerial and senior industry leadership on efforts to deliver UK capabilities for net zero aviation;
- identify and optimize the strategic, economic, and international benefits of developing these industries in the UK, and overcome the barriers the industry faces in achieving these goals;

- accelerate the design, manufacture, testing, certification, infrastructure, and commercial operation of zero-emission aircraft and aviation systems in the UK through sustained investment in applied research and development (R&D) and fostering greater collaboration across sectors;
- accelerate the delivery of SAF by supporting the investment in first-of-a-kind SAF plants, supporting research and development of new pathways, and driving down production costs through upscaling and innovation;
- support grassroots innovation in these areas and make the UK the best place in the world to develop new aviation technology;
- challenge existing approaches by involving disruptors and innovators in the dialogue."

The establishment of a similar type of body in India is highly recommended to develop a clear vision with quantifiable goals. Developing a domestic SAF industry is a complex undertaking with multiple stakeholders across the entire supply chain that have to work together towards a common objective. The above two examples can assist in establishing a stakeholder- and government-driven vision for a domestic SAF industry. Consultations at this level should ideally be carried out by ministers from relevant government departments and chief executive officer-level stakeholders. Without the involvement of the government departments that can implement the vision, a council will not be effective.

3.5.2 Technical needs

Development of new SAF technology pathways can be supported through research and development grants. Indian companies are developing novel technologies for SAF production, for example, the proprietary HEFA technology being commercialized by CSIR-*Indian* Institute of Petroleum (CSIR-IIP). This pathway is still in the process of obtaining ASTM certification. Assistance can further be provided with certification of new pathways, which can be a costly exercise. India could consider establishing its own testing facility to assess new SAF technologies. In the UK, a "SAF Clearing House" was established to provide technical support and funding towards the development, testing, and qualification of new SAF pathways (*UK Sustainable Aviation Fuels (SAF) Clearing House*, n.d.).

With respect to feedstock development, technical assistance can be provided for the development of new feedstocks, for example, non-edible oilseeds that can provide sustainable feedstocks for the HEFA process. In the case of MSW, improved collection and sorting may be required, as well as analysis of MSW in various potential locations for a SAF facility to determine the biogenic content and assess suitability for technologies such as gasification. In the case of feedstocks such as rice straw, significant efforts need to target an improved supply chain with standardized collection that optimize the cost of feedstocks for 2G ethanol production.

3.5.3 Establish a domestic sustainability framework and procedure for life cycle assessment

The CORSIA framework for sustainability, including its life cycle methodology and default carbon intensities for pathways, was developed for international aviation only as a way to determine how SAF consumption can meet the offset obligations of airlines under CORSIA. In the process, the CORSIA sustainability criteria and LCA methodology have become a global standard that is applied in multiple countries. However, other LCA methodologies are used in various countries, e.g., the Argonne GREET model in the US, the California GREET model in California, the GHGenius model in British Columbia, etc. Due to the use of different assumptions and data, the model used can give different results for carbon intensity, and some models may not include induced land use change (ILUC). The need for harmonized carbon accounting has been highlighted by organizations such as the IEA (IEA, 2024), but this is still in progress.

It is critical that sustainability standards and a methodology for calculating carbon intensity are established in domestic legislation, as this will create consistency and certainty across the board. Multiple fuel products may be produced in one facility, and it is untenable that the sustainability and carbon intensity of one product (SAF) be determined using CORSIA while other fuel products use different calculation methods.

For current biofuels produced in India, there are no sustainability requirements, and carbon intensity is not calculated. This prevents India from demonstrating GHG emissions reductions in transportation and could, therefore, be useful for demonstrating India's commitment under the Paris Agreement. At the same time, existing 1G ethanol could potentially be used for SAF production, which could create two parallel systems with some ethanol facilities implementing sustainability standards and requiring sustainability certification (with additional cost and administrative burdens), while other companies don't.

It is, therefore, important to create a domestic sustainability framework to ensure certainty. India has announced a SAF mandate for 2027, 2028, and 2030, which is a national policy distinct from CORSIA. Domestic legislation will be required to make this an official mandate with a regulatory obligation on fuel suppliers to blend SAF into existing jet fuel. Such legislation will need to incorporate sustainability standards, certification, and LCA. Other countries also use this type of legislation to implement minimum emissions reductions (carbon intensities) for SAF that are much stricter than CORSIA (which requires only a 10% reduction). These minimum emissions reduction requirements are further linked to other policies that provide incentives or other types of favourable conditions. For example, domestic legislation could provide financial incentives such as tax credits for SAF with a sliding scale, allowing greater incentives for lower carbon intensity SAF (as in the US). In the EU, a minimum of 65% emissions reductions of SAF are required to meet ReFuelEU Aviation mandate obligations.

The DGCA has announced that CORSIA will be the only sustainability framework applicable for both domestic and international aviation and this should be included in legislation or regulations. A comprehensive sustainability framework that specifies the LCA methodology is therefore recommended for India. ICAO States, including India, agreed in 2023 at the third ICAO Conference on Aviation and Alternative Fuels (CAAF/3) that, in the interests of providing regulatory transparency, certainty, stability and assurances of environmental integrity to feedstock producers, fuels producers and financial institutions, the CORSIA sustainability criteria, sustainability certification, and the methodology for the assessment of life cycle emissions used for 'CORSIA eligible fuels', should be used as the accepted basis for the eligibility of SAF, LCAF and other aviation cleaner energies used in international aviation (paragraph 12 of the ICAO Global Framework for SAF, LCAF and other Aviation Cleaner Energies (adopted on 24 November 2023)).

In the case of co-processing, a specific method for calculating the carbon intensity of the renewable portion and the total fuel blend is included under CORSIA. However, this relies on C-14 analysis of co-processing fuels to accurately determine the renewable content. Where mixed (biobased and fossil-based) feedstocks are used for SAF production, for example, MSW, waste tires, etc., an accurate determination of the biobased content is required to determine the carbon intensity of the final SAF. C-14 analysis must be done at specialized laboratories, and consideration should be given to establishing a facility in India that can carry out such analysis. There are very few facilities globally, of which Beta Renewables in Florida is used by companies around the world for C-14 analysis. Having a facility in India can lower the cost of analysis and support a developing SAF industry.

3.5.4 Sustainability certification assistance

SAF producers will require sustainability certification under CORSIA, and this was discussed in SECTION 2. This will require accredited sustainability certification bodies in India to verify sustainability in terms of the CORSIA guidelines. This is currently being put in place. Additional issues around certification were also highlighted. A formal application must be made to CORSIA for adding feedstocks that are or will be used for SAF production in India.

Stakeholders in the sugarcane industry have also indicated that India should apply for a default core value carbon intensity for sugarcane ethanol from Indian feedstocks, as data has shown that it would be lower than the default CI value which is currently listed. Requests relating to feedstocks can only be submitted by ICAO Member States, international organizations, or an approved Sustainability Certification Scheme (SCS) under CORSIA. In addition, it should be noted that such local/regional values currently only exist for ILUC, not for core LCA.

3.5.5 Training needs

Education and awareness will be an important part of developing a domestic SAF industry in India. The SAF sector and supply chain are complex, and many different groups must work towards a common goal. Groups that can be targeted in education and awareness campaigns should include passengers, airport employees, farmers, biomass aggregators, the UCO collection value chain, voluntary buyers for Scope 3 (such as large corporations), industry bodies, certification bodies, etc. Education and awareness campaigns can include formal training sessions, information leaflets, etc., and perhaps consideration could be given to holding an India-specific SAF conference on an annual basis to bring together all stakeholders and identify ongoing challenges and obstacles.

Milestones can be publicized, for example, the production of the first SAF volumes in India, and blending campaigns at one or more airports (led by airlines) to demonstrate the safe integration of SAF into the existing blending infrastructure and airplanes.

3.6 FINANCING SAF DEVELOPMENT

As shown in 3.1, the total capital investment required to construct SAF facilities can be very significant, particularly for gasification/FT and PTL technologies. The production cost of SAF is also significantly higher than conventional jet fuel and is expected to remain higher for the foreseeable future. Projected improvements and reduction of production costs are expected to materialize, but many pathways will remain more expensive than conventional jet fuel prices.

Financing the initial investment costs for the construction of facilities is critical, particularly for first-of-a-kind facilities and technologies that are not proven at the commercial level. As a nascent industry, SAF production represents a high risk for investors, as most technologies must still reach commercial levels (except for HEFA). Multiple closures of the first commercial plants, such as the recent Fulcrum Bioenergy gasification and FT facility, demonstrate the high risk involved. Fulcrum had received more than USD 467 million in investment from multiple sources but had significant technical challenges and failed to produce substantial volumes of fuel (Chemical and Engineering News, 2024).

SAF development relies on creating a supporting policy framework that helps to derisk investment and attract financing. Financing is particularly critical for the construction of first-of-a-kind facilities that represent a high risk until an emerging technology has been successfully demonstrated. However, financing is needed for all stages of development, from low technology readiness levels where research and development is carried out through pilot and demonstration phases.

Financing for emerging technologies in various development stages and for construction of first-of-a-kind facility can include:

- Public financing – capital grants and loan guarantees,
- Government procurement contracts or direct investment,
- Private financing – investment from airlines and Scope 3 corporations, venture capital, etc.,
- Incentives, e.g., tax credits, subsidies,
- Price guarantee mechanisms, and
- Others, such as green bonds.

Once SAF becomes available in substantial volumes, financing of the green premium (the price gap between SAF and conventional jet fuel) becomes relevant. Jet fuel is about 30% of the cost for airlines, and buying SAF at a much higher price can make an airline uncompetitive if the green premium is reflected in higher ticket prices while other airlines are not using SAF. Where an obligatory mandate is in place and all airlines use blended SAF, a level playing field is created between airlines, which overcomes this challenge. However, organizations such as the International Air Transport Association (IATA) argue that mandates alone are not adequate and that incentives are also needed. A combination (basket) of policies with different mechanisms targeting different challenges in the SAF supply chain can spread the higher cost of SAF blending and use. Long-term mandates that create a structural demand, combined with long-term, firm offtake agreements (not just a memorandum of understanding), and the establishment of a stable policy framework providing long-term security will derisk investment and create a favourable investment environment and drive consumption of SAF.

Providing financial assistance in the form of capital grants and loan guarantees can be used to reduce the initial cost of building a first-of-a-kind facility, but will also create a favourable environment for investment. Once a pioneer facility is operating successfully, the investment risk is expected to be lower and financing more readily obtained.

Different technologies may require different levels of investment, as there is a significant variation in initial capital cost for the construction of a facility. Therefore, giving the same capital grant across the board means that some technologies will benefit more. For example, a USD 75 million grant for the construction of FT-based facilities was shown to only reduce the initial investment costs by <15%, while the same-sized grant will cover almost 70% of the investment costs needed to construct a corn Ethanol-to-Jet facility, and 45% of a 2G Ethanol-to-Jet facility (Figure 31 (Brandt et al. 2021). Providing a grant or loan guarantee as a percentage of capital invested could overcome this type of obstacle.

In addition to large grants for the construction of a facility, a grant program for smaller infrastructure projects could be considered. For example, grant funding for the installation of blending facilities where unblended SAF can be delivered, stored, and blended, or for upgrading existing facilities to support SAF production, delivery, and storage. Smaller grants might also focus on regional supply chains that could support the infrastructure and distribution needs of smaller airports. Other options include assisting airports with blending infrastructure or assisting with feedstock and other supply-chain-related issues.

Larger grants might be awarded to infrastructure projects used to facilitate and scale fuel production, transportation, blending, and storage. They could also help with the installation of equipment used to enable SAF production at an existing fuel production facility or a facility that is processing biomass or waste.

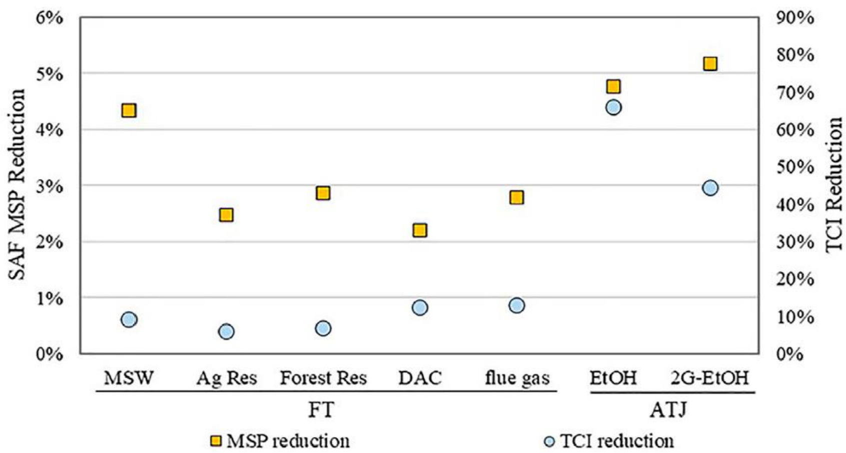


Figure 31. Percentage reduction of baseline MSP and TCI for pioneer plant with a $75 million capital grant (Brandt et al. 2021).

Broader climate financing mechanisms can be leveraged for SAF-specific projects. NITI Aayog, a government of India planning body, is examining structuring mechanisms for operationalising a potential National Green Financing Institution, including a bank modelled on NaBFID / NABARD, repurposing existing institutions like IREDA; Climate fund in GIFT city, Green InvIT, etc. (non-exhaustive list), along with analysing best practices from green banks around the world (The Economic Times Energy, 2025a). Additionally, due to great global interest in SAF development, India could leverage its strong sustainability credentials to directly attract international capital for SAF.

Recently, IREDA obtained board approval to raise up to INR 5000 crore (around USD 570 million) through QIP (Qualified Institutions Placement) of equity shares (The Economic Times Energy, 2025b). These funds raised through QIP will strengthen green financing capabilities, accelerate loan book growth, and support India's clean energy targets. Further, its subsidiary, IREDA Global Green Energy Finance IFSC Limited, has been registered with IFSCA, allowing it to commence operations as a finance company at GIFT City, Gujarat, further aiding its visibility and accessibility for potential SAF producers.

India has experience in promoting the development of nascent industries such as solar energy and has used innovative measures such as green bonds, which have been successful in India, the world's second-largest market for green bonds, with transactions worth more than USD 10 billion in the first half of 2019 (World Economic Forum, 2021). Government agencies such as the National Bank for Agriculture and Rural Development (NABARD) (for collection projects), public-sector banks (PSBs), such as the State Bank of India (SBI) and Small Industries Development Bank of India (SIDBI), can play an important role in promoting sustainable finance in green bond issuance, as demonstrated by the Indian Renewable Energy Development Agency and Indian Railway Finance Corporation (World Economic Forum, 2021).

Offtake agreements play an important role in securing financing for SAF production. Many airlines around the world have signed long-term offtake agreements with SAF production companies. According to the ICAO Dashboard, 58 million m^3 in offtake agreements have been signed to date (ICAO, n.d.-d). There is also potential for offtake agreements with corporations seeking to offset Scope 3 emissions resulting from business travel.

The expansion of the National Policy on Biofuels to include SAF can open access to equivalent policy mechanisms that can support the financing of a SAF industry. Beyond blending targets, the policy established guaranteed pricing, long-term ethanol contracts, and financial support for building new facilities and upgrading existing ones. These mechanisms can be extended to SAF by, for example, establishing guaranteed pricing for 2G ethanol to support AtJ production.

A Viability Gap Financing (VGF) scheme could be implemented for SAF production facilities(*Viability Gap Funding Scheme - Public Private Partnerships in India*, n.d.). The Viability Gap Funding (VGF) Scheme aimed at supporting infrastructure projects that were economically justified but fell marginally short of financial viability.

Other types of financial mechanisms can include tax credits, advanced depreciation, subsidies for utilities and infrastructure, etc., that will make SAF plants commercially viable and will aid risk diversification for biofuel producers. The creation of a credit market as used in low carbon fuel standards can play an important role in financing SAF production facilities. Credits are based on CO_2 reduction per tonne and, therefore, play a direct role in climate targets. While the value of credits fluctuates, they have been as high as USD 500 per tonne of CO_2 in British Columbia (where a maximum is not in place) and up to USD 200 in California (where a maximum value is in place). The US Renewable Fuel Standard also uses a credit market in the form of RINs that can be bought and sold to meet compliance targets.

Bridging the price gap between conventional jet fuel and SAF will likely be partially met through increased ticket prices. A report from the World Economic Forum Clean Skies for Tomorrow calculated that an "additional cost of USD 1.80 on all domestic flights at a 10% blend spread over the total 190 million domestic passengers projected in 2030 could be incurred"(World Economic Forum, 2021).

SECTION 4. ACTION PLAN

4.1 POLICY AND REGULATORY FRAMEWORK

As previously discussed, policy enablers are essential for establishing a SAF sector in India due to the many challenges faced by the industry. The aviation sector has very limited options for decarbonising, with SAF required to contribute the majority of emissions reductions. This is unlike other transportation sectors where many alternatives are available, e.g., electric vehicles and alternative fuels such as compressed biogas, hydrogen, etc.

Multiple types of policies have been used globally to support the development of nascent industries such as bioethanol and biodiesel, solar and wind energy, etc. Various countries, such as the USA, the EU, the UK, etc., have implemented SAF-specific policies, and their impact is already noticeable in driving SAF development. These policies can serve as an example of the types of approaches that can be followed in India while the existing policy framework and specific needs in India are taken into account. There are many existing policies and frameworks in India that were developed for other sectors that can be readily modified to include SAF. This can form part of a broader package of measures to develop a domestic SAF industry in India to supply domestic needs and potential additional SAF for exports.

However, it is critical that a broad, long-term vision for a domestic SAF industry be developed by all major stakeholders and all relevant government departments, with the government tasked with implementing the vision through policies and regulations.

4.1.1 Recommendation 1 - Establish a SAF Council representing stakeholders

Establish a SAF Council representing stakeholders but led by government departments/agencies. The Council must have sufficient authority and develop a long-term vision for a domestic SAF sector. Representatives from airlines, airports, fuel producers, feedstock producers, and government departments must be at the CEO or DG level. This body can be structured similarly to the Jet Zero Council in the UK with a clear mandate and objective. The entire SAF strategy and the following recommendations can be implemented through working groups established under the SAF Council.

4.1.2 Recommendation 2 - Formulate a long-term goal for a SAF sector in India

The current mandate for 1% SAF in 2027, 2% in 2028, and 5% in 2030 is not obligated at this stage but reflects an ambition or aspiration. Long-term, binding mandates up to 2040 or 2050, linked with India's commitment towards the ICAO net zero by 2050, and long-term aspirational goals need to be defined. The mandate must provide certainty to investors and create a firm market demand for SAF.

As highlighted in 3.2.6, binding and enforceable mandates ensure a "level playing field" as all airlines operating in the country are equally treated, avoiding a competitive distortion. In contrast, without blending mandates, airlines that wish to voluntarily purchase SAF are placed at a competitive disadvantage as their fuel costs are higher than other airlines that don't purchase SAF.

The mandate must be clearly designed and specify the consequences of non-compliance. While a volumetric mandate can be used, it is recommended that the carbon intensity of SAF be incorporated by stipulating a minimum level of emissions reductions or linking the volumetric and CI reduction similar to a low carbon fuel standard. The UK and ReFuelEU Aviation policies can be used as examples, with the incorporation of principles of LCFS policies.

Setting concrete goals for the number of SAF facilities targeted for 2030 with specific volumes is recommended.

4.1.3 Recommendation 3 – Develop a basket of SAF-specific policies and integrate it with existing biofuels policy

Identify a suite of policies that can assist in financing a thriving domestic SAF industry and support the construction of SAF facilities. Develop mechanisms such as producer incentives, blender incentives, capital grants or loan guarantees, price guarantee mechanisms, etc.

Integrate SAF policy with the existing National Biofuels Policy to ensure climate mitigation in different transportation sectors. As SAF has very high production costs and is the only alternative for the aviation sector, it could potentially be given preferred access to feedstocks. Specifically, it should be clarified whether current ethanol production could be used for SAF production or whether blending ethanol with petrol will be the priority. The impact of competition for feedstocks between biodiesel and SAF must also be addressed and clarified. Current blending into the gasoline and diesel pool is not currently focused on emissions reductions, and life cycle assessments are not carried out to determine the climate impact of blending. However, based on CORSIA default CI values, sugarcane ethanol can provide a very low CI for the production of SAF, while maize offers very limited emissions reductions. Potentially, maize ethanol could be used for blending into gasoline, while sugarcane-based ethanol could be used for SAF production.

Emissions reductions from the use of SAF cannot be claimed under CORSIA and India's Nationally Determined Contributions (NDC) under the Paris agreement as that would constitute double counting. Table 38 lists some of the main policies that could be considered for India.

Table 38. Summary of different types of policies that could be considered.

Type of Policy Intervention	Benefits / Impacts	Comments
Tax Incentive or Exemption	Increase SAF production Stimulate sustainable feedstock production and processing	In India, similar benefits available for producing bioethanol under the NBP-2018 can be extended for SAF as an enabler. Benefits under NGHM for Green H2 production could also be re-structured and offered for SAF production. Climate finance options from institutions like IReDA, NABARD, SIDBI and other PSB (public sector banks) being used may also be leveraged for SAF production Producer tax incentives will likely be far more effective than a blenders tax credit to incentive production, particularly as co-processing will initially be the main route for SAF production. Fuel suppliers in India are already fully committed
Innovation Fund	Fund and promote R&D Promote innovation and best practice in SAF supply	In India, similar benefits available for producing Bioethanol under the NBP-2018 can be extended for SAF as an enabler. Benefits under NGHM for Green H2 production could also be re-structured and offered for SAF production. Climate finance options from institutions like IReDA, NABARD, SIDBI and other PSB (public sector banks) being used may also be leveraged for SAF production Explore options to develop a centralized body to provide advice on feedstock production or into an existing body such as ICAR (Indian Council of Agricultural Research) Provide funding to developing technologies and near-commercial projects through OIDB, CSIR
Capital funding (e.g. Grants, Low-interest loans)	Support first-of-a-kind SAF production plants Support the scale-up of SAF pathways at higher TRL Smaller grants can be provided for earlier TRL levels, e.g. for	In India, similar benefits available for producing Bioethanol under the NBP-2018 can be extended for SAF as an enabler. Benefits under NGHM for Green H2 production could also be re-structured and offered for SAF production. Climate finance options from institutions like IReDA, NABARD, SIDBI and other PSB (public sector banks) being used may also be leveraged for SAF production.

	building pilot scale and demonstrations scale facilities.	
Small grant for financing infrastructure or research	Infrastructure such as blending facilities.	This could also be used to assist studies relating to feedstock supply chains or similar studies.
Contracts for Difference	De-risk first-of-a-kind SAF production plants.	Existing examples used in other sectors can be considered, including the current structure under development in the UK
Direct subsidy	De-risk first-of-a-kind SAF production plants.	In India, similar benefits available for producing bioethanol under the NBP-2018 can be extended for SAF as an enabler. Examples from other regions can be used, e.g., in Australia, the Fuel Security Services Payment pays refiners a production payment during loss-making periods based on the volume of fuels (petrol, diesel, jet fuel) they produce.
Blending mandates	Create an obligation to increase the share of SAF in the jet fuel market. Obligates major CJF producers to ensure SAF is sold. Create long-term, predictable demand.	In India, similar benefits available for producing bioethanol under the NBP-2018 can be extended for SAF as an enabler. Mandates can be structured using examples from regions such as the EU and UK that follow different approaches, e.g. the UK has a buyout option and less strict carbon intensity requirements. Blending mandates should be combined with incentives.
Emission Intensity mandates	Create an obligation to use low-carbon fuels, including SAF, which generates long-term demand.	This type of policy could be structured similar to low carbon fuel standards as used in California and other regions. This will drive the broader climate goals of India as a party to the UNFCCC as it will be applied to all transportation sectors.
Voluntary SAF purchase	Bridge the cost differential of procuring SAF. Improve awareness and transparency around SAF.	Global corporations can sign firm offtake agreements for purchasing SAF to offset Scope 3 emissions. Airline passengers are provided options to offset their climate impact through purchase of SAF. Providing information to passengers on the carbon footprint of travel can create awareness.
Domestic carbon pricing or cap-and-trade	Increase the price of fossil fuels, which decreases their usage and increases SAF demand.	Examples from other regions can be used, such as the EU emission trading system, air carriers must surrender carbon allowances for emissions from intra-EU flights, each representing one tonne of CO_2, equivalent to their emissions reported in the previous year. However, to benefit SAF development, revenue should be diverted into a fund that directly benefits the SAF industry (e.g. Innovation Fund).
Minimum levels of public procurement	Generate critical early demand that helps de-risk and kick-start SAF production. Provide leading example for private off takers.	Where jet fuel is used by government bodies, direct procurement of SAF can be carried out. SAF can also be purchased by the government to offset Scope 3 emissions incurred by the government for travel. As a firm offtake agreement, this could support financing of new facilities.

4.1.4 Recommendation 4 - Develop a sustainability policy harmonized with and including CORSIA standards

Sustainability standards for biofuels and other renewable fuels must be integrated with domestic legislation and harmonized with CORSIA standards and the CORSIA LCA methodology to avoid different standards for different transportation sectors within the same country. For purposes of incentives or funding, additional regulations may apply (e.g., stricter carbon intensity reductions). A sustainability standard that places a value on emissions reductions is important; e.g., greater benefits should be given to SAF that provide greater emissions reductions (or lower carbon intensity).

The DGCA has announced that CORSIA will be the only sustainability framework applicable for both domestic and international aviation and this should be included in legislation or regulations. This is aligned with the ICAO Global Framework for SAF, LCAF and other Aviation Cleaner Energies adopted on 24 November 2023 by its Member States, who agreed (see paragraph 12 of the Framework) that the CORSIA framework should be used globally as the accepted basis for the eligibility of sustainable fuels used in international aviation.

4.1.5 Recommendation 5 – Establish a working group to identify and address feedstock challenges.

Many feedstock challenges were identified in SECTION 2this report. For example, there is a need to increase UCO collection and enforce the unsafe use of UCO for food purposes to provide larger volumes of these waste feedstocks for SAF production.

Feedstock supply chain improvement to optimize and reduce costs is also a critical area that needs to be addressed. The economic production of 2G ethanol from rice straw relies on optimized supply chains that maximize the quantity, quality, and cost of rice straw supplied at 2G ethanol facilities. Standardising harvesting, baling, transport, and storage practices can reduce costs along the supply chain and ensure maximum production at ethanol plants. This must go hand in hand with education and awareness amongst farmers and biomass aggregators.

In the case of MSW, improved collection, sorting, and separation of recyclables must be addressed. Analysis of MSW and determination of biogenic content (C-14 analysis) will assist in identifying the suitability of these waste streams for different technology pathways.

There is competition for different feedstocks, which should be addressed. Bagasse is currently used extensively for bioenergy production but is a highly desirable feedstock for 2G ethanol production. The wider impacts of shifting a feedstock to SAF production rather than the current application.

To ensure that India can produce CORSIA-certified SAF, any potential feedstocks that are considered for SAF production but not currently included as a feedstock in CORSIA must be identified, and the state, in conjunction with feedstock suppliers and SAF producers, must submit an application to CORSIA for its inclusion, plus a clarification on its sustainability and carbon intensity. Some feedstocks in India may also have a lower carbon intensity than current default values under CORSIA, for example, sugarcane Ethanol-to-Jet. Indian advantages should be highlighted and exploited to the maximum.

4.1.6 Recommendation 6 - Demonstrate the SAF downstream supply chain.

Carry out trials at one or more airports with SAF blends being uplifted into aircraft through the hydrant fuel supply. This will demonstrate the supply chain and the safety of SAF to airport personnel, passengers, and the general public. This will also create awareness of SAF and affirm the commitment of stakeholders to SAF development and use. Such a trial will also highlight the practical considerations for blending locations and infrastructure needs. Under ASTM regulations, neat SAF is first approved under the appropriate ASTM D7566 Annex, after which the SAF blend is approved under Table 1 of ASTM D7566. Where such blending takes place outside the airport tank farm, a dedicated blending facility must be in place, as well as the ability to sample and test the SAF blend before insertion into the fuel tank farm.

4.1.7 Recommendation 7 – Assess obstacles for the access of SAF and SAF blends to airports

It is likely that, in the medium to long term, SAF will be produced at different locations to current petroleum refineries, and this will impact the supply of jet fuel and SAF blends to airports. Currently, jet fuel is supplied to airports by pipelines built by Public Sector Undertakings (PSU) oil firms - IOCL, BPCL, and HPCL. These pipelines are not common carrier pipelines, and third parties do not have automatic access under current regulations. Any obstacles that will prevent independent SAF producers from accessing the airport supply chain should be assessed.

4.1.8 Recommendation 8 – Launch an education and awareness campaign

A specific working group can develop an education and awareness campaign with different target audiences and types of media. A five-year plan can be structured and potentially include the organization of a SAF conference in India.

4.2 CRITICAL SUCCESS FACTORS

- Creation of a SAF Council to develop a long-term vision and strategic plan for SAF in India – stakeholders should be represented by CEOs to ensure agreement and real decision-making.
- Implementation of a long-term regulated demand driver, e.g. mandate.
- Integration of SAF within existing biofuels policies to address competition and achieve synergy towards long-term climate goals.
- Implementing policies such as financial mechanisms for SAF development.
- Incorporation of a sustainability framework in domestic legislation for all biofuels and clarifying LCA methodology that is harmonized with CORSIA to prevent separate standards.

4.3 ACTION PLAN

Table 39. Overview of the opportunities and challenges of identifying and establishing viable SAF supply chains in India.

Strengths	Weaknesses
Significant volumes of sustainable feedstocks available Using residues such as rice straw will have broader climate impacts through avoiding burning Development of SAF and construction of SAF plants provide jobs and income to farmers India's government has enacted strong policies for other biofuels	Most SAF technologies not commercial and must still be demonstrated High risk investment High investment costs for construction of SAF plants High production cost of SAF Current policies are not adequate to drive SAF development Competition between aviation and road transportation
Opportunities	**Threats**
Indian airlines can meet CORSIA obligations through SAF SAF plants can also produce other fuels such as renewable diesel and naphtha that can decarbonize other transportation sectors and reduce oil imports India can meet its SAF demand and export SAF to other regions SAF development can address many external challenges facing India such as air pollution India can leverage their advantages in feedstocks to produce low cost SAF compared to other regions India's favourable geographic location positions it for export to South East Asia and Europe	Indian feedstocks are exported rather than used in India for SAF production Favourable policies in other jurisdictions drive export of SAF Lack of supportive and adequate policies in India makes investment in Indian SAF facilities uneconomical

Table 40. Description of recommended actions to identify and establish viable SAF supply chains in India.

SHORT-TERM (2025-2028)	
Technology timeline	Action steps
Co-processing of fats and oils based on waste fats and oils implemented at multiple refineries *Small commercial facility based on CSIR-IIP HEFA technology* *First alcohol-to-jet facility is completed and producing SAF (mainly based on 1G ethanol)* *First waste gas to ethanol facility*	A SAF Council is established and a vision for SAF to 2050 is developed by the council A policy working group is established under the council to design supportive policies are designed by, including long-term and binding targets and financial mechanism such as tax credits. A comprehensive analysis is carried out by the working group to assess the impact of each policy, the funds required and the source of funding Specific areas covered in the policy should include funding for pioneer facilities through capital grants and loan guarantees; ongoing funding for R&D; and funding/grants for small infrastructure projects in the SAF sector and supporting grants Working group to develop a revenue certainty mechanism
	Downstream demonstration of SAF blending and integration at an airport and creating awareness of SAF – lead by airport and fuel supplier
	Set up working group on feedstocks (increasing UCO collection; improving rice straw supply chains)
	Set up working group to develop a domestic policy on sustainability aligned with CORSIA that covers all transportation fuels
	Set up working group to develop education and awareness campaigns for targeted groups with a five-year plan
	Establish a policy on public procurement and SAF - lead by government department responsible for procurement
	Investigate potential aggregated demand and offtake agreement for Scope 1 and 3 emissions reduction to support construction of new facilities -

MEDIUM-TERM (2028 - 2035)	
Technology timeline	Action steps
Further expansion of HEFA production (assume ASTM coprocessing blend limit is increased) *Multiple alcohol-to-jet facilities are completed based on 1G and 2G ethanol* *Multiple 2G ethanol facilities are completed based on bagasse and rice straw as feedstocks, and waste gas fermentation* *Co-processing of waste tire and plastic pyrolysis oil (depending on ASTM approval)* *Pyrolysis and HTL becomes ASTM certified with biocrudes used in co-processing (strong potential for marine fuels as a co-product)* *First PtL facility based on biogenic CO2 from ethanol production*	Ongoing funding for pioneer facility construction and R&D Funding of feedstock expansion, feedstock quality, and feedstock supply chain improvement projects Expand development of alternative oilseeds as feedstocks Carry out studies to develop improved and cost-effective supply chains for feedstocks such as rice straw Involve bodies like ICAR in feedstock research for SAF development that meets sustainability criteria. Apart from long term targets, they can also contribute to some mid-term targets listed above
LONG-TERM (2035 - 2050)	
Technology timeline	Action steps
2G ethanol expands to supply more AtJ facilities (waste gas fermentation and cellulosic ethanol from bagasse and rice straw) *Multiple facilities using gasification and FT synthesis based on MSW* *PtL facilities based on biogenic CO_2 from ethanol production* *PtL facilities based on waste gas capture*	Ongoing assessment of progress in meeting the long-term visions for SAF development Identify technologies that are still emerging, along with the financing, R&D, or other support needed for their development. Participation of Indian innovation bodies like CSIR, ANRF, Academic Institutions (IITs/NITs), supplemented with funding through bodies like OIDB and Climate Finance Institutions to be explored. Apart from long term targets, they can also contribute to some mid-term targets listed above Ongoing assessment of potential cost improvements in feedstock and production costs with a view to SAF production for export

REFERENCES

Agarwal, A., Prakash, O., & Bala, M. (2021). Camelina sativa, a short gestation oilseed crop with biofuel potential: Opportunities for Indian scenario. In *Oil Crop Science* (Vol. 6, Issue 3, pp. 114–121). KeAi Communications Co. https://doi.org/10.1016/j.ocsci.2021.07.001

Agribusiness Valorinternational. (2024). *Raízen to build cellulosic ethanol plant in Goiás*. https://valorinternational.globo.com/agribusiness/news/2024/10/02/raizen-to-build-cellulosic-ethanol-plant-in-goias.ghtml

Agriculture| National Portal of India. (n.d.). Retrieved August 17, 2025, from https://www.india.gov.in/topics/agriculture

ALL INDIA DISTILLERS ASSOCIATION. (n.d.). Retrieved August 17, 2025, from https://www.aidaindia.org/about-aida.html

Ananth, P., Ghai, D., & Girdhar, V. (2023). Decarbonization of the Indian Pulp and Paper sector. *Quarterly Journal of Indian Pulp and Paper Technical Association*, *35*, 62–65.

Argus Media. (2024). *Japan aims to tighten SAF supply regulations*. https://www.argusmedia.com/en/news-and-insights/latest-market-news/2582074-japan-aims-to-tighten-saf-supply-regulations

Argus Media. (2025). *Brazil SAF industry set to take off in 2027*. https://www.argusmedia.com/en/news-and-insights/latest-market-news/2674362-brazil-saf-industry-set-to-take-off-in-2027

ASTM. (n.d.). *D4054 Standard Practice for Evaluation of New Aviation Turbine Fuels and Fuel Additives*. Retrieved August 17, 2025, from https://store.astm.org/d4054-24.html

BBC. (2025). *Millions of UK tyres meant for recycling sent to furnaces in India*. https://www.bbc.com/news/articles/c14jy2dd8jeo

Biobased Diesel Daily. (n.d.). *Requirements and Solutions for Pretreatment of HVO Feedstocks*. Retrieved August 17, 2025, from https://www.biobased-diesel.com/post/requirements-and-solutions-for-pretreatment-of-hvo-feedstocks

BioBiz. (n.d.). *Sawdust in India - Availability, Supply Chain, Prices, Surplus*. Retrieved August 17, 2025, from https://biobiz.in/s/bring/in/2

Brandt, K., Geleynse, S., Martinez-Valencia, L., Zhang, X., Garcia-Perez, M., & Wolcott, M. P. (2021). *Alcohol to jet techno-economic analysis, v. 2.2*. Washington State University. https://doi.org/10.7273/000001461

Brandt, K., Tanzil, A. H., Martinez-Valencia, L., GARCIA-PEREZ, M., & Wolcott, M. P. (2021a). *Fischer Tropsch techno-economic analysis, v. 2.2*. Washington State University. https://doi.org/10.7273/000001459

Brandt, K., Tanzil, A. H., Martinez-Valencia, L., GARCIA-PEREZ, M., & Wolcott, M. P. (2021b). *Hydroprocessed esters and fatty acids techno-economic analysis, v. 2.2*. Washington State University. https://doi.org/10.7273/000001460

Brandt, K., Tanzil, A. H., Martinez-Valencia, L., Garcia-Perez, M., & Wolcott, M. P. (2023). Pyrolysis techno-economic analysis, v. 2.2. In *Open access database*. Washington State University. https://rex.libraries.wsu.edu/esploro/outputs/dataset/Pyrolysis-techno-economic-analysis-v-21/99900630810201842

Brandt, K., & Wolcott, M. P. (2021). *Fischer Tropsch feedstock pre-processing techno-economic analysis, v. 2.1*. Washington State University. https://doi.org/10.7273/000001463

CAAFI | Commercial Aviation Alternative Fuels Initiative. (n.d.). *TOOLS*. Retrieved August 17, 2025, from https://www.caafi.org/tools

Capgemini. (2025). *Out of the frying pan, into the sky*.

Central Electricity Authority. (n.d.). *Executive Summary Report - Central Electricity Authority*. Retrieved August 17, 2025, from https://cea.nic.in/executive-summary-report/?lang=en

Central Pollution Control Board, D. (2021). *Annual Report 2020-21 on Implementation of Solid Waste Management Rules, 2016*.

Chand Malav, L., Yadav, K. K., Gupta, N., Kumar, S., Sharma, G. K., Krishnan, S., Rezania, S., Kamyab, H., Pham, Q. B., Yadav, S., Bhattacharyya, S., Yadav, V. K., & Bach, Q. V. (2020). A review on municipal solid waste as a renewable source for waste-to-energy project in India: Current practices, challenges, and future opportunities. *Journal of Cleaner Production*, *277*. https://doi.org/10.1016/j.jclepro.2020.123227

Chemical and Engineering News. (2024). *Fulcrum BioEnergy abandons trash-to-fuel plant in Nevada*. https://cen.acs.org/energy/Fulcrum-BioEnergy-abandons-trashfuel-plant/102/web/2024/06

Chinimandi. (n.d.). *Minister on sugar MSP hike demand: Govt consulting with other concerned Ministries/Departments and seeking comments - ChiniMandi*. Retrieved August 17, 2025, from https://www.chinimandi.com/minister-on-sugar-msp-hike-demand-govt-consulting-with-other-concerned-ministries-departments-and-seeking-comments/

ChiniMandi. (2025). *Minister on sugar MSP hike demand: Govt consulting with other concerned Ministries/Departments and seeking comments* -. https://www.chinimandi.com/minister-on-sugar-msp-hike-demand-govt-consulting-with-other-concerned-ministries-departments-and-seeking-comments/

Clariant. (2023). *Clariant shuts its sunliquid® bioethanol plant in Romania*. https://www.clariant.com/en/Corporate/News/2023/12/Clariant-shuts-its-sunliquid-bioethanol-plant-in-Romania

CSIRO. (2023). *India generates 26,000 tonnes of plastic waste every day. This is how we reduce that number.* https://www.csiro.au/en/news/all/articles/2023/december/circular-economy-roadmap-india

Deloitte. (2024). *Green wings India's SAF revolution in the making*.

Dhodapkar R, Bhattacharjya S, Niazi Z, Porter NB, Retamal M, Sahajwalla V, & Schandl H. (2023). *National Circular Economy Roadmap for Reducing Plastic Waste in India*.

Directorate of Economics and Statistics. (n.d.). *Statewise land use*. Retrieved September 7, 2025, from https://desagri.gov.in/wp-content/uploads/2024/09/Final-file-of-LUS-2022-23-for-uploading.pdf

DOE. (2016). *Biorefinery Optimization Workshop Summary Report*. *October 2016*. https://static1.squarespace.com/static/53a09c47e4b050b5ad5bf4f5/t/58b5928203596ec6631c4065/1488294533706/biorefinery_optimization_workshop_summary_report.pdf

Down to Earth. (2018). *Biodiesel in India: The Jatropha fiasco*. https://www.downtoearth.org.in/energy/biodiesel-in-india-the-jatropha-fiasco-61321

EASA. (2024). *2024 Aviation Fuels Reference Prices for ReFuelEU Aviation EASA*. https://www.easa.europa.eu/en/document-library/general-publications/2024-aviation-fuels-reference-prices-refueleu-aviation

Food and Agricultural Organization. (2022). ESTABLISHING RESIDUE SUPPLY CHAINS TO REDUCE OPEN BURNING THE CASE OF RICE STRAW AND RENEWABLE ENERGY IN PUNJAB, INDIA. In *The role of genetic resources for food and agriculture in adaptation to and mitigation of climate change*. FAO. https://doi.org/10.4060/cb9570en

FSSAI. (n.d.). *Handling and disposal of used cooking oil*. Retrieved August 17, 2025, from https://www.google.com/url?client=internal-element-cse&cx=009166207481149357514:nohrtd59j_a&q=https://www.fssai.gov.in/upload/uploadfiles/files/Guidance_Note_Used_Oil_12_11_2018.pdf&sa=U&ved=2ahUKEwjNoaXaopWPAxWFVjUKHZWUBrgQFnoECAcQAg&usg=AOvVaw3LS-g322iuFOMUhcMpONR6

GreenAir News. (2025). *Major boost for SAF production as UK fuel standards body approves raising co-processing blend limit to 30%*. https://www.greenairnews.com/?p=7289

IATA. (2023). *SAF deployment*.

ICAO. (n.d.-a). *Conversion processes*. Retrieved August 17, 2025, from https://www2023.icao.int/environmental-protection/GFAAF/Pages/Conversion-processes.aspx

ICAO. (n.d.-b). *Conversion processes*. Retrieved August 17, 2025, from https://www2023.icao.int/environmental-protection/GFAAF/Pages/Conversion-processes.aspx

ICAO. (n.d.-c). *CORSIA default life cycle emission values*. Retrieved August 17, 2025, from https://www.icao.int/sites/default/files/environmental-protection/CORSIA/Documents/CORSIA%20Eligible%20Fuels/ICAO-document-06-Default-Life-Cycle-Emissions-June-2025.pdf

ICAO. (n.d.-d). *SAF Offtake Agreements*. Retrieved August 17, 2025, from https://www2023.icao.int/environmental-protection/GFAAF/Pages/Offtake-Agreements.aspx

ICAO. (n.d.-e). *SAF Rules of Thumb*. Retrieved August 17, 2025, from https://www.icao.int/environmental-protection/saf-rule-of-thumb

ICAO. (2024). *SAF Guidance Potential Policies*. https://www.icao.int/environmental-protection/saf-guidance-potential-policies

IDR Online. (2024). *Waste to energy: Smokescreen or solution?* https://idronline.org/article/climate-emergency/waste-to-energy-smokescreen-or-solution/

IEA. (n.d.). *India - Countries & Regions - IEA*. Retrieved August 17, 2025, from https://www.iea.org/countries/india/energy-mix

IEA. (2024). *Carbon Accounting for Sustainable Biofuels*. www.iea.org

India: CO2 Country Profile - Our World in Data. (n.d.). Retrieved August 17, 2025, from https://ourworldindata.org/co2/country/india

India: Leading Agricultural Product Exporters. (n.d.). Retrieved August 17, 2025, from https://www.ibef.org/exports/agriculture-and-food-industry-india

Indian sugar mills association. (n.d.). Retrieved August 17, 2025, from https://www.indiansugar.com/NewsDetails.aspx?nid=42607

Indian sugar mills association Statistics. (n.d.). Retrieved August 17, 2025, from https://www.indiansugar.com/statics.aspx

Jamal, F. (2023). *Accelerating Biodiesel Blending in India | TERI*. https://www.teriin.org/policy-brief/accelerating-biodiesel-blending-india

Jet Zero Council - GOV.UK. (n.d.). Retrieved August 17, 2025, from https://www.gov.uk/government/groups/jet-zero-council

Joint Inspection Group. JIG - Aviation Fuel Supply Standards. (n.d.). Retrieved August 17, 2025, from https://www.jig.org/

Know India: National Portal of India. (n.d.). Retrieved August 17, 2025, from https://knowindia.india.gov.in/profile/rivers.php

Konde, K. S., Nagarajan, S., Kumar, V., Patil, S. V., & Ranade, V. V. (2021). Sugarcane bagasse based biorefineries in India: Potential and challenges. *Sustainable Energy and Fuels*, *5*(1), 52–78. https://doi.org/10.1039/d0se01332c

Kumar Vijay, M. (2024). Tree-Borne Oilseed Cultivation: Research Gaps and Future Perspective. In *Seed Res* (Vol. 52, Issue 2). https://www.researchgate.net/publication/387456815

Land Resources And Land Use Patterns In India. (n.d.). Retrieved August 17, 2025, from https://pwonlyias.com/udaan/land-resources/

Land Use Statistics – At a Glance. (n.d.). Retrieved August 17, 2025, from https://desagri.gov.in/document-report-category/land-use-statistics-at-a-glance/

Li, M., Xu, F., Zhao, Y., Sun, D., Liu, J., Yin, X., Li, Z., Zhao, J., Li, H., & Bao, X. (2023). High-Efficient Production of Cellulosic Ethanol from Corn Fiber Based on the Suitable C5/C6 Co-Fermentation Saccharomyces cerevisiae Strain. *Fermentation*, *9*(8). https://doi.org/10.3390/fermentation9080743

Lin, Y., Sadekuzzaman Roni, M., Thompson, D. N., Hartley, D. S., Griffel, M., & Cai, H. (2020). *HERBACEOUS FEEDSTOCK 2020 STATE OF TECHNOLOGY REPORT*. http://www.inl.gov

List of Sawmills in India. (n.d.). Retrieved August 17, 2025, from https://rentechdigital.com/smartscraper/business-report-details/list-of-saw-mills-in-india

Mani, M., Bandyopadhyay, S., Chonabayashi, S., Markandya, A., & Mosier, T. (2018). *South Asia's Hotspots: The Impact of Temperature and Precipitation Changes on Living Standards*. https://doi.org/10.1596/978-1-4648-1155-5',

Ministry of Environment, F. and C. C. G. of I. (n.d.). *Waste-Tyre*. Retrieved August 17, 2025, from https://eprtyres.cpcb.gov.in/

Ministry of New and Renewable Energy. (n.d.). *Overview and current status of CBG in India*. Retrieved August 17, 2025, from https://cdn.cseindia.org/attachments/0.11235300_1687759489_cse---overview-and-current-status-of--cbg-in-india.pdf

MINISTRY OF NEW AND RENEWABLE ENERGY. (n.d.). *Waste to Energy Programme India*. Retrieved August 17, 2025, from https://mnre.gov.in/en/waste-to-energy/

Ministry of Petroleum and Natural Gas. (n.d.). *National Biofuels Policy*. Retrieved August 17, 2025, from https://mopng.gov.in/en/page/11

Ministry of Power. (n.d.). *Power Sector at a Glance ALL INDIA | Government of India*. Retrieved August 17, 2025, from https://powermin.gov.in/en/content/power-sector-glance-all-india

Modern Diplomacy. (2024). *China's New Policy on Sustainable Aviation Fuel (SAF): A Step Towards Greener Future*. https://moderndiplomacy.eu/2024/08/22/chinas-new-policy-on-sustainable-aviation-fuel-saf-a-step-towards-greener-future/

Mongabay. (2024). *[Explainer] Why are waste tyres a growing environmental concern?* https://india.mongabay.com/2024/02/explainer-why-are-waste-tyres-a-growing-environmental-concern/

Norton Rose Fulbright. (2024). *A new sustainable aviation fuel mandate: The UK Government's latest step in supporting the decarbonisation of the UK aviation industry*. https://www.nortonrosefulbright.com/es-mx/knowledge/publications/b5f9f70c/a-new-sustainable-aviation-fuel-mandate

OECD. (2022). *Global Plastics Outlook*. https://www.oecd.org/en/publications/2022/06/global-plastics-outlook_f065ef59.html

Overview and Status of CBG in India. (n.d.).

Profile - India At A Glance - Know India: National Portal of India. (n.d.). Retrieved August 14, 2025, from https://knowindia.india.gov.in/profile/india-at-a-glance.php

Prussi, M., Lee, U., Wang, M., Malina, R., Valin, H., Taheripour, F., Velarde, C., Staples, M. D., Lonza, L., & Hileman, J. I. (2021). CORSIA: The first internationally adopted approach to calculate life-cycle GHG emissions for aviation fuels. In *Renewable and Sustainable Energy Reviews* (Vol. 150). Elsevier Ltd. https://doi.org/10.1016/j.rser.2021.111398

Reuters. (n.d.). *India's fast economic growth lays firm ground for next government*. Retrieved August 17, 2025, from https://www.reuters.com/world/india/indias-march-qtr-gdp-growth-78-yy-2024-05-31/

Roy, P. S., Roy, A., Joshi, P. K., Kale, M. P., Srivastava, V. K., Srivastava, S. K., Dwevidi, R. S., Joshi, C., Behera, M. D., Meiyappan, P., Sharma, Y., Jain, A. K., Singh, J. S., Palchowdhuri, Y., Ramachandran, R. M., Pinjarla, B., Chakravarthi, V., Babu, N., Gowsalya, M. S., … Kushwaha, D. (2015). Development of Decadal (1985–1995–2005) Land Use and Land Cover Database for India. *Remote Sensing 2015, Vol. 7, Pages 2401-2430*, *7*(3), 2401–2430. https://doi.org/10.3390/RS70302401

Satat : Home. (n.d.). Retrieved August 17, 2025, from https://satat.co.in/satat/#/

Sharma, K. D., & Jain, S. (2019). Overview of Municipal Solid Waste Generation, Composition, and Management in India. *Journal of Environmental Engineering*, *145*(3). https://doi.org/10.1061/(asce)ee.1943-7870.0001490

Statista. (2024). *The Indian Waste-to-Energy Failure*. https://www-statista-com.eu1.proxy.openathens.net/chart/33467/number-of-waste-to-electricity-plants-in-india/

Tallow Production in India. (n.d.). Retrieved August 17, 2025, from https://www.reportlinker.com/dataset/67b99467e1838abefe77bd96f21547a47510af31

The Economic Times. (n.d.-a). *Create a direct correlation between FRP and sugar selling price, says ISMA's Deepak Ballani*. Retrieved August 17, 2025, from https://economictimes.indiatimes.com/small-biz/sme-sector/create-a-direct-correlation-between-frp-and-sugar-selling-price-says-ismas-deepak-ballani/articleshow/118570809.cms?from=mdr

The Economic Times. (n.d.-b). *Government launches programme for converting used cooking oil into biodiesel in 100 cities*. Retrieved August 17, 2025, from https://economictimes.indiatimes.com/industry/energy/oil-gas/government-launches-programme-for-converting-used-cooking-oil-into-biodiesel-in-100-cities/articleshow/70617703.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst

The Economic Times Energy. (2025a). *Govt plans National Green Financing Institution to achieve climate goals: NITI Aayog*. https://energy.economictimes.indiatimes.com/news/renewable/govt-plans-national-green-financing-institution-to-achieve-climate-goals-niti-aayog/118556877

The Economic Times Energy. (2025b). *IREDA to raise ₹5,000 crore through QIP; govt stake to be diluted by up to 7%*. https://energy.economictimes.indiatimes.com/news/renewable/ireda-to-raise-5000-crore-through-qip-govt-stake-to-be-diluted-by-up-to-7/118543664

The Hindu BusinessLine. (2024). *India becomes dumping ground of waste tyres, need to act fast: ATMA*. https://www.thehindubusinessline.com/economy/logistics/india-becomes-dumping-ground-of-waste-tyres-need-to-act-fast-atma/article67813031.ece

Think Tank, E. P. (2022). *ReFuelEU Aviation initiative: Sustainable aviation fuels and the fit for 55 package | Think Tank | European Parliament*. https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2022)698900

UK Sustainable Aviation Fuels (SAF) Clearing House. (n.d.). Retrieved August 17, 2025, from https://www.safclearinghouse.uk/

US Department of Agriculture. (2025). *Biofuels Annual*.

US Department of Energy - BETO. (2023). *2023 Billion-Ton Report: An Assessment of U.S. Renewable Carbon Resources*. https://www.energy.gov/eere/bioenergy/2023-billion-ton-report-assessment-us-renewable-carbon-resources

US Dept of Energy. (n.d.). *Sustainable Aviation Fuel Grand Challenge Roadmap Implementation Framework Fact Sheet*. Retrieved August 17, 2025, from https://www.energy.gov/eere/bioenergy/articles/sustainable-aviation-fuel-grand-challenge-roadmap-implementation-framework

USDA. (2022). *Oilseeds and Products Annual - Canada*.

USDA. (2024). *Biofuels Annual India*. https://pib.gov.in/PressReleasePage.aspx?PRID=1988727#:~:text=2023%2C%20the%20ethanol%20production%20

USDA Foreign Agricultural Service. (2024). *Sugar semi-annual*.

Viability Gap Funding Scheme - Public Private Partnerships in India. (n.d.). Retrieved August 17, 2025, from https://www.pppinindia.gov.in/vgfguidelines

Volpe National Transportation Systems Center. (n.d.). *The Freight and Fuel Transportation Optimization Tool*. Retrieved August 17, 2025, from https://www.volpe.dot.gov/our-work/policy-planning-and-environment/volpe-tool-evaluates-freight-and-fuel-transport-options

World Bank Group. (2018). *What a Waste 2.0*.

World Economic Forum. (2021). *Deploying Sustainable Aviation Fuels at Scale in India*.

WSS Energy Consulting. (n.d.). *Sourcing and use of biogenic CO_2 - and associated challenges*. Retrieved August 17, 2025, from https://www.wssenergy.com/post/sourcing-and-use-of-biogenic-co%E2%82%82---and-associated-challenges

Yale Program on Climate Change Communication. (2023). *Climate Change in the Indian Mind,*. https://climatecommunication.yale.edu/publications/climate-change-in-the-indian-mind-2023/toc/3/

Zhou, Y., Searle, S., & Anup, S. (2021). *TECHNO-ECONOMIC ANALYSIS OF CELLULOSIC ETHANOL IN INDIA USING AGRICULTURAL RESIDUES*. www.theicct.orgcommunications@theicct.org

APPENDIX – STAKEHOLDER ENGAGEMENT

LIST OF STAKEHOLDERS PRESENT DURING KICK-OFF WORKSHOP ON 23 / 24 JANUARY 2025

- DGCA India
- ICAO
- EASA
- CBR-Partner
- FAA
- IOCL
- IOCL R&D
- Manager (AE)
- HPCL
- BPCL
- MRPL
- Reliance Ind
- Praj
- LanzaTech
- LanzaJet
- EIL
- EIL
- Hyd
- BIAL, B'lore
- NIAL
- Blue Stone Energy
- RRSP Mktg Pvt Ltd
- M11 Industries Pvt Ltd
- ISMA
- BIS
- QCI
- NABCB
- Air India
- AI Express
- AIRBUS
- BOEING

LETTER TO ALL THE PARTICIPANTS INVOLVED IN THE KICK-OFF WORKSHOP

Dear Valued SAF Stakeholder & Participant in above workshop,

The 2-day interaction we had on the subject was indeed an invaluable learning experience for all of us who participated.

Many aspects of SAF, including the following, were discussed, and deliberated by all concerned stakeholders:

(i) feedstocks (both currently qualifying under CORSIA and also those having potential to qualify); this includes all

(ii) technology pathways (both currently ASTM approved and also those under in-process of approval)

(iii) potential SAF production capacity creations at different locations (near refinery or otherwise)

(iv) infrastructure creation for feedstock aggregation, SAF production and SAF blending (in to ATF) and it's supply to airport facilities,

(v) SAF Sustainability Certification (by the international bodies approved for the purpose)

(vi) eligibility of ensuing CORSIA credits on production and sale of SAF and their trading mechanism

The ICAO Consultant team for the India Business Study Report, with the facilitation by DGCA, would like to continue this dialogue with the stakeholders on all topics of discussion listed above, to get valuable insights and specific inputs that would go towards making of the Feasibility Study and Business Implementation Study being prepared, very meaningful, purposeful and implementable for the benefit of India to join the league of nations producing and trading in SAF.

We would, therefore, look towards receiving specific inputs from each one of you in the SAF value chain, preferably in the form of brief note, which covers the following areas:

(1) General –

a. What do you consider to be the main obstacles/challenges to the development of domestic production and consumption of SAF in India?

b. What is necessary, in your opinion, to overcome these obstacles?

c. What types of policies do you think should be considered/implemented in India to promote the production and consumption of SAF.

(2) Feedstocks –

a. If you are a potential feedstock supplier for SAF production, please provide information on the type of feedstock and potential volumes that are available in India.

b. Are there any additional feedstocks that you think should be included in the Feasibility study? UCO, TBO, Tallow, Nonedible oils, Agri-residue (including bagasse), all forms of MSW; other than above listed, sources of biogenic CO2 (from ethanol, pulp and paper, Biogas plants), waste tires and waste plastics as well for which valorisation towards SAF production can be examined by the ICAO team.

c. What are the challenges for accessing feedstocks and using it for SAF production?

d. What types of policies and/or regulations do you think are necessary to access and utilize feedstocks for SAF production in India.

(3) Technology pathways –

a. If you are a technology provider, briefly describe your technology.

b. What is the TRL of the pathway and what type(s) of feedstock will be required for the pathway?

c. In your opinion, what are the challenges for developing this technology and commercialising it for SAF production?

d. What types of policies and/or regulations do you think are necessary for developing SAF technologies in India?

(4) SAF production capacity creation

a. Are you planning a SAF production facility in India?

b. What is the proposed location, technology, and feedstock? Please provide a website or other information

c. What is the current status of the plans, e.g. Announcement, permitting, FEED, FID, etc.

d. Do you have or plan to sign an offtake agreement with a potential SAF consumer?

e. In your opinion, what are the challenges for developing this technology and commercialising it for SAF production?

f. What types of policies and/or regulations do you think are necessary for developing SAF technologies in India?

(5) SAF Sustainability Certification under CORSIA

a. Are you experiencing any challenges with obtaining CORSIA sustainability certification for your feedstock or fuel?

b. Are there any other obstacles to obtaining sustainability certification, e.g. chain of custody issues with feedstock suppliers?

(6) Upstream and downstream supply chains for SAF production and SAF delivery to airports

a. What are the obstacles for feedstock supply chains and what types of actions (e.g. regulations and policies) are needed to overcome these obstacles?

b. What are the obstacles for downstream supply of SAF to airports, e.g., understanding the logistics, absence of blending locations? How can this be addressed?

(7) Policies needed

a. SAF production costs are projected to be much higher than conventional jet fuel. What policies are needed to assist producers in lowering this price gap?

b. What policies are needed for airlines to purchase SAF at higher prices?

c. Who should contribute to the high cost of SAF?

d. How can SAF production and consumption be supported by policies or other actions?

In case any of the SAF value chain stakeholders would like to add anything from their side into the note other than what has been listed above they are welcome to do so.

SUMMARY OF STAKEHOLDER INPUTS

As India is working on its internal SAF policy and roadmap, it is imperative that a holistic view is taken on existing SAF feedstocks and regulations around the world. Becoming the world's leading SAF provider will require the creation of a SAF ecosystem underpinned by strong, long-term policy incentives for feedstock, production, and utilization of SAF. India has significant potential to be the global leader in SAF production due to strong supply side dynamics, including significant sources of low carbon-intensity feedstocks such as: energy crops, agricultural waste, industrial and refinery off gases, and MSW.

General

- *Main obstacles/challenges would be clarity in policy on expected taxation, price and mandate for development of domestic production of SAF.*
- *Clarity from the government on policy and taxation which would encourage production.*
- *A digital platform to be created where all the feedstock suppliers, SAF producers, certification agencies, airliners come together for collaborative business deals*
- *Promote partnerships (national/international)*
- *streamlined authorization, permitting, and paperwork processes for plant construction.*
- *Enhance "indigenous technologies" through various R&D centres*
- *R&D Grants and Funding*
- *Support the establishment of pilot and demonstration plants to validate SAF technologies and generate data for commercialization.*
- *Facilitate collaborations between research institutions, technology providers, and industry players to accelerate technology development and deployment.*
- *Improve Public Awareness*
- *Institute well defined guidelines (both incentives & deterrents) to blenders, to airports, airlines etc in support of establishing OFFTAKE agreements from producers*
- *SAF can be considered as an additive to ATF and its price can be delinked from ATF.*

Policy and financing recommendations

Clear and stable regulations

Blending mandate

- *Firm Blending Mandates gradually involving domestic aviation sector in a phased manner.*
- *Up to 2050 and beyond*
- *To include penalties for non-compliance*
- *since SAF is a drop-in fuel, encouragement to be given for maximum blending and not restricting to any specific percentage level*
- *both supply-side and demand-side policies will be critical to get this nascent industry off the ground. Demand-focused policies such as ambitious mandate*

- *Mandates need to take a long-term view with targets increasing over time. Ambitious mandates are important, as early mandates can be easily met by existing production, mandates need to incorporate mechanisms such as a HEFA cap to drive advanced technologies such as alcohol-to-jet and newer technologies that will be more poised to scale to meet global demand.*
- *Providing Incentives or mandates with penalties as done in other parts of the world.*

Financing mechanisms

- *supply and demand-side policy mechanisms*
- *Tax credits to SAF producers;*
- *a purchasers tax credit on a per-gallon basis*
- *Financial incentives such as production-linked incentives, tax credits, and direct subsidies*
- *Tax exemptions on feedstock procurement,*
- *capital grants for SAF producers,*
- *reduced GST on SAF*
- *Viability Gap Funding*
- *SAF Certificates that can be traded in Carbon Credit market;*
- *Passenger SAF levy*
- *Subsidies based on GHG emission reductions;*
- *Credit for emissions reduction;*
- *Incentivize sustainability*
- *carbon credit-based incentives, tax incentives on SAF usage*
- *Revenue certainty mechanism e.g. Guaranteed Strike Price, Buyer of last resort, Mandate Floor price as in the UK*
- *Clean Fuel Production Credit*
- *Subsidized feedstocks*
- *an Emissions Trading Scheme (ETS) on domestic and international flights in India, with allowances for SAF*
- *A clear incentivized taxation mechanism to be defined for the SAF and the blended fuel. SAF to be introduced under GST mechanism.*
- *Blended fuel shall also be under the GST mechanism so that the blender and end user can claim the GST offset*
- *Tax for blended fuel should be applied in the proportion of the blending % instead of a single tax rate on the full value.*
- *Capital cost subsidy (Viability Gap Funding- VGF) to ease the capital expenditure burden. Extended PM JI-VAN Yojana to SAF should allow larger scale up of the newer technologies.*
- *Clean tech funds, climate CSR funds need to divert for capital subsidy at a lower IRR expectation.*
- *About 50% Interest subvention for first 10 projects of AtJ pathway with low (5 to 6%) rates.*
- *The government can also fix the price for the first 5 years to ensure steady and predictable SAF pricing to encourage capacity augmentation.*
- *Govt shall also ensure offtake guarantees for the first five or ten plants for 10 years.*
- *Further incentives to producers linked to the fuel's CI score will be established. This will encourage the industry to reduce fuel CI.*
- *Export orientation: The government should allow the export of SAF to diversify the demand for fuel and encourage investments in the field*

- *SAF production and consumption be supported by creation of hubs with special incentives*
- *Provide incentive on commercializing technology and scaling up technology*
- *Incentives for Technology Adoption: Offer tax breaks, subsidies, and other incentives to encourage the adoption of indigenous SAF production technologies.*
- *Incentives should last 10 years*
- *Production and purchaser tax credits on a per gallon basis in the United States as in the US or a low carbon fuel standard type policy*
- *Production linked incentives to be provided to SAF producers based on volume of SAF produced. SAF pricing model to be developed considering carbon credits*
- *: Capital subsidies, tax incentives, and viability gap funding (VGF), loans at lower interest rates may be provided to encourage SAF production*
- *Incentives also play a key role in getting these first and second of a kind plants built. Significant CAPEX support early on in these projects goes a long way to reduce overall cost of the businesses and helps reduce the overall risk profile for these innovative companies working to build a new industry and compete against an 80-year-old fossil jet fuel industry. These incentives can come in the form of grants, low interest loans, or loan guarantees. Large CAPEX grants or investment tax credits – the likes of which have been particularly successful in Japan, with smaller grants for pre-Final Investment Decision (FID) development such as the UK Advanced Fuels Fund or ARENA in Australia also being useful.*
- *Financing programs and tax policies that reduce risk and encourage private sector capital investment in SAF production are required*
- *Tax Incentives and Subsidies for SAF Production: Financial incentives such as production-linked incentives, tax credits, and direct subsidies can reduce the cost gap between SAF and fossil-based aviation fuel. Tax exemptions on feedstock procurement, capital grants for SAF producers, and reduced GST on SAF can enhance economic viability.*
- *Implementation Carbon Credit and Tax System*
- *Incentives for SAF production or mandate with penalties as done in other countries.*

Who should cover the higher cost of SAF?

- *Government through incentives, Airlines through premium pricing on SAF, and end consumers through minimal price increase on tickets,*
- *Public in general;*
- *High per capita polluting regions with pre-defined thresholds to aid contributions*
- *Oil Marketing companies should take the cost burden*
- *Emission Trading Scheme (ETS)*
- *Reduced or waived landing, parking or navigation charges for flights operating with SAF*
- *credits for Scope and Scope 2 emission offsetting*
- *Government should subsidise SAF or should include SAF blended fuel under GST to encourage Scheduled and non-scheduled operators to use SAF blended fuel.*

Book and claim

- *Introduction of Book-and-Claim procedures and SAF credits / Certificates system;*
- *Book and Claim recognition*

- *Voluntary purchases and Scope 3 emissions - Voluntary SAF certificates purchase programme for Corporates*
- *Corporate Voluntary Program for Scope 3 emissions*

Feedstocks

- *Organise Feed stock supply chain*
- *ensuring consistent feed stock quality to the SAF plant*
- *Addressing competition (e.g., biodiesel production, ethanol),*
- *Long-term contracts to be mandated between Feed supplier and SAF producer.*
- *Incentives to promote sustainable behaviour by users and for collection.*
- *Domestic ethanol production should therefore be directed towards Sustainable Aviation Fuel (SAF) due to its abundance and versatility, and the ability to make it from various feedstocks such as Municipal Solid Waste (MSW), agricultural waste, energy crops, and off-gases.*
- *not picking and choosing feedstock winners and losers.*
- *Centralized collection efforts - "hub and spoke" centres and facilities for collection to aid in lowering the cost and increasing the efficiency of production of fuels from these feedstocks.*
- *Funding for feedstock and intermediary product producers to aid the development of the market - support for infrastructure across the whole value chain, from feedstocks to production facility, through to supplying SAF to the airports.*
- *Allow use of sugarcane-based 1G ethanol (the lowest hanging fruit)*
- *Grain Based 1G Ethanol: India has capacity to produce 5to 8 Bn Litres of ethanol from the grains. With technology to lower the CI score and when the carbon capture technologies are deployed in India, this is also a potential feedstock for the SAF.*
- *As UCO and other non-edible oil availability is very limited in India, cultivation of short-duration or rotational crops and also plantation of oil-bearing trees like Pongamia, Jatropha to be encouraged.*
- *Imports of UCO, POME and other suitable feedstock imports to be allowed for production of SAF in India.*
- *Variety of feedstock is available in India such as (i) agriculture residues, (ii) maize/sugar production (iii) used cooking oil, (iv) municipal solid waste, among others. However, challenges are in terms of feedstock being collected and purposed for SAF production. Thus, aggregation of feedstock is the foremost challenge. This requires detailed feedstock assessment and establishment of robust value chain.*
- *Introduction of EPR (Extended Producer Responsibility) on Suppliers of Edible Oil so that a mandatory proportion of edible oil will be recovered as UCO by the suppliers.*
- *Ban on export/ High Export Tariff of feedstocks for SAF such as UCO will act as an embargo and also reduce the costs.*
- *Categorization of molasses as a 'waste' to enable a better Carbon Intensity score for SAF*

Improve feedstock availability

- *Ban on feedstock exports*
- *discouraging biomass burning,*
- *enforcement of policies such as Extended Producer Responsibility (EPR) for UCO, etc.*

- *Policies should facilitate access to feedstock for project developers - measures to prevent excessive competition for feedstock—such as ring-fencing a portion specifically for SAF*
- *curtailing the exports of used cooking oil.*
- *subsidies for collection, storage, and transportation to encourage participation from farmers and waste generators.*
- *HEFA feedstocks - setting up of regional collection centers with pre-processing units can reduce the availability risks and maintain the feed quality.*
- *Adequate storage facilities and effective transportation networks by UCO aggregators and other feed stock collectors*
- *Government supported programs to organize and incentivize the collection and aggregation of feedstocks, especially from small-scale farmers and households may be implemented.*
- *Subsidies and incentives to be provided for the development of storage facilities, transportation networks, and pre-processing plants near feedstock sources.*
- *Policies should be considered to increase the competitiveness of using these feedstocks to create bio- based ethanol and SAF. As of now, without government support, these feedstocks have more incentive to remain as wastes polluting land and air, missing valuable opportunities to displace virgin fossil feedstocks*
- *separate Public sectors may also be created for making availability of Feedstocks on sustainable basis for not only SAF, but for other Bio-Fuels also*

Adding feedstocks not currently under CORSIA

- *Waste gas from refineries to be included in acceptable feed list for 3G ethanol production*
- *Fossil CO2 from refineries also to be included in the list*
- *Other non-edible tree borne oils such as Pongamia which is abundantly available in India may be studied and added to CORSIA eligible feeds.*
- *Palm Stearin, which is a byproduct of palm oil refinery having LCA values equivalent to PFAD, also may be studied to demonstrate its carbon foot print and sustainability benefits.*
- *Exploring expansion of Tree Borne Oils - programs like Karnataka, Chhattisgarh to be further developed on a large scale and adopted across all the states in the country.*
- *widen the portfolio of feedstocks that can be used for production of SAF e.g. seeds like pomgamia pinnata (Karanj), simarouba glauca (Paradise Tree)*

Supply chains - feedstocks

- *Suitable feedstock collection and aggregation mechanisms and robust supply chain mechanisms to be built for aggregating feedstocks such as UCO, tallow and TBO for HEFA based technology pathways and for agri residue and forest-residue biomasses for FT-based technologies.*
- *Adequate storage facilities and effective transportation networks by UCO aggregators and other feed stock collectors.*
- *Government supported programs to organize and incentivize the collection and aggregation of feedstocks, especially from small-scale farmers and households may be implemented.*
- *Subsidies and incentives to be provided for the development of storage facilities, transportation networks, and pre-processing plants near feedstock sources. Long-term contracts to be mandated between Feed supplier and SAF producer.*

Downstream supply chain and blending

- *Book-and-Claim mechanism should be developed and implemented to allow for a cost-effective and efficient SAF distribution system. wherein the administrative record flow does not necessarily connect to the physical flow of the product throughout the supply chain. DGCA is requested to formulate this proposed Book-and-Claim model along with a dedicated registry and framework for SAF credits / certificates to be used in Indian Airports.*
- *Laboratory facilities must be established at the airport for ASTM certification of SAF-blended ATF. Additionally, infrastructure for SAF storage and blending must be developed accordingly.*
- *investment to develop a dedicated supply and blending logistics for SAF.*
- *All the SAF producers to be allowed to blend SAF into the ATF at their battery limit or within their existing infrastructure.*
- *Accounting of SAF to be done based on "Mass Balance" approach*
- *"Book-and-claim" to implemented.*
- *all the refiners to be allowed to continue their business as usual and supply to the nearest airport and SAF produced and certified should be allowed to be traded to the end-consumers (airlines) via paper credit/certificate. This will help the country not to spend on additional investment for SAF supply logistics.*
- *harmonized regulatory guidelines and certification procedures that allow for the transport of SAF via pipelines and storage in Jet-A tanks onsite at the airport can drive down the cost of SAF and encourage higher utilization of SAF at airports.*
- *The use of these co-mingled storage and transportation options will require proper book and claim procedures, and airlines and airports must work with ICAO, IATA, the DGCA, and other organizations such as ACI to have proper documentation procedures in place.*
- *Establish procedures for blending SAF with conventional jet fuel, transportation guidelines, and refuelling protocols to ensure safe and efficient operations.*
- *Consider Incentives for Infrastructure development for SAF blending.*

Sustainability Certification of feedstocks and SAF

- *CORSIA certification: Establishment of additional certification bodies in India that are recognized by ISCC, RSB and Class NK SCS. This will increase the accessibility and affordability of certification services for SAF producers. Develop specialized training programs to enhance industry expertise on CORSIA certification requirements. This should include workshops, seminars, and certification courses focused on the CORSIA process, documentation, and compliance standards. Promote the development and standardization of LCA methodologies tailored to the Indian feed stocks to reduce inconsistencies and enhance the credibility of sustainability claims. Establish a robust regulatory framework for SAF certification that aligns with ICAO's CORSIA standards. This framework should include clear guidelines for certification, monitoring, and reporting*
- *A comprehensive SAF certification methodology needs to be developed by DGCA through Indian certification bodies at par with international standards to address the concerns among various stakeholders including the fuel producers and consumers.*
- *Book-and-Claim methodology through a Registry for accurate traceability based on Block-chain technology or similar robust models are currently not available.*

- *Potential challenges in obtaining CORSIA sustainability certification due to limited number of certification bodies, traceability requirements for feedstock, limited domestic expertise on CORSIA, lack of clarity on certification process etc.,*
- *Lack of awareness and understanding of CORSIA requirements among feedstock suppliers can lead to non-compliance. There may be Chain of custody tracking issues with multiple feedstock sources.*
- *Lack of certification agencies being very scarce*
- *A review of the CORSIA methodology, ensuring that it is fit for purpose for India's goals, resources and infrastructure.*
- *to ensure that local feedstocks are eligible under CORSIA*
- *Indigenous Certification system for cheaper and timely testing and validation of feedstocks and SAF including the CI and traceability requirements, aligning with international standards.*
- *Relaxation from addition of denaturants to Ethanol which will be used as a feedstock in AtJ-based SAF production.*
- *Have a "single point" authority for certification, for GHG calculations, etc available easily for stakeholders in India*
- *Mechanism to establish the C.I. number of each of these feedstocks along with their validation and certification on the lines of CORSIA. Demands for certification may vary from ones that has been established in some of the developed markets. - Country specific practices needs to be developed and recognized by the certification agencies and global policy makers to facilitate the propagation of the SAF.*
- *expand the definition of waste gases in Table 1 of the CORSIA Methodology for Calculating Actual Life Cycle Emissions Values to include waste gases that were previously used, as long as displacement is considered*
- *Ensuring processes to expedite certification of feedstocks.*
- *regulatory certainty around certification requirements.*
- *Streamlined supply chain from feedstock to airport and practical way to meet certification requirements.*
- *Use of "book and claim" to claim emissions reductions from renewable electricity and low carbon natural gas, or alternatively allow power purchase agreements (PPA). This is necessary for developing projects on the ground without additional high costs of needing to install direct electricity generation.*

1. *Certification Agencies for Process and Carbon Intensity (CI) Calculations:*
    - *Identify and establish process certification agencies in India equipped to calculate Carbon Intensity (CI) numbers for SAF production processes on a LCA basis. Need to establish along with validation and certification on the lines of CORSIA, for all feedstocks mentioned above.*
    - *Study various CI calculation models, such as CORSIA, GREET, SimaPro etc., to identify the India-specific changes that need to be made, evaluated, and adapted to Indian agricultural practices.*
2. *Establishment of Environmental Credit system:*
    - *Appoint a nodal agency to establish a credit mechanism for counting, certifying, and claiming the credits generated by using SAF.*
    - *Developing the methodology and certification addressing the local challenges.*

- *The beneficiary for such credit must be defined.*
- *Mechanism to divide scope 1 and scope 3 credits and to claim/monetize them in the market*
- *Establishing a platform to trade these credits*
- *These certifications to be internationally acceptable, applicable and tradeable.*

3. *Procedure for Qualifying Various Feedstocks & Waste Feedstocks:*
    - *Develop a procedure to define and qualify waste feedstocks suitable for SAF production, ensuring adherence to sustainability criteria.*
    - *A robust policy to define the waste feedstock and certification of these waste feedstock. The policy should account for the local conditions.*
    - *Work on providing Incentives for non-food crops [like industry residue, crop residue, energy crop (inter-cropping) eg. Molasses are considered as a co-product under CORSIA guidelines. And Corn starch/protein extracted rice slurry to be considered as waste].*
    - *Inclusion of sustainable agricultural practices and CCUS in the CI number calculation for CORSIA.*
4. *Region-Wise Emission Factors for Feedstocks:*
    - *Agricultural practices vary vastly across different regions in India. Specify region-wise default emission factors for various feedstocks used in SAF production to calculate carbon intensity accurately.*
    - *Incentive scheme to be developed and made available to encourage sustainable agri-practices at the grass root level.*
5. *Certification Process for Multi-Feedstock Setup:*
    - *A SAF production plant may use different feedstocks depending on the viability and availability. Define the certification process for SAF production facilities utilizing multiple feedstocks, ensuring consistency and accuracy in carbon intensity calculations.*
    - *For example, a facility may process 1G and 2G ethanol in the same batch. Establish the mechanism to certify that the CI number is either assigned based on the % mix (Mass balance-based approach) or two separate batches to be identified with 2 different CI scores.*
6. *Mechanism & Frequency of CI Re-Evaluation:*

    6.1. The LCA CI certification process starts at the Agri-production stage. As India's Agri market and production are very fragmented, it is extremely difficult to collect and certify data at the individual farm level.

    1..1. Establish a certification mechanism and sustainable monitoring to collect and qualify data at the regional level.

    1..2. Mechanism for self-certification and sustainable monitoring to be adopted and made acceptable to international bodies.

    6.2. Determine the frequency of re-evaluating Carbon Intensity (CI) for SAF production processes, considering process changes and value chain updates.
7. *Compliance Requirements: Establish compliance standards for feedstock sourcing, production processes, fuel properties, and overall fuel quality, aligning with globally acceptable standards.*

Certification of SAF (ASTM)

- *Identify and specify the minimum parameters that SAF producers must adhere to according to ASTM D7566 standards.*
- *Ensure the availability of Indian laboratories for testing and approval of SAF, ensuring adherence to international quality and safety standards.*
- *Determine the certification process, as per ASTM D7566, and the responsible party, e.g., SAF producers, buyers, or other stakeholders like OMC/ engine manufacturers, carriers etc.*
- *Nodal agency to issue such certificates. Preferably a global nodal agency having regional affiliated agencies.*
- *For the future, possibility to be explored to define the fuel specification and the CI number to qualify for SAF both in terms of sustainability and fit to use, instead of the pathway approach.*
- *Fast-forwarded authorization of India's homegrown technologies such as CSIR-IIP's DIL-SAAF needs to be obtained to lower technology costs.*