Deloitte.

Green wings
India's SAF revolution in the making

October 2024

Table of contents

Foreword

As we stand at the crossroads of a new era in aviation, the urgency of transitioning towards sustainable practices has never been more critical. The aviation sector, a cornerstone of global connectivity and economic development, faces mounting pressure to address its environmental impact. Sustainable Aviation Fuel (SAF) represents a step toward a cleaner, more resilient future for air travel.

With its burgeoning aviation industry, India is uniquely positioned to lead this global transformation. As the third-largest domestic aviation market, India's growing emissions pose significant challenges and present unprecedented opportunities. The development and adoption of SAF offer a promising solution to these challenges, enabling the sector to achieve its net-zero targets while fostering economic growth and creating new avenues for innovation.

This report delves into SAF's potential as a key driver of decarbonisation in the aviation sector. It explores the technological pathways, economic implications and strategic initiatives necessary to scale SAF production and adoption in India. The findings underscore the importance of a coordinated effort among government, industry and stakeholders to build a robust SAF ecosystem to meet domestic and international demands.

At Deloitte, we are committed to supporting this transition. Through our research and collaboration with industry leaders, we aim to provide insights and guidance that will help shape the future of aviation. By embracing SAF, India can meet its sustainability goals and position itself as a global leader in sustainable aviation.

This report, compiled through a series of deep conversations with key leaders within the industry in India and across the globe, presents a unique opportunity to be part of a significant industry milestone. As you explore it, we hope it inspires action and fosters the collective ambition required to navigate the complexities of this journey. Together, we can propel the aviation sector into a new era of sustainability, ensuring that the skies remain a symbol of progress and opportunity for future generations.

Viral Thakker
Partner & Leader
Sustainability & Climate
Deloitte South Asia

Ashwin Jacob
Partner & Leader
Energy, Resources & Industrials
Deloitte India

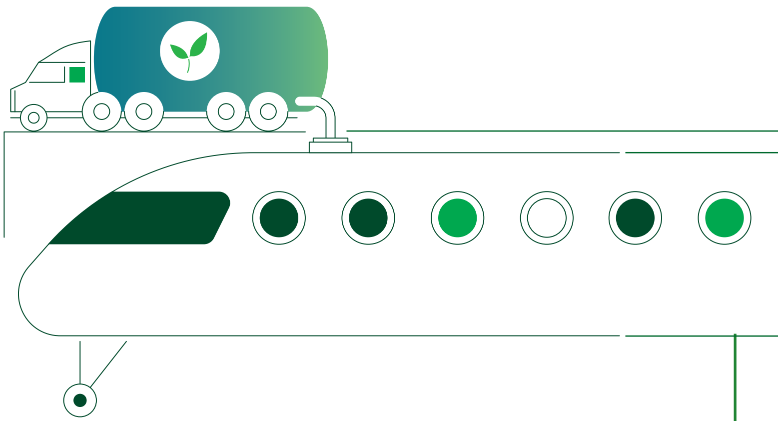
Executive summary

India's aviation sector is forecast to grow at ~11 percent over the next few years due to infrastructure development, aircraft capacity addition, increasing Tier 2/3 connectivity and evolving passenger preferences for air travel. India's demand for Aviation Turbine Fuel (ATF) will also grow in line with growing passenger and freight traffic. Additionally, with the Indian government's push for electrification in road transportation, the share of aviation in India's transport emissions is likely to double from ~5 percent currently to 8 percent to 10 percent by 2030.

International Civil Aviation Organization (ICAO) has introduced the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) scheme to limit aviation emissions to 85 percent of 2019 levels, necessitating decarbonisation efforts in the sector. Leading industry bodies such as the International Air Transport Association (IATA) have also undertaken to achieve net-zero operations by 2050. Likewise, large corporations have announced their targets for reducing business travel emissions.

Globally, aviation decarbonisation can be achieved through multiple levers such as operational improvement, hydrogen fuel, electric aircraft and SAF. Operational improvement initiatives, which have helped the aviation sector substantially reduce fuel consumption in the last two decades, can deliver only a limited impact in the future. New technologies such as hydrogen fuel and electric aircraft are still in nascent stages. And the forecast for any meaningful and commercial-scale deployment is only after 2040. As a result, SAF is emerging as a key decarbonisation lever expected to contribute between 53 percent and 66 percent in achieving the net-zero targets for the aviation sector.

In Indian context, Alcohol-to-Jet technology will play a key role due to high availability of feedstock.



India stands at a pivotal juncture in the journey towards the adoption of SAF. The country has set indicative SAF blending targets for international flights – 1 percent by 2027 and 2 percent by 2028. However, there are no mandates for domestic flights yet. Globally, countries are taking ambitious blending mandates. For example, the European Union (EU) has laid a detailed roadmap until 2050 for using bio-SAF and synthetic SAF. Additionally, the EU's regulations also specify feedstock acceptable for SAF production. These regulations are more stringent than the International Civil Aviation Organization (ICAO) guidelines. For example, while ICAO allows agriculture crops as feedstock for SAF, the EU mandates only using feedstocks that are not being diverted from the food value chain.

Airline operators have also taken voluntary targets for SAF blending. About 50 airlines globally, accounting for approximately 40 percent of global Revenue Tonne Km (RTK), have announced or committed to SAF blending of 5–10 percent until 2030. To that effort, more than 70 airline operators have also entered into more than 130 agreements for SAF offtake with 50 producers. Mandates and targets like these are expected to drive the global demand for SAF. It is estimated that the global demand for SAF will reach 17–18 million tonnes by 2030.

ICAO has approved 11 technological pathways, and another 11 are under evaluation. Among these, the Hydro-processed Esters & Fatty Acids (HEFA) pathway is the most mature technology pathway. Alcohol-to-Jet (AtJ) and Fischer Tropsch are two other promising and emerging pathways. Power-to-Liquid (PtL) is the last key technology pathway and produces synthetic SAF. Each pathway has multiple feedstock options and offers varying degrees of biofuel yield, SAF output and the allowed blending percentage. However, in the Indian context, AtJ will be the technology pathway in the near future. To begin with, 1G ethanol could be explored for SAF production. Subsequently, for higher blending mandates, 2G ethanol would be the preferred route owing to availability of agriculture residue and stringent regulations. Other feedstocks such as industrial waste/off-gases, sweer sorghum and seaweed can give further impetus to AtJ as those can be alternate feedstock for ethanol production.

However, cost economics vary significantly depending on the feedstock and technology used. For instance, the capex for AtJ with 2G ethanol from agriculture residue is thrice the capex for AtJ with 1G ethanol from sugar or maize. The production cost of SAF using 1G ethanol is ~2x the price of ATF, rising to ~3.3x the price for SAF with 2G ethanol.

2027	2028	2030	2040
Announced	Recommended		Recommended
0.03 Mt (At 1% blending for intl.)	0.06 Mt (At 2% blending for intl.)	~0.8 Mt (At 5% blending for intl.)	~4.5 Mt (At 15% blending for intl.)

India

	2030	2040
Global[1]	~18 Mt (For 2050 net-zero)	~185 Mt (For 2050 net-zero)

Global demand is rising with net zero commitments

India's production has the potential of exceeding domestic demand, even at higher blending mandates

Agriculture residue

~230 Mt surplus, largely being burnt or unused

Sugar

~33 Mt production, being used for food security and ethanol production

Maize

~37 Mt production, being used for feed and ethanol production

Municipal Solid Waste (MSW)

~61 Mt production, likely to increase with economic growth

Used Cooking Oil (UCO)

~2.4 Mt collection, being used in food, feed, soaps & biodiesel production

AtJ is emerging as the key technology pathway due to feedstock availability

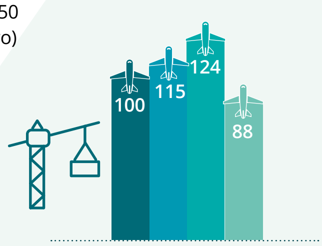
1G Ethanol can be evaluated to kick-start SAF adoption

Sustainable Aviation Fuel (SAF)

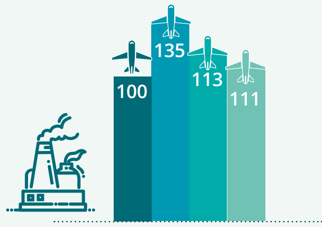
8-10 Mt

India production potential

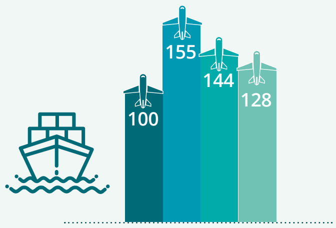
India is competitive to export to major airline hubs – Middle East & Europe - due to lower cost, and its proximity to demand centres



International construction Cost 2024[3]



machinery and equipment cost



Shipping distance to Amsterdam Port[2]

India | China | Thailand | Malaysia

Investment in India will drive additional direct and indirect socio-economic impact

20-25 Mt
Carbon emission reduction

3-4 Mt
Renewable diesel production

US$ 70-85 bn
Capital investment required

1.1-1.4 Mn
Jobs generated across the value chain

US$ 5-7 bn
Oil import savings

10-15%
Additional annual income for farmers (US$2-2.4 bn)

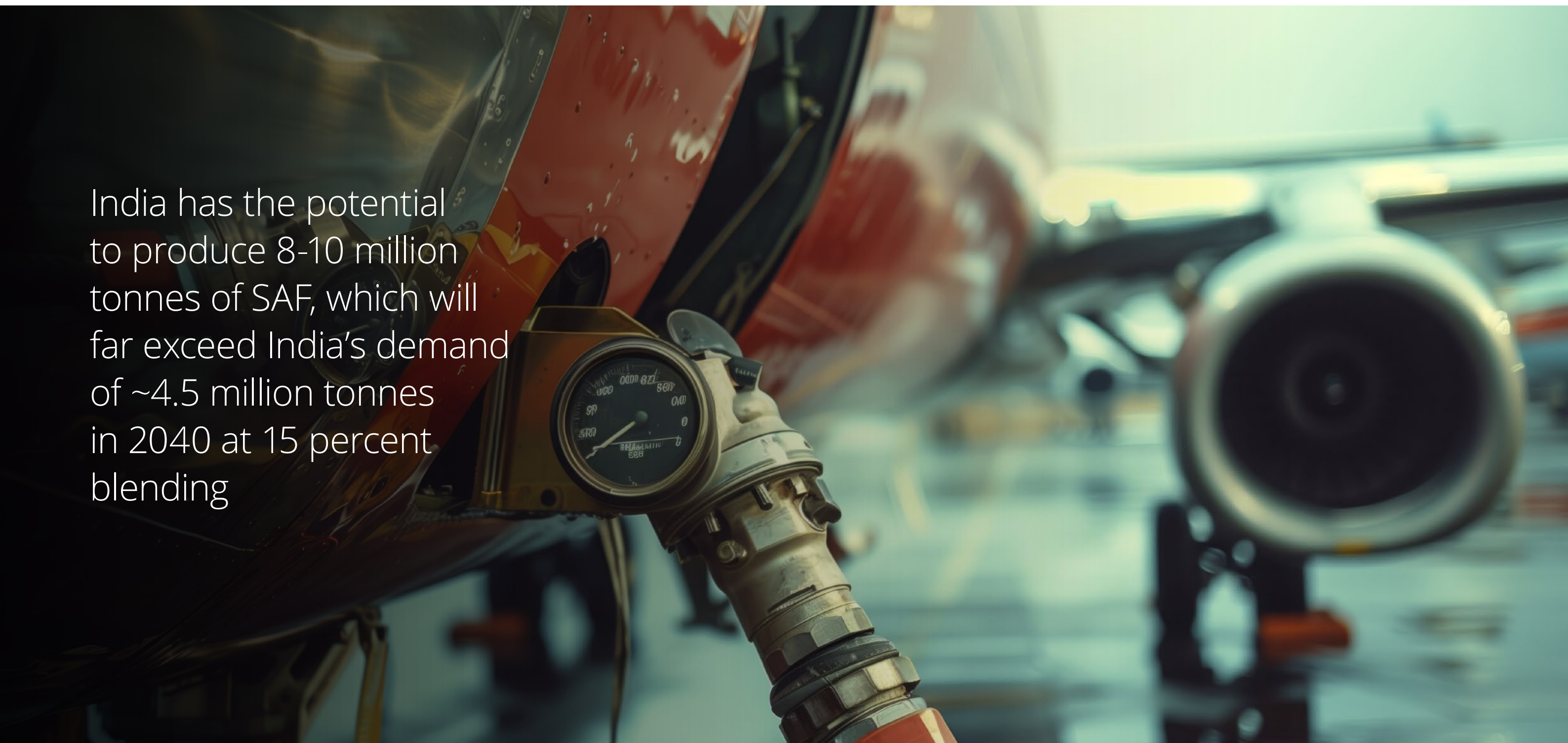
Note: 1. IATA estimates; 2. Shipping distance estimated for following ports: Mumbai in India, Guangzhou in China, Bangkok in Thailand, Port Kelang in Mayalsia, Amsterdam in Netherlands, Dubai in UAE; 3. The index is based on a survey of construction costs which covers 20 building functions. Cost considered for following cities: Mumbai in India, Shenzhen in China, Bangkok in Thailand, Kuala Lumpur in Malaysia
Source: IATA, MoPNG, PIB, Arcadis, ILO statistics, sea-distances.org, Expert inputs, Literature review, Deloitte analysis

While airline operators are apprehensive about passing on this additional cost to passengers, a comparative analysis of historical price trends, passenger traffic and capacity additions indicates a limited impact of the increase in ticket prices on passenger traffic. Moreover, few international airlines have even piloted green fares, including on Indian routes, and have found them to be successful with adoption among passengers.

India currently accounts for ~2.5 percent of global ATF demand. Given India's abundant feedstock for SAF and high exposure to exports for ATF (50 percent of ATF produced being exported), India is well-positioned to capitalise on the rising global demand for SAF. A conservative estimate of the annual production potential of 8–10 million tonnes basis key feedstock availability would far exceed India's estimated requirement of ~0.8 million tonnes by 2030 at 5 percent blending rates and ~4.5 million tonnes by 2040 at a 15 percent blending rate.

While India builds 8–10 million tonnes capacity of SAF on one side, it will also enable India to build 3–4 million tonnes capacities for Renewable Diesel (RD) as that is one of the key byproducts. This build out of SAF production will drive capital investments to the tune of INR 6-7 lakh crore (US$70-85 billion) by 2040. This capital investment will directly and indirectly result in employment generation (1.1-1.4 million jobs) across the value chain, including production facilities, feedstock aggregation, warehousing and other associated functions. SAF will also be able to generate additional famer income of INR16,000–20,000 crore (US$2-2.4 billion) per annum by 2040 by selling agriculture residue SAF production.

However, concerted efforts are required from all ecosystem stakeholders to address existing challenges and realise their potential. This includes establishing a clear and long-term regulatory roadmap, formalising SAF feedstock supply chains, creating ecosystem partnerships, institutionalising financial incentives and transparent pricing mechanisms, and identifying certification agencies to fast-track investments.



India has the potential to produce 8-10 million tonnes of SAF, which will far exceed India's demand of ~4.5 million tonnes in 2040 at 15 percent blending

India's aviation emissions are expected to grow

Aviation has led to a more connected India and continues to play a key role in the country's economic growth. While India is currently the third-largest domestic aviation market by passenger traffic, behind the US and China[1], it is also highly under-penetrated in domestic and international seats per capita compared with some of its global counterparts.[2] India's passenger traffic is forecast to register ~11 percent CAGR from ~190 million in 2023 to ~390 million in 2030.[3] Furthermore, its freight traffic is expected to post ~13 percent CAGR from ~2.2 million tonnes in 2023 to ~5.1 million tonnes in 2030.[4] This growth is expected to be driven by accelerated infrastructure development due to investments by the government, the addition of aircraft capacity by leading domestic players, increasing regional connectivity and evolving income demographics, which is changing the preferred transportation mode among citizens.

Accelerated infrastructure expansion

- Over US$20 billion investment is in the pipeline in aviation infrastructure
- The number of airports expected to increase from 148 to 240 by 2030

Significant aircraft capacity addition

- About 30 percent of 3,550 aircraft orders in 2023 globally were from Indian carriers
- Over 1,500 aircraft are expected to be added by 2035, making India the third-largest country in terms of fleet size

Increased Tier-2/3 connectivity

- Share of air traffic in metro cities has decreased from 68 percent in 2015 to 57 percent in 2021
- Govt. policies such as UDAN have boosted regional connectivity to small and medium cities at economical rates

Changing income demographics

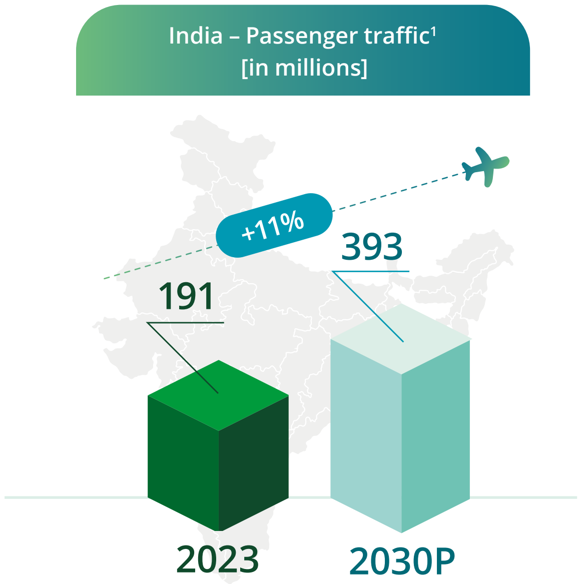
- India's per capita GDP is projected to increase from ~US$2,500 in 2023 to ~US$4,000 in 2030

According to a report submitted by India in December 2023 to the United Nations Framework Convention on Climate Change, carbon emissions from the Indian aviation sector accounted for 5 percent of the country's transportation emissions.[5] At ~70 percent, emissions from the aircraft engines and the auxiliary power unit are identified as the primary sources of aviation emissions. Ground support equipment and vehicles operating inside airports are key contributors to non-aircraft emissions.

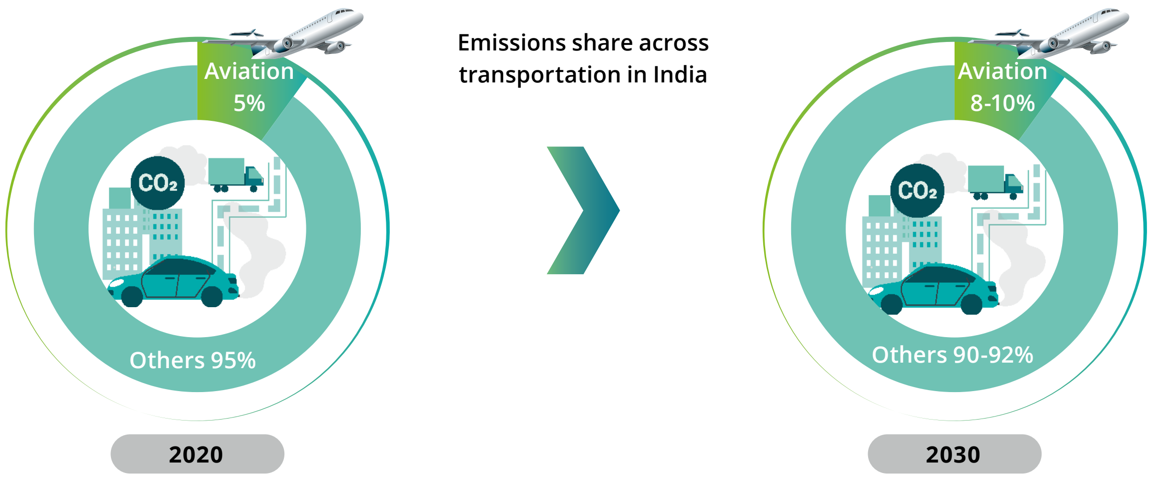
However, the severity of aviation emissions is estimated to increase. As a result of the growing aviation sector, the demand for Aviation Turbine Fuel (ATF) in India is estimated to double from 8.2 million tonnes in 2024 to 15–16 million tonnes in 2030.[6] Moreover, the Indian government has set an ambitious target of achieving 30 percent EV penetration in domestic sales of automobiles by 2030;[7] the Council on Energy, Environment & Water (CEEW) estimates that one-third of the four-wheelers and half of the two-wheelers sold in 2030 could be electric.[8] As a result, domestic aviation is forecast to emerge as one of the key sources of emissions within India's transportation sector, doubling from 5 percent currently to nearly 8–10 percent by 2030.

India's aviation sector is expected to grow at 11-13% as a result of infrastructure development, capacity addition, changing demographics & government policies.

India aviation sector is expected to grow at 11-13%...

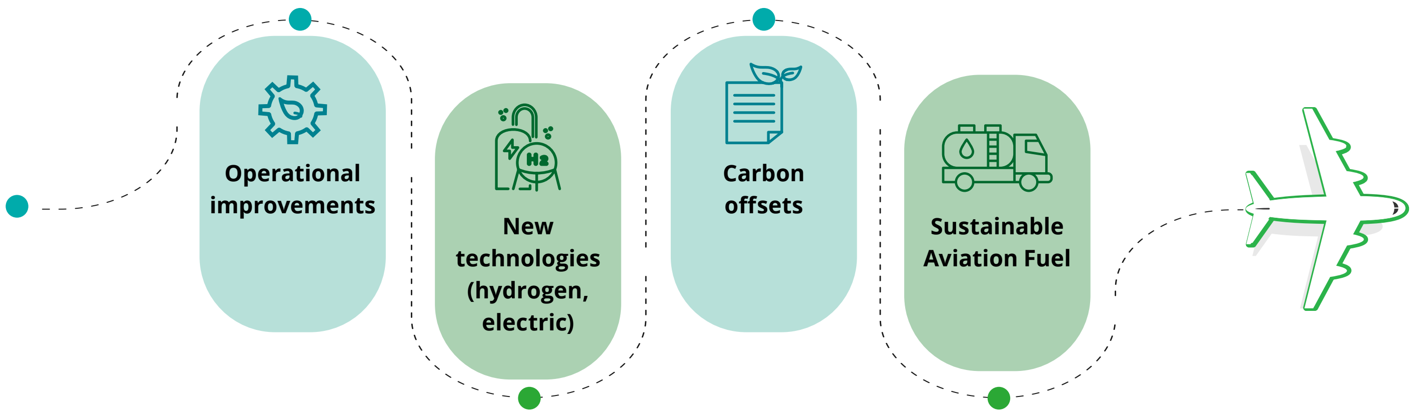


...As a result, aviation's share in transportation emissions will double



Note: 1. As per Vision 2040 for civil aviation, India's passenger traffic and freight traffic is expected to reach 1.1 billion and 17 million tons respectively by 2040.
Source: IATA, DGCA, UNFCC, CEEW,, Literature review, Deloitte analysis

SAF will play a key role in decarbonising aviation



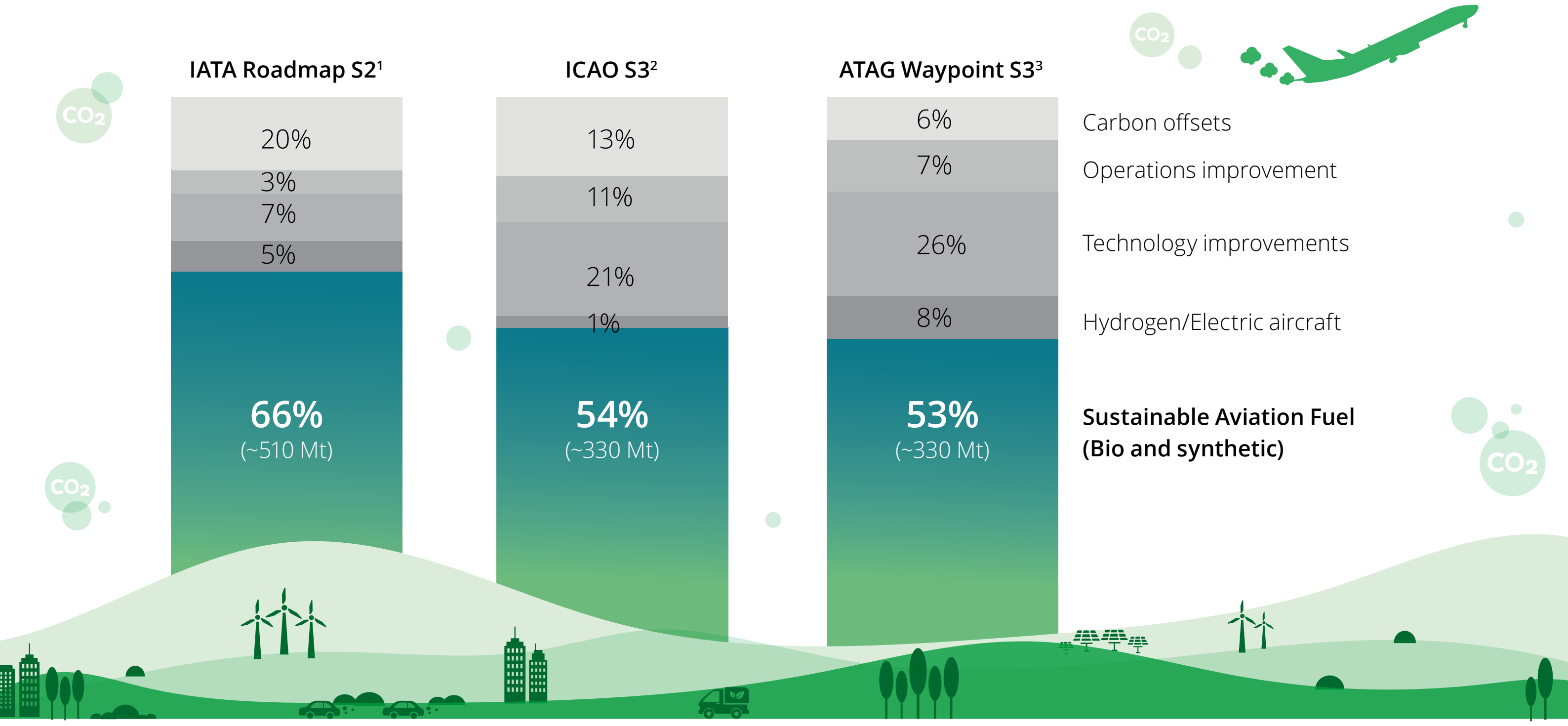
For the last few years, **operational improvements** have been used to decarbonise aviation. Operational improvement measures, such as weight reduction, aerodynamics optimisation and system improvements, have improved fuel efficiency, resulting in ~55 percent improvement in fuel burn per passenger per km since the 1990s.[9] Other improvement measures, such as optimised air traffic management operations, limited use of auxiliary power units and reduced taxi time, have also contributed to decarbonisation efforts. While these measures can be scaled rapidly, they can only deliver limited impact in the future.

The development of **new aircraft technologies** is a crucial second lever, although it is still in its early stages. Radical new propulsion technologies such as hydrogen-fuel aircraft, electric aircraft and hybrid aircraft and advanced aircraft configurations featuring optimised aerodynamic designs such as canard wings and blended wings offer an opportunity to move away from conventional jet engines and tube-and-wing aircraft. For example, in January 2023, the first 19-seater aircraft flew with a retrofitted hydrogen-electric powertrain on the left wing[10] and in September 2023, a 40-seater aircraft was powered by a hydrogen fuel cell.[11] However, these technologies and configurations remain in their infancy. Currently, IATA forecasts regional/commuter aircraft with retrofitted hydrogen fuel cells to come into operation by 2030, short-to-medium range hydrogen aircraft by 2035 and wide-body long-distance aircraft no sooner than 2045–2050.[12] This timeline is expected to be similar for electric aircraft as well. However, these forecasts may be optimistic, as hydrogen and electric aircraft face unique challenges, such as the requirement of larger fuel tanks, separate hydrogen storage and fuelling infrastructure, high battery cost and weight and battery charging infrastructure. Thus, despite its promising potential, the difficulty in developing and deploying these emerging aircraft technologies could lead to delays in attaining commercial maturity.

Carbon offsetting is the third lever that indirectly impacts carbon emissions. It involves compensatory measures such as carbon credits and green certificates to offset emissions. As an indirect carbon emission reduction mechanism, carbon offsetting has faced criticism in recent years for being poorly regulated, with concerns about greenwashing, temporary reduction and inaccurate or non-standard measurements prevailing across the market.

Hydrogen and electric aircraft technologies are currently nascent and will take time to deploy at scale.

Decarbonisation levers for aviation sector across 2050 net-zero roadmaps

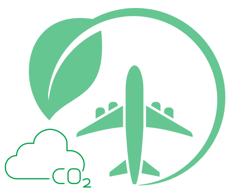


Note: 1. IATA Roadmap S2 refers to IATA's Net Zero Roadmap published in 2023; 2. ICAO S3 refers to ICAO's roadmap considering Aggressive/speculative scenario, medium traffic growth; 3. ATAG Waypoint S3 refers to roadmap with aspirational and aggressive technology perspective

Source: IATA, Aviation Benefits, ICAO, Deloitte analysis

SAF is emerging as one of the most important decarbonisation levers owing to feedstock availability and rapidly scaling technology pathways. SAF refers to the blending of liquid biofuel produced sustainably from feedstocks with no environmental challenges, such as used oils and agriculture residues, or synthetically through a process that captures carbon directly from the air. Some early signals of SAF adoption registered include the increased production of SAF from 0.08 million tonnes in 2021 to 0.5 million tonnes in 2023,[13] as well as the flight of the world's first commercial aircraft with 100 percent SAF in November 2023, which flew from London to New York with 88 percent of SAF produced from waste fats and the remaining 12 percent made from plant sugars.[14] While SAF acts as a drop-in fuel, its adoption is hindered by challenges such as high capital investment and fragmented feedstock availability. Nonetheless, aircraft manufacturers such as Boeing have committed to delivering commercial airplanes capable and certified to fly on 100 percent SAF by 2030.[15] In India, multiple airline operators – Indigo,[16] Vistara,[17] AirAsia[18] and SpiceJet[19]– have undertaken test flights with SAF blends as high as 25 percent.

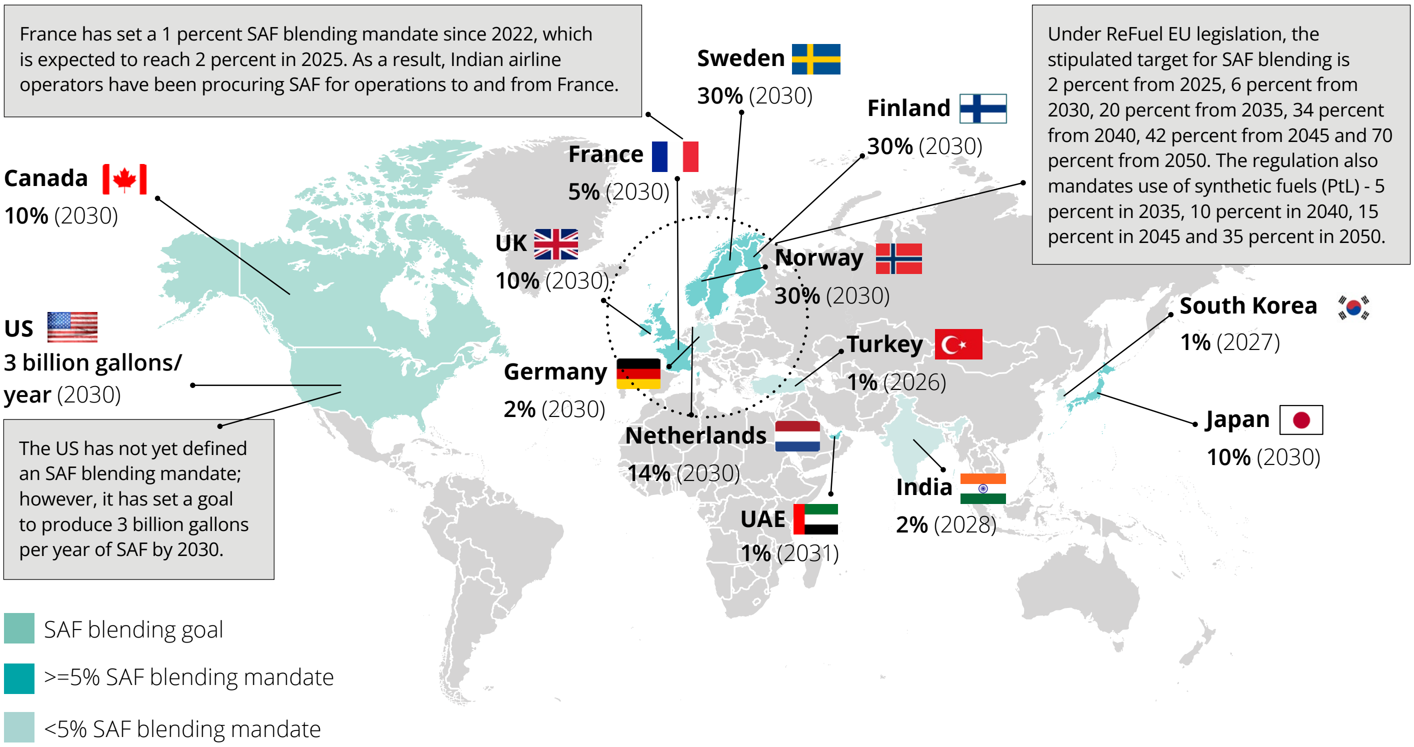
Leading international aviation bodies such as IATA, ICAO and ATAG estimate that SAF will contribute 53–66 percent to achieving net-zero carbon emissions by 2050, making it one of the most important decarbonisation levers.



SAF will potentially contribute 53-66% in achieving 2050 net-zero commitments of the aviation sector.

Mandates and net-zero commitments are driving SAF demand

Globally, countries are mandating SAF blending. The EU has taken the lead by providing a comprehensive roadmap until 2050. The EU Council has published ReFuelEU Aviation laws stipulating the requirement for aviation fuel suppliers to gradually increase the share of SAF blended aviation fuel supplied at EU airports. The regulations necessitate fuel suppliers to deliver minimum blends of 2 percent in 2025, 6 percent in 2030, 20 percent in 2035, 34 percent in 2040, 42 percent in 2045 and 70 percent in 2050. The regulation also outlines the share of synthetically produced aviation fuels (renewable fuels of non-biological origin – PtL SAF) – 5 percent in 2035, 10 percent in 2040, 15 percent in 2045 and 35 percent in 2050.[20] To further stimulate demand and prevent anti-tankering, i.e., refuelling at locations where fuel prices are lower, the EU legislation also necessitates aircraft operators to uplift a minimum of 90 percent of their annual aviation fuel requirements from EU airports. Unlike ICAO, which allows for agricultural produce such as molasses and maize for SAF production, EU mandates require SAF production from specific feedstocks such as agriculture residue.



Note: 1. Equivalent to ~14% SAF blending considering total ATF consumption in USA (2021) and 3 billion gallons per year SAF production goal by 2030.
Source: IATA, Literature research, Deloitte analysis

Europe's ReFuelEU legislation has the most clear, long-term and stringent path.

Moreover, European countries have also defined SAF blending mandates, which require airline operators to procure SAF. For example, France set a SAF blending mandate of 1 percent in 2022, which is expected to reach 2 percent in 2025. As a result, airline operators, including from India, are already procuring SAF for flight operations from France. Other countries, such as Japan and Canada, have also defined their SAF blending targets of 10 percent until 2030.

Leading international aviation bodies have also declared net-zero targets, which will potentially drive the demand for SAF. IATA, representing over 300 airline members, has committed to achieving net zero by 2050.[22] With 190+ member states, ICAO has adopted a collective Long-Term Aspirational Goal (LTAG) for net-zero carbon emissions by 2050.[23] ICAO has also introduced the CORSIA scheme to promote the adoption of market-based measures for aviation emissions from International Flights. CORSIA requires airline operators of member states to maintain emissions levels at 85 percent of the baseline 2019 levels.[24]

Although 126 member states[25] have opted to participate in the voluntary phase until 2026, India has opted out and will join the mandatory phase starting in 2027. As a result, starting in 2027, all Indian aircraft operators flying international flights to and from CORSIA member states will have to limit their carbon emissions levels per the mandate.

India is also taking steps to address aviation emissions through SAF. It has set indicative SAF blending targets for international flights, starting with a 1 percent blend by 2027 and doubling to 2 percent by 2028.[21] These indicative targets apply only to international flights and are aligned with global sustainability initiatives.

Leading domestic and international airlines have also declared SAF targets. About 50 airlines, accounting for ~36 percent of the global passengers and ~41 percent of the global Revenue Tonne KM (RTKM), have made long-term SAF blending targets either in the form of actual announcements or commitments made as part of World Economic Forum's (WEF) Clean Skies for Tomorrow Coalition. This includes airline operators across the globe, such as Air France, Cathay Pacific, Delta and Finnair. These targets translate to almost 12–14 million tonnes of SAF requirement by 2030.[26] To that effort, airline operators have also signed offtake agreements with potential SAF producers across the globe.[27]

Beyond this, **large corporates are also taking up targets to reduce airline emissions per FTE.** This can also substantially impact SAF demand as business travel represents ~25 percent of global air travel.[28] Preliminary estimates indicate that if Indian corporates with extensive travel requirements, such as consulting firms, Global Capability Centres (GCCs) and technology companies, take a target of reducing aviation emissions intensity per FTE by ~40 percent, projected additional SAF demand will be ~0.1 - 0.2 million tonnes.

Thus, mandates and net-zero commitments will drive SAF demand going forward. It is estimated that global SAF demand will increase to ~18 million tonnes in 2030, ~185 million tonnes in 2040 and ~360 million tonnes in 2050 for the aviation industry to achieve net-zero commitments by 2050.[29] In India, based on the current SAF blending mandates of ~2 percent by 2028 for international flights, SAF demand will reach 0.03 million tonnes. If the blending mandate is increased to 5 percent in 2030 and 15 percent in 2040 for domestic and international flights, the demand for SAF will reach ~0.8 million tonnes in 2030, going up to ~4.5 million tonnes in 2040.

Overview of SAF offtake agreement signed

133
SAF offtake agreements signed

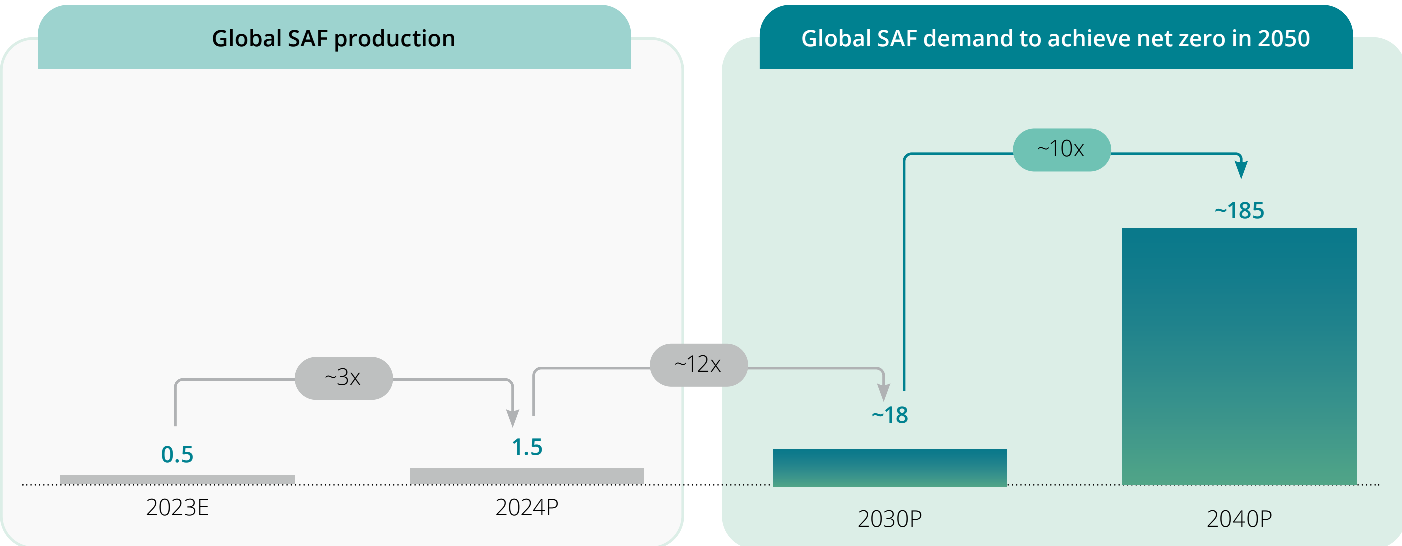
42.5 Mt
Volume under offtake agreements

50
SAF fuel producers across the globe by 2027

71
Purchasers across the globe

In India, demand for SAF will increase to ~0.8 and ~4.5 million tonnes for 5 percent blending in 2030 and 15 percent blending in 2040, respectively.

SAF current production and projected demand for net zero in 2050, in million tonnes

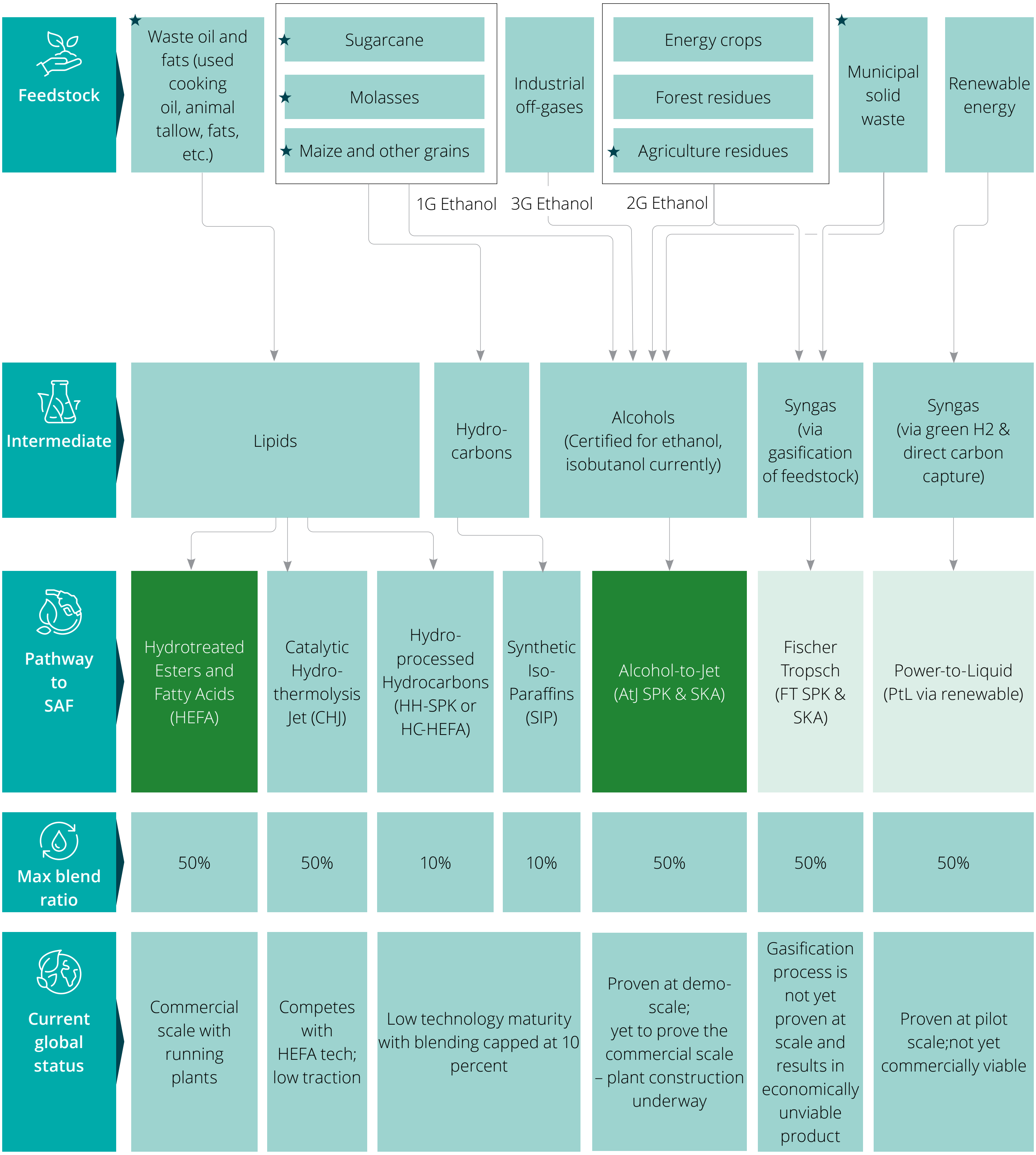


SAF production should increase 12 times to meet the expected global SAF demand in 2030 to reach net zero in 2050.

Source: IATA, Literature research, Deloitte analysis

Feedstock availability will drive technology selection

There are multiple pathways to producing SAF – 11 conversion processes approved by ICAO as of July 2023, with another 11 processes under evaluation.[30] The processes can convert a range of feedstocks into biofuels. The share of SAF, renewable diesel and other light ends varies across technology pathways and feedstocks.



Legend: ★ Key feedstocks available in India ■ Mature/Emerging pathway relevant for India ■ Nascent pathway relevant for India

Source: CORSIA, Literature Research, Deloitte analysis

Hydroprocessed Esters and Fatty Acids (HEFA) is the most technologically mature pathway that uses waste oils or used cooking oils or fats as a feedstock. Currently, all operational SAF facilities globally are based on the HEFA pathway. The process involves the removal of oxygen by hydrodeoxygenation, followed by cracking and isomerisation of paraffinic molecules to jet fuel chain length. The pathway offers a high biofuel yield of 80–90 percent. The share of SAF in the product yield can vary between 15 percent and 50 percent, depending on the feedstock and other operating parameters. However, some of the challenges related to this pathway include (a) the quality of feedstock and resultant yield is highly dependant on the source and usage of the waste or used coiking oils and fats (b) organised collection and aggregation can be challenging due to a fragmented and under developed supply chain and (c) impurities can result in higher purification costs.

Alcohol-to-Jet (AtJ) is another important pathway that involves dehydration, oligomerisation and hydro-processing to convert alcohol feedstock to SAF. This pathway offers a drop high biofuel yield of ~60 percent, potentially achieving a higher share of SAF (~70–90 percent) in the product yield, the remaining being renewable diesel and light ends.[31] Unlike lipids intermediate in HEFA, alcohols have a standard chemical formula (such as C_2H_5OH for ethanol) and thus exhibit limited variation, with no differences arising from the feedstock used for alcohol production. Dehydration of alcohol to produce olefins (for example, bioethanol to bio-ethylene) is a nascent technology, and only a select few plants exist globally. Meanwhile, oligomerisation and hydroprocessing are processes that are prevalent in the oil and gas industry, specifically in petrochemical plants and are used for dimerisation and paraffins production, respectively. However, scaling up and integrating these processes at a large scale for SAF manufacturing could pose engineering challenges. Ethanol and iso-butanol are the two approved alcohol feedstocks for this pathway. However, the specific source of the alcohol is not specified. The technology pathway is at TRL 7, with a few established demonstration plants. Lanzajet's Freedom Pines Fuels facility is the world's first ethanol-based AtJ SAF facility.[32]

HEFA is the most mature technology pathway

Fischer Tropsch (FT) is one of the oldest processes approved by ASTM. In the FT process, carbon-containing materials such as waste and residue are gasified into synthetic gas (syngas), which consists of hydrogen and carbon monoxide. This syngas is then catalytically converted to liquid hydrocarbon fuel blending components in the reactor. Currently, two processes have been certified: One for producing Synthetic Paraffinic Kerosene (SPK) and another for producing Synthetic Kerosene Aromatics (SKA). The yield for the FT-SPK process is low at ~20 percent, with 25–40 percent of the product yield being SAF and the remaining being renewable diesel. Despite being one of the oldest processes, the gasification of the feedstock remains a challenge as it is typically designed around the specific feedstocks and requires substantial investment, followed by a long construction period and a prolonged period for process stabilisation.

Power-to-Liquid (PtL) is another emerging pathway to produce sustainable aviation fuel. In the PtL process, green hydrogen, generated from renewable energy, is combined with carbon monoxide, produced from carbon dioxide captured from industrial sites, to create synthetic gas (syngas). This syngas is then converted into SAF using the FT process. As carbon capture technology is still in its early stages of development and green hydrogen manufacturing technology has not yet been commercialised, the overall maturity of this pathway remains low. However, as capital investments for these technologies decrease, the pathway can become an attractive and viable option.

Per scenarios simulated by ATAG, HEFA, while being the most mature pathway, is projected to contribute less than 10 percent to the overall SAF production by 2050. The AtJ and FT pathways, which rely on advanced feedstock, such as agriculture residue, forestry residue and MSW, are expected to be promising technology pathways until 2035–2040. After 2040, PtL will emerge as a key pathway due to the increased maturity of green hydrogen and carbon capture technologies and potential constraints in the availability of feedstock for AtJ and FT. As a result, in 2050, AtJ and FT will potentially contribute 40–50 percent to the overall SAF production.[33]

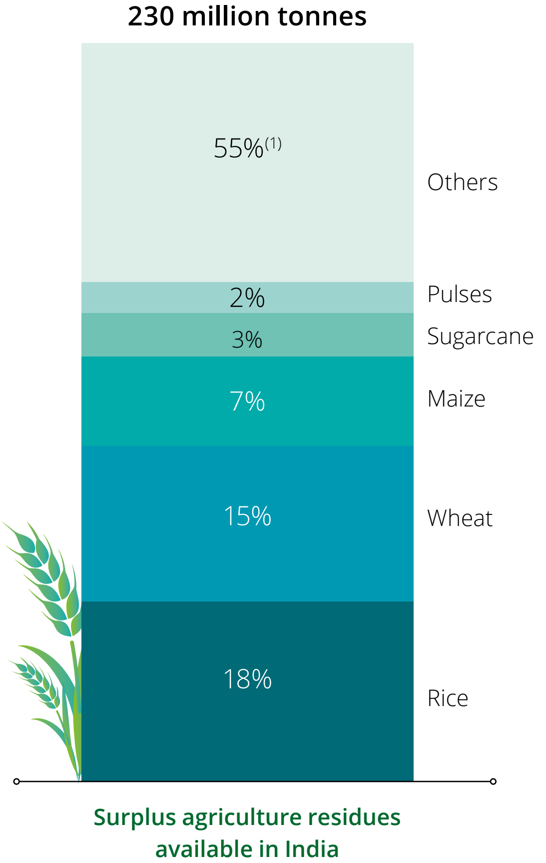
However, selecting a specific technology is also contingent upon other feedstocks-related factors, such as availability and ease of procurement.

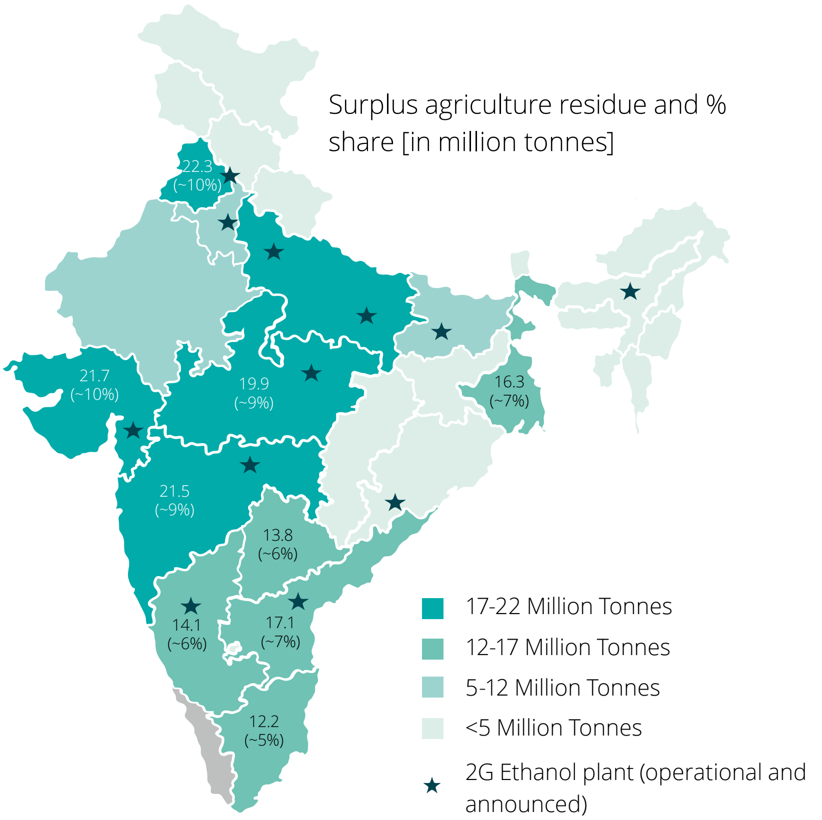
In India, feedstocks for HEFA technology – **waste oil, used cooking oil (UCO) and animal tallow** – are neither readily available nor can they be procured easily due to their fragmented distribution. For example, India is estimated to have ~2 million tonnes of UCO, with ~65 percent available from commercial establishments and the remaining from households.[34] The Indian government has taken initiatives to ensure the optimal disposal of UCO. However, it is estimated that approximately 60 percent of the UCO is improperly reused, often finding its way back into the food supply as food business operators dispose of it to small restaurants and roadside vendors.[35] Although UCO has been identified as a key feedstock for renewable diesel manufacturing and the government has established detailed guidelines for its collection, the supply chain remains underdeveloped in the country.[36] These challenges limit the potential of HEFA technology in India.

Meanwhile, AtJ can be deployed using multiple feedstocks: **sugar and molasses, grains, agriculture waste, industrial waste (including off-gases, etc.) and municipal solid waste.** These feedstocks are first used to manufacture alcohol (ethanol predominantly) and then converted to SAF.

Sugar feedstocks, such as sugarcane syrup, B-heavy molasses and C-heavy molasses, are currently used to produce **1G ethanol**, mainly for blending with motor spirits under the Ethanol Blended Petrol (EBP) Programme. While India maintains an excess stock of 5–7 million tonnes of sugar, the use of sugar as a feedstock is controlled and regulated by the government in terms of the type and quantity that can be diverted from sugar production to ethanol manufacturing. For example, in December 2023, the Indian government banned the use of sugarcane syrup and B-heavy molasses for ethanol production. It restricted the diversion of feedstock from sugar to ethanol manufacturing to ~1.7 million tonnes. **Grain-based feedstocks such as maize** have also gained traction for **1G ethanol** manufacturing, with more than 40 percent of ethanol used in the EBP programme now being produced from maize.[37] Recently, the government also reduced the import duty on maize from 60 percent to 15 percent to promote maize-based ethanol production and compensate for the shortfall in availability. **Agriculture residue** is another emerging feedstock for **2G ethanol** production. Rice, wheat and maize are three key sources of agricultural residue available across the country. It is estimated that ~230 million tonnes of surplus agriculture residue are unused and being burnt.[38] The Oil Marketing Companies (OMCs) plan to establish 2G ethanol plants across the country using agriculture residue.

2G ethanol is also emerging in India; rice, wheat and maize are key sources for agriculture residue.





Note: Other feedstock used by 2G ethanol plant includes bagasse residue, bamboo, coconut fronds, corn stover, bajra, rapeseed mustard, groundnut, etc.
Source: National Biomass Atlas of India, Deloitte analysis

Haryana government's crop residue management programme

2022
The pilot programme

The Government of Haryana, with support from Deloitte, implemented a crop residue management programme

6 villages in Karnal

69% drop in stubble burning

2k lives shared

2023
Scaled up to 111x times

666 villages in 9 districts which contributed to ~91% of active fire locations.

54% drop in stubble burning

5.5k lives shared

- **300+** **Awareness and outreach events**
- **150k+** **WhatApp messages** Extensive radio campaign using a call-to-action anthem developed by Deloitte. Vans with PA systems and digital screens also used to spread awareness through audiovisual content
- **50k** **IEC kits** with targeting messaging
- **150+** **New jobs** created by donating equipment sets and generated ~20% of the stubble needed for IOCL's ethanol plant in Panipat
- **67.5k** **Farmers reached** through door-to-door campaigns
- Facilitating connects with bio-energy plants, ethanol production, briquette production paper mills, and gaushalas

Krishi Yantra Saathi App
AI-enabled platform for farmers to share equipment

- **150k** farmers registered
- **5,497** farmers requested help – 43% small and marginal farmers
- **61%** equipment owners registered
- **575k** acre land cleared (~50% of addressable area)

2024
Expand to Punjab

+

Krishi Yantra Saathi being rolled out to **15 villages in Patiala**

Using agriculture residue for ethanol and SAF production also addresses the problem of stubble burning and allows farmers to generate additional income from the waste. In 2022, Deloitte supported the Government of Haryana in implementing a Crop Residue Management programme, which was scaled up subsequently. The programme helped reduce stubble burning by ~54 percent and enabled feedstock availability for IOCL's Panipat 2G ethanol plant.

Ethanol can also be produced using industrial waste such as refinery off-gases, biogenic carbon emissions, etc. and municipal solid wastes. Ethanol produced using such feedstocks are referred to as 3G ethanol. In India, IOCL is setting up a 3G ethanol demonstration plant in Panipat. Globally, multiple plants are also being discussed and evaluated where municipal solid waste will be converted to ethanol.

Technology selection also hinges on feedstock availability – Alcohol-to-jet using agriculture residue is the most promising opportunity for India.

Pathway	Feedstock		Life cycle emissions (gCO_2e/MJ)[39]	Availability for SAF	Ease of procurement
HEFA	Edible oil crops/palm oil		20.7 (PFAD)	Low	Medium
	Waste and residue lipids	Used cooking oil	13.9	Low	Low
		Animal waste fat	22.5	Low	Low
	Oil trees, oil cover crops, algae, halophytes		46.8 (Jatropha oilseed)	Low	Low
FT	Municipal solid waste		5.2*	Medium	Medium
	Agriculture residues		7.7	High	Medium
	Forestry residue		8.3	Low	Low
AtJ	Sugary/Starch crops/sweet Sorghum		32.6 (Sugarcane) 100.6 (Corn grain)	Low	Low
	Agriculture residues		24.6	High	Medium
	Forestry residue		24.9	Low	Low
PtL	Point source and direct carbon capture			Low	Low
	Reusable plastic waste			Low	Medium

* 0% non-biogenic carbon
Source: ICAO, Deloitte analysis

Legend: Low Medium High

Limited availability and variation in quality of used cooking oil will hinder adoption of HEFA in India.

Per estimates, the AtJ pathway using 2G ethanol derived from agriculture residues (from rice, wheat and maize) manifest as India's most promising pathway for SAF production in the near future. At a conservative growth estimate of 2 percent, surplus agriculture residue is estimated to reach ~300 million tonnes by 2040. If 25-30 percent of the agriculture residue is consumed for SAF production can result in potential SAF output of 7.4-8.6 million tonnes by 2040. The output can potentially increase if higher share of agriculture residue can be used for SAF.

At the same time, the AtJ pathway with 1G ethanol can be considered to kick-start production in the country and ensure availability for meeting India's blending mandates for international flights. It is estimated that 0.1-0.2 million tonnes of SAF can be targeted for production through 1G ethanol route. 1G ethanol sources will potentially not be the main feedstock going forward as these feedstock compete for domestic consumption for food security as well as for ethanol for fuel blending under EBP.

The availability of Municipal Solid Waste (MSW) can further help increase the SAF output by 0.6–1.0 million tonnes by 2040, assuming 10 percent availability with SAF. The potential could further increase with higher municial solid waste generation, better segregation capabilities and higher diversion of SAF production. However, used cooking oil will potentially contribute a limited quantity of 0.1–0.2 million tonnes towards SAF production.

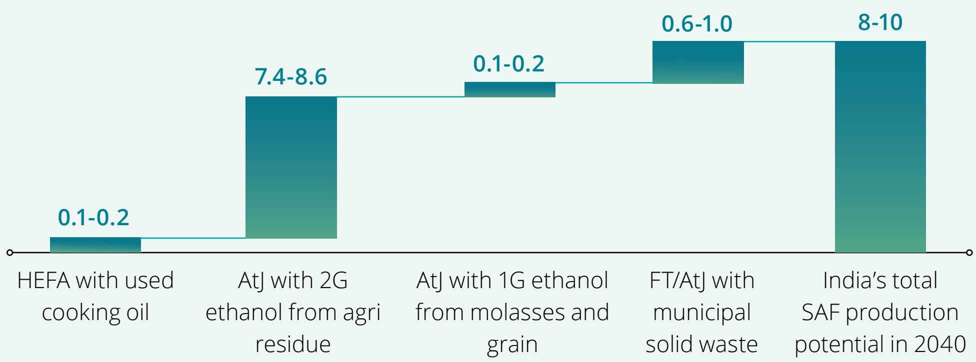
In totality, by 2040, India will have the opportunity to produce 8–10 million tonnes of SAF. This far exceeds India's potential demand of ~4.5 million tonnes in 2040 at higher SAF blending rates of 15 percent.

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

Other alternate and innovative feedstocks that are under development can give further impetus to ethanol and SAF manufacturing. **Sweet sorghum** is an interesting feedstock that is being evaluated for ethanol production. It offers multiple benefits vis-à-vis conventional ethanol feedstocks. For example, the stalk can be used for ethanol production, and the grain can be used for food consumption. It can be grown in multiple seasons. It also has a low water footprint and cultivation cost, thereby offering farmers a higher earning potential. **Seaweed** is another such feedstock. It can be cultivated on coastal non-arable land and efficiently degraded by an engineered enzyme to produce ethanol and SAF. Currently, the technology is in nascent stages.

India has a potential to produce 8–10 Mt SAF, predominantly via Alcohol-to-Jet pathway

India's SAF production potential via various technology pathway and feedstocks [in million tonnes]



Alternate feedstock (such as sweet sorghum, seaweed and industrial off gases), and higher consumption of agriculture residue, municipal solid waste and used cooking oil can give further impetus to SAF potential in the country.

Source: CPCB, NITI Ayog, PJTSAU, DFPD Sugar Directorate, Eat Right India, Literature review, Deloitte analysis

SAF blending will have minimal impact on ticket prices

The levelised production cost of SAF can be multi-folds higher than that of conventional ATF and is influenced by multiple factors such as capital expenditure, operating expenses and feedstock costs.

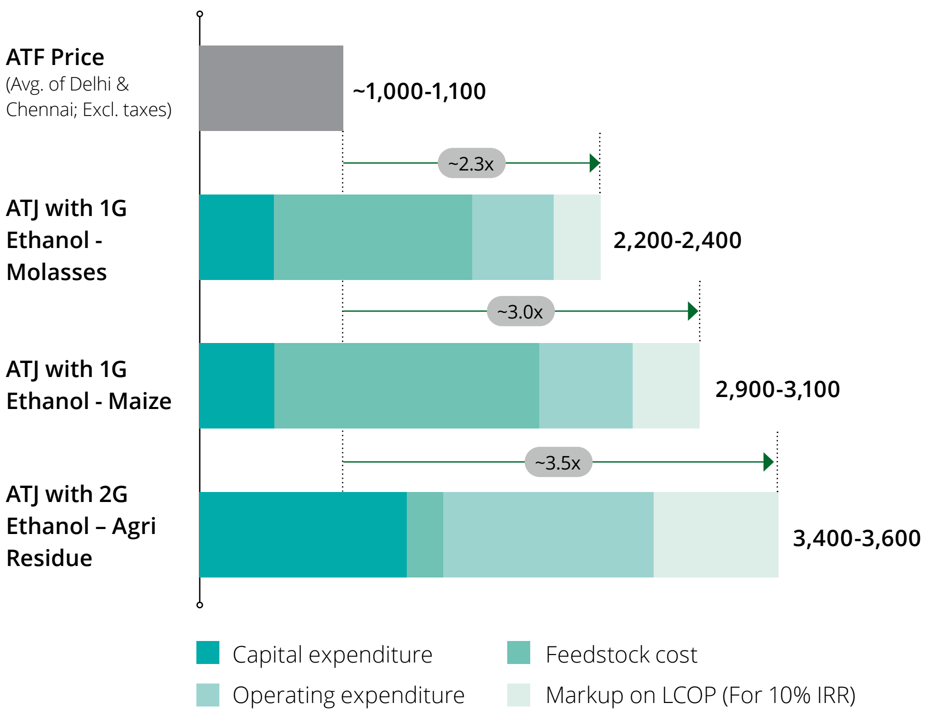
HEFA and PtL are on opposite ends when it comes to the levelised cost of SAF, with HEFA being the most economical among the key technology pathways. While HEFA offers the least expensive levelised cost, it is still estimated to be about twice as expensive as conventional ATF. In HEFA, the cost of feedstock – UCO, hydrogen – is the key driver of levelised cost of production.

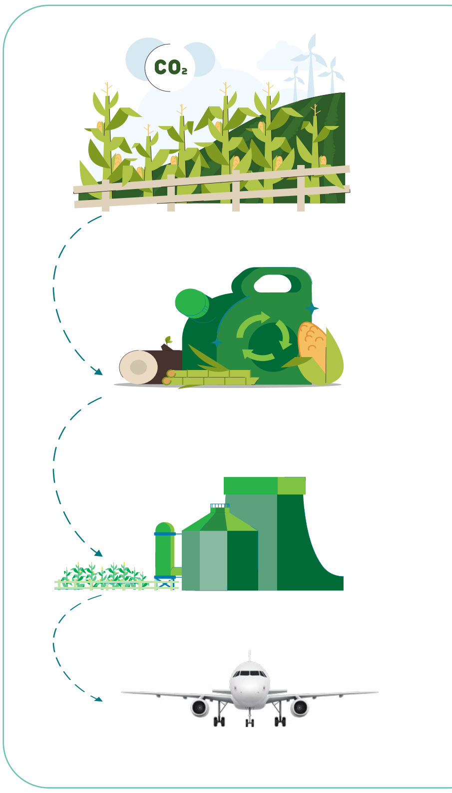
The AtJ pathway with 1G ethanol from sugar and molasses has a well-established ethanol production process. However, the high capital and operating expenses of converting ethanol to SAF contribute significantly to the overall cost. As a result, the SAF produced through the AtJ pathway with 1G ethanol is anywhere between 2.3x and 3x of the conventional ATF. Additionally, SAF with maize as feedstock is expensive due to higher feedstock cost. The AtJ pathway with 2G ethanol from agriculture residue is even more expensive to produce vis-à-vis the 1G ethanol route and is estimated to be ~3.5x the conventional ATF. This is primarily due to the higher capex of ~INR900 crore[40] required for 2G ethanol compared with approximately INR100 crore[41] for 1G ethanol, both for a 100 KLPD capacity. Consequently, the overall levelised cost for AtJ vis-à-vis agriculture residue is higher.

While the Fischer Tropsch process has lower operating expenses, it uses gasification technology that is still not fully mature, leading to higher capital investment costs and, therefore, a higher levelised production cost. PtL, on the other extreme, is the most expensive SAF option due to its dependency on green hydrogen and carbon capture technologies, which are commercially unviable at this moment.

Commercially, SAF produced through 1G and 2G Ethanol will be ~2.3x and ~3.5x of ATF prices

SAF selling price in USD/T, normalised for renewable diesel and light-end sales





Note: 1. USD to INR conversion factor: 83; 2. Density of ATF = 776 kg/m3; 3. Capex and Opex estimates are based on secondary research and industry interactions. 4. Feedstock prices assumed: Maize – INR 22/kg; B Molasses (sugar) – INR 12.5/kg; Rice stubble(2G) – INR 2/kg; 5. ATF Prices are taken average of latest Delhi and Chennai price as published on IOCL website on 1st August 2024; 6 VAT@ 25% for Delhi and 29% for Chennai and excise duty @ 11% has been removed from the published ATF Price.
Source: Secondary research, Industry experts, Indian Oil Corporation Limited, Deloitte analysis

The cost of producing SAF can be reduced by optimising engineering, improving design and product yield, achieving scale or undertaking brownfield expansion to use existing infrastructure. Additionally, institutionalising a robust carbon market will provide platform for ecosystem stakeholders to trade certificates and make SAF projects economically viable.

2-5 percent of SAF blending will result in ticket price increase 2-5 percent for domestic flights and 1-3 percent for international flights

SAF blending rate	**Domestic flights**[3] (e.g. Mumbai-Delhi)		**International flights**[4] (e.g. Mumbai-Heathrow)	
	Addl. Fuel Cost[1,2] [US$]	Additional fuel cost per PAX [US$/PAX] (% of ticket price)	Addl. Fuel Cost[1,2] [US$]	Additional fuel cost per PAX [US$/PAX] (% of ticket price)
2%	~160	~1.1 (~2%)	~2,170	~9.0 (~1%)
5%	~405	~2.8 (~5%)	~5,430	~22.7 (~3%)
10%	~810	~5.6 (~9%)	~ 10,860	~45.4 (~6%)
15%	~1,215	~8.4(~14%)	~16,290	~68.1 (~9%)

Note: 1. Price of ATF is considered to be INR 99,800 / kL, average of as published price ex-Delhi & ex-Chennai by IOCL on 1st August 2024. This translates into US$ 1,500/Mt of ATF; 2. Price of SAF is considered to be ~3,600 US$/ton which is weighted average price of SAF produced via 1G ethanol (avg. of Maize & Molasses) (~10%) & 2G ethanol (Agri residue) (~90%) & 5% GST on biofuels. 3. Estimates for Domestic flights are for Mumbai Delhi flight with ~145 passengers in Airbus 320 with 80% PLF. Ticket price is assumed to be INR 5,000/-; 4. Estimates for international flights are for Mumbai Heathrow with ~240 passengers in Dreamline 787 with 80% PLF. Ticket price is assumed to be INR 60,000/-
Source: DGCA, IOCL, Expert discussions, Deloitte analysis

As fuel cost accounts for ~40 percent of an airline operator's operating expenses and airlines typically operate on thin margins, airlines are likely to pass on the additional cost to passengers through higher ticket prices.

While passing on any additional cost due to SAF blending to customers, our analysis of historical domestic airline traffic and airline service prices suggests that limited increase in ticket prices may not have a significant impact on the passenger traffic.

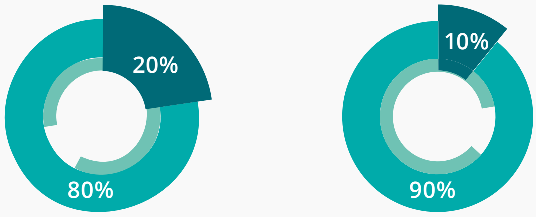
A few leading international airlines, such as Lufthansa, SAS and Discover Airlines, have also introduced "Green Fares." These tickets are offered at a premium compared with regular fares. The additional proceeds are used to offset and reduce flight-related carbon emissions . Green fares also have additional benefits, such as flexible rebooking options and extra miles or points, making them more attractive than regular fares.

As a case in point, Lufthansa launched green fares in February 2023 on selected intercontinental flights, including flights between Frankfurt and Bengaluru. Since its inception, more than 1 million passengers have chosen this new fare option. In its first year, ~3 percent of passengers opted for green fares, with higher adoption rates of ~11 percent in business class. While the fares are particularly popular on routes within the EU — such as Hamburg-Munich, Zurich-London, Frankfurt-Berlin — Lufthansa has reported increasing demand across ticket classes and routes. The fares fully offset individual, flight-related carbon emissions, with the share of offset achieved through SAF and climate protection projects being 20:80 for green fares across Europe and 10:90 for green fares on selected intercontinental flights. Lufthansa ensures that the required quantity of SAF is blended and fed into airport infrastructure within six months, although individual flights do not receive blended fuel due to operational challenges.[42]

Lufthansa launched a green fare option in February 2023 on its European and North African routes and subsequently on selected long-haul routes.

Green fare by Lufthansa

CO2 emissions offsetting contribution



Green fares across Europe

Green fares on selected intercontinental flights

SAF ■ Climate protection projects

Economy Green, Premium Green, Business Green and First Green offer all the benefits of Lufthansa's different fare categories, along with **more flexible rebooking options and additional miles (+10–20%) and points (+10–20%)**

Green fare scheme – Outcome in Year (Feb 2023–Feb 2024)

1 million
passengers opted for green fare

3%
of total passengers opted for green fare

11%
green fare booking of total business class bookings made via the Lufthansa group portal

77,000
tons of CO2 offset since launch

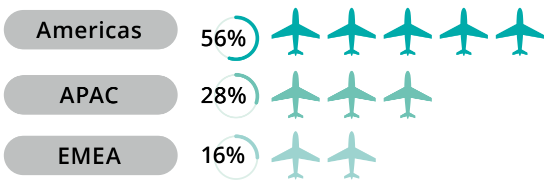
Source: lufthansagroup.com

Success stories like these offer hope and opportunity for Indian aviation players to develop and launch similar offerings in the Indian market.

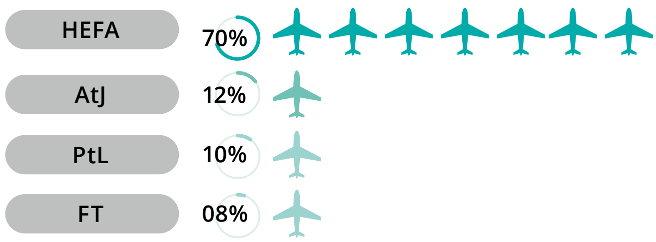
India can produce SAF for the world

SAF production increased to 600 million litres (~0.47 million tonnes) in 2023 and is estimated to reach 1,900 million litres (~1.5 million tonnes) in 2024. Most of the existing facilities today are based on the HEFA technology pathway. Neste, for instance, has a HEFA-based facility with a capacity of 1 million tonnes of SAF in Singapore[43] and an additional 0.1million tonnes of SAF capacity in Finland. In the US, World Energy and Montana Renewables have set up HEFA-based facilities of 0.1 million tonnes and 0.08 million tonnes, respectively. Eco Ceres, another leading player, has set up an HEFA-based facility in China with a capacity of 0.3 million tonnes, producing around ~0.1 million tonnes of SAF.[44] Beyond these capacities, there are also demonstration facilities for Alcohol-to-Jet. Lanzajet has commissioned an AtJ facility in Georgia and is setting up AtJ facilities in India, along with Indian Oil Corporation Limited,[45] and in Japan in partnership with Mitsui and Cosmo Oil.[46]

Capacity announced by region



Capacity announced by technology



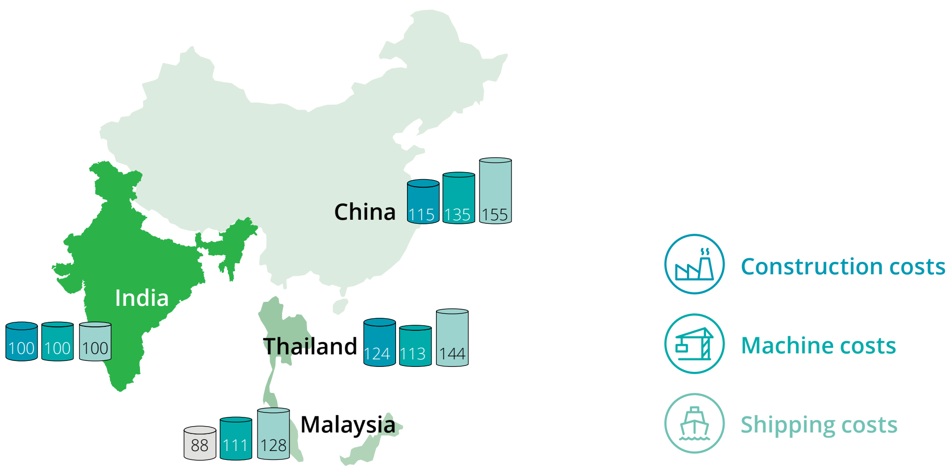
Note: The capacities are only the announced capacities. There is limited visibility on the actual stage (except for operational / planned) of each of these projects.
Source: Argus Media, Deloitte analysis

Of the overall capacities announced, the Americas lead with more than 55 percent of the capacity announced globally, followed by ~28 percent in the APAC region. However, APAC is expected to lead in capacity addition through 2050. According to the forecasts by ATAG, APAC will lead the capacity addition through 2050 and is estimated to account for 40 percent of the global SAF capacity. This growth is expected to be driven by the feedstock availability in the region.

India's significant role in the global aviation fuel market, coupled with its high ATF exports, presents a substantial opportunity for the country to expand into SAF production. India exports ~50 percent of its ATF production, accounting for 2–3 percent of the global demand. This existing capacity and experience in ATF production and trade position India favourably to become a leading supplier of SAF as global demand rises. Moreover, the SAF production potential of 8–10 million tonnes far exceeds the potential domestic demand of 4.5–4.6 million tonnes of SAF at 15 percent blending rates in 2040. With an estimated global demand of ~185 million tonnes of SAF for achieving net-zero commitments, this domestic supply surplus manifests into an attractive export opportunity for India.

India also emerges as a competitive geography vis-à-vis other potential SAF producers such as China, Malaysia and Thailand for supplying SAF to major airline hubs such as Middle East (Dubai) and Europe (Germany, Amsterdam, etc.). This is driven by India's competitiveness across two key areas. Firstly, India offers lower cost of construction, machinery and labour. Except for the cost of construction where India is second to Malaysia amongst the four APAC countries under consideration for SAF, India offers a more optimal cost structure in terms of machinery cost and minimum wages. Secondly, close proximity to demand hubs translates into lower shipping costs. For example, shipping distance from India to Netherlands is two-thirds of that from China.

India's cost competitiveness & proximity to major airline hubs will play in its favour



Note: 1. Construction costs is for construction of buildings for 2024; 2. Machine cost refers to Machinery and Equipment Index published by ICP in 2021; 3. Shipping cost refers to indexed shipping distance from the source country to Amsterdam port.
Source: ILO statistics, World Bank, Arcadis, sea-distances.org, Deloitte analysis

India is competitive to export to major airline hubs – Middle East and Europe - due to lower cost, and its proximity to demand centres.

Indian aviation emissions will become material by 2030 – Imperative to take action now to decarbonise

Indian aviation contributes ~5 percent to the country's transportation emissions. It is expected to increase to almost 8–10 percent by 2030 due to changing mode share, increasing passenger traffic, capacity addition by aircraft operators, infrastructure development and government policies.

SAF is a key lever to decarbonise the aviation sector with a potential contribution of 53–66 percent to net zero

There are broadly four key methods to decarbonise – SAF fuels usage, efficiency improvements, hydrogen/electric aircraft and carbon offsetting. Leading international agencies, such as IATA and ICAO, estimate SAF to contribute 53–66 percent to decarbonisation. Other levers will have less than 10 percent contribution.

Mandates and decarbonisation targets will likely drive the demand for SAF to ~18 Mt by 2030 and ~185 Mt by 2040

Countries have SAF blending targets. For example, the EU has defined an SAF blending roadmap until 2050. International agencies have also defined net-zero commitments. Airlines and corporates are focusing on decarbonising business travel. This will translate into a global demand of ~18 Mt by 2030 and ~185 Mt by 2040.

HEFA can be considered for near term; AtJ and FT are to be evaluated for long term considering feedstock availability

HEFA is the most mature technology pathway for SAF production currently. However, feedstock (UCO) availability in India restricts its ability to scale up. AtJ and FT are the key technologies for the future due to their dependency on agri residue as feedstock and the ability to use other feedstocks such as sugar and maize.

India has enough feedstock to produce 8–10 Mn T of SAF and be a major supplier to the world

India's vast availability of feedstocks – agri residue, municipal waste, user cooking oil – presents an opportunity for India to lead in SAF production and become a key supplier to meet global demand. India's conservative potential of 8-10 million tonnes will far exceed domestic demand, resulting in export opportunity.

Customer traffic will not alter with extra cost due to SAF; Customers are also willing to pay extra for green fares

Fuel expenses account for ~40 percent of airlines' operating expenses. If passed on to passengers, SAF blending cost will not considerably impact traffic – A typical price increase for a 5 percent blending would be 2–5 percent. Moreover, green fares launched by a few airlines have successful case studies for the world.

India is competitive in exporting to major airline hubs due to lower costs and its proximity to demand centres

India is an attractive destination for SAF capacities due to its proximity to major airline hubs – Middle East and Europe – vis-à-vis other APAC countries such as China, Malaysia and Thailand. Moreover, it also offers competitive cost structures.

Jet-setting SAF adoption and delivering impact

While India has taken an indicative SAF blending target of 1 percent in 2027 and 2 percent in 2028 for only international flights, an opportunity exists for India to lead the SAF journey by laying down a detailed and robust roadmap for SAF blending from now till 2040, across domestic and international flights, in line with our NDC targets and CORSIA mandates. Assuming a blending mandate of 5 percent for 2030 and 15% for 2040, India's demand for SAF will stand at ~0.8 million tonnes in 2030, increasing to ~4.5 million tonnes in 2040. Of this, only 25% of the demand will be for international flights and the remaining 75% of the demand for the domestic flights.

However, given the feedstock availability, India can produce 8–10 million tonnes of SAF, giving it the opportunity to export SAF and meet the global SAF demand. Such SAF production will lead to a reduction in aviation carbon emissions by 20–24 million tonnes of CO2e. Establishing SAF production facilities in India presents a significant opportunity. It will also drive direct and indirect socio-economic impact.

First, all SAF technology pathways offer biofuel output with **renewable diesel as an important byproduct**. Any impetus to SAF production will also drive renewable diesel production and availability, thereby supporting the Indian government's aim of reducing oil imports and reducing emissions. It is estimated that at 8–10 million tonnes of SAF production capacity, India will have additional renewable diesel availability of 3–4 million tonnes. This will support India in reducing its annual oil import bills by US$5-7 bn and contribute towards energy security.

Second, establishing SAF production facilities will attract substantial **capital investments**. At the proposed production capacity capital investment of INR6–7 lakh crore (US$70–85 billion) will be infused into the economy. Subsequently, capital investments might be optimised with scale, engineering optimisation, etc.

Third, **capital investment** will also generate employment[47]. It is forecast that SAF-related capital investment will generate 1.1-1.4 million employment opportunities across the value chain.

Fourth, the capital investment and subsequent production of SAF will further translate into **additional farmer income** of INR16,000–20,000 crore per annum. Further, The diversion of agriculture residue for SAF production will also result in health benefits due to a reduction in crop burning.

However, accelerating SAF production and adoption in India will require coordinated efforts and initiatives from all the ecosystem stakeholders, including the government, aircraft operators, corporates, refiners/producers, investors and technology service providers.

The lack of a regulatory roadmap for SAF adoption presents a significant barrier. There is no clear roadmap beyond 2028, especially for domestic flights. To overcome this, the Indian government should **establish a clear, long-term roadmap for SAF.** It should also formally set blending and production targets under the National Biofuels Policy to serve domestic and international markets. Setting these targets and institutionalising the necessary enablers can provide the right impetus for the ecosystem.

For example, regulatory programmes such as Renewable Purchase Obligations (RPO) promoted initial investments in renewable energy at a discount at a time when these were financially unviable. Likewise, in 2018, the Indian government established a framework for ethanol blending in motor spirits. Under the framework, the government set a 20 percent blending target for 2026, allowed multiple feedstocks (such as rice and maize) for ethanol production, provided financial assistance through the interest subvention scheme and ensured pricing support and transparency to promote investment. This prompted active industry participation in setting up 1G ethanol plants. Likewise, for SAF, the EU has set mandates for fuel suppliers and aircraft operators to ensure the supply and demand of SAF-blended fuels. Similar strategies in India would give confidence to the ecosystem stakeholders, provide impetus for signing SAF offtake agreements and promote capital investments.

The unorganised feedstock supply chain is another crucial challenge in SAF adoption. Feedstock such as agriculture residue and used cooking oil lack organised supply chains in India. On the other hand, municipal solid waste lack segregation facilities and infrastructure. This disorganisation will create difficulties in ensuring a continuous feedstock supply for SAF producers. Thus, the government should encourage the ecosystem stakeholders to **develop formal and organised systems for feedstock collection, storage, segregation and logistics** to significantly improve the reliability, availability and support of continuous SAF production. This will require concerted efforts from upstream stakeholders to ensure feedstock availability for proposed biorefineries. Key stakeholders, such as Farmer Producer Organisations (FPO), need to play an active role in accelerating supply chain set-up – collection, logistics and storage – in association with producers.

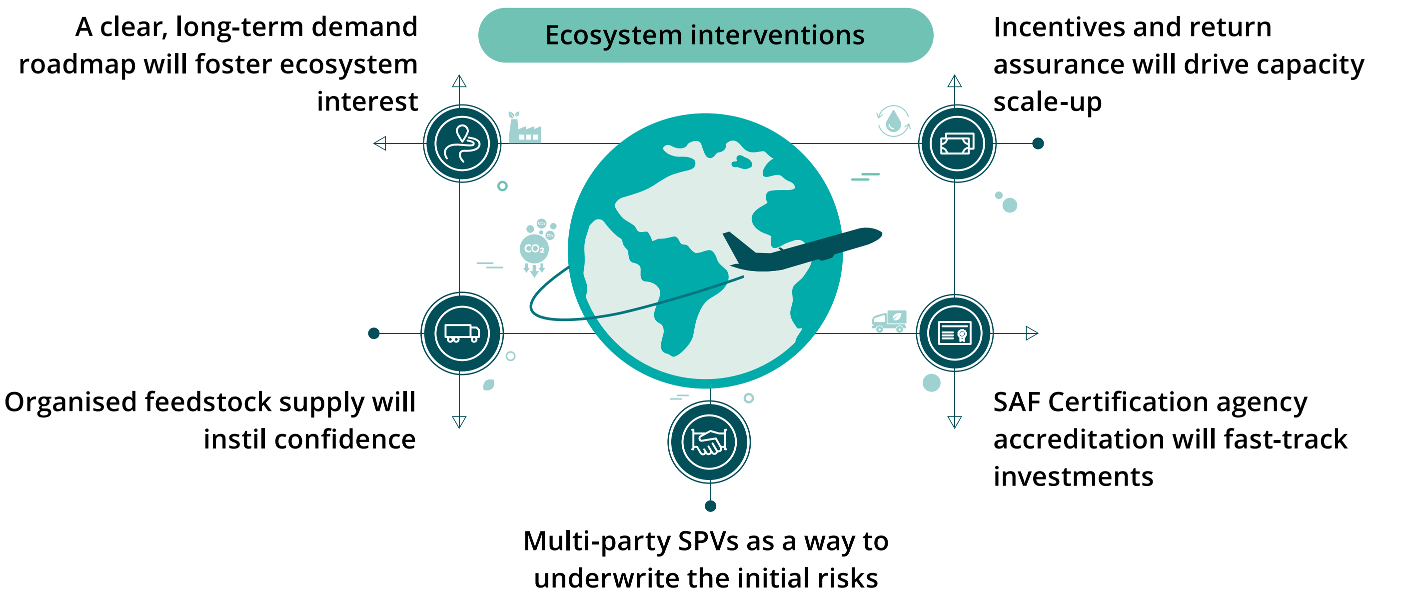
Given the nascent technology, ecosystem stakeholders are apprehensive about taking the first step and are keen to be the second to invest. **Multi-party Special Purpose Vehicles (SPVs)** consisting of airlines, SAF manufacturers, OMCs, FPOs and technology providers in different combinations can help overcome the initial inertia before the SAF flywheel starts moving, bringing the expertise from different players to help de-risk the capital investments.

As the SAF facilities are capital-intensive and technologies are in a nascent stage, **incentives and return assurance** will drive capacity scale-up. Financial assistance in the form of PLIs, VGF, tax cuts and interest subventions has mobilised investments in energy transition such as ethanol, green hydrogen and RE. The government could also consider providing tax relief for SAF. For example, the GST on bioethanol meant for fuel blending was reduced from 18 percent to 5 percent[48].

Moreover, transparency in SAF pricing is another notable concern. Unlike ATF, which has an established market, limited visibility on SAF pricing makes it difficult for stakeholders to predict and plan for costs. The ecosystem players should **establish a more transparent, predictable and formal pricing mechanism in the initial years** to reduce uncertainty and assure investor returns.

Another issue is the lack of SAF certification agencies in India. Currently, no Indian agency is accredited to certify SAF facilities in accordance with global standards, which is a critical step in the production process. It is imperative to **identify and nominate an Indian agency that will be able to certify SAF facilities** in accordance with global standards – ICAO, CORSIA, etc. This will give confidence to investors with an interest in SAF, expedite certification and drive investments.

There is also merit in **formalising and expediting the implementation of a carbon market** in India. With the introduction of a carbon tax, several sustainability projects that currently seem unviable could become attractive investments.



Thus, while India's potential capacity for SAF production is significant, multiple interventions are required to fully realise this potential. A strategic focus on SAF would strengthen India's leadership in the aviation sector as it transitions toward more sustainable practices.

Connect with us

Viral Thakker
Partner and Leader
Sustainability & Climate
Deloitte South Asia
vthakker@deloitte.com

Ashwin Jacob
Partner and Leader
Energy, Resources & Industrials
Deloitte India
ashwinjacob@deloitte.com

Prashanth Nutula
Partner
Deloitte India
pnutula@deloitte.com

Contributors

Debashish Biswas
Vivek Mittal
Kuntal Shah
Ayush Rungta
Rishi Bigghe
Hardik Patel
Shweta Haribalaji

Note of thanks

We would like to thank **Soumitra Satapathi, Professor, Department of Physics, Indian Institute of Technology (IIT) Roorkee**, for his invaluable insights and guidance in curating this report.

Acknowledgement

Esha Bharadwaj
Shikhar Bajpai
Shakya Sengupta
Gaurav Saket
Nandita Jain
Vasudha Pathak
Rahul Dhuria
Vidhy Das

List of abbreviations

Sr. No.	Abbreviation	Description	Sr. No.	Abbreviation	Description
1.	1G	1st Generation	32.	IATA	International Air Transport Association
2.	2G	2nd Generation	33.	ICAO	International Civil Aviation Organization
3.	2W	2-Wheeler	34.	KLPD	Kilolitres per Day
4.	3W	3-Wheeler	35.	km	Kilometres
5.	APAC	Asia Pacific	36.	KTPA	Kilotons per Annum
6.	ASTM	American Society for Testing and Materials	37.	L	Litres
7.	ATAG	Air Transport Action Group	38.	LTAG	Long-Term Aspirational Goal
8.	ATF	Aviation Turbine Fuel	39.	Mn	Million
9.	AtJ	Alcohol-to-Jet	40.	MRV	Monitor, Report and Verify
10.	C2H5OH	Ethanol	41.	MSW	Municipal Solid Waste
11.	CAGR	Compounded Annual Growth Rate	42.	MT	Metric Tons
12.	CEEW	Council on Energy, Environment and Water	43.	MUM	Mumbai
13.	CHJ	Catalytic Hydro-thermolysis Jet	44.	PLI	Production Linked Incentive
14.	CO2	Carbon Dioxide	45.	PNGRB	Petroleum & Natural Gas Regulatory Board
15.	CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation	46.	PtL	Power-to-Liquid
16.	Cr	Crore	47.	RE	Renewable Energy
17.	DEC	December	48.	SAF	Sustainable Aviation Fuel
18.	DEL	Delhi	49.	SIP	Synthesize Iso-Paraffins
19.	EU	European Union	50.	SKA	Synthetic Kerosene with Aromatics
20.	EV	Electric Vehicle	51.	SPK	Synthetic Paraffinic Kerosene
21.	FBO	Food Business Operators	52.	T	Tons
22.	FSSAI	Food Safety and Standards Authority of India	53.	TPC	Total Polar Compounds
23.	FT	Fischer Tropsch	54.	TPD	Tons per Day
24.	FTE	Full Time Employee	55.	TRL	Technology Readiness Level
25.	FY	Financial Year	56.	UCO	Used Cooking Oil
26.	GCC	Global Capability Centre	57.	UK	United Kingdom
27.	GDP	Gross Domestic Product	58.	US	United States of America
28.	GST	Goods & Service Tax	59.	VAT	Value Added Tax
29.	Gt	Gigatons	60.	WEF	World Economic Forum
30.	HC	Hydrocarbon			
31.	HEFA	Hydrotreated Esters & Fatty Acids			

References

1. "India's Domestic Aviation: A Deep-Dive into a Decade of Growth," OAG, June 2024, https://www.oag.com/blog/indias-domestic-aviation-market
2. "InterGlobe Aviation Ltd Company Presentation," Indigo, March 2024, https://www.goindigo.in/content/dam/goindigo/investor-relations/presentation/2023-24/Company-Presentation-2024.pdf
3. "Handbook on civil aviation statistics," DGCA, FY 2022-23, https://www.dgca.gov.in/digigov-portal/?page=jsp/dgca/InventoryList/dataReports/aviationDataStatistics/handbookCivilAviation/HANDBOOK%202022-23.pdf&main4252/4205/sericename
4. "Vision 2040 for the civil aviation industry in India," FICCI, January 2019, https://static.investindia.gov.in/s3fs-public/2020-02/VISION-2040-FOR-THE-CIVIL-AVIATION-INDUSTRY-IN-INDIA.pdf
5. "India. National Communication (NC). NC 3,", UNFCCC, 2023, https://unfccc.int/documents/636235
6. "Aviation Turbine Fuel demand," PNGRB, May 2024, https://www.pngrb.gov.in/pdf/public-notice/COII_15052024.pdf
7. "Electric Vehicles," Office of the principal scientific adviser to the government of India, https://www.psa.gov.in/mission/electric-vehicles/36
8. "India Transport Energy Outlook," CEEW, June 2022, https://www.ceew.in/sites/default/files/ceew-research-transport-energy-use-carbon-emissions-decarbonisation.pdf
9. "Net zero 2050: operational and infrastructure improvements," IATA, June 2024, https://www.iata.org/en/iata-repository/pressroom/fact-sheets/fact-sheet-netzero-operations-infrastructure/#:~:text=The%20aviation%20industry%20has%20a,per%20passenger%20km%20since%201990
10. "ZeroAvia Makes Aviation History, Flying World's Largest Aircraft Powered with a Hydrogen-Electric Engine," PRNewswire, January 2023, https://www.prnewswire.com/news-releases/zeroavia-makes-aviation-history-flying-worlds-largest-aircraft-powered-with-a-hydrogen-electric-engine-301726022.html
11. "Universal Hydrogen Successfully Completes First Flight of Hydrogen Regional Airliner," Business Wire, March 2023, https://hydrogen.aero/press-releases/universal-hydrogen-successfully-completes-first-flight-of-hydrogen-regional-airliner/#:~:text=%E2%80%93(BUSINESS%20WIRE)%E2%80%93Universal,an%20altitude%20of%203%2C500%20MSL.
12. "Aircraft Technology Net Zero Roadmap," IATA, https://www.iata.org/contentassets/8d19e716636a47c184e7221c77563c93/aircraft-technology-net-zero-roadmap.pdf
13. "SAF Volumes Growing but Still Missing Opportunities" IATA, December 2023, https://www.iata.org/en/pressroom/2023-releases/2023-12-06-02/
14. "Virgin Atlantic flies world's first 100% Sustainable Aviation Fuel flight from London Heathrow to New York JFK," bp, https://www.bp.com/en/global/air-bp/news-and-views/press-releases/Virgin-Atlantic-flies-worlds-first-100-Sustainable-Aviation-Fuel-flight-from-London-Heathrow-to-New-York-JFK.html
15. "Boeing Doubles Sustainable Aviation Fuel Purchase for Commercial Operations," Boeing, February 2023, https://investors.boeing.com/investors/news/press-release-details/2023/Boeing-Doubles-Sustainable-Aviation-Fuel-Purchase-for-Commercial-Operations-Buying-5.6-Million-Gallons-for-2023/default.aspx
16. "IndiGo joins WEF Sustainability Campaign 'Clear Skies for Tomorrow'," Indigo, August 2022, https://www.goindigo.in/press-releases/indigo-joins-wef-sustainability-campaign-clear-skies-for-tomorrow.html
17. "Vistara operates first commercial India flight with sustainable fuel," Times of India, May 2023, https://timesofindia.indiatimes.com/city/mumbai/vistara-operates-first-commercial-india-flight-with-sustainable-fuel/articleshow/99998141.cms
18. "Making history, AirAsia India, Praj and IOCL join hands to fly first commercial flight in India powered by a blend of 'indigenous' Sustainable Aviation Fuel," Praj Industries, May 2023, https://www.praj.net/wp-content/uploads/2023/05/230519-Press-Release-Praj-IOCL-AirAsia.pdf
19. "SpiceJet, Boeing and CSIR-Indian Institute of Petroleum Join Hands to Lead the Way in Sustainable Aviation Fuel for the Indian Aviation Industry," SpiceJet, March 2022, https://corporate.spicejet.com/PressReleaseNewsPageNew.aspx?strNews=IIPjoinshand
20. "Disentangling Refuel EU: How will it shape the SAF market?," SkyNRG, November 2023, https://skynrg.com/refueleu-how-it-will-shape-the-saf-market/
21. "Sustainable Aviation Fuel (SAF/Bio- ATF) indicative blending percentage targets set," Press Information Bureau, November 2023, https://pib.gov.in/PressReleasePage.aspx?PRID=1979705
22. "Our Commitment to Fly Net Zero by 2050," IATA, https://www.iata.org/en/programs/sustainability/flynetzero/
23. "States adopt net-zero 2050 global aspirational goal for international flight operations," ICAO, October 2022, https://www.icao.int/Newsroom/Pages/States-adopts-netzero-2050-aspirational-goal-for-international-flight-operations.aspx
24. "COVID-19 impacts and 2022 CORSIA periodic review," ICAO, https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-and-Covid-19.aspx
25. "CORSIA States for Chapter 3 State Pairs," ICAO, October 2023, https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA%20States%20for%20Chapter%203%20State%20Pairs_4Ed_rev_web.pdf
26. "SAF Volumes Growing but Still Missing Opportunities", IATA, December 2023 https://www.iata.org/en/pressroom/2023-releases/2023-12-06-02/
27. "SAF Offtake Agreements", ICAO, September 2024 https://www.icao.int/environmental-protection/GFAAF/Pages/Offtake-Agreements.aspx
28. "Reduce your corporate travel emissions by -50% or more of pre-Covid levels by 2025 or sooner," Travel Smart, https://travelsmartcampaign.org/
29. "Net zero 2050: sustainable aviation fuels", IATA, May 2024, https://www.iata.org/en/iata-repository/pressroom/fact-sheets/fact-sheet---alternative-fuels/
30. "Conversion processes," ICAO, July 2023, https://www.icao.int/environmental-protection/GFAAF/Pages/Conversion-processes.aspx
31. "Sustainable Aviation Fuels Pathways and Product Slate," IATA, May 2024, https://www.iata.org/en/iata-repository/publications/economic-reports/sustainable-aviation-fuels-pathways-and-product-slate/.

32. "First Ethanol Alcohol-to-Jet Sustainable Aviation Fuel Production Facility Unveiled," Office of energy efficiency & renewable energy, January 2024, https://www.energy.gov/eere/bioenergy/articles/first-ethanol-alcohol-jet-sustainable-aviation-fuel-production-facility.
33. "Fueling Net Zero", ATAG Waypoint, September 2021, https://aviationbenefits.org/media/167495/fueling-net-zero_september-2021.pdf
34. "RUCO Booklet," Eatrightindia, https://eatrightindia.gov.in/ruco/file/ruco_booklet.pdf
35. "Background Note on Used Cooking Oil," Eatrightindia, https://eatrightindia.gov.in/ruco/file/Background%20Note-UCO.pdf
36. "Guidelines for UCO collection," Eatrightindia, https://eatrightindia.gov.in/ruco/guidelines_for_collection.php
37. "Ethanol used in petrol now more from maize, damaged foodgrains than sugar, Indian express," July 2024, https://indianexpress.com/article/india/ethanol-used-in-petrol-now-more-from-maize-damaged-foodgrains-than-sugar-9481641/
38. "National Biomass Atlas of India," Ministry of New and Renewable Energy, https://www.nibe.res.in/biomass-atlas.php
39. "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels", ICAO, March 2024, https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20Emissions%20-%20March%202024.pdf
40. IOCL Panipat 2G Ethanol plant
41. Input from Expert Interview
42. "One year of Green Fares at the Lufthansa Group," Lufthansa group, March 2024, https://newsroom.lufthansagroup.com/en/one-year-of-green-fares-at-the-lufthansa-group-more-than-one-million-passengers-choose-new-fare-for-more-sustainable-travel/
43. "Singapore Airlines Group orders SAF from Neste," Biodiesel Magazine, May 2024, https://biodieselmagazine.com/articles/singapore-airlines-group-orders-saf-from-neste
44. "Focus: Chinese firms invest in 'green' jet fuel, anticipating blending rule," Reuters, May 2024, https://www.reuters.com/sustainability/climate-energy/chinese-firms-invest-green-jet-fuel-anticipating-blending-rule-2024-05-16/
45. "Indian Oil Signs MOU With LanzaJet on Sustainable Aviation Fuel," LanzaJet, August 2023, https://www.lanzajet.com/news-insights/indian-oil-signs-mou-with-lanzajet-on-sustainable-aviation-fuel-saf
46. "Production of Sustainable Aviation Fuel (SAF)/LanzaJet," Mitsui & Co, https://www.mitsui.com/solution/en/solutions/lowc-fuel/lanzajet-en
47. "Sustainable Aviation Fuel," ATAG, https://atag.org/industry-topics/sustainable-aviation-fuel
48. "Tax Breakes on Ethanol," Press Information Bureau, December 2021, https://pib.gov.in/PressReleasePage.aspx?PRID=1782275