Advancing Electro-SAF (e-SAF) for India's Aviation Decarbonisation

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Glossary

Abbreviation	**Full Form**
CCTS	Carbon Credit Trading Scheme
CERC	Central Electricity Regulatory Commission
CfD	Contracts for Difference
COD	Commercial Operations Date
DAC	Direct Air Capture
EC	Environmental Clearance
EHVAC	Extra High Voltage Alternating Current
EJ	Exajoules
e-SAF	electro-Sustainable Aviation Fuel
EU	European Union
FSR	Foreign Subsidy Regulation
GA	Green Ammonia
GH	Green Hydrogen
GM	Green Methanol
HVDC	High Voltage Direct Current
ICX	Indian Carbon Exchange
IMO	International Maritime Organisation
IPR	Industrial Policy Resolution
LCOM	Levelized Cost of Green Methanol
MMTPA	Million metric tons per annum
MPA Singapore	Maritime & Port Authority Of Singapore
MTJ	Methanol to Jet
RE	Renewable Energy
RED	Renewable Energy Directive
ROW	Right of Way
RTU	Right to Use
STU	State Transmission Charges
SIGHT	Strategic Interventions for Green Hydrogen Transition

About Indo-German Energy Forum (IGEF)

The Indo-German Energy Forum (IGEF) was established by the Indian Prime Minister and the German Chancellor to enhance and deepen the strategic dialogue about the ongoing energy transition between India and Germany. The forum aims at initiating strategic cooperation projects between German and Indian governments, institutions, and the private sector. It aims at promoting cooperation in energy security, energy efficiency including energy conservation, renewable energy, investment in energy projects, and collaborative research and development in identified areas, considering the environmental challenges of sustainable development. The Support Office to the Indo-German Energy Forum (IGEF-SO) is implemented by GIZ and has been tasked provide liaison services for all stakeholders, identifies possible topics for dialogue and supports private sector projects.

About SAF Association

SAF Association is an industry body (section 8, not for profit) actively building a comprehensive ecosystem for Sustainable Aviation Fuel (SAF) in India and focusing on development, certification, and commercialization. SAFA connects all key stakeholders across the value chain for scaling SAF production including both bio-based and synthetic pathways and achieving its decarbonization potential of aviation. SAFA is committed to advancing net-zero aviation by accelerating SAF production and adoption, in close collaboration with policymakers, industry leaders, and civil society etc.

Executive Summary

India's aviation sector is at a defining juncture where electro–Sustainable Aviation Fuel (e-SAF) will shape the country's pathway to net-zero aviation. With air traffic set to surge, aligning growth with sustainability demands a robust e-SAF ecosystem built on clear policy, finance, and technology foundations.

This report presents an integrated assessment of India's e-SAF landscape - highlighting opportunities, barriers, and actionable pathways to accelerate adoption. While India holds strong advantages in renewable energy, green hydrogen, and CO_2 utilisation, the sector faces early-stage challenges including high costs, lack of mandates, and limited policy coordination.

To address these, the report recommends five strategic priorities:

- **Policy Alignment:** Recommended to formulate a National SAF Policy with progressive blending mandates (1-5% by 2030) and integration into India's carbon market.
- **Financing Innovation:** Advised to introduce pre-FID support, green finance classification, and enable carbon credit access to attract private and international investment.
- **Technology Readiness:** Proposed that support for pilot-scale e-SAF projects and airport blending infrastructure will demonstrate technical and regulatory readiness.
- **Capacity Building & Global Collaboration:** Urged that establishing a national training and R&D framework linked to global Power-to-X (PtX) initiatives for technology transfer, skill development, and institutional capacity would strengthen the ecosystem
- **Phased Roadmap:** Advocated to adopt a phased approach—from pilot projects (2025–27) to scale-up (2027–30) and export competitiveness (2030–35)—to ensure market maturity and global leadership in sustainable aviation fuels.

Together, these actions can establish India as a regional e-SAF hub, driving aviation decarbonisation, green job creation, and global climate leadership.

1 Introduction

1.1 Aviation as an Enabler of Economic Growth, Trade, and Connectivity

India's aviation sector stands as a critical pillar of national growth, driving economic activity, regional integration, and global competitiveness. As the world's third-largest domestic aviation market after the United States and China, India's air transport industry has become an essential contributor to the economy and an enabler of social and cultural connectivity across its vast geography.

In **2023**, aviation contributed an estimated USD 53.6 billion to India's GDP - around 1.5 percent of the national total - supporting 7.7 million jobs across airlines, airports, manufacturing, air navigation services, and tourism-related sectors. Within this, the industry directly employs nearly 370,000 professionals, while aviation-enabled tourism adds USD 27.1 billion to GDP and sustains an additional 5 million jobs.[1]

Figure 1: India's Aviation Sector: A Growth Engine for the Nation

Beyond its economic impact, aviation strengthens India's social fabric and global linkages. It connects families and communities, enables access to education and healthcare, and supports emergency and disaster response. The sector enhances business and investment flows, facilitates access to capital and new markets, and accelerates knowledge transfer and innovation.

India's aviation market is forecasted to expand rapidly - passenger traffic is expected to grow at a Compound Annual Growth Rate (CAGR) of ~10 percent, from 220 million in 2023-24 to nearly 390 million by 2030, while freight traffic is projected to grow at ~13 percent CAGR, from 2.4 million tons to 5.1 million tons in the same period. This surge is being propelled by rising air travel preferences, enhanced connectivity across Tier 2 and Tier 3 cities, fleet expansion, and infrastructure modernisation.[2]

As India advances toward its vision of becoming a global aviation hub, the sector's share in national transport emissions is expected to rise - from roughly 5 percent today to 8-10 percent by 2030, underscoring the urgency for a sustainable transition.[3]

1.2 The dual reality: rapid aviation growth vs. rising carbon footprint

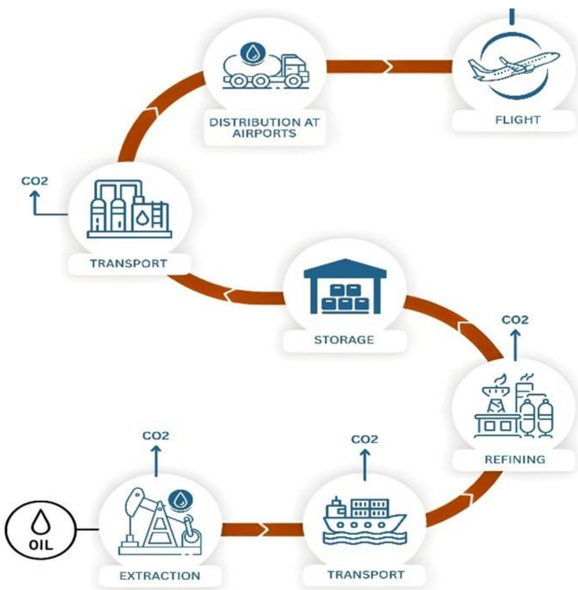
Global aviation sector is on a rapid growth trajectory, fuelling economic activity, regional integration, and global connectivity. However, this growth comes with a significant environmental challenge: a rising carbon footprint.

Globally, aviation accounted for approximately 2.5% of energy-related CO_2 emissions in 2022 (~800 Mt CO_2), nearly reaching pre-pandemic levels, according to the International Energy Agency (IEA). Over recent decades, aviation emissions have grown faster than those from rail, road, or shipping. If considered a country, the aviation sector would rank among the world's top 10 emitters.[4]

In India, the sector's carbon footprint is already substantial - emitting an estimated 25-30 million tons of CO_2 annually, representing roughly 1% of the nation's total greenhouse gas (GHG) emissions, according to the Directorate General of Civil Aviation (DGCA).[5] The demand for Aviation Turbine Fuel (ATF) is expected to nearly double, from around 8.2 million tons in 2024 to 15-16 million tons by 2030.

With the projected surge in passenger and freight traffic, these emissions are set to rise further, underscoring the urgent need for sustainable aviation practices. Addressing this challenge is critical not only for India's climate goals but also for ensuring the long-term viability of the aviation industry itself.

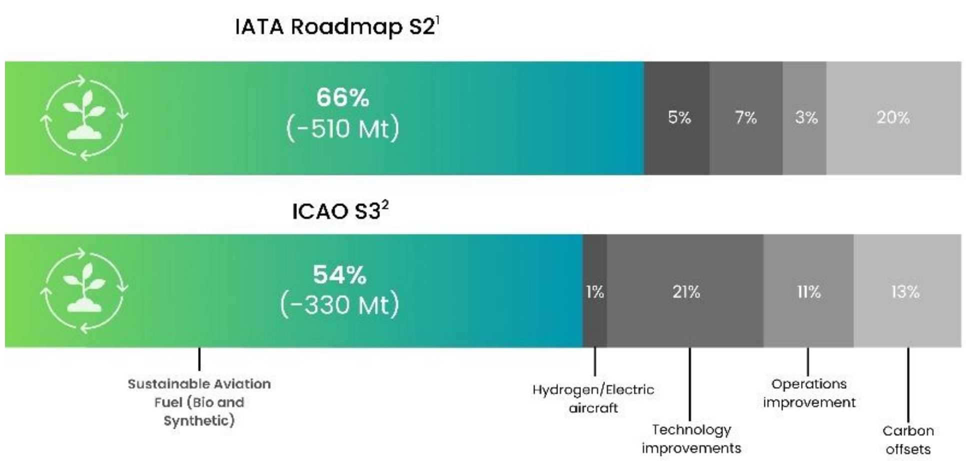
Figure 2: Carbon Lifecycle of Fossil Jet Fuel



1.3 Sustainable Aviation Fuels (SAF): A Key Decarbonisation Lever

The aviation sector, though vital for global connectivity and economic growth, is emerging as one of the fastest-growing sources of greenhouse gas emissions and could consume up to 20% of the world's remaining carbon budget by 2050. To remain viable and aligned with the Paris Agreement's 1.5°C target, the industry must achieve net-zero emissions by mid-century through large-scale adoption of sustainable aviation fuels (SAF), technological innovation, and compliance with global frameworks like the International Civil Aviation Organization's Carbon Offsetting and Reduction Scheme for International Aviation (ICAO's CORSIA). Decarbonising aviation is no longer optional - it is essential for regulatory compliance, market competitiveness, and maintaining the industry's social license to operate in a net-zero world.

Figure 3: Decarbonisation levers for aviation sector across 2050 net-zero roadmaps



Decarbonising aviation requires a multi-pronged approach that addresses emissions across the sector. Key strategies include improving operational efficiency through optimised flight routes and air traffic management, developing advanced aircraft technologies such as lighter airframes and hybrid-electric or hydrogen propulsion, and investing in electrification. Complementary measures include carbon offsetting and participation in carbon markets like CORSIA, integrating renewable energy across airport operations, and leveraging digitalisation and data analytics for fuel optimisation and real-time emissions tracking. Supported by enabling policies, green finance, and global collaboration, these levers collectively chart a pathway toward a sustainable and climate-resilient aviation ecosystem.

Among these levers, Sustainable Aviation Fuel (SAF) stands out as a near-term, high-impact solution. SAF is a low-carbon alternative to conventional jet fuel, produced from renewable or waste-based feedstocks such as used cooking oil, agricultural residues, municipal solid waste, or captured carbon combined with green hydrogen. Depending on the production pathway, SAF can reduce lifecycle greenhouse gas emissions by up to 80%, making it one of the most effective tools for immediate carbon reduction.[6] As a "drop-in fuel", SAF can be used in existing aircraft and fuelling infrastructure without modification, enabling scalable adoption. It also plays a critical role in helping airlines and countries achieve CORSIA compliance, net-zero goals, and Paris Agreement commitments, while also contributing significantly to limiting global warming to 1.5°C, promoting energy diversification, green value chains, and sustainable economic growth.

2 SAF and the Global Context

2.1 Global SAF Landscape: Trends, Adoption, and Impact

The aviation sector accounts for approximately 2-3% of global CO_2 emissions, and this share is projected to rise as air travel expands worldwide. Following a temporary dip during the pandemic, passenger demand rebounded to pre-COVID levels in 2023, with the International Air Transport Association (IATA) projecting that global passenger numbers will reach 4.6 billion by 2025 and 10 billion by 2050.[7] If this growth continues unchecked, aviation-related emissions will rise proportionally, underscoring the urgent need for decarbonisation measures.

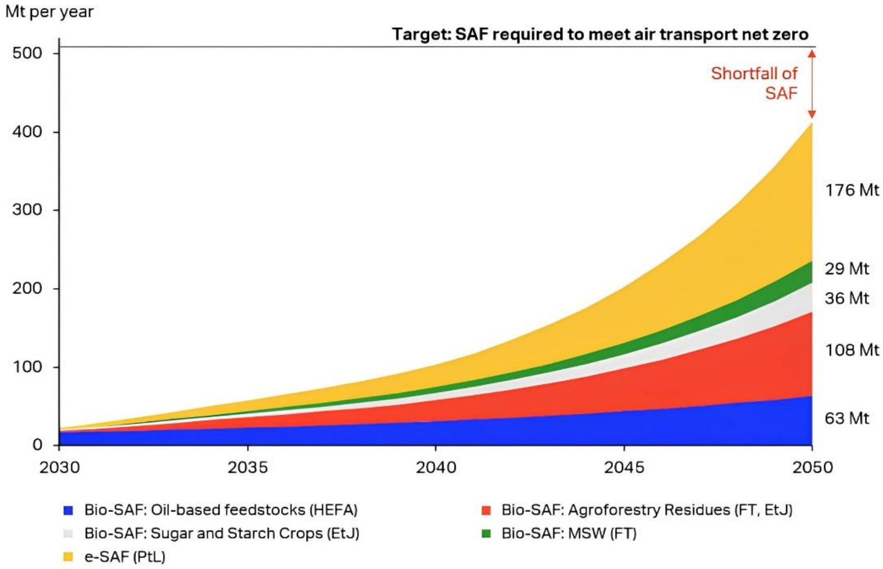
In this context, SAF has emerged as the most viable near-term solution to reduce aviation's climate impact. SAF can be seamlessly integrated into existing aircraft and fuel infrastructure, enabling significant emission reductions without major technological overhauls. Unlike conventional jet fuel refined from fossil crude, SAF is derived from renewable or waste-based feedstocks such as used cooking oil, animal fats, agricultural residues, municipal solid waste, alcohols, and captured carbon. These feedstocks recycle carbon already present in the atmosphere, enabling lifecycle CO_2 emission reductions of up to 70% compared to conventional jet fuel.

The ICAO has recognised SAF as a central pillar in achieving the industry's net-zero emissions goal by 2050. Governments across the world have introduced policy frameworks, incentives, and blending mandates to accelerate the production and uptake of SAF, complemented by voluntary commitments from airlines and fuel producers.

Globally, SAF production has begun to scale up but still represents a small share of total jet fuel demand. Production volumes doubled between 2023 and 2024, reaching 1 million tons (1.3 billion litres) — equivalent to 0.3% of total jet fuel production and 11% of global renewable fuel output. In 2025, production is expected to increase to 2.1 million tons (2.7 billion litres), representing 0.7% of global jet fuel supply and 13% of renewable fuel capacity.[8] Looking ahead, global SAF demand is projected to reach around 17 million tons per annum (Mt/a) by 2030, accounting for approximately 4-5% of total jet fuel consumption. This projection reflects a combination of government-mandated targets and voluntary airline commitments, signalling strong momentum towards cleaner aviation.[9] Today, there are 11 conversion processes for SAF production which have been approved by ASTM International and 11 other conversion processes are currently under evaluation.[10]

Oil-based Hydroprocessed Esters and Fatty Acids (HEFA) pathway is projected to account for just over 15% of the SAF in 2050 and is the only pathway that is projected to fully utilise the oil-based feedstocks available for SAF. Of the five technology pathways, e-SAF is projected to contribute the single largest amount of SAF in 2050, accounting for just over 40%.[11]

Figure 4: Estimated global SAF production potential, forecast



2.2 Bio-SAF vs. e-SAF: Pathways, Potential, and Trade-offs

Both Bio-SAF and e-SAF are chemically similar to conventional jet fuel. This allows them to be used as drop-in replacements, meaning they can be blended with conventional jet fuel and used in current aircraft without requiring any modifications. Currently, the maximum allowable blend is 50% SAF, though research is ongoing to enable the use of 100% SAF in the future. While biomass-derived SAF remains an important initial step, e-SAF offers a long-term solution for near-zero carbon aviation.[13]

The global SAF policy landscape is rapidly evolving. While Europe remains the most advanced market, Asia-Pacific, Latin America, and the Middle East are emerging as significant SAF growth regions. These developments offer new market opportunities, investment potential, and strategic advantages for early movers in SAF production and deployment.

Table 1 – Bio-SAF vs E-SAF

Feature	Bio-SAF	e-SAF / Synthetic e-Fuel
Definition	Jet fuel produced from sustainable feedstocks (excluding petroleum), engineered to reduce lifecycle GHG emissions.	Produced from renewable electricity, water, and captured CO_2; uses renewable-powered electrolysis for H_2 and designed for near-zero lifecycle emissions.
Feedstock	Biomass: waste oils/fats, algae, agricultural residues, energy crops.	CO_2 (industrial sources or direct air capture), water, renewable electricity.
Production Process	HEFA, Fischer-Tropsch (FT) (from biomass gasification), Alcohol-to-Jet (AtJ), Direct sugar-to-hydrocarbons (DSHC), Hydrothermal liquefaction (HTL).	Renewable electrolysis (PEM, SOEC) for H_2, CO_2 capture (point source or DAC), Fischer–Tropsch (FT) or Methanol-to-Jet (MtJ) synthesis.
Scalability	Limited by sustainable biomass availability, land-use conflicts, and logistical challenges.	High potential; scalable with renewable electricity, CO_2 capture, and electrolysis deployment.
Land Use Impact	Variable: low for waste oils, high for dedicated energy crops; potential deforestation, habitat loss, and indirect land-use changes.	Minimal; can be sited on industrial areas, brownfields, or non-arable land.

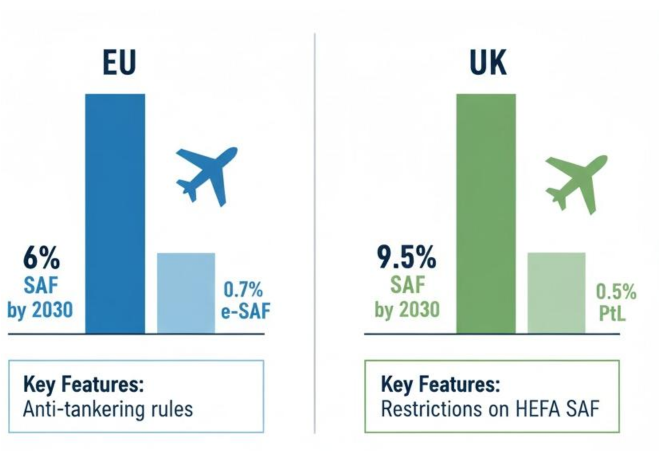
Water Usage	Highly variable; substantial for energy crops, raising water resource concerns.	Primarily for electrolysis; modern systems and water recycling minimise footprint.
Lifecycle GHG Emissions	Typically 50–80% reduction compared to conventional jet fuel; depends on feedstock and process efficiency.	Near-zero or negative emissions, especially with DAC and 100% renewable electricity.
"Drop-in" Compatibility	Engineered to meet Jet A/Jet A-1 standards for seamless integration with existing aircraft and infrastructure.	Designed as a "drop-in" fuel; FT or MtJ synthesis ensures ASTM International-compliant specifications.
Energy Density (MJ/kg)	~42.8 MJ/kg (similar to conventional jet fuel); depends on final composition.	~42.8 MJ/kg (FT route); refining can control energy content precisely.
Aromatic Content (%)	Controlled to meet Jet A/A-1 specs (8-15%) for engine seal swell and combustion performance.	Precisely controllable via FT or MtJ, ensuring compliance with ASTM International standards.
Freezing Point (°C)	≤ -47°C to prevent crystallisation at high altitudes.	Engineered to meet strict freezing point requirements through refining control.
Viscosity (cSt at -20°C)	≤ 8 centistokes (cSt) to ensure proper flow and pump performance.	Precisely controlled via chain length and branching in FT synthesis.
Commercial Maturity	Higher; HEFA is widely deployed, with operational facilities globally.	Early stage; limited production, high scale-up and cost challenges.
Production Cost (USD/gallon)[12]	HEFA: \$2.84–\$5.68; FT (biomass): \$5.68–\$11.36; depends on feedstock and logistics.	e-SAF: \$7.57–\$15.14+; cost influenced by DAC and electricity; expected to decline with technology and scale.
Feedstock Price Volatility	Highly sensitive to biomass supply and commodity markets.	Mainly driven by electricity cost; long-term PPAs can improve stability.

2.3 Global Policy Spotlight

Policy momentum for SAF is rapidly expanding beyond traditional leaders such as the US, EU, and UK. Across Asia-Pacific, Latin America, and the Middle East, governments are introducing SAF blending mandates, targets, and roadmaps that could soon rival - or even exceed - transatlantic demand.

This signals a critical turning point: as the aviation sector faces growing pressure to decarbonise, new SAF markets are establishing regulatory frameworks for scaled deployment. Early movers - producers, investors, and airlines - can secure strategic footholds, forge local partnerships, and diversify demand before supply chains consolidate.

Figure 5: Established markets for SAF



Established Markets: EU and UK

The EU and UK continue to anchor global SAF deployment through robust regulatory mandates, which provide the most advanced and enforceable SAF requirements globally, setting the baseline for other regions.

Table 2 – Emerging Markets

Country	Type	Target / Mandate	Notes
Brazil	Mandate	1% GHG reduction in 2027; 3% by 2030; 10% by 2037	Domestic flights
Singapore	Target	1% by 2026; 3-5% by 2030	Non-binding
Japan	Mandate	10% by 2030	50% GHG savings
Malaysia	Mandate	1% by 2027; 47% by 2050	
Turkey	Mandate	1% in 2025; 5% by 2030	International flights
Indonesia	Mandate	1% by 2027; 2.5% by 2030; 50% by 2060	
India	Target	1% in 2027; 2% in 2028; 5% by 2030	International flights, non-binding
South Korea	Mandate	1% by 2027	International flights
China	Target / Mandate	50,000 tons by 2025; anticipated 5% by 2030	
Chile	Target	50% by 2050	Non-binding
Australia	Target	≥10% by 2030	Non-binding
Thailand	Target	1% by 2026; 1-2% by 2030; 8% by 2036	Non-binding
UAE	Target	1% by 2031	Voluntary
Oman	Under development	—	No mandate/target yet
Philippines	Under development	—	SAF roadmap being drafted
Saudi Arabia	Under development	—	Exploring SAF policy
New Zealand	Under discussion	—	Emissions reduction planning underway

2.4 Lessons for India: Building the Pillars of e-SAF for a Sustainable Future

India's current SAF roadmap includes voluntary and non-binding targets. To unlock serious investment and signal market confidence, India must move towards progressive and enforceable blending mandates. The status of Electro-Sustainable Aviation Fuel (e-SAF) in India is currently in the early stages of policy framing, R&D interest, and feasibility assessment, rather than large-scale commercial production. India's pathway to developing electro-SAF (e-SAF) must follow a lifecycle approach that integrates renewable power, carbon capture, hydrogen production, and aviation infrastructure. Lessons from global leaders highlight the need for five key pillars: sustainable CO_2 sourcing, a strong renewable and green hydrogen base, technology and infrastructure readiness, enabling policy and market mechanisms, and international certification alignment. By linking e-SAF with India's National Green Hydrogen Mission and Carbon Credit Trading Scheme, and fostering global partnerships for technology transfer, India can establish a credible, cost-effective, and future-ready e-SAF ecosystem-positioning itself as a leader in sustainable aviation across the Global South.

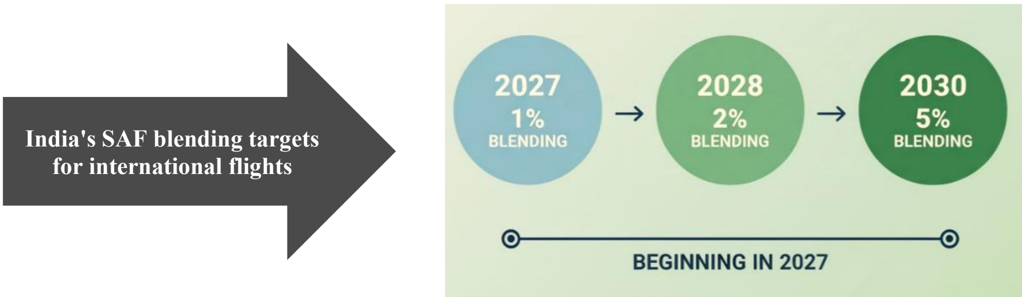
3 India's Policy, Institutional, and Market Landscape for e-SAF

3.1 National climate commitments and aviation sector emissions

India's climate ambitions are reflected through the Nationally Determined Contributions (NDCs) and the announcement of Net Zero emissions by 2070. At COP26, the Hon'ble Prime Minister of India announced the Panchamrit climate action plan for India to achieve the NDC. The country has also announced its vision to be 'Viksit' or 'developed' by 2047.

India's Ministry of Civil Aviation (MoCA) has announced participation in ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and the Long-Term Aspirational Goal (LTAG) from 2027 - marking a key step in aligning India's aviation sector with global climate goals. India will join the mandatory phase, with offset obligations for airlines beginning in 2027 based on 85% of 2019 emissions, to be met through the use of SAF or approved carbon credits. To support this transition, MoCA has proposed indicative SAF blending targets for international flights - 1% in 2027, 2% in 2028, and 5% by 2030 - developed in coordination with NITI Aayog, MoPNG, and Oil Marketing Companies (OMCs). Complementing this, DGCA has aligned regulations with ICAO's environmental standards, while MoPNG's Bio-ATF Programme Committee is advancing domestic SAF production capacity.

Figure 6: India's SAF blending targets for international flights



India's Aviation Sector and the Emissions

India's aviation market is on a strong growth trajectory, driven by rapid infrastructure development, aircraft capacity expansion, and increasing connectivity to Tier 2 and Tier 3 cities. Passenger traffic is projected to grow at a compound annual growth rate (CAGR) of around 10%, increasing from 220 million in 2023–24 to nearly 500 million by 2030, while freight traffic is expected to expand at a CAGR of ~13%, rising from 2.4 million tons to 5.1 million tons during the same period. Overall, the aviation sector is anticipated to grow at approximately 11% annually over the next few years, supported by evolving consumer preferences and modernization of airports across the country.

This growth, however, presents significant sustainability challenges. The Indian aviation industry currently emits an estimated 25-30 million tons of CO_2 annually, accounting for about 0.7% of the nation's total greenhouse gas emissions. Airports alone contribute nearly 10% of these emissions, underscoring their environmental impact. With the sector consuming roughly 9 million tons of Aviation Turbine Fuel (ATF) each year, emissions are expected to rise alongside the surge in passenger and cargo demand.

As India advances its electrification agenda in road transport, the relative share of aviation in national transport emissions is projected to increase from the current ~5% to between 8% and 10% by 2030. Managing this growing carbon footprint will be crucial for aligning the aviation sector with India's broader climate and net-zero goals, highlighting the urgent need to scale up sustainable aviation fuel (SAF) deployment, improve energy efficiency, and integrate green airport practices across the country. SAF production will reduce crude imports and cut emissions by 20-25 million tons annually.[14]

Ongoing Industry Engagement for SAF and E-SAF

Indian airlines have begun exploring SAF readiness. In 2018, SpiceJet conducted India's first biofuel-powered demonstration flight using a 25:75 blend of bio-ATF and conventional jet fuel. Aircraft manufacturers such as Airbus and Boeing already certify their aircraft to operate with up to 50% SAF blends, with a shared goal of achieving 100% SAF compatibility by 2030.

India also engages with global industry initiatives like the World Economic Forum's Clean Skies for Tomorrow (CST) Coalition, which brings together airlines, airports, fuel producers, and OEMs to accelerate SAF adoption worldwide.

A representative from the CST Coalition is a member of India's Bio-ATF Programme Committee, ensuring international knowledge exchange and policy alignment.

India's e-SAF landscape is also witnessing growing industry collaboration to advance technology deployment and build production capacity:

- **Honeywell and NTPC Green (2025):** Partnered to develop SAF using Honeywell's eFining™ technology, integrating captured CO_2 and green hydrogen from NTPC's facilities. The study is expected to be completed by mid-2025.[15]

- **Praj Industries and Axens (2023):** Joined hands to co-develop advanced SAF projects in India, combining Praj's biofuel expertise with Axens' conversion technologies.[16]

- **IndianOil Green Hydrogen Initiative (Mathura Refinery):** Developing India's first green hydrogen plant to enable future Power-to-Liquid (PtL) SAF pathways.[17]

These collaborations reflect growing alignment between technology providers, public enterprises, and refiners to establish a robust e-SAF value chain in India.

3.2 Renewable Energy and Green Hydrogen Readiness

India's renewable energy and green hydrogen landscape has rapidly evolved over the past decade, positioning the country as a frontrunner in the global energy transition. The nation's pursuit of energy security, self-reliance, and climate resilience underpins its ambitious renewable energy agenda, which forms a critical foundation for advancing e-SAFproduction. A robust and reliable renewable electricity supply - combined with advancements in electrolyser manufacturing and carbon capture - will be key enablers for scaling e-SAF pathways across India.

Renewable Energy Expansion and Achievements

Between December 2023 and December 2024, India recorded significant growth in renewable energy capacity, reinforcing its commitment to the *Panchamrit* goals and the national target of achieving 500 GW of renewable energy capacity by 2030. As of December 2024, the total installed renewable energy capacity stood at 209.44 GW, marking a 15.84% increase from 180.80 GW in December 2023. The year 2024 saw the addition of 28.64 GW, representing a 119% year-on-year increase in capacity addition compared to 2023.

National Green Hydrogen Mission (NGHM)

Launched in January 2023, the National Green Hydrogen Mission represents a transformative step towards developing a green hydrogen-based economy in India. The Mission targets the production of 5 million tons (Mt) of green hydrogen annually by 2030, backed by investments exceeding INR 8 lakh crore (≈ USD 91 billion) and the creation of over 600,000 jobs. With an allocation of INR 19,744 crore (≈ USD 2.25 billion), the mission supports electrolyser manufacturing, hydrogen storage, transportation, and utilisation infrastructure. A 50% subsidy for electrolyser manufacturing has been introduced to encourage domestic production and technology localisation. In 2024, tenders were awarded for 412,000 tons per year of green hydrogen capacity and 1,500 MW of electrolyser manufacturing.

The establishment of three hydrogen production hubs across strategic industrial corridors marks a pivotal advancement for green hydrogen infrastructure. This hydrogen ecosystem - with its focus on renewables-based electrolysis and carbon-free production - forms the cornerstone of India's e-SAF readiness, as hydrogen is a critical input for synthetic aviation fuels.

Renewable and Hydrogen Synergies for e-SAF

The convergence of renewable power, hydrogen production, and carbon capture is essential to unlocking India's e-SAF potential. Renewable electricity will drive electrolysers that produce green hydrogen - the primary energy vector for e-SAF synthesis - while CO_2 from biogenic and industrial sources can serve as the carbon feedstock.

By integrating these systems, India can establish *"Renewable Energy–Hydrogen–Aviation Fuel Clusters"* that optimise resource use and reduce production costs. The synergy between the Ministry of New and Renewable Energy's (MNRE) renewable energy expansion and the National Green Hydrogen Mission provides the backbone for such clusters, offering a pathway to large-scale, export-ready e-SAF production.

3.3 Gaps in India's e-SAF Ecosystem

India's progress toward developing a domestic e-SAF ecosystem remains in a nascent phase. While the country possesses significant renewable energy potential, a strong bioenergy base, and an emerging green hydrogen industry, the e-SAF value chain is still unstructured and fragmented. Several technological, regulatory, financial, and institutional challenges persist across the production, certification, and market integration spectrum.

I. Technological and Feedstock Readiness

Despite strong momentum in related areas such as biofuels and green hydrogen, India currently lacks operational demonstration projects for e-SAF production. Critical processes such as Reverse Water–Gas Shift (RWGS), Fischer–Tropsch (FT) synthesis, and Power-to-Liquid (PtL) technologies remain at a low maturity level domestically. Most of the technology and equipment are imported, and indigenisation efforts are still in their infancy.

A fundamental gap lies in the integration of renewable hydrogen and captured carbon dioxide (CO_2). Although industrial CO_2 sources are abundant, biogenic CO_2, which is essential for export markets and lifecycle compliance under global sustainability frameworks, remains scarce. India's bioenergy and ethanol sectors could serve as key suppliers of biogenic CO_2, but the linkages between these value chains and the e-SAF ecosystem are yet to be established. In parallel, the production of low-cost green hydrogen - a prerequisite for e-SAF - faces infrastructure and cost challenges. The country's electrolyser manufacturing capacity is limited, and renewable electricity integration remains inconsistent. Until hydrogen prices fall below commercial thresholds, e-SAF pathways will struggle to achieve cost competitiveness.

II. Policy and Regulatory Ambiguity

A key gap in India's e-SAF ecosystem is the absence of a unified national policy or mission framework. Existing initiatives - such as the National Green Hydrogen Mission and National Biofuel Policy - operate in parallel but without integration into a cohesive SAF roadmap. This policy fragmentation results in uncertainty for investors, technology providers, and airlines, delaying long-term project planning and international alignment.

Specific policy and regulatory gaps include:

- No **national SAF or e-SAF blending target.**
- Lack of **fiscal incentives** such as tax rebates, GST inclusion, or accelerated depreciation.
- No **standardised certification** aligned with ASTM or EU Renewable Fuels of Non-Biological Origin (RFNBO) standards.
- Absence of **central coordination** among multiple regulatory agencies, including MNRE, MoPNG, MoCA, and DGCA.

III. Economic Viability and Financing Barriers

High capital costs, technology risks, and the lack of guaranteed demand make e-SAF projects financially unattractive in their current form. Production costs remain five to six times higher than fossil jet fuel, driven by expensive hydrogen, low conversion efficiency, and small production scales. India also lacks pre-investment (pre-FID) funding mechanisms**,** viability gap financing, and concessional lending frameworks to support first-of-a-kind projects. Financial institutions are cautious due to uncertainties in technology performance, offtake guarantees, and policy continuity. Without mandatory blending mandates or long-term offtake agreements, project developers struggle to demonstrate bankability. The absence of carbon pricing and tradable SAF credit systems further limits potential revenue streams, confining project economics to direct fuel sales alone.

IV. Infrastructure and Supply Chain Limitations

India's existing aviation fuel infrastructure - though robust for conventional ATF - requires dedicated upgrades for blending, certification, and traceability of e-SAF. Currently, there are no dedicated storage, transfer, or pre-blending facilities for SAF at major airports. The absence of testing and certification laboratories capable of validating SAF against international standards (ASTM D7566/D1655) also limits readiness. Further, there is no coordinated framework linking refineries, OMCs, and airport operators to enable seamless integration of SAF supply chains. These infrastructural and logistical gaps constrain early demonstration and scaling efforts.

V. Fragmented Industry and Institutional Coordination

The e-SAF ecosystem in India currently operates in silos. Technology developers, airlines, Oil Marketing Companies(OMCs), research institutions, and financiers engage independently, with limited cross-sectoral coordination. There is no dedicated platform or industry consortium to facilitate knowledge exchange, joint planning, or standard-setting across the value chain.

Airlines remain reluctant to commit to offtake agreements without regulatory mandates, while Engineering, Procurement and Construction (EPC) contractors and developers face integration challenges in system design and risk management. This lack of institutional coordination constrains scalability and increases project duplication.

VI. Research, Innovation, and Capacity Gaps

India's research and innovation ecosystem for e-SAF remains underdeveloped. There is minimal domestic work on process optimisation, catalyst development, and system integration for Power to Liquid (PtL) and Reverse Water–Gas Shift (RWGS) pathways. Public funding and dedicated R&D programs are limited, and coordination between research institutions and industry remains weak.

Demonstration facilities - such as hydrogen valleys and living labs - exist, but e-SAF has not yet been integrated into these initiatives. The lack of pilot-scale demonstration projects prevents validation of technology performance and deters investor confidence. Additionally, there are gaps in technical skills and institutional capacity for fuel testing, certification, and lifecycle assessment. No standardised testing or accreditation framework exists for SAF quality assurance, posing a barrier to commercialisation.

VII. Carbon Accounting, Certification, and Traceability Gaps

There is no national monitoring, reporting, and verification (MRV) system for carbon accounting across the e-SAF value chain. Producers will lack mechanisms to quantify and certify lifecycle emission reductions in accordance with CORSIA, EU ETS, or ISO frameworks.

Without a digital traceability platform connecting producers, blenders, and end users, it is difficult to validate emission reductions, allocate environmental credits, or enable book-and-claim trading systems. This absence of transparent certification and traceability undermines investor and consumer confidence in the environmental integrity of Indian e-SAF.

VIII. Market Demand and Social Integration Deficits

India's domestic demand for SAF or e-SAF remains negligible due to the absence of compliance mandates, fiscal incentives, and cost competitiveness. Airlines have no economic incentive to voluntarily procure SAF, and fuel producers lack secure offtake channels.

3.4 Enablers for Advancing e-SAF in India

Despite the multiple structural challenges constraining the development of e-SAF, India possesses distinctive enablers that can be leveraged to establish global leadership in the sector. These enablers span across renewable energy capacity, technology innovation potential, institutional collaboration, financing mechanisms, and digital governance systems. Harnessing these strengths can help bridge the transition from pilot-scale demonstration to large-scale commercialisation.

I. Abundant Renewable Energy Potential and Green Hydrogen Synergies

India's rapidly expanding renewable energy base - now exceeding 190 GW of installed solar and wind capacity - provides the single most critical enabler for e-SAF production. The availability of low-cost renewable electricity directly underpins the viability of Power-to-Liquid (PtL) pathways by ensuring a sustainable and cost-competitive source of green hydrogen.

Ongoing initiatives under the National Green Hydrogen Mission (NGHM), coupled with state-level renewable energy policies, create a favorable foundation for the production of hydrogen at scale. As costs of electrolysers and renewable power continue to fall, the integration of hydrogen production with CO_2 utilisation for e-SAF synthesis will become increasingly viable. This synergy can form the backbone of India's domestic e-fuel ecosystem and position the country as a cost-competitive producer for global markets.

II. Leveraging Bioenergy Infrastructure and Biogenic CO_2

India's extensive bio-energy ecosystem - spanning ethanol distilleries, biogas plants, and biomass gasifiers - offers a complementary feedstock base for e-SAF. Capturing biogenic CO_2 from these facilities can substantially reduce lifecycle emissions while creating a pathway for bio-electro integration.

This dual-feedstock model not only ensures environmental integrity but also extends economic participation to rural stakeholders. By linking e-SAF projects with existing biofuel supply chains, India can promote an inclusive transition that benefits the farming community and strengthens local circular economies. Such hybrid models - integrating bio and electro routes - can yield carbon-negative outcomes and enhance long-term sustainability.

III. Limited large-scale carbon storage (sequestration)

While India is advancing in carbon capture (CCUS) technologies, large-scale carbon storage (sequestration) remains limited. The country lacks extensive deep saline aquifers or depleted oil and gas reservoirs suitable for long-term CO_2 storage. As a result, India's current focus is on carbon utilisation pathways – converting captured CO_2 into value-added products like e-fuels, green methanol, urea and building materials – aligning economic and environmental goals.

IV. Emerging Technological Capabilities and R&D Momentum

India's research ecosystem has begun to show promising traction in green hydrogen, carbon capture, and catalytic process development. Public research agencies and premier institutes have initiated collaborative work on Reverse Water-Gas Shift (RWGS) reactions, Fischer-Tropsch (FT) synthesis, and Alcohol-to-Jet (AtJ) pathways.

Building on the scientific and industrial base created by earlier biofuel programs, India now has the capacity to indigenise components of the e-SAF value chain - such as reactor design, catalyst optimisation, and system integration. Establishing pilot-scale demonstration plants under public-private-research partnerships (PPRPs) will further accelerate technology readiness and reduce dependence on imported systems. This growing innovation ecosystem, if strategically linked with government missions and industry consortia, can serve as a cornerstone for developing indigenous e-SAF technology platforms.

V. Strengthening Financing Mechanisms and Investment Confidence

Financial confidence in e-SAF projects can be strengthened through innovative risk-sharing and blended-finance mechanisms. The growing participation of multilateral and bilateral agencies - through programs similar to the German H2Uppp and PtX Development Fund—offers access to concessional loans, viability-gap funding, and technical assistance.

At the domestic level, the increasing appetite of financial institutions to invest in green technologies, coupled with frameworks such as green bonds and infrastructure-status eligibility, can lower the cost of capital. Mandated blending targets and long-term offtake commitments from airlines or OMCs will enhance project bankability.

Further, a major enabler for e-SAF financing lies in leveraging carbon markets under India's Article 6 cooperation framework, where SAF is included in the national technology list. Verified emission reductions from e-SAF can generate internationally transferrable carbon credits, creating dual revenue streams from fuel sales and climate finance. Aligning India's Carbon Credit Trading Scheme (CCTS) with Article 6.2 mechanisms and CORSIA compliance frameworks will ensure transparency, attract international investment, and strengthen India's position as a global supplier of low-carbon aviation fuels.

As the SAF market matures globally, India's ability to align financing models with international carbon markets and credit instruments will further stimulate investor confidence and attract global capital.

VI. Institutional Collaboration and Ecosystem Integration

Coordination among ministries - such as MNRE, MoPNG, MoCA, and NITI Aayog - alongside private industry and academia, will be essential for building a unified e-SAF ecosystem. Institutional mechanisms such as inter-ministerial task forces, industry alliances such as SAF Association, and centres of excellence can ensure that technology, finance, and regulation evolve in tandem. This will also help standardise certification practices, enable data-sharing frameworks, and establish knowledge partnerships with global technology providers.

By fostering such institutional synergies, India can transition from fragmented experimentation to a coherent, mission-driven e-SAF program.

VII. Digitalisation, Carbon Transparency, and Data Traceability

Digital traceability systems represent a key enabler for both domestic and export markets. Platforms capable of tracking SAF production, lifecycle emissions, and environmental benefits - from feedstock to fuel usage - can ensure transparency, credibility, and alignment with international compliance regimes such as CORSIA, EU ETS, and RFNBO.

The deployment of integrated digital tools, similar to emerging book-and-claim frameworks, will enable producers and airlines to manage emission attributes and trade SAF certificates efficiently. This digital backbone not only enhances investor and consumer confidence but also creates a transparent marketplace for verified low-carbon fuels.

VIII. Growing Market Momentum and Airline Engagement

India's aviation sector is expanding rapidly, with strong commitments to net-zero pathways by 2050. This creates an inherent demand driver for sustainable fuels. Several airlines are already exploring SAF surcharges and voluntary blending initiatives, signalling early market readiness.

As international carriers begin complying with global SAF mandates, domestic airlines will face both commercial and reputational incentives to adopt cleaner fuels. This emerging market pull, supported by corporate sustainability reporting frameworks such as Business Responsibility and Sustainability Report (BRSR) and Environmental, Social, and Governance (ESG) disclosures, will stimulate early adoption and encourage the formation of long-term offtake contracts.

IX. International Collaboration and Technology Transfer

India's proactive engagement with countries and organisations leading in the PtL and e-SAF domains - such as Germany, the EU, and the UK - serves as a strong enabler for technology transfer, capacity building, and co-financing. Bilateral partnerships can help deploy proven process technologies, establish demonstration facilities, and align certification standards with global benchmarks.

Such collaborations can also provide India access to advanced electrolysis systems, CO_2 capture technologies, and SAF upgrading processes, reducing the gestation time for commercial deployment.

3.5 Policy Recommendations for Accelerating e-SAF Deployment in India

To translate India's strong technical and institutional enablers into a mature e-SAF ecosystem, a coherent and phased policy framework is imperative. The following recommendations outline a strategic roadmap spanning regulatory, financial, technological, and institutional domains. They aim to de-risk early investments, build market confidence, and align India's aviation decarbonisation with global sustainability benchmarks.

I. Short-Term (0–3 Years): Building Foundations and Market Confidence

a) Establish a National e-SAF Policy Framework

India urgently requires a unified national policy on Sustainable Aviation Fuels, with a dedicated focus on e-SAF pathways. It must clearly define eligible feedstocks, emission accounting methodologies, lifecycle thresholds, and certification procedures aligned with ASTM, ISO and EU RFNBO standards to enable international market compatibility. This "umbrella framework" should integrate elements of the National Green Hydrogen Mission, Bioenergy Mission, and Carbon Capture Utilization and Storage (CCUS) strategy.

b) Introduce Mandatory Blending Targets

A phased blending mandate - starting at 1% SAF blending by 2027 and rising to 5–10% by 2035, within this, set a minimum sub-target of 0.5–1% e-SAF (Power-to-Liquid fuels) to encourage early market entry and this will lead to the creation of a stable market demand and build investor confidence. These targets should differentiate between SAF and e-SAF, ensuring visibility for electro-based fuels within the national decarbonisation framework.

c) De-Risk Early Projects Through Pre-FID Support

A pre-Final Investment Decision (pre-FID) funding window, modeled on the UK's *Advanced Fuel Fund*, should be introduced to finance early-stage project development, feasibility studies, and pilot-scale demonstrations. Grants, low-interest loans, or viability gap funding can help bridge initial capital gaps and accelerate first-mover projects.

d) Enable Green Financing and Tax Incentives

E-SAF projects should be recognised as infrastructure assets, enabling access to institutional financing and green bonds. Fiscal incentives such as accelerated depreciation, GST inclusion, income tax holidays, and interest subvention should be introduced to lower the cost of capital and attract private investment. Further, to attract financing, India should classify SAF production as a green, sustainable activity under its upcoming climate finance taxonomy.

e) Create Standards and Certification Infrastructure

Immediate establishment of testing, certification, and quality assurance facilities for SAF and e-SAF is essential. These facilities should be capable of validating fuel properties, lifecycle emissions, and compliance with domestic and export standards. A central Bureau of Sustainable Fuels Certification under BIS or DGCA could coordinate standardisation.

f) Establish a National Mission on E-SAF

There is a need to establish an SAF Mission under a mission-mode approach (e-SAF being a part of it), bringing together key ministries and stakeholders such as MNRE, MoPNG, MoCA, MoEFCC, DST and NITI Aayog, to harmonise policy, finance, R&D, and regulatory functions. This coordination will prevent duplication, streamline project approvals, and enhance stakeholder alignment.

g) Public Procurement Mandates

Promote the adoption of SAF-backed travel or offset schemes among public sector undertakings (PSUs) and various government departments.

II. Medium-Term (3–7 Years): Scaling Up Production and Market Maturity

a) Promote Public–Private Partnerships and Hydrogen Valleys

The concept of Living Labs or Hydrogen Valleys, as initiated by the Department of Science and Technology (DST), should be expanded to include e-SAF demonstration hubs. These hubs can integrate hydrogen, CO_2 capture, and fuel synthesis technologies on a 5–50 MW scale, enabling technology validation and industry participation.

b) Integrate e-SAF with the Green Hydrogen and CCUS Missions

E-SAF production should be formally recognised as a priority use case under the National Green Hydrogen Mission, leveraging existing subsidies and PLI schemes for electrolyser manufacturing. Simultaneously, integration with CCUS initiatives can facilitate CO_2 capture and utilisation, ensuring complete carbon circularity.

c) Establish Long-Term Offtake Mechanisms

Government and airline operators should co-develop long-term offtake agreements (LTAs) to ensure revenue security for producers. These can include price floors or Contracts-for-Difference (CfD) models that compensate producers when fossil jet fuel prices fall below production costs.

d) Develop Carbon Market Linkages

The government should integrate e-SAF into emerging carbon credit frameworks, including India's Carbon Credit Trading Scheme (CCTS). Verified lifecycle emission reductions from e-SAF projects should be tradable as high-integrity carbon credits, creating additional revenue streams and attracting climate finance.

e) Enable Domestic R&D and Technology Localization

Targeted research grants and innovation challenges should support universities, startups and public laboratories in developing indigenous technologies for CO_2 capture, FT synthesis, and AtJ conversion. Domestic intellectual property generation should be incentivised through patent support and commercialisation grants.

f) Strengthen Digital Traceability and MRV Systems

Development of a national Digital SAF Registry, interoperable with global systems such as CORSIA and EU ETS, will enhance traceability and transparency. Digital "Book-and-Claim" systems should be piloted to allow airlines to claim SAF benefits even when physical supply is not directly available.

III. Long-Term (7–15 Years): Establishing Global Leadership and Export Competitiveness

a) Foster Export-Oriented Production Hubs

By leveraging India's low-cost renewable power and abundant CO_2 resources, the country can position itself as a global e-SAF export hub by 2040. Export-oriented clusters should be developed near renewable corridors and ports, aligned with international sustainability certification systems.

b) Create an Integrated Power-to-X (PtX) Policy Ecosystem

A comprehensive Power-to-X policy should integrate hydrogen, e-fuels, methanol, ammonia, and e-SAF within a unified regulatory and investment framework. This will ensure consistency across value chains, encourage cross-sectoral innovation, and enable efficient resource utilization.

c) Establish International Partnerships for Technology and Markets

India should continue to deepen partnerships with the EU, Germany, Japan, and multilateral agencies to secure technology transfer, co-investment, and access to export markets. Joint research programs and knowledge-sharing platforms can help align standards and improve competitiveness. Undertake capacity building programs specifically for e-SAF with organizations like International PtX Hub and other European/German partners.

d) Encourage Industrial Symbiosis and Circular Carbon Models

In the long term, industrial clusters integrating cement, steel, and refinery sectors can become major CO_2 suppliers for e-SAF production, promoting circular carbon utilization. This approach will also support India's broader net-zero industrial transition and resource efficiency objectives.

e) Embed SAF in National Climate and Industrial Policy

Sustainable aviation fuel should be explicitly incorporated into India's Nationally Determined Contributions (NDCs) and Industrial Decarbonization Roadmaps. Embedding SAF metrics within corporate ESG and BRSR frameworks will institutionalize demand and sustain market growth beyond initial policy support.

4 The e-SAF Value Chain in India

The e-SAF (electrofuel-based Sustainable Aviation Fuel) value chain represents a transformative opportunity for India to decarbonize its aviation sector while driving industrial innovation and green growth. It connects multiple sectors — renewable energy, hydrogen production, carbon capture, refining, and aviation — into one integrated ecosystem. For India, the goal is to leverage its strengths in renewable power, industrial capacity, and policy ambition to build a globally competitive e-SAF industry.

I. Feedstock and Resource Inputs

India's feedstock landscape is uniquely positioned to support large-scale e-SAF production. Three primary resources — renewable electricity, carbon dioxide (CO_2), and water — form the foundation of the value chain.

Renewable Electricity

India has emerged as one of the world's fastest-growing renewable energy markets, with over 180 GW of installed capacity (solar, wind, hydro, biomass) as of 2025 and a national target of 500 GW by 2030. This clean power base, combined with rapidly falling solar and wind tariffs (₹2–2.5 per kWh), offers the lowest renewable electricity costs globally — a decisive advantage for e-SAF competitiveness.

Strategically co-locating e-SAF facilities near renewable energy parks — such as those in Gujarat (Khavda), Rajasthan, Tamil Nadu, and Karnataka — can provide stable green power for hydrogen electrolysis and synthetic fuel synthesis. Hybrid renewable clusters with battery storage can ensure round-the-clock availability, overcoming intermittency issues that often constrain PtL projects elsewhere.

Carbon Dioxide Sources

India produces over 2.5 billion tons of CO_2 annually, a significant share of which can be captured from industrial point sources — cement, steel, fertilizer, ethanol, and refinery operations.Additionally, India's growing network of biogas and ethanol plants offers biogenic CO_2, which is essential for low-carbon or carbon-negative e-SAF production and for compliance with European import standards under the RFNBO framework.

Developing CO_2 capture hubs around industrial corridors — such as Jamnagar, Hazira, Panipat, and Vizag — and linking them with hydrogen and e-fuel plants via short-distance pipelines can create integrated low-carbon industrial clusters.

Water Resources

Electrolysis for green hydrogen requires demineralized water. Given India's water stress in several regions, siting electrolysis plants near coastal zones, refineries, or wastewater treatment facilities is prudent. Treated industrial wastewater or desalinated seawater can be viable options, aligning with India's National Water Mission principles for reuse and circularity.

II. Green Hydrogen Production

Hydrogen is the backbone of e-SAF synthesis, and India has already built strong policy momentum through the National Green Hydrogen Mission (NGHM). The Mission allocates over ₹19,700 crore in incentives, with significant funding for domestic electrolyser manufacturing and green hydrogen production.

By 2030, India targets 5 MMT per annum of green hydrogen capacity, supported by 24 Hydrogen Valleys across states such as Gujarat, Maharashtra, Tamil Nadu, and Odisha. These valleys — combining renewable generation, electrolysis, and industrial off-take — can act as anchor zones for e-SAF projects.

Electrolyser manufacturing is scaling rapidly under the PLI Scheme, with Indian companies such as Reliance, L&T, and Adani investing in domestic gigawatt-scale capacity. Localization of electrolyser components (membranes, catalysts, power electronics) will drive down hydrogen costs from the current \$4–5/kg **to** \$2/kg by 2030 — a crucial threshold for e-SAF competitiveness.

Moreover, integrating hydrogen production with refineries and petrochemical complexes can enable shared infrastructure for storage, compression, and transport, optimizing costs and improving safety compliance.

III. CO_2 Capture, Utilization, and Integration

India's industrial base provides both the challenge and opportunity for carbon management. While total emissions remain high, several sectors — including cement, steel, and ethanol — have established CO_2 capture pilots.

The upcoming Carbon Capture, Utilization and Storage (CCUS) Mission by the Department of Science and Technology (DST) and NITI Aayog will identify geological storage basins and support carbon utilization technologies such as methanol, ethanol, and e-SAF production.

From a near-term perspective, carbon utilization for fuels like e-SAF offers an economically viable route, avoiding the high costs of deep geological storage. Creating regional CO_2 utilization hubs near existing refinery and ethanol clusters can ensure a continuous and traceable CO_2 feedstock supply.

Furthermore, direct air capture (DAC), though nascent in India, could evolve as a long-term enabler for fully carbon-neutral aviation fuel once DAC costs decline below \$100 per ton.

IV. Fuel Synthesis and Conversion Technologies

India's technological diversity and refinery infrastructure make it ideally suited for multiple e-SAF pathways:

- **Fischer–Tropsch (FT) Route:**
  A mature process converting CO_2-derived syngas and green hydrogen into hydrocarbons, compatible with existing refinery setups. India's large public sector refineries can host pilot FT units integrated with hydrogen facilities.

- **Methanol-to-Jet (MtJ):**
  A flexible pathway using methanol as an intermediate, enabling gradual decarbonization while leveraging India's growing methanol economy and existing methanol plants.

India's refining hubs — Jamnagar, Mathura, Paradip, and Panipat — already have advanced catalytic and hydro-processing units that can be repurposed for SAF synthesis. Pilot-scale integration of Power-to-Liquid modules into these complexes can demonstrate technical feasibility while minimizing capital investment.

V. Storage, Blending, and Certification Infrastructure

India's aviation fuel supply system, among the most advanced in Asia, provides a strong base for SAF deployment. However, to accommodate e-SAF, dedicated storage tanks, blending skids, and contamination-free transfer pipelines are needed at refineries, depots, and airports. Certification and traceability remain critical. SAF must comply with ASTM D7566 specifications before re-certification as Jet-A1 under ASTM D1655. India should develop a National SAF Certification Framework, harmonizing BIS and DGCA, standards with international norms.

VI. Distribution and End-Use Integration

India's network of pipelines and aviation fuel depots already connects major refineries to airports, allowing e-SAF to be introduced as a drop-in fuel without major infrastructure overhaul.

Initial deployment should focus on five major metropolitan airports — Delhi, Mumbai, Bengaluru, Hyderabad, and Chennai — which collectively account for over 60 % of India's jet fuel consumption. These airports can act as SAF demonstration hubs, supported by local blending facilities and traceability systems.

Airlines can participate through long-term offtake agreements or book-and-claim mechanisms, enabling them to purchase SAF credits even if physical fuel supply is limited. This model is already used successfully in Europe and can be replicated under India's domestic carbon market.

VII. Digital Monitoring, Traceability, and Carbon Accounting

Digital transparency will be central to the success of India's e-SAF ecosystem. Platforms integrating blockchain, MRV (Monitoring, Reporting, and Verification), and carbon accounting can track fuel origin, blending ratios, emissions reductions, and ownership of environmental attributes.

Under the Article 6 mechanisms of the Paris Agreement, SAF is recognized as an eligible mitigation technology. Integrating e-SAF projects into India's National Carbon Market and Internationally Transferred Mitigation Outcomes (ITMO) framework will allow project developers and airlines to trade carbon credits globally, enhancing financial viability.

Such digital infrastructure can also help align SAF projects with CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation), providing airlines with verified compliance credits while maintaining transparency across the value chain.

VIII. Institutional and Ecosystem Support

India's innovation ecosystem provides a strong foundation for scaling e-SAF. The Department of Science and Technology (DST), through its Mission Innovation and Living Labs programs, has established collaborative platforms linking industry, academia, and start-ups to pilot low-carbon technologies. These can be leveraged to demonstrate e-SAF pilot projects within Hydrogen Valleys or refinery clusters, showcasing technology integration and cost reduction.

Inter-ministerial coordination among MoPNG, MNRE, MoCA, DST, and NITI Aayog will be critical to streamline regulatory approval, align fiscal incentives, and build investor confidence.Industry associations such as the SAF Association and Carbon Markets Association of India can play a convening role, facilitating stakeholder engagement and policy dialogue. Therefore, India's e-SAF value chain is emerging at the intersection of renewable energy, industrial innovation, and aviation decarbonization. By leveraging its renewable power base, industrial CO_2 availability, and refining infrastructure, India can build a globally competitive Power-to-Liquid ecosystem.

The next phase of progress will depend on synchronized policy action — encompassing green hydrogen integration, carbon utilization, certification, financing, and digital transparency. With targeted public–private partnerships and pilot demonstrations, India can transition from policy aspiration to global leadership in sustainable aviation fuels over the coming decade.

5 Framework for Capacity Building with Global Partners

India's e-SAF transition requires a coordinated, multi-tiered capacity-building framework that simultaneously develops technical expertise, strengthens institutions, enhances market readiness, and deepens international collaboration. The following six-pillar framework provides a structured roadmap for operationalizing capacity building at the national, state, and industry levels — supported by global partnerships and finance mechanisms.

Pillar 1: Skill and Human Resource Development

- Integrate e-fuel modules into existing programs at IITs, NITs, and polytechnic institutes—covering hydrogen systems, CO_2 capture, electrolysis, fuel upgrading, and safety standards.
- Develop specialized training programs on certification (ASTM, CORSIA, Book & Claim) in collaboration with ICAO and IATA.
- Launch exchange programs and fellowships with international partners such as the EU, Japan, and Germany to share expertise on Power-to-Liquid (PtL) technology and SAF logistics.
- Build regional training clusters in states with comparative advantages—feedstock management (Punjab, Haryana), electrolysis and conversion (Gujarat, Maharashtra), and refining (Tamil Nadu, Odisha).

Pillar 2: Research, Innovation, and Demonstration

- Establish National e-SAF Innovation Hubs at CSIR, IITs, and TERI for process optimization, catalyst development, and techno-economic studies.
- Support pilot and demonstration projects integrated with the National Green Hydrogen Mission and state hydrogen valley initiatives.
- Develop joint research programs with global partners (e.g., International PtX Hub Germany, Clean Aviation Europe, NEDO Japan) for co-development and validation of e-SAF pathways.
- Introduce competitive grants and public–private innovation challenges for early-stage R&D, including CCU integration and renewable energy coupling.

Pillar 3: Institutional Strengthening and Governance

- Develop an India-specific SAF certification and sustainability standard aligned with international norms (ASTM D7566, ICAO CORSIA, EU RFNBO).
- Strengthen DGCA and BIS laboratories for fuel testing, lifecycle carbon verification, and sustainability auditing.
- Build institutional capacity at state-level agencies to support SAF blending targets, land use policies, and feedstock logistics.

Pillar 4: Industry Engagement and Market Readiness

- Promote public–private partnerships (PPPs) for pilot and commercial projects, leveraging both policy incentives and private capital.
- Organize annual investment and innovation dialogues bringing together domestic and international investors, technology partners, and policymakers.

Pillar 5: International Collaboration and Finance Access

- Mobilize blended finance and concessional capital from global institutions such as GCF, ADB, KfW, and World Bank for early-stage e-SAF projects.
- Participate in bilateral technology partnerships (e.g., Indo-German Green Hydrogen & e-Fuels Partnership, US-India Clean Energy Initiative) for technology transfer and joint project development.
- Build knowledge-sharing alliances with international SAF innovation programs, ensuring India's regulatory and certification systems remain globally harmonized.

Pillar 6: Monitoring, Knowledge Dissemination, and Learning Networks

- Partner with global think tanks (IEA, ICCT, WRI) for benchmarking India's progress and sharing lessons from international SAF pilots.
- Conduct annual progress reviews and public reports to maintain accountability and policy responsiveness.
- Foster multi-stakeholder learning networks involving academia, industry, and international experts to sustain long-term capacity enhancement.

6 Stakeholder-Driven Roadmap for e-SAF Adoption in India

A successful e-SAF transition in India requires not only technological progress and policy alignment but also a collaborative, stakeholder-driven approach that synchronizes efforts across government, industry, academia, and international partners. The roadmap for e-SAF adoption must reflect India's distinct advantages — low-cost renewable power, industrial CO_2 potential, and a rapidly growing aviation sector — while addressing systemic challenges through coordinated action.

The following stakeholder-driven roadmap outlines the key roles, responsibilities, and milestones for each group across short-, medium-, and long-term horizons.

6.1 Short Term (2025–2027): Building the Foundation

Government and Regulators

- Voluntary SAF adoption up to 1% of total ATF consumption at major airports (Delhi, Mumbai, Bengaluru, Hyderabad).
- Align Bureau of Indian Standards (BIS) and DGCA norms with global standards (ASTM D7566, CORSIA) to enable domestic certification and international recognition of SAF produced in India.
- Launch National SAF Mission guidelines defining feedstock eligibility, sustainability criteria, and fiscal incentives.
- Provide capital grants and pre-FID funding to de-risk first demonstration projects and signal policy stability.

Industry and Technology Developers

- Commission 2–3 demonstration plants co-located with refineries or renewable hydrogen hubs to establish proof of concept for Power-to-Liquid (PtL) and Alcohol-to-Jet (AtJ) technologies.
- Collaborate with global technology providers through joint R&D and technology transfer partnerships, focusing on catalyst improvement and process integration.

Airlines and Airports

- Partner with SAF producers to conduct green flight corridors and Book-and-Claim pilot programs, showcasing early adoption and consumer engagement.
- Develop blending and storage infrastructure at major airports through joint ventures with Oil Marketing Companies (OMCs).

Financial Institutions

- Create pilot financing frameworks under green finance and ESG mandates to familiarize lenders with e-SAF risk structures.
- Introduce carbon-linked credit enhancements and viability gap funding mechanisms for early projects.

Academia and Research Bodies

- Initiate capacity-building and certification training for engineers and operators on SAF blending, lifecycle assessment, and carbon accounting.
- Establish university-led test beds and living labs (aligned with DST's Living Lab model) to validate emerging technologies.

6.2 Medium Term (2027–2030): Scaling and Integration

Government and Regulators

- Introduce a mandatory 2–5% SAF blending target across all domestic civil aviation fuel by 2030. Within this, set a minimum sub-target of 0.5–1% e-SAF (Power-to-Liquid fuels) to encourage early market entry.
- Operationalize Contracts for Difference (CfD) or Green Aviation Credit schemes to ensure price stability and attract investors.
- Integrate SAF projects into India's National Carbon Market and Article 6 cooperation framework, enabling credit generation from verifiable emission reductions.
- Expand blending mandates from pilot airports to Tier-2 cities and OMC terminals, ensuring broader market coverage.

Industry and Technology Developers

- Commission commercial-scale e-SAF facilities (100–300 kilotons/year), leveraging blended finance models and PPPs.
- Diversify feedstock through integration of biogenic CO_2 from ethanol, biogas, and waste-to-energy plants.
- Build partnerships for hydrogen and carbon capture integration, aligning with India's National Hydrogen Mission.

Financial Sector

- Institutionalize green loan taxonomies that classify SAF production as an eligible sustainable activity under India's climate finance framework.
- Partner with multilateral banks and sovereign green funds to access concessional capital for scale-up.

Academia and Research Institutions

- Strengthen applied research networks among CSIR, IITs, and private industry to develop cost-efficient catalysts, CO_2 utilization, and electrolysis technologies.
- Launch national training academies for SAF project developers, financiers, and policymakers, supported by international institutions such as ICAO and GIZ.

Airlines and OMCs

- Establish long-term offtake contracts and take-or-pay models to provide bankable demand signals to producers.
- Collaborate with technology providers to develop data-driven SAF traceability systems ensuring transparency across the supply chain.

6.3 Long Term (2030–2035): Market Maturity and Global Leadership

Government and Policy Institutions

- Raise total SAF blending requirement to 10 - 15% of ATF. Increase e-SAF share to 4–5% within this, aligned with aligned with declining hydrogen costs and renewable capacity expansion.
- Position India as a regional export hub for SAF, leveraging competitive production costs and trade partnerships with South Asia and the Middle East.
- Institutionalize a National SAF Steering Group to coordinate cross-ministerial actions, monitor lifecycle GHG savings, and guide market evolution.

Industry and Technology Providers

- Scale production capacity to 1 million tons annually, supported by continued innovation and economies of scale.
- Advance towards cost parity (<1.5× fossil ATF) through efficiency gains and optimized value chains.
- Develop strategic export partnerships under bilateral clean energy and carbon trade agreements.

International Collaboration

- Deepen engagement with ICAO, IATA, the EU, and bilateral partners (Germany, Japan, and the UK) for technology transfer, certification alignment, and Article 6 carbon cooperation.
- Participate in bilateral technology partnerships (e.g., Indo-German Green Hydrogen & e-Fuels Partnership, US-India Clean Energy Initiative) for technology transfer and joint project development.

Finance and Carbon Markets

- Channel international climate finance and carbon revenues into R&D and infrastructure expansion.

7 Conclusion

India's transition toward electro–Sustainable Aviation Fuel (e-SAF) represents a defining step in aligning its aviation growth with national and global climate goals. With its expanding renewable energy base, emerging green hydrogen economy, and established refining infrastructure, India is well-positioned to become a frontrunner in low-carbon aviation fuel production. Yet, unlocking this potential demands a coordinated national effort that integrates technology development, policy support, financing innovation, and institutional capacity building.

In the near to medium term, India is expected to scale up Ethanol-to-Jet (EtJ) technology routes using food crop-based, molasses-based, and advanced ethanol. Over time, gasification and Fischer–Tropsch (FT) pathways leveraging agricultural and forestry residues may emerge as complementary routes. Hydroprocessed Esters and Fatty Acids (HEFA) and Power-to-Liquid (PtL) pathways, including e-SAF, will play critical roles in diversifying the fuel mix. Given India's strong renewable power potential and diverse biomass availability, the country can build a regionally tailored SAF ecosystem leveraging multiple feedstocks and technologies.

The evolution of India's e-SAF ecosystem will hinge on three foundational pillars: policy clarity, investment confidence, and ecosystem integration. A clear regulatory framework—including blending mandates, lifecycle carbon accounting, and interoperability with global sustainability standards—will provide long-term market certainty. Financial mechanisms such as pre-FID funding, viability gap support, and integration with carbon markets will help de-risk early projects.

South Asia's estimated SAF production potential by 2050 is about 40 million tonnes[18], India can position itself as a regional hub for sustainable aviation fuels—strengthening energy security, creating green jobs, and contributing meaningfully to global net-zero aviation goals.

Annexure I – Stakeholder Mapping

Stakeholder Mapping :

To compile a database of stakeholders with a presence in India active along the SAF/eSAF value chain. The database shall include the basic information on the companies/organisations, such as name, product and service offering and general contact information, including country of origin. The stakeholders should be categorised and mapped visually.

Methodology:

The methodology adopted to map the stakeholders, included the following steps:

• Identification – where all relevant organisations, institutions and individuals were identified through both desk study as well as consultations with a selected stakeholder group.

• Selection of the relevant stakeholders: More than 30 relevant stakeholders from different categories have been targeted in the eSAF value chain for the purpose of conducting the roundtable.

The following groups have been identified:

• Ministries, regulators, departments, and individuals that are responsible for development of policies and regulations in the subject area/sectors.

• Industry associations and businesses operating in the subject area/sector that have a significant interest on eSAF value chain.

• Industrial establishments and/or research organisation who are taking interest in technology development and providing supplies to the users.

• Banks and other lenders who could be involved in providing co-financing for the climate mitigation and adaptation projects.

• Transport Fleet Operators who could be the potential users of the new environment friendly fuel and be the cause for reducing the effects of climate change

• Academia, research institutions, think tanks that generate knowledge and provide technical support to government and industry.

The exercise of mapping of stakeholders continued with consultations with a key group of relevant members of the key ministries, academic, private sector actors/companies, and non-profit institutions in India.

S.No	Category	Organization	Contact	Website
1	Academia	CSIR - Indian Institute of Petroleum and Engineers India Limited	ajay@iip.res.in	https://www.iip.res.in/iih-and-training/contact-us/
2	Academia	CBR-Partner	info@cbr-partner.de	https://cbr-partner.de/imprint-legal-notice/
3	Airline	Boeing	media@boeing.com	https://www.boeing.co.in/
4	Airline	Airbus Industries	info@airbus.com	https://www.airbus.com/en/airbus-contact-us
5	Airline	Air India	nodalofficer@airindia.com	https://www.airindia.com/
6	Association	SAF Association	Secretary@safassociation.com	https://www.safassociation.com/service.php
7	Bank and Financials	Bank of India	cgro.boi@bankofindia.bank.in	https://bankofindia.bank.in/
8	Bank and Financials	State Bank of India (SBI)	gm.customer@sbi.co.in	https://sbi.bank.in/web/customer-care/contact-us
9	Bank and Financials	Agence Française de Développement (AFD)	afdnewdelhi@afd.fr	https://www.afd.fr/en/form/contact-us

10	Government Authorities	Ministry of Civil Aviation	secy.moca@nic.in	https://civilaviation.gov.in
11	Government Authorities	Directorate General of Civil Aviation	dgca@gov.in	https://www.dgca.gov.in/digigov-portal/
12	Government Authorities	Ministry of New and Renewable Energy	prasad.chaphekar@gov.in	https://mnre.gov.in/
13	Government Authorities	Ministry of Science and Technology - Department of Biotechnology	webupload@dbt.nic.in	https://dbtindia.gov.in/
14	Government Authorities	Ministry of Environment, Forest, and Climate Change	itdiv-moefcc@gov.in	https://moef.gov.in/
15	Government Authorities	Centre for High Technology	jyoti.pandey25@cht.gov.in	https://cht.gov.in/
16	Government Authorities	Airport Authority of India	pgofficerchq@aai.aero	https://www.aai.aero/
17	Government Authorities	NITI Aayog	dheeraj.k@gov.in	https://www.niti.gov.in/content/contact-us
18	Government Authorities	Ministry of Petroleum & Natural Gas	indiaportal@gov.in	https://services.india.gov.in/service/ministry_services?cmd_id=1897&ln=en
19	Government Authorities	NABCB (National Accreditation Board for Certification Bodies)	contact.nabcb@qcin.org	https://nabcb.qci.org.in/
20	Government Authorities	EIL	eilmbd@eil.co.in	https://engineersindia.com/
21	Government Authorities	BIS	fmcs@bis.gov.in	https://www.bis.gov.in/?lang=hi
22	Government Authorities	QCI	info@qcin.org	https://qcin.org/
23	SAF Producer	Indian Oil Corporation Ltd (IOCL)	sharmaa@indianoil.in	https://iocl.com/contact-us
24	SAF Producer	Bharat Petroleum Corporation Limited (BPCL)	info@bharatpetroleum.in	https://www.bharatpetroleum.in/contact-us.aspx/1000
25	SAF Producer	LanzaJet	erik.birkerts@lanzajet.com	https://www.lanzajet.com/
26	SAF Producer	Avaada Group	avaada@avaada.com	https://avaada.com/
27	SAF Producer	Mangalore Refinery and Petrochemicals (MRPL)	mrplmlr@mrpl.co.in	https://www.mrpl.co.in/en/
28	SAF Producer	GPS Renewables	info@gpsrenewables.com	https://gpsrenewables.com/
29	SAF Producer	National Thermal Power Corporation (NTPC)	ntpccc@ntpc.co.in	https://ntpc.co.in/contact-us
30	SAF Producer	ZR2 Group	info@zr2group.com	https://zr2group.com/
31	SAF Producer	Axens Group	harpreet-kaur.kathuria@axensgroup.com	https://www.axens.net/
32	SAF Producer	Reliance Industries Ltd	info@ril.com	https://www.ril.com/
33	SAF Producer	ESSAR	vmanagement@essar.com	https://www.essar.com/contact-us/
34	SAF Producer	New Era Clean tech	info@neweracleantech.com	https://neweracleantech.com/
35	State	Uttar Pradesh Government	upinformation@nic.in	https://up.gov.in/en
36	Technology	Praj Industries	info@praj.net	https://praj.net/
37	Technology	Topsoe	info@topsoe.com	https://www.topsoe.com/

Annexure II - Experts Consulted

This report draws upon the insights and perspectives of distinguished experts from government, industry, academia, and international organizations who were consulted during the preparation of this document. Their valuable contributions helped shape a holistic understanding of India's emerging e-SAF ecosystem, investment landscape, and policy pathways.

Government and Policy Experts

1. **Mr. Upendra Tripathy** – Former Secretary, Ministry of New and Renewable Energy (MNRE)
2. **Dr. Anita Gupta** – Head, Climate, Energy and Sustainable Technologies (CEST) Vertical, Department of Science and Technology (DST)
3. **Dr. Prasad Arvind Chaphekar** – Deputy Secretary, Ministry of New and Renewable Energy (MNRE)
4. **Mr. Bodhishotto Bhattacharjee** – Deputy General Manager – Corporate Affairs and Policy & Infrastructure, Essar Group
5. **Mr. Rohit Kumar,** Secretary General, SAF Association
6. **Mr. Frank Mischler,** Director (Policy), International PtX Hub

Industry Leaders and Technical Experts

7. **Dr. Shantanu Gupta** – Co-Chairman, SAF Marketing Committee (SAF Association) & Former Executive Director, Indian Oil
8. **Mr. Balasaheb Darade** – Chairman, e-SAF Committee, SAF Association & Founder, New Era Cleantech
9. **Mr. Vineet Bakshi** – Director, Business Development, LanzaJet & LanzaTech
10. **Mr. Jonathan Wood** – Chief Commercial Officer, Nova Pangaea Technologies
11. **Mr. Frank Mischler** – Director, Policy, International PtX Hub
12. **Mr. Sarvesh Kumar** – Chief General Manager (Hydroprocessing, Catalysts & Technical Services), Indian Oil R&D Centre
13. **Mr. Nick Houseman** – Chairman, Technology Innovation Committee, SAF Association & Co-Founder, Azzera
14. **Mr. Prashant Naik** – Senior Director, Business Development, Lummus Technology
15. **Mr. Rakesh Kumar** – Chief Business Officer, New Era Cleantech
16. **Mr. Ishan Gulati** – Manager (Planning & Promotion), JGC Corporation
17. **Mr. Rishi Bigghe** – Associate Director, Deloitte India
18. **Mr. Guranchal Singh** – Principal, Research & Analytics, Argus Media
19. **Mr. Harshal Arekar** – Manager, MEC Intelligence
20. **Ms. Kriti Sharma** – Director, Sunday Power Agritech Pvt. Ltd.
21. **Mr. Shailesh Agarwal** – Financial Consultant
22. **Mr. Amr Aly** – Country Manager, EgyptAir
23. **Mr. Piyush Dhawan** – Advisor, Climate Law Association
24. **Mr. Dipti Lavya Swain** – Founder & Managing Partner, DLS Law Offices
25. **Mr. Ujjval Bhatt** – Senior Staff Consultant, KBC Advanced Technologies

26. **Mr. Samyak Pandey** – Editor, Global Biofuels, S&P Global Commodity Insights

27. **Mr. Pranav Jain** – Chartered Accountant & Financial Analyst

28. **Mr. Kumar Abhishek** – Energy Advisor, GIZ India

29. **Axens Group** – Technical Partner and Process Technology Expert

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