India's Future in Sustainable Aviation

The Decarbonisation Route

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1.0 Introduction

India's aviation market is the third largest worldwide, after the United States of America (USA) and China. Its domestic traffic constitutes 69% of the total airline traffic in South Asia (Vipra, 2022). This sector witnessed an average annual growth of 16% over the last decade, which can be mainly attributed to the increase in income and low-cost aviation. Various government policies and initiatives, including the Ude Desh Ka Aam Nagrik (UDAN) Policy, which aimed at enhancing rural connectivity, have also aided in the growth of the sector (Ministry of Civil Aviation, 2016a, 2016b). Under the initiative Nextgen Airports for Bharat Nirman (NABH) introduced in 2018, the Ministry of Civil Aviation is currently undertaking activities to expand the airport capacity in the country by more than five times, which would facilitate a billion trips per year (PIB Delhi, 2018).

However, aviation is one of the fastest growing sources of greenhouse gas (GHG) emissions driving global climate change. According to the World Economic Forum (2019), if the aviation sector was considered a country, it would be among the world's top 10 GHG emitting nations. At present, aviation turbine fuel (ATF), a major fuel used in the aviation industry, is a petroleum refinery output. GHG emissions from the Indian aviation sector have increased by 2.5 times in 2018 (25 million tonnes of CO_2 equivalent [$MtCO_2e$]) compared with the levels in 2005 and are growing at a compound annual growth rate of 7.34% (GHG Platform India, 2022). In addition, recent studies globally reckonthat the impact of aviation emissions is 2–4-folds greater than the current estimates owing to radiative forcing caused by non-CO_2 and water vapour emissions (Lee et al., 2021). Additionally, theair pollutants and particulate matter emitted during ground-level aircraft idling and taxiing[1] have significant public health impacts.

The aviation market in India is expected to continue on a growth trajectory. According to the Sustainable Alternative Futures for India (SAFARI) model developed at the Center for Study of Science Technology and Policy, the number of aviation passengers may increase by 4-folds by 2030 and 15-folds by 2050 compared with the current numbers (2018). The SAFARI model also estimates that GHG emission levels due to aviation transportation (including freight) will increase by 3.6–3.8 times by 2030 and 12.6–14 times by 2050 compared with the levels in 2018 (Figure 1).

[1] Taxiing is the slow movement of an aircraft on the ground before take-off or after landing.

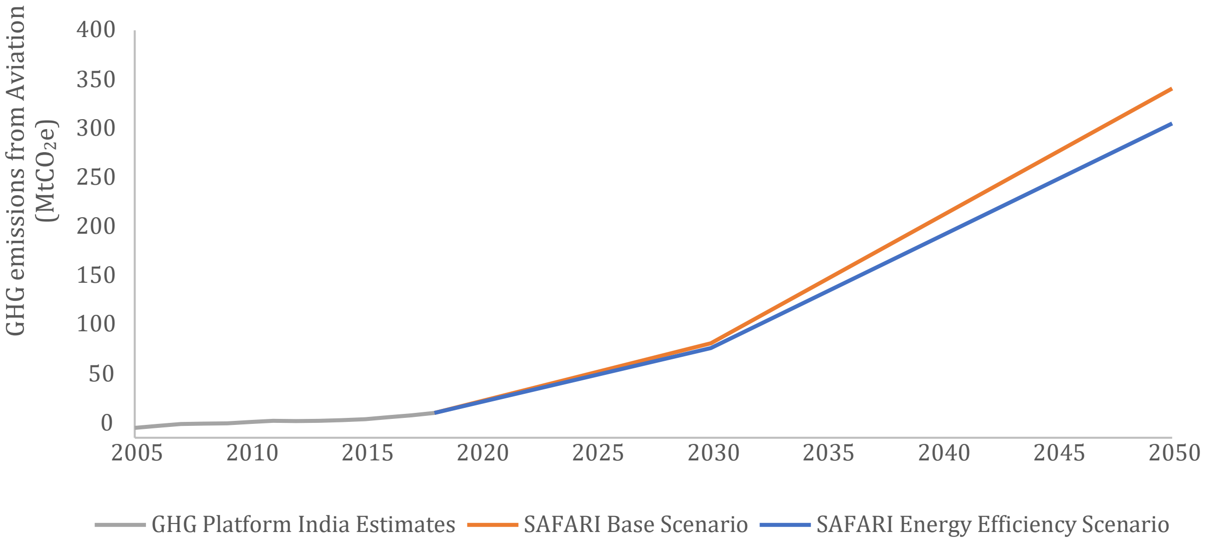

Figure 1: Emissions from the Indian Aviation Sector[2]

Sources: GHG Platform INDIA, 2022; CSTEP, 2020

Given the expected growth in the sector and its adverse impact on climate, decarbonising the aviation sector is crucial for India to reach its 2070 net-zero target. Towards this end, we identified decarbonisation options for the Indian aviation sector. In addition, a preliminary analysis of the cost of investments was conducted and the decarbonisation potential of the major decarbonisation measures was estimated.

[2] This figure excludes emissions at airports and those due to international flights arriving in India.

2. 0 Decarbonisation Measures for the Aviation Sector

We identified various decarbonisation measures suitable for the aviation sector in India (Table 1). Based on the strategy for emission reduction, the measures are classified into three categories: (1) activities to reduce ATF consumption, (2) development of alternative propulsion systems, and (3) formulation of low-carbon sustainable fuel. Because the aviation sector has the highest carbon footprint per kilometre, shifting to other transportation modes, such as high-speed electric trains, can also reduce emissions in the transportation sector. However, the scope for a modal shift is limited to distances of less than 1000 km.

Table 1: Decarbonisation Measures for the Aviation Sector

Decarbonisation measures	Decarbonisation potential (tail-pipe emissions)	Technology readiness (globally)	Scale-up potential
Activities to reduce ATF consumption			
Efficiency improvement activities in existing aircraft	10%	High	High
Improved airspace management and airport operations		High	High
Improvement of aircraft designs, engines, and component materials	Up to 22%	Medium	Medium to High
Development of alternative propulsion systems			
Hybrid-electric aircraft	Up to 20%	Low to Medium	Low to Medium
All-electric aircraft	100%	Low	Low
Hydrogen-powered aircraft	50%–90%	Low	Low
Formulation of low carbon or sustainable fuels			
Sustainable alternative fuels	Up to 100%	Low to Medium	Medium to High

Sources: Compiled from Air Transport Action Group Project, 2021; ICAO, 2017; ITF, 2021

Although decarbonisation measures that focus on reducing ATF consumption can be easily adopted, these measures have low decarbonisation potential. The vision document of the International Civil Aviation Organisation (ICAO) on aviation alternative fuels and future objectives reports that the implementation of decarbonisation measures, including natural fleet renewal, efficiency improvement, air traffic management (ATM), and infrastructure improvements, has the maximum potential to reduce ATF consumption by only 29% globally in 2050 (ICAO, 2017). Therefore, to achieve a significant reduction in GHG emissions, the aviation industry needs new low-carbon propulsion technologies and alternative fuels.

Alternative propulsion systems based on electricity have zero tail-pipe emissions and can achieve significantly lower life-cycle GHG emissions with renewable electricity. However, a major limitationof electric aircraft is the weight of the batteries, which limits the vehicle size and flight ranges. In fact, even for short-haul flights, the battery technology to ensure commercial viability is yet to be developed. Similar limitations can be observed in the case of hydrogen-powered aircraft. Moreover,the current hydrogen-powered aircraft technology is not suitable for long-haul flights and will require significant research and development (R&D). Based on the current progress, even the mid- range hydrogen-powered aircraft can be commercially introduced globally only after 2050 (Mckinsey & Company, 2020).

Sustainable aviation fuel (SAF)—a fuel with properties similar to ATF and derived from sustainable sources such as used cooking oil, animal fats, and other oils—can help reduce CO_2 emissions by up to 100% of tail-pipe emissions and up to 65% of life cycle emissions compared with ATF. Moreover,the existing aircraft can handle the current maximum certified blend of 50% SAF with ATF and morethan 3 lakh flights worldwide have been powered by SAF (World Economic Forum, 2021). The American Society of Testing and Materials (ASTM)—an international organisation for developing voluntary consensus standards—has approved various sources of raw materials and production processes for the commercial production of SAF (Commercial Aviation Alternative Fuels Initiative, 2020). At present, among various approved raw materials and methods, SAF production via hydro- processing[3] accounts for the highest share in global production (skynrg, 2020). This is mainly because of technology maturity and cost competitiveness compared with other process methods (see Annexure 1 for details of various processes and raw materials).

Since the technology for the commercial plying of electric and hydrogen flights is still at a nascent stage and has limitations for long hauls, the aviation sector needs to rely heavily on other decarbonisation measures such as low-carbon or sustainable fuels at least till 2050 and enable the transition towards net zero.

[3] An organic compound made by replacing the hydrogen of an acid by an alkyl or other organic group

3.0 Global Best Practices

After road transport, the aviation sector is being pursued as the next decarbonisation target around the globe. In addition to most countries focusing on adoption of SAF as well as energy-efficient and low-carbon-footprint aircraft designs and electric aircraft (for short-range flights and take-off and landing), there are few country-specific initiatives.

The United Kingdom (UK) has already initiated decarbonisation activities in its aviation sector by initiating strategies such as ATM, air space modernisation, ground operation, and influencing consumer behaviour. Even though emissions from international aviation do not directly account for nationally determined contributions, the UK has included its share of international aviation and shipping emissions in its carbon budget to remain consistent with the Paris Agreement temperature goal[4] (Department of Business, Energy & Industrial Strategy, 2021). The UK has also introduced emission trading systems, a greenhouse gas removal market, and renewable transport fuel certificates (RTFCs)[5], which mandates suppliers to comply with obligatory targets for the sale of sustainable and low-carbon fuels (Department of Business, Energy & Industrial Strategy, 2020; Department of Transport, 2022). The consumers are made aware of the environmental impact of their flight, and sustainable choices are made available to them during the time of booking flights, thereby bringing the whole ecosystem of aviation under the sustainable practice umbrella.

The USA majorly targets the upgradation of aircraft and aircraft technology in addition to focussing on SAF. The National Aeronautics and Space Administration, USA, is supporting R&D for battery- powered aircraft intended for take-off and landing in long hauls and 100% battery-operated aircraft in short hauls. Other remarkable interventions by the USA include the dedicated Aviation Climate Action Plan—detailing a whole-of-government approach and policy framework for decarbonising their aviation sector to achieve sectoral net-zero by 2050 (Federal Aviation Administration, 2021). Another interesting intervention in France and Austria involves a ban on short-haul flights on select routes where the equivalent train ride is 2.5–3 h or less (unless they connect to an international flight) (Avila, 2022). Annexure 2 provides further details on the best practices worldwide.

[4] Paris Agreement temperature goal: To limit global warming to well below 2°C and pursue efforts towards 1.5°C
[5] RTFCs equivalent to 10.637% of the volume of fossil and unsustainable renewable fuel supplied were mandated for the year 2020

4.0 Current Scenario in India

Owing to climate commitments and decarbonisation activities in the aviation sector globally, several efforts toward decarbonisation have been initiated in the aviation sector in India. India will be part of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)[6], with the offsetting requirements expected to be applicable for India from 2027 onwards (Ministry of Civil Aviation, 2021). Airlines flying in India have also started following stringent efficiency measures and updating their fleet with state-of-art technologies and more fuel-efficient engines (IndiGo, 2021). Since 2019, the Indira Gandhi International Airport, Delhi, has been using TaxiBot, a semi- robotic hybrid special purpose vehicle for aircraft taxiing, which has helped airlines save 2.1 lakh litres of ATF as of 2021 (ET Bureau, 2021).

With regard to the adoption of low-carbon fuels in the Indian aviation sector, some airlines have already used blended ATF–SAF in demo flights (Indian Transport and Logistics News, 2021). The Indian Institute of Petroleum under the Council of Scientific & Industrial Research (CSIR, CSIR-IIP) has established a pilot plant for SAF production at Dehradun for flight tests by the Indian Air Force. The maiden biofuel flight in the country by SpiceJet was also fuelled by the CSIR-IIP production facility (Tripathi, 2022). Recently, CSIR-IIP, SpiceJet, and Boeing have joined hands to explore opportunities for the use of SAF in the Indian aviation industry. CSIR-IIP is also currently awaiting ASTM certification for the commercial production of SAF at a capacity of 15,000 litres per day (approximately 3,200 tonnes annually)[7]. This is expected to be operational as soon as the certification is obtained, which may take up to a year (Science Communication and Dissemination Directorate, 2022).

The recent amendment (May 2022) in the National Policy on Biofuels 2018 allows more feedstocks for biofuels and the promotion of biofuel production in India under the 'Make in India' Programme, enabling India to be well-positioned in SAF production (PIB Delhi, 2022).

[6] CORSIA requires aircraft operators purchase emission offsets or use CORSIA Eligible Fuels (CEF) such as SAF to reduce international CO_2 emissions above a defined baseline.
[7] 1 tonne of ATF = 1,250 litres (Same conversion is considered for SAF due to similarity in properties). To estimate the annual production, we assumed that the plant will operate for 270 days annually.

5.0 Road Map for Decarbonising India's Aviation Sector

5.1 Strategies

Decarbonisation of the Indian aviation sector by 2050 requires a combination of strategies including fleet renewal with efficient flights, operational improvements in ATM, and the use of an SAF–ATF blend. In addition, the wide adoption of TaxiBots to cater to air-taxiing at Indian airports would considerably reduce GHG emissions. Meanwhile, research in electrification and hydrogen fuel to develop solutions for aviation is needed. Adequate support should be provided by the government to encourage research and pilot studies on SAF production processes and various domestically available feedstocks.

5.2 Deployment Pathways

Indian airlines have maintained a good track record in reducing ATF consumption through the use of more energy-efficient fleet. At present, around 50% of India's in-service fleet comprises A320neoAirbus aircraft, which are 15%–20% more fuel-efficient than their previous generation models (Prabhakar, 2022). Additionally, Indian airlines are now inducting a larger number of A320neo and 737MAX Boeing aircraft, which are more energy-efficient and will result in reduced emissions (Boeing, 2017; Prabhakar, 2022).

Seeking international collaborations and learnings from global best practices will aid in reducing inefficiencies in the current ATM system in the Indian aviation sector. The aviation sector could seek collaborations with developed nations partnering in CORSIA and ICAO to improve its ATM systems. The ICAO's recent initiative 'No Country Left Behind' aims to provide comprehensive assistance to developing countries in implementing ICAO standards and recommended practices.

Considering costs, technology maturity, and feedstock, hydro-processing and alcohol-to-jet fuel methods are viable approaches for the mass production of SAF to ensure wide-scale deployment in India. The major feedstocks can include used cooking oil, animal fats, and other oils as well as agricultural residues such as straw, husks, chaffs, and surplus sugar molasses.

Furthermore, India needs to develop plans to achieve an SAF–ATF blend target of 1.2% (including passenger and freight) by 2030. This is in line with the voluntary targets of transporting 100 million domestic passengers in India on a 10% blend of SAF by 2030 set under the Clean Skies for Tomorrow Initiative, a coalition across the aviation sector wherein many Indian airlines, airports, and institutes participate to facilitate the net-zero transition. The country has enough feedstock for SAF production to cater to the entire aviation sector till 2030. In addition, approximately 140 million tonnes of cropresidue is burnt in India, causing air pollution. SAF production using these feedstocks can help meetthe blending targets while curbing these emissions to some extent (Jain et al., 2018). Moreover, designing an appropriate collection mechanism with fair pricing for used cooking oil can reduce its reuse in the food industry.

Based on the CO_2 emission factors for ATF and SAF and the projected fuel consumption from SAFARI, we estimated that with a 1.2% blend of SAF in 2030, the projected emissions from this sector can be reduced by 1 $MtCO_2e$[8]. The current analysis also revealed that nearly 0.33 million tonnes of SAF willbe required to achieve a 1.2% blend by 2030.

[8] CO_2 emission factor for ATF = 3.05 tonne of CO_2/tonne of ATF (estimated from data of ATF consumption andCO_2 emissions in 2018 from GHG Platform India Phase IV)

The current cost of SAF per tonne is expected to be INR 82,500–1,12,500 for hydro-processing, INR 90,000–1,20,000 for alcohol-to-jet fuel (using sugar streams), and INR 1,35,000–1,65,000 for alcohol-to-jet fuel (using agricultural residues) in India (World Economic Forum, 2021). Based on our estimate, around INR 37 billion will be required to achieve a 1.2% blend by 2030.

Additionally, there is a need to conduct a detailed study on shifting to railways in major short routes, similar to those in Europe (Oxera, 2022). With seven high-speed rail projects on the horizon, airlines may be forced to rethink short-haul flights, considering the higher cost of operations due to frequentlandings and take-offs (Pandey, 2020). Hence, shifting short-haul trips to railways can be considered a decarbonisation measure. However, many factors need to be considered before this shift. Is the rail infrastructure already built and capable to handle the shift? Are people willing to shift to railways considering the time vs cost-effectiveness? What is the optimum shift required in terms of the number of passengers and trips and total distance (in km) to achieve maximum decarbonisation?

5.3 Challenges Ahead

Challenges in improving the ATM system: With an increase in airspace demand, the maintenance and improvement of efficiency levels will be challenging. Any change in the ATM system needs to ensure the safety of all aircraft operations. Without continued investment in infrastructure, excess fuel burn per flight will increase.

Raw material for SAF production: Although India has a sufficient supply of raw materials to fuel all aviation by 2030, the production needs to take a leap. There is a lack of segregation, collection and supply mechanism, and infrastructure for all ASTM-approved raw materials. Biomass cultivation for SAF production may lead to unsustainable agricultural practices, such as the cultivation of extensive oil palms and water-intensive crops, mono-cropping, and conversion of land into non-edible crops. These practices go against all climate resilient agriculture good practice guidance. They will not only enhance the risk of these systems and the farmers dependent on them, but also have long reaching impacts on health, nutrition, food and water security, without which India cannot achieve any of its adaptation goals.

Cost of SAF: Although SAF is a cleaner fuel, a major hurdle in its adoption is its cost. SAF is nearly 1.5times costlier than the current aviation fuel. However, many studies showed that at massive deployment, the cost of SAF would be on par with that of ATF. This would require commercial deployment support, which would play a critical role in reducing production costs.

Procedural delays for SAF production approval: The certifications and approvals for the commercial production of SAF currently require at least one year. These procedural delays would slow down the scaling up of SAF production. At present, the production of only 3,200 tonnes of SAF is in the pipeline. For meeting the 1.2% blending target by 2030, the production capacity needs to be increased by more than 100 times.

Challenges in aircraft electrification: Battery-operated flights are expected to have zero tail emissions and are considered the most eco-friendly aviation option, followed by hydrogen fuel cells, which mayreduce emissions by 75%–90% (Mckinsey & Company, 2020). However, there are certain challenges in the adoption of these technologies. Electric and hydrogen solutions are unlikely to cover flights

CO_2 emission factor for SAF = 0 (considered only tail-pipe emissions) beyond 1,500 km. In addition, the current battery technology does not offer the power-to-weight ratio for long-haul flights. Thus, they can essentially be used to cater to air-taxis.

5.4 Future Directions

Given the high investments and infrastructure requirements, the decarbonisation of the Indian aviation sector will be challenging. However, the availability of surplus raw materials for SAF production and the predicted high growth of the sector can pave the way for low-carbon transitions. India should advocate a combination of decarbonisation measures as its strategy. Moreover, an effective combination of investments, massive production build-up of SAF, feedstock supply chain improvements, and intensive collaborations with leading countries to learn the best practices in ATM and other operations is required. For the successful adoption of these strategies, efficient policies and government support will be required to bridge all such gaps to enable low-carbon transitions.

The Ministry of Aviation along with the Ministry of New and Renewable Energy and Ministry of Environment, Forest and Climate Change needs to develop a holistic government approach and policy framework for a net-zero pathway for the Indian aviation sector. In addition, similar to the USA's Aviation Climate Action Plan, a plan accounting for the country-specific requirements and challenges can be developed.

Policy mechanisms, such as a mandate for 1.2% SAF blending by 2030 (near-term target) for all and higher blending rates for major airlines for select flights, will help in creating an ensured demand forSAF and thus provide the hand-holding that is required for SAF production entities. This type of surety or in-principal agreement to buy a large quantity of SAF could accelerate the mass production of SAF. Policies also need to focus on blending targets for the medium-term as well. Such a mandatewill also have co-benefits such as reduced pollutant emissions, crude oil imports, and pollution due to crop burning. Furthermore, source mapping of raw materials and feedstock should be undertaken to ensure that there will be no supply-side hold-ups if a mandate of this nature comes into force.

An SAF policy along the lines of the National Biofuel Policy should be introduced to support feedstocks that do not conflict with food supply and to resolve land-use concerns. A nodal agency forthis policy—an umbrella institution bringing transportation, energy, and agriculture departments under one roof—will help effectively address cross-sectoral matters and develop a cleaner and cheaper aviation fuel.

Furthermore, if India decides to levy carbon tax/carbon pricing, given the remarkable increase in emissions from the sector expected in the near-to-mid-term future, a portion of the tax should be diverted to subsidising the price of SAF, infrastructure development for ATM systems, and other efficiency improvement measures. Broadly, financial support is also required for funding clean aviation technology R&D. In the absence of an economy-wide carbon tax, major airline companies should be mandated to invest 1% of annual net profits for R&D and upscaling of SAF as well as otherclean energy technologies, such as electric and hydrogen-fuelled engines.

A strategic public–private partnership is needed to ensure the consolidation of the value-chain for SAF as well as other energy-efficiency measures in the country. The government should consider encouraging more private investment for SAF under the umbrella of corporate social responsibility (CSR). At present, the aviation sector is among the bottom three sectors in terms of meeting CSR commitments, which involves the expenditure of 2% of the net profits gained during three previousfinancial years in the current year (KPMG, 2020). The new amendment to the Companies (CSR) Rules, 2014, and Section 135 of the Companies Act, 2013, requiring the transfer of the unspent CSR amountto a dedicated account will aid in pooling of funds (Ministry of Corporate Affairs, 2021).

The decarbonisation of the aviation sector will be multifaceted and complex, and there are several noteworthy barriers to decarbonisation. Policy implementation with country- and region-specific directives will be core to the acceleration of this process. Efforts should be focused on cost-effectiveSAF production and scaling up, in addition to the adoption of global best practices in this sector. Seeking more intensive collaborations and strategic partnerships in aviation will lay the foundationfor a systemic low-carbon transition.

Annexure 1.

Processes and Raw Materials for Sustainable Aviation Fuel Production

1. Hydro-processed esters and fatty acids[9] from used cooking oil, animal fats, and other oils
2. Fisher-Tropsch or gasification[10] of municipal solid waste (bio and plastic) as well as agricultural and forest residues
3. Alcohol-to-jet fuel produced from agricultural or forest residue and surplus sugar cane molasses[11]
4. Power-to-liquid fuel[12] produced with hydrogen technology and carbon captured from industries

Sources: (Federal Aviation Administration, 2021; skynrg, 2020; World Economic Forum, 2021)

[9] Esters: An organic compound formed by replacing the hydrogen of an acid by an alkyl or other organic group. Many naturally occurring fats and essential oils are esters of fatty acids.
Fatty acids: An acid consisting of a hydrocarbon chain and a terminal carboxyl group (–COOH), especially any of those occurring as esters in fats and oils.
[10] Gasification process: Gasification is a process that converts biomass- or fossil fuel-based carbonaceous materials into gases: nitrogen (N2), carbon monoxide (CO), hydrogen (H2), and carbon dioxide (CO_2).
[11] Sugar cane molasses: Sugarcane molasses is a viscous, dark, and sugar-rich by-product of sugar extraction from sugarcane.
[12] Production of hydrogen through electrolysis and synthesis with carbon dioxide to produce liquid hydrocarbon.

Annexure 2.

Best Practices in Different Countries

Countries	SAF research and development (R&D)	Efficient aircraft	Consumer behaviour	Carbon market	E-aircraft & hydrogen	Institutional integration
United Kingdom (Hirst, 2021)	• SAF supply is rewarded through the renewable transport fuel obligation, which provides tradeable certificates for every litre of certain sustainable fuels used for aviation. • Government has also provided grant funding to businesses through competitive schemes. • UK-based company Rolls-Royce aims to make all their civil aero-engines in production compatible with 100% SAF by 2023, double the current maximum blend.	Measures to improve the fuel efficiency of conventional aviation, such as changes to aircraft, air traffic management, airspace modernisation, and ground operations at airports.	Strategies to influence consumers to make sustainable choices via provision of reliable environmental information at the time of booking.	Market for greenhouse gas removal. CORSIA program, EU Emissions Trading System (EU ETS) and the UK ETS.	• Zero emission flight technologies (hydrogen-electric and battery-electric crafts) have been demonstrated in the UK. • UK invested in the FlyZero project, a first of its kind research project to explore the market and design opportunity of potential zero emission commercial flight.	The Jet Zero Council SAF Delivery Group has been set up for the government and industry to work together to establish UK SAF production facilities and accelerate the delivery of the fuel to market.

USA (FACT SHEET: Biden Administration Advances the Future of Sustainable Fuels in American Aviation, 2021)	• Aim to produce 3 billion gallons of SAF, 20% reduction in aviation emission • $4.3 billion funding for fuel producers	R&D to increase efficiency by 30%			R&D with the National Aeronautics and Space Administration on energy density for electrification of aircraft for take-off and landing for long-range flight and 100% electrification for short-range flight.	• USA plans for a dedicated aviation climate action plan. • The Dept. of energy, agriculture, and transport to come together to bring the cost of SAF at par with that of conventional fuel. • The Dept. of Defense is investing in a range of initiatives to improve the efficiency of legacy aircraft and develop more energy- efficient new aircraft.

Germany (Welle, 2021)	• 2% SAFs from 2025, rising to 5%—including a sub-quota of 0.7% for e-kerosene—from 2030. • A pilot project to produce carbon-neutral synthetic kerosene by combining green hydrogen and sustainable carbon dioxide captured from the air and biomass.					
European Union (Dyk, 2021)	Europe proposed a ReFuelEU Aviation regulation mandating minimum SAF blending volumes in aviation fuel, rising from 2% in 2025 to 5% in 2030 and 63% in 2050.					

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