International Transport Forum

Sustainable Aviation Fuels
Policy Status Report

Case-Specific Policy Analysis

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The International Transport Forum

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A shared vision for increasing SAF use is one outcome of the group. The ITF Secretariat and Norway submitted the information paper A Policy Vision for Promoting the Scale-Up of Sustainable Aviation Fuels (SAFs) to the 41st ICAO Assembly. The information paper shares insights from the Aviation Common Interest Groupon priorities for scaling up SAF, and this report's structure follows its recommendations. Thanks go to the reviewers of the Information Paper: Ashan Edoo (Canada), César Velarde (ECAC), Elisabeth Windisch (ITF), Ingrid Cherfils (Sweden), Jagoda Egeland (ITF), Jan Petter Steinland (Norway) and José Ramón Fernández Sampedro (Spain).

The information paper can be found at: www.icao.int/Meetings/a41/Documents/WP/wp_504_en.pdf.

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The DT Implement project is part of the ITF's wider Decarbonising Transport (DT) initiative. The DT initiative is a key instrument to help governments and industries translate climate ambitions into actions. It unites over 70 governments, organisations, institutions, foundations and companies. More information on the DT Initiative is available at https://www.itf-oecd.org/decarbonising-transport.

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Abreviations and acronyms

ASTM	American Society for Testing and Materials
ATJ-SPK	Alcohol to jet synthetic paraffinic kerosene
CCU	Carbon capture and utilisation
CHJ	Catalytic hydrothermolysis jet fuel
CO_2	Carbon dioxide
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DAC	Direct air capture
EU	European Union
EV	Electric vehicle
FT	Fischer-Tropsch
FT-SKA	Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources
GHG	Greenhouse gas
H_2	Hydrogen
HC-HEFA-SPK	Synthesized paraffinic kerosene from hydrocarbon – hydroprocessed esters and fatty acids
HEFA	Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
ILUC	Indirect land-use change
LCAF	lower-carbon aviation fuel
LCFS	Low carbon fuel standard
LTAG	Long-term global aspirational goal
MSW	Municipal solid waste
PtL	Power-to-liquid
R&D	Research and development
RED	Renewable Energy Directive

RTFO	Renewable Transport Fuel Obligation
SAF	Sustainable Aviaton Fuel
SIP	Synthesized iso-paraffins from hydroprocessed fermented sugars
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change

Executive summary

What we did

This report presents recommendations to promote the production and deployment of Sustainable Aviation Fuels (SAFs), which can replace conventional, fossil aviation fuel to reduce carbon dioxide (CO_2) emissions from aircraft. The insights come from discussions in the ITF's Decarbonising Aviation Common Interest Group, an expert forum on SAF policies bringing together government and industry representatives. The group was established in 2021 under the ITF's Transport Decarbonisation: Driving Implementation (DT Implement) programme and is chaired by Norway and Sweden. The group met four times in 2021/2 to discuss strategies for the accelerated expansion of SAF production and use. In addition to insights from these meetings, the report draws on a stocktake of existing policy frameworks to promote SAF in aviation.

What we found

The aviation sector has pledged to become climate neutral by 2050. SAFs are the only available low-carbon fuel technology for air travel today. They are thus indispensable for the sector to reach its climate targets. This is the case for long-haul flights in particular, which are responsible for most of aviation's fuel consumption.

Several governments have put in place policies to promote the deployment of SAF. The most advanced programmes benefit from prior experience with policies that brought biofuels into road transport. Specifically, these policies feature targeted mechanisms to reduce production costs.

The aviation industry expects SAF to deliver most of the necessary emission reductions. Many airlines have started to deploy SAF, albeit at small volumes. Fuel producers have invested in additional capacity. Ramping up SAF production requires concerted efforts from governments and companies in the aviation sector. These must begin now, to enable an uptake fast enough to meet aviation's decarbonisation target.

What we recommend

Invest in Sustainable Aviation Fuels now to lower production costs to levels that allow widespread use

SAFs are expensive and their supply is limited today. Policy makers need to set incentives to produce more SAFs to reduce costs and increase uptake. One incentive is to reward airlines that are already using SAF despite the barriers. Another is to help producers to activate their existing facilities for SAF production. Co-processing bioenergy feedstocks in conventional fuel production can increase SAF supply in the short term. Third, mobilising investments into production facilities that use advanced technologies helps achieving commercial production scale, leading to lower costs and a growing market. Finally, measures to facilitate the flexible distribution of SAF will overcome logistical constraints at a stage when SAF is only available in few locations. They could include schemes that let suppliers deliver SAF to the general fuel supply, rather than to specific airports or aircraft.

Support all sustainable production technologies and feedstock types that deliver credible emission reductions

There are several SAF types available today. They vary in their fuel feedstock type and production technologies. Different countries may choose to prioritise different SAF types, but support should focus on fuels that reduce emissions the most. To this end, governments should provide production incentives for fuels with high emission reduction potential. Policies should offer targeted support for fuel technologies that – while perhaps less competitive today – promise to deliver emission reductions at large production scales in the longer term.

Other important sustainability aspects include the need to prevent indirect land-use change (ILUC). Policies can enable the emergence of an international SAF market by aligning national policies regarding carbon accounting methods and monitoring measures. Such alignment also eases compliance with various regulatory or voluntary frameworks for internationally operating airlines.

Expand existing SAF frameworks to help aviation deliver on international climate objectives

The International Civil Aviation Organisation (ICAO) adopted a long-term global aspirational goal (LTAG) whereby international aviation acheives net-zero emissions by 2050. Doing so requires a strong scale-up of SAF. Several governments have adopted support frameworks. However, frameworks that mandate or incentivise fuel production and deployment concentrate on a few leading markets. Without additional policy ambition, the sector risks falling short of reaching international climate objectives. Governments must increase the reach of existing frameworks now.

Capture opportunities for industrial development and energy supply resilience

Promoting SAF offers opportunities beyond climate benefits, includingdomestic industrial development and reducing energy imports. Many regions that rely on fuel imports today already have bioenergy resources or the posibility of generating renewable electricity. They can effectively supply domestic fuel production. SAF production is typically more decentralised compared to fossil fuels, offering opportunities for local industry.

Create transport decarbonisation strategies that incorporate all transport sectors to maximise emission savings

Governments should focus on holistic decarbonisation strategies that embrace all transport modes and available technology options. Several markets already use biofuels to reduce emissions in road transport. Their policy experience could provide valuable lessons for a wider implementaion of SAF. Drop-in fuels, which are entirely compatible with today’s aircraft, are the only available decarbonisation option for aviation today. Technology breakthroughs in hydrogen and battery electric aircraft are pending. Governments can maximise emission reductions and energy savings today across all transport modes by directing available drop-in fuels to hard-to-decarbonise sectors, including aviation, while promoting alternative, more energy-efficient decarbonisation technologies in sectors where they are available. For example, electrifying road vehicles may reduce the sector’s reliance on biofuels and unlock feedstock for SAF production in some contexts.

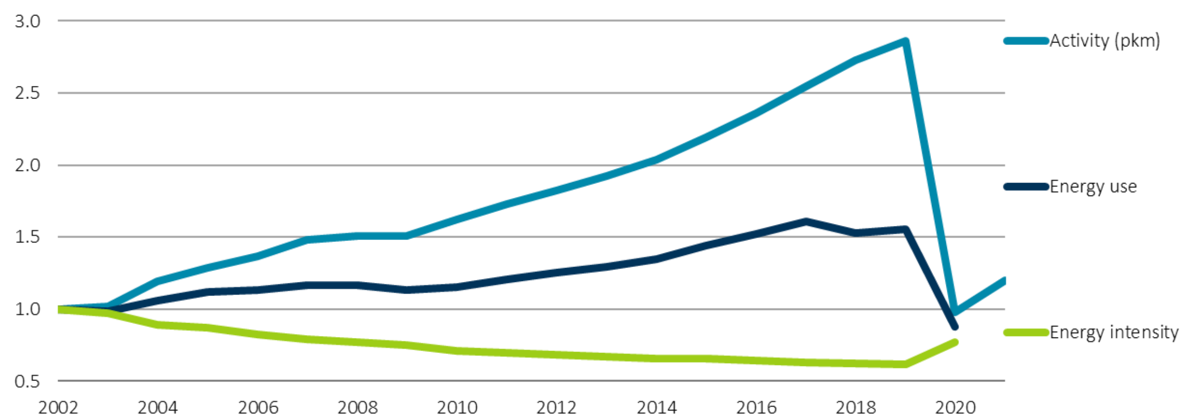
How sustainable aviation fuels can decarbonise aviation

One-fourth of greenhouse gas (GHG) emissions come from transport, making decarbonising transport a policy priority for reaching international climate objectives (ITF, 2023a). Promoting vehicle and fuel technologies that reduce emissions per trip is a principle for fostering sustainable development in the sector. Dynamic low-carbon technology developments exist, especially in road transport, where electric vehicles (EVs) have gained high market shares. However, reducing emissions in aviation, maritime and some heavy-duty road transport is more challenging than in other transport modes. Decarbonising aviation is especially difficult due to its high reliance on fossil fuels, reaching 99.85-99.9% of all fuel use today (IATA, 2023a).

The aviation sector accounts for 14% of global transport emissions (ITF, 2023a). Modern aircraft burn up to 20% less kerosene than older models (IATA, 2023b), and more efficient operations could help reduce the environmental footprint per passenger. However, the global demand for air travel is growing, and the absolute sector emissions with it, despite decreasing carbon intensity per passenger. Global revenue passenger-kilometres, a metric for air travel activity volume, increased by 76% in the ten years before Covid-19 (ICAO, 2023a). The sector's fuel use grew at lower rates than activity in this period thanks to efficiency improvements, but still increased by 39% (Figure 1). The Covid-19 health crisis disrupted aviation strongly and caused a 44% drop in air travel in 2020. Many of the remaining flights operated with empty seats, increasing the average energy use per traveller and reversing the trend of efficiency gains (Figure 1).

Currently, air travel is on a solid growth path as the industry recovers from the health crisis. Revenue-passenger kilometres reached 88% of pre-pandemic levels in spring 2023 (IATA, 2023c). The industry expects air travel demand to double until 2040, with the most increase in the developing world with significant latent air travel demand (IATA, 2023c). The strong growth prospect and slower uptake of low-carbon technologies compared to other sectors make aviation a priority sector for decarbonisation policies.

Figure 1. Change in activity, energy use and energy intensity of passenger air transport, 2002-21
index change from 2002



Source: ICAO (2023a), IEA (2023a).

Notes: Energy intensity is the ratio of energy use and activity

National and international policy frameworks promoting emission reductions are less advanced for aviation than other sectors. For example, international and domestic aviation do not pay fuel taxes in most markets while governments commonly impose fuel taxes on road transport to raise funds and price externalities. Governments may regulate domestic flights and negotiate environmental provisions in bilateral air transport agreements for international connections, but environmental regulation for aviation generally lags behind other sectors. One reason is the sector's exposure to international competition, where a patchwork of environmental rules could distort the markets and harm a country's aviation industry. Despite these challenges, several countries have adopted environmental regulations for the aviation sector, such as incentivising low-carbon fuels, implementing environmental taxes, or limiting domestic short-haul flights.

The International Civil Aviation Organization (ICAO) is the United Nation's (UN) body responsible for environmental regulations for international aviation. Its mandate includes defining an emission pathway for the sector, which is not covered by the UNFCCC Paris Agreement. In 2021, ICAO launched the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) for climate-neutral growth compared to the 2019 base year in participating member states (IATA, 2023d). Governments in 2022 agreed on a long-term global aspirational goal (LTAG) for international aviation of net-zero carbon emissions by 2050. The LTAG is the most comprehensive environmental sector agreement to date and provides a clear direction. Detailed sector plans to implement low-carbon programmes and technologies are needed to reach it.

Sector scenarios expect that most emission reductions needed to achieve the LTAG will come from sustainable aviation fuel (SAF). SAF reduces emissions because it can replace fossil kerosene in conventional aircraft and usually has a lower carbon intensity than oil products. Already deployed in small albeit growing volumes, it has more potential to cut emissions starting in the short term than novel aircraft technologies like hydrogen or (hybrid-) electric aircraft. Their market entry is uncertain, and their expected range will make them unviable on long flights, which are responsible for most emissions (ITF, 2023a). SAF are the sector's best bet to reduce emissions without curtailing activity. As such, safeguarding the LTAG relies on effective policies to support SAF production and deployment. Some governments have implemented policies to stimulate SAF deployment, and more countries are developing strategies.

What are sustainable aviation fuels?

SAFs are liquid aviation fuels with the same properties as conventional jet fuel that originate from renewable energy resources, either bioenergy or renewable electricity. Their compatibility with existing aircraft technology and refuelling infrastructure makes them so-called “drop-in-fuels”. The compatibility advantage of SAFs with existing airliners means they can start reducing sector emissions without fleet replacements. Aircraft have a long, more than 20-year lifetime on average, and planes that enter the global fleet today will still operate in 2050, the sector’s net-zero target date (World Bank, 2022).

SAFs’ lifecycle emissions determine their carbon footprint. They consist of the fuel’s carbon content (direct emissions) and emissions that occur during fuel production (upstream emissions). Direct emissions do not differ between conventional jet fuel and various SAF types due to their near-identical characteristics, including carbon content. However, the upstream emissions vary between SAF types and conventional fuels and determine whether a fuel can realise net-savings. Factors that influence upstream emissions are, for example, emissions associated with feedstock production and the carbon intensity of electricity used in production processes.

There are three groups of SAF types with drop-in properties:

- first-generation biofuels from lipids, including synthesized paraffinic kerosene from hydroprocessed esters and fatty acids (HEFA)
- advanced biofuels from biochemical pathways and thermochemical pathways
- power-to-liquid (PtL) fuels, or e-kerosene, that use green electricity to produce hydrogen through electrolysis and combine it with carbon to synthetic hydrocarbons.

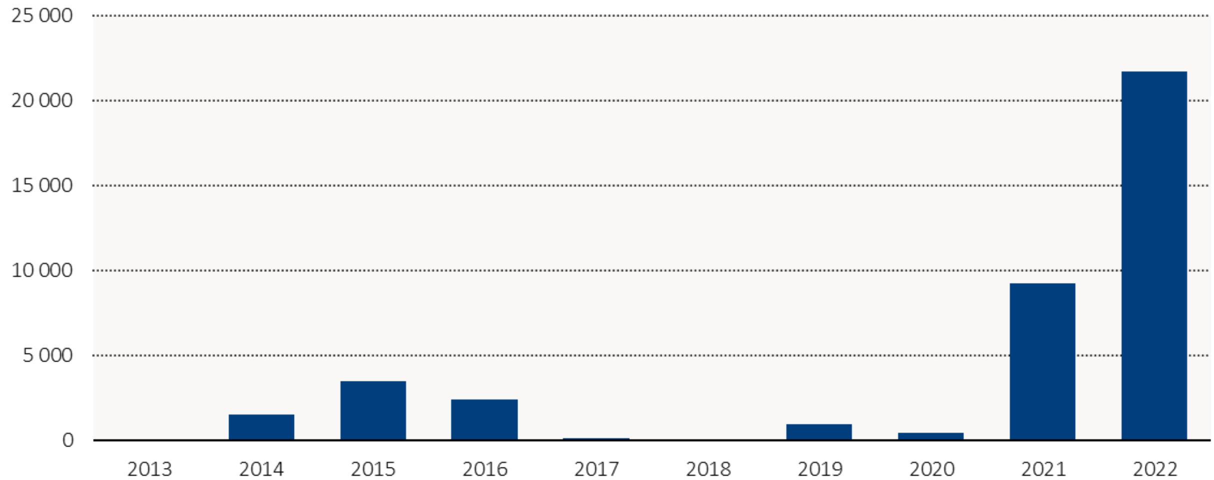
These SAF types differ not only in their emission footprint, but also in the technology readiness level of their production processes and equipment, costs, and feedstock availability. HEFA is the most advanced and least expensive production pathway today and supplies almost all SAF in the sector. The SAF market is still evolving, and no global price standard exists. Production costs for HEFA are twice that of conventional jet fuel, and advanced bioenergy and PtL are even less cost-competitive at today’s production costs (IEA, 2021). Existing deployment relies on emerging policy frameworks and voluntary SAF purchases by airlines and aviation users willing to pay a premium.

Existing sustainable aviation fuel deployment

In 2021, the global airline industry pledged to become climate neutral by 2050 through the International Air Transport Association (IATA), and expects SAF to deliver 65% of the necessary emission reductions (IATA, 2023a). SAF deployment has increased dynamically in recent years, but their share within aviation fuel demand remains marginal. Voluntary industry uptake is the strongest driver for SAF market growth to date, and many airlines have entered into purchase agreements with SAF producers to reduce their environmental impacts.

Government incentives for producing low-carbon fuel are another driver for SAF deployment. Most existing frameworks focus on road fuels, but some governments have implemented or planned policy frameworks tailored to promote SAF. Compliance requirements in some markets that have implemented first SAF mandates also contribute to market growth, as can anticipation for future regulations. As governments implement more comprehensive packages, there may be a gradual transition from voluntary industry uptake to policy frameworks – incentives and mandates – as the most relevant market driver.

Figure 2. Announced sustainable aviation fuel trades per year (million litres)



Source: ICAO (2023b).

Note: The figure shows the volumes of offtake agreements tracked by the ICAO SAF Uptake Tracker, an online database of announced SAF trades (ICAO, 2023b). Offtake agreements are contracts to purchase purchase all or some of a project's production.

SAF market size estimates for 2022 reach 300 to 450 million litres, representing just 0.1% to 0.15% of global aviation fuel use (IATA, 2023a). Public announcements for SAF offtake agreements – to purchase all or some of a project's production – herald strong market growth despite currently low deployment levels. Transactions in the ICAO SAF Uptake Tracker, an online database of announced SAF trades (ICAO, 2023b), reveal a sharp increase in ordered quantities from 0.4 to over 9 billion litres between 2020 and 2021 and a transaction volume of close to 22 billion litres for 2022 (Figure 2). These announcements generally cover a delivery timeframe between two and five years. United Airlines, Delta, Lufthansa Group, Air France-KLM and the One World Alliance are the leading SAF buyers (ICAO, 2023b).

SAF producers respond to the increasing market demand by investing in additional production capacity. Yet, supply may remain tight for some time as new plants are built. Bringing a new production facility online typically takes five years for established fuel pathways like HEFA and longer for advanced technologies not yet operating commercially (IATA, 2023a). A database of announced SAF production capacity to come online in 2022-2025 shows that 83% of additional production will likely come from HEFA, followed by Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene (FT) at 13% and alcohol to jet synthetic paraffinic kerosene (ATJ-SPK) at 2%. OECD countries will host over 90% of this additional production capacity, continuing the current concentration of facilities in a few developed markets (World Bank, 2022).

Sustainable aviation fuel production pathways

Several production pathways exist for SAF. SAF is derived either from bioenergy or the PtL pathway. The technology standardisation body ASTM has certified seven SAF production pathways that use bioenergy feedstocks and two pathways that use co-processing of bioenergy feedstocks in conventional fuel production (ICAO, 2023c). Certification of the PtL pathway is pending.

All pathways result in fuels with characteristics close enough to conventional aviation fuel to replace its use in existing aircraft and refuelling technology. Existing certification allows up to a 50% blending of SAF with traditional aviation fuels.. Despite the shared characteristics of the final fuels, the SAF pathways differ substantially in production costs, maturity of technology components, emission reduction potential, current feedstock availability and long-term scalability. The following section briefly outlines the different production pathways. ITF (2021) provides a more detailed description of their costs, scalability and emission reduction potential.

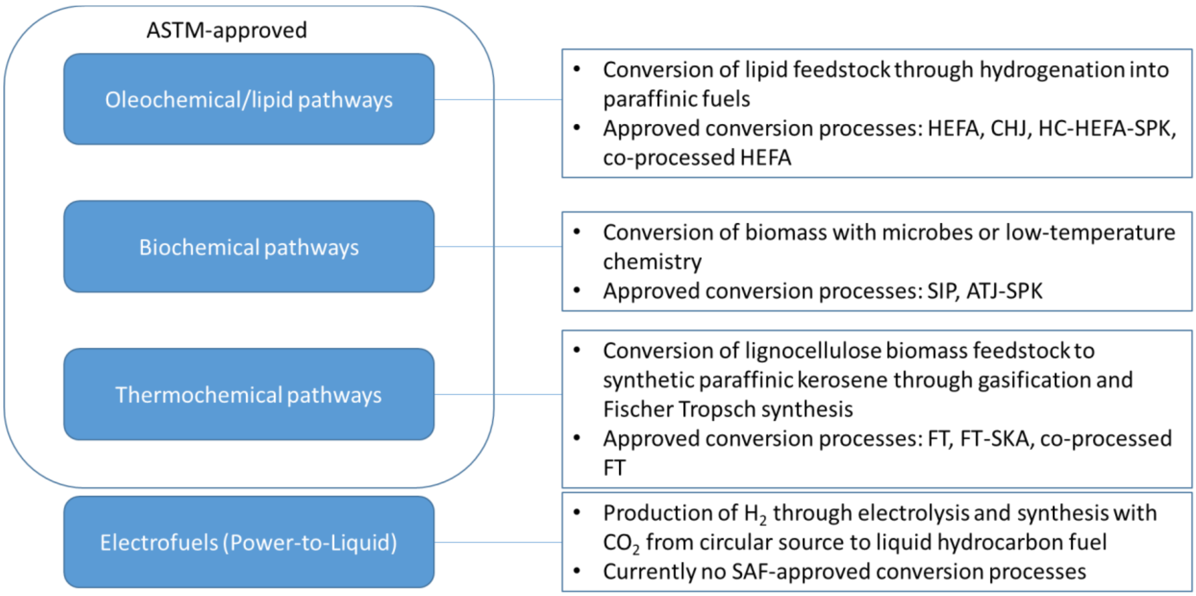
Bioenergy-based pathways to produce sustainable aviation fuels

The seven ASTM-certified SAF production pathways using bioenergy fall into three categories: oleochemical or lipid, thermochemical, and biochemical. Figure 3 lists pathway groups for producing drop-in SAF.

The oleochemical (or lipid) pathway transforms lipid biomass (e.g., vegetable oils, animal fat or used cooking oil) through hydrogenation into paraffinic fuels that blend with conventional jet fuel. The ASTM-certified oleochemical pathways are HEFA, catalytic hydrothermolysis jet fuel (CHJ), synthesized paraffinic kerosene from hydrocarbon – hydroprocessed esters and fatty acids (HC-HEFA-SPK), and co-processed HEFA that feed biomass into fossil fuel production. The HEFA pathway is technologically mature, comparably cheap and supplies almost all existing SAF in the market today. Plants produce a biodiesel fraction of about 80% destined for road vehicles and a SAF fraction of about 15-20% (IRENA, 2021). Biodiesel is common in many markets today, and synergies between this road fuel and SAF benefit the latter's production. However, there are concerns about the costs and availability of sustainable feedstock for this commercial SAF category. Waste feedstocks such as used cooking oil and animal fat are finite, and building efficient supply chains is a priority. Crop-based vegetable oils, like palm oil or rapeseed, are subject to sustainability concerns, and some SAF policy frameworks, notably ReFuelEU Aviation, exclude them from eligibility (European Parliament, 2023).

Biochemical processes are a second SAF production category. They and convert biomass through biological processes such as fermenting sugars from sugar cane or corn to alcohol or enzymatic hydrolysis followed by biological sugar conversion. The two ASTM-certified pathways in this group are synthesized iso-paraffins from hydroprocessed fermented sugars (SIP) and ATJ-SPK. First commercial plants use biochemical pathways today, albeit with less mature technology and higher costs than for HEFA production. Mobilising feedstock supply chains is a priority, and the pathways may benefit from synergies with ethanol production for road fuels. However, competing ethanol demand in other sectors could inhibit this pathway from scaling up (IRENA, 2021).

Figure 3. Sustainable aviation fuel production pathway groups



Notes: ASTM: United States-based technology standardisation body; SAF: sustainable aviation fuels; HEFA: synthesized paraffinic kerosene from hydroprocessed esters and fatty acids; CHJ: catalytic hydrothermolysis jet fuel; HC-HEFA-SPK: synthesized paraffinic kerosene from hydrocarbon – hydroprocessed esters and fatty acids; co-processed HEFA: co-hydroprocessing of esters and fatty acids in a conventional petroleum refinery; SIP: synthesized iso-paraffins from hydroprocessed fermented sugars; ATJ-SPK: Alcohol to jet synthetic paraffinic kerosene; FT: Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene; FT-SKA: synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources; co-processed FT: co-hydroprocessing of Fischer-Tropsch hydrocarbons in a conventional petroleum refinery.

Source: ICAO (2023c).

Finally, thermochemical pathways convert lignocellulosic feedstocks such as wood, grasses, and residues from agriculture and forestry (e.g., straw, twigs and rice husks) into jet fuel. This process uses the gasification of biomass to produce syngas, a mixture of hydrogen and carbon monoxide. The Fischer-Tropsch process then synthesises these elements into hydrocarbons. Today, the production technologies are less mature than for HEFA, but may become more competitive in the future.

Reducing technology costs and improving process efficiency are more significant concerns than feedstock availability. The lignocellulosic feedstock is less prone to unintended impacts such as indirect land-use change (ILUC) or competition with food production and could scale more than feedstock for oleochemical and biochemical pathways. Municipal solid waste (MSW) is another feedstock under consideration. ASTM has certified three thermochemical conversion processes: FT, FT-SKA and co-hydroprocessing of Fischer-Tropsch hydrocarbons in a conventional petroleum refinery (co-processed FT).

Producing sustainable aviation fuels from the power-to-liquid pathway

PtL pathways use electrolysis to produce hydrogen from electricity. The Fischer-Tropsch process then synthesises the newly-produced hydrogen with carbon into synthetic hydrocarbons. Suitable carbon sources are direct air capture (DAC), a process extracting CO_2 from atmospheric air, or point-source carbon capture, a process that extracts emissions from industrial processes. For PtL pathways to reach a better emission profile than conventional fossil fuels, they must use renewable electricity in all production processes. PtL fuel production only operates at a pilot scale today, and several technology components, especially electrolysers and DAC, must advance their technology readiness level for PtL to become commercial.

Producing fuel from renewable electricity eliminates some of the feedstock availability and sustainability concerns associated with bioenergy pathways. The PtL pathway yields e-kerosene and e-diesel and can reduce emissions in several transport sectors. However, it may be difficult to expand renewable electricity generation fast enough for e-kerosene to replace significant shares of fossil kerosene (ITF, 2023b). Green hydrogen is an essential decarbonisation technology in several sectors, and promoting related technologies can realise cross-sectoral benefits.

Invest in sustainable aviation fuel now to lower production costs for future use

Most SAF production technologies can realise cost reductions. The diverse production pathways of different SAF types can replace fossil kerosene, but each comes with distinct advantages and challenges. Factors such as feedstock availability and costs, technology readiness and costs, and the emission profile of alternative pathways impact when they will become available, how much SAF they can deliver, and what emission reductions they can achieve.

SAF costs limit their market uptake today and vary between pathways. They result from production plants' capital and operating cost and feedstock value, with varying impacts of these price components between SAF types. For example, HEFA's production costs depend more on feedstock prices than on technology costs. In contrast, technology costs are higher than production costs for the advanced bioenergy and PtL pathways (IRENA, 2021).

The cheapest SAF today is HEFA from the lipid pathway. It is the only commercially operating, mature technology because it uses the same production technologies as biodiesel. Traders do not disclose prices of individual transactions, yet estimates for HEFA production costs reach USD 0.9-1.3 per litre (IEA, 2021). The capacity of new and announced plants has increased recently. In 2023, Neste's Singapore plant completed an upgrade that doubled its production capacity to 2.6 million tons of biofuel per year with a SAF fraction up to 1 million tons per year (Neste, 2023). Maximising economies of scale through larger plant sizes and mobilising supply chains of lipid feedstock may reduce HEFA costs as this fuel type scales up in the short term.

Advanced bioenergy pathways do not operate at a commercial scale today, and the potential production cost reductions are more uncertain than for HEFA. Their more elaborate production processes result in higher technology costs than for HEFA production. These high technology equipment costs contrast with comparably low feedstock costs. This holds especially for lignocellulosic biomass, which is, for example, agriculture and forestry residues or grown on land unsuitable for food production. Feedstock for the alcohol-to-jet pathway is an exception, as it has other high-value end-uses than fuel production (IRENA, 2021). Reducing technology costs is a priority for making advanced biofuel production pathways more competitive in the mid-term. Production cost estimates for thermochemical aviation biofuels range from USD 1-2 per litre of fuel (ITF, 2021).

E-kerosene production is the least advanced production pathway and currently only operates in pilot projects. E-kerosene has a wide production cost range of USD 0.6-2.8 per litre of fuel, and strategic support for this technology will be essential (ITF, 2021). For e-kerosene to be a competitive fuel in the long term, technology costs for renewable electricity production, electrolysers and DAC must fall.

Targeted policies can reduce costs and increase deployment

The SAF sector grew dynamically in recent years thanks to voluntary market uptake by pioneering users and emerging policy frameworks. Projected SAF demand for achieving the ICAO LTAG reaches 450 billion litres by 2050. Several countries have adopted national SAF deployment targets. SAF deployment only represented 0.01-0.015% of jet fuel use in 2022 (IATA, 2023a). Reaching deployment targets requires a robust SAF production increase now. SAF’s high prices and limited supply hold the market back. Increasing production could unlock cost reductions through technology learning and economies of scale, especially for advanced production pathways that currently do not operate commercially.

Expanding existing low-carbon fuel strategies to the aviation sector emerges as a priority to increase SAF supply, even if at an early market stage and in small volumes. Governments can kick-start the SAF industry without causing market disruptions while SAF supply is limited by mandating the use of small volumes of SAF. For example, France, Sweden and Norway mandate SAF use at low percentages of fuel use (S&P Global, 2022). Low carbon fuel standard (LCFS) programmes that include incentives for SAF production drove early market growth in the United States. The concentration of the current SAF production in markets that offer policy incentives supports that they are necessary to enable early market growth.

These policy interventions offer certainty to investors, thus mobilising funding for projects that can reduce production costs in the near term and prepare for mass deployment in the long term. The expected market price, production costs and feedstock availability determine the expected investment returns. Investors also want visibility on future SAF demand and market size before they finance SAF production. Voluntary SAF uptake from pioneering airlines is an important market driver for existing market uptake but may not offer enough market certainty to mobilise investments at the scale necessary to reach long-term decarbonisation objectives in the sector.

Simplifying compliance with policies while safeguarding their objectives is essential to avoid stifling early market growth and regulatory pressure on the industry. For example, governaments can offer flexibility for meeting fuel blending requirements to avoid logistical challenges. These challenges may arise if regulated parties must meet a SAF mandate for each individual flight or airport. This is especially true in an early market stage when SAF is produced at few locations. The resulting long fuel transports increase costs and emissions. Governments can ease compliance measures through a mass balance system that allows fuel suppliers to meet blending requirements on average. Deliveries can be made to a general fuel pool or a book-and-claim system that separates market transactions from physical fuel deliveries.

European policy makers are making moves in this direction. Fuel suppliers must comply with the ReFuelEU Aviation’s blending mandate starting at 2% in 2025; they can fulfill it on average across their airport portfolio rarther than at every airport where they operate (European Council, 2023). Ensuring that SAF is supplied at all airports, including remote ones, may become a policy priority when SAF increasingly replaces conventional fossil kerosene in the aviation system. Besides easing policy compliance, book-and-claim systems can also aid voluntary fuel uptake by separating SAF trade from physical fuel deliveries. A White Paper from the Clean Skies Tomorrow programme describes a SAF certificate system that would simplify market transactions and establish a transparent system for involved parties to claim emission savings from the voluntary SAF uptake (WEF, 2022).

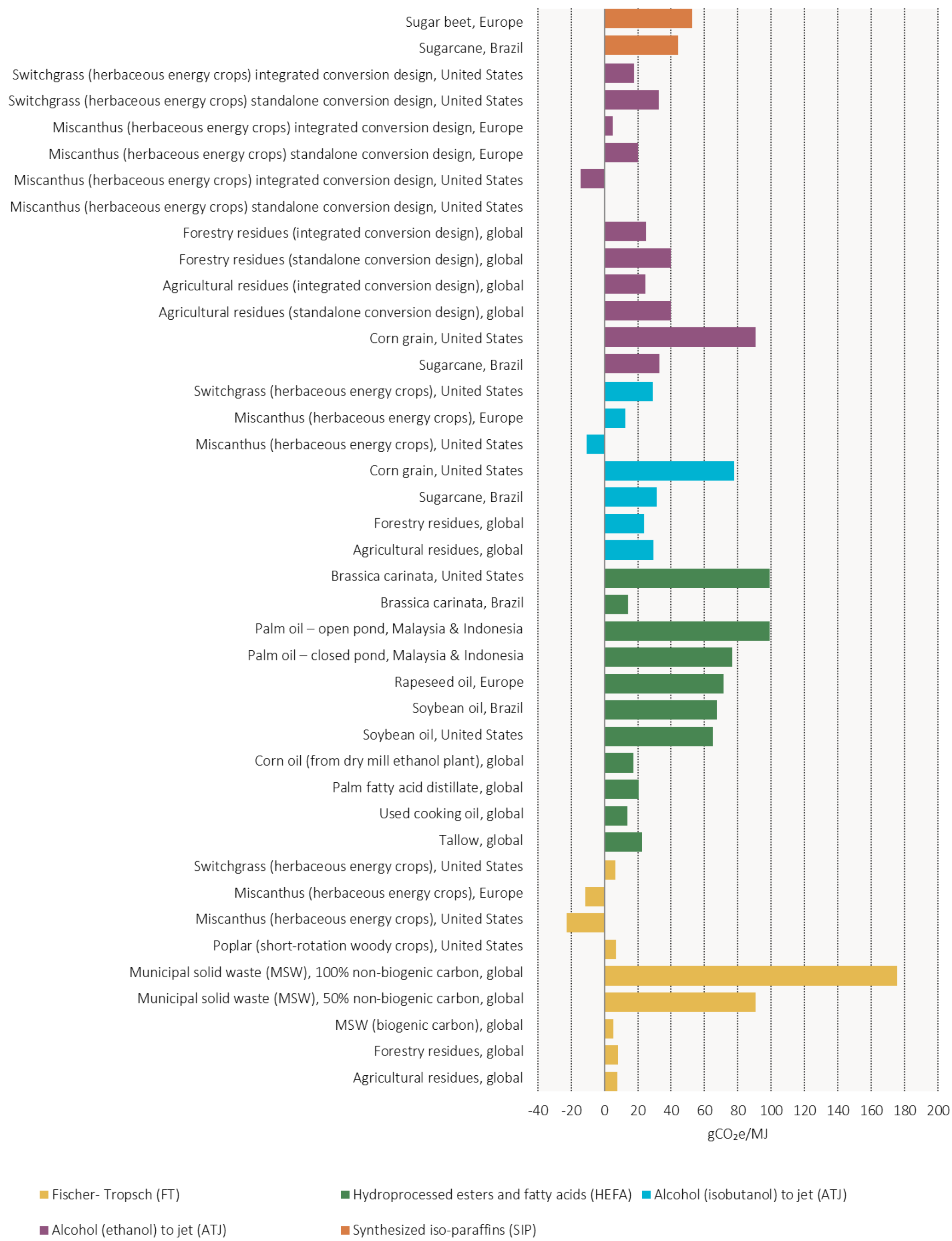
Co-processing can leverage existing fuel production assets to bring low-carbon feedstock into the aviation sector. Co-processing introduces low-carbon feedstocks into conventional fuel production processes. It reduces the fuel’s emission intensity and can assist in developing SAF feedstock supply chains, using existing production facilities while in the current lack of dedicated biofuel plants. Co-processing produces fuels with a higher emission intensity than SAF and does not offer the same decarbonisation benefits, yet it can be an important first step for a more comprehensive transition in the sector. ASTM has certified two co-processing pathways for SAF production: co-processed HEFA and co-processed Fischer-Tropsch (ICAO, 2023c).

Policy interventions that mobilise investments in the less mature advanced bioenergy and the PtL pathways now can assist in building future supply. The ReFuelEU Aviation proposal with a sub-blending target for e-kerosene, reaching 1.2% within a 6% overall SAF target by 2030, is one example of a policy with targeted support for advanced pathways (ITF, 2022). Supporting the early market growth of less advanced SAF types is essential to reach mid- and long-term deployment targets because scaling SAF technologies from pilot projects to commercial production takes time. HEFA production is commercial today and represents almost all existing SAF supplies. This pathway underwent a ten-year scaling process from first pilot projects and test flights to commercial production. SAF from advanced bioenergy and the PtL pathways are yet to reach commercial scale and will be important pillars for reaching mid- and long-term SAF deployment targets.

Embrace all sustainable production pathways and feedstock types that deliver credible emission reductions

The carbon content between different SAF types and fossil kerosene does not vary. However, different production processes and feedstock types result in distinct well-to-tank (upstream) emission profiles that determine the mitigation potential of different SAF types. Influencing factors include inputs into feedstock production – such as fertiliser –, the energy intensity of production processes, and the carbon intensity of energy used in production processes. Bioenergy feedstock production may induce ILUC, which can have a strong impact on the emission profile of final fuel products and even increase emissions compared to fossil kerosene. The various factors that influence the emission profile of SAF make the carbon intensity of fuel products very case-dependent. However, default emission factors for different SAF types, such as for eligible fuels under ICAO CORSIA, reveal that the advanced bioenergy and PtL pathways generally maximise emission savings, except for HEFA produced from a waste feedstock.

Figure 4. Default values for life-cycle CO_2 emissions of CORSIA-eligible fuels



Note: MSW: Municipal solid waste; gCO_2-eq/MJ: grammes of CO_2 equivalent per megajoule. Negative values reflect cases where indirect land-use change affects more than offset positive emissions from feedstock production and conversion. They are provisionally allowed during the pilot phase of CORSIA (2021-23). A decision on whether to continue allowing negative values will be made by the end of the pilot phase (2023).

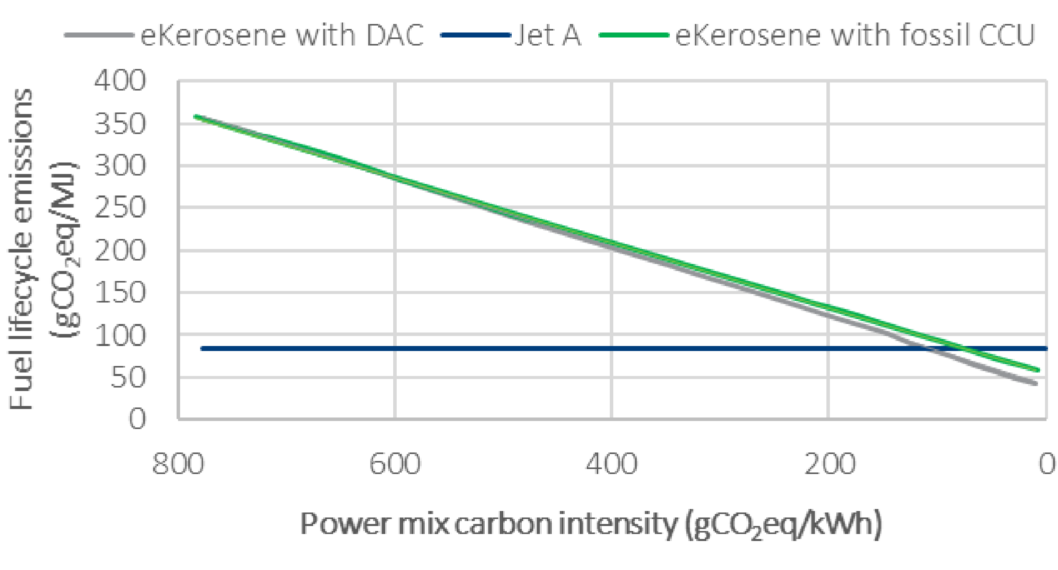
Source: (ITF, 2021) based on ICAO (2022a).

SAF from lipid bioenergy pathways such as HEFA from palm oil, rapeseed and soybeans, and the biochemical pathway using corn ethanol tend to have a higher emission intensity than other SAF types. In some cases, it reaches or exceeds the emission intensity of fossil jet fuel at 89 gCO_2 per MJ, thus offsetting any carbon savings. Growing energy crops for these SAF types is susceptible to causing ILUC, which is responsible for the better part of several pathways' carbon footprints (ICAO, 2022a).

HEFA delivers the most emission benefits if produced from waste products such as used cooking oil or animal fat. These fuels' default lifecycle emission factors are significantly lower than those of other fuels of the HEFA group. However, their supply may be limited, thus constraining the amount of SAF and absolute emission reductions they can deliver. Advanced bioenergy SAF pathways, such as ATJ-SPK from agricultural and forestry residues and lignocellulosic energy crops, tend to have lower default lifecycle emission factors than first-generation biofuels, as do thermochemical bioenergy pathways that produce fuel through gasification and Fischer-Tropsch synthesis. ILUC emissions of several fuel types are negative, meaning that these fuels sequestrate more CO_2 than they emit (ICAO, 2022a).

E-kerosene is currently not approved as SAF under CORSIA and so not listed in the default lifecycle emission factors in Figure 4. E-kerosene's emission performance depends strongly on the carbon intensity of electricity to operate electrolysis and drops sharply against an increasing carbon intensity of the power mix (Figure 5). The source of carbon – from DAC or point source sequestration (carbon capture and utilisation, CCU) also affects the lifecycle emissions of e-kerosene. The input electricity must have a carbon intensity of 110 gCO_2-eq/kWh or less to safeguard climate benefits compared to conventional jet fuel (ITF, 2023b). For comparison, the average carbon intensity of the European Union (EU) grid in 2019 was 255 gCO_2-eq/kWh. The grid carbon intensity of Austria, Finland, France, Lithuania, Luxembourg, and Sweden met the threshold for emission savings in that year (European Environment Agency, 2023).

Figure 5. Life-cycle GHG emissions for e-kerosene, gCO_2-eq/MJ



Notes : DAC=direct air capture, CCU = carbon capture and utilisation.

Source: Adapted from ITF (2023b), based on Ueckerdt et al. (2021) with data from Moirangthem (2016).

Choosing which sustainable aviation fuel types to prioritise for policy support

Policies that promote SAF to reduce climate impacts from aviation should focus on fuel feedstocks and production technologies that maximise emission savings. The lifecycle emission footprint of fuels is the most relevant indicator to measure climate benefits and can guide policy design to promote SAF market scale-up. However, there are further important considerations than the default lifecycle emission factor. The carbon footprint of individual fuel deliveries is case-dependent. Policy makers may choose to avoid fuel types prone to unintended consequences that can reduce or even offset the fuel types' benefits. Feedstock scalability should also be analysed, as available resources may constrain a fuel type's potential absolute emission reductions. For example, HEFA from used cooking oil and animal fat offer strong emission reduction potentials but face a finite feedstock supply, thus restricting these fuels' total contribution to sector decarbonisation targets.

Policy frameworks should accommodate fuels' varying market readiness. They should also enable the market growth of expensive pathways that can maximise savings in the long term at high production scales. Table 1 summarises considerations for evaluating different SAF categories.

Table 1. Benefits and challenges of different sustainable aviation fuel pathways

Pathway category	Scalability	Costs	Emission benefits
Oleochemical/lipid	(+) most commercial technology that can support early sustainable aviation fuel scale-up (-) sustainable feedstock supply faces limitations	(+) low technology costs (-) limited cost reduction potential, waste feedstock limitations may increase costs	(+) high if using waste feedstock (-) limited if using energy crops
Biochemical	(+) high feedstock availability (-) early technology deployment stage	(+) cheap feedstock (-) high technology costs, competing feedstock uses for some fuels	(+) high, especially if using agriculture and forestry residues
Thermochemical	(+) high feedstock availability (-) early technology deployment stage	(+) cheap feedstock (-) high technology costs	(+) highest emission benefits among bioenergy pathways
Power-to-Liquid	(+) not dependent on biomass feedstock (-) nascent technology deployment stage of electrolysers and direct air capture	(+) high cost reduction potential (-) high costs and uncertainty of cost reductions	(+)high if produced with renewable electricity (-)savings depend on fast power grid decarbonisation

Different SAF types' costs and market readiness evolve and may influence policy support allocations. Advanced SAFs (biochemical, thermochemical and PtL) can deliver large-scale emission reductions but are currently the most expensive options. First-generation biofuels (oleochemical) are the cheapest SAF today and maximise emission reductions if produced from waste feedstock, but maintaining supply may become difficult as fuel production increases. While these fuels will deliver the most short-term market growth due to their cost competitiveness and existing production scale, they may lose market shares to more advanced SAF types as they become more competitive mid- and long term.

Some countries invest in SAF programmes for more reasons than maximising emission reductions. For example, some developing countries will promote the production of energy crops to produce HEFA despite the relatively low emissions benefit because it allows rural areas to improve their livelihood. These countries may see the benefit of producing other fuels with higher emission savings but the production technology may not be available in the region.

Expand existing sustainable aviation fuel policy frameworks to help aviation achieve international climate objectives

The aviation industry must transition to SAF fast to meet emission targets. The industry expects SAF to provide 65% of the emission reductions necessary to reach the ICAO LTAG by 2050, which is the equivalent to an annual demand of 450 billion litres or 1 000 times the current production levels (IATA, 2023a). Fuel producers, airlines and governments must make concerted efforts to ensure aviation delivers on this objective. A priority for governments is to expand existing policy frameworks to increase SAF production and deployment. This section presents policy design options from frameworks developed by ICAO and selected governments.

ICAO environmental frameworks embrace sustainable aviation fuels to reduce emissions

The International Civil Aviation Organization (ICAO) is the UN body responsible for international aviation regulations, including environmental issues and other sector objectives. In 2010, member states adopted the goals of achieving average fuel efficiency improvements of 2% per year between 2020 to 2050 and carbon-neutral sector growth from 2020 to 2040 (ICAO, 2010).

ICAO's recommended instruments to reduce aviation emission, the so-called basket of measures, are: operational improvements; aircraft technology; deploying SAF; and the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), a voluntary market-based measure (ICAO, 2019).

In 2018, ICAO launched the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) to encourage carbon-neutral growth in the aviation sector between 2020 and 2040. The two-year pilot phase started in 2021 with volunteering member states. Aviation emissions during the pilot phase have been lower than expected due to the sector disruption from Covid-19, meaning that airlines in participating countries could meet reduction targets without additional reduction measures (ITF, 2021). Following CORSIA's pilot phase, the programme will enter its first phase, which will take place from 2024-26 and for which participation is still voluntary. A second phase, from 2027-35, will then apply to all states exceeding a minimal traffic threshold, representing the majority of international aviation activity (ICAO, 2023d).

Airlines in CORSIA countries can offset emissions growth over the threshold by buying tradeable carbon credits or deploying CORSIA-eligible fuels. Both lower-carbon aviation fuel (LCAF) and SAF are eligible under CORSIA, whereby the former includes fossil fuel with reduced carbon intensity due to measures applied during fuel production. CORSIA sustainable aviation fuels include first- and second-generation biofuels from several feedstock families and production technologies (Figure 4). Eligibility criteria require fuels to demonstrate a 10% lifecycle emission reduction compared to conventional fossil fuels at 89 gCO_2/MJ. This emission reduction threshold is less stringent than in other SAF frameworks, such as in the EU (65%), the United Kingdom (50%) and the United States (50%). In addition to GHG emission reduction requirements, CORSIA stipulates eligibility criteria pertaining to other impact categories, such as land conversion, water use and food security, as well as certification guidelines for fuel deliveries (ICAO, 2022b). CORSIA is the only global framework facilitating SAF deployment. However, the higher carbon abatement costs of SAF compared to offsets limit CORSIA's effectiveness in promoting SAF. Airlines may opt for buying offset certificates instead of SAF (IRENA, 2021).

In 2022, member states at the 41st ICAO Assembly adopted an LTAG for international aviation to reach net-zero CO_2 emissions by 2050 (ICAO, 2023e), increasing international aviation's climate ambitions. The prior feasibility study for a collective emission target, "Report on the feasibility of a long-term aspirational goal (LTAG) for international civil aviation CO2 emission reductions", recognised SAFs as the most important measure to reduce emissions, reinforcing their role in sustainable aviation (ICAO, 2022b). The LTAG is designed as an aspirational sector target without an enforcement mechanism. Such a design could limit its effectiveness in promoting SAF in the short term. However, it is an important step for global emission reductions and SAF deployment that sets the scene for future funding, capacity building, and technology transfer programmes.

To this end, ICAO set up its Assistance, Capacity-building, and Training for Sustainable Aviation Fuels (ICAO ACT-SAF) programme in 2022 to assist states in promoting SAF (ICAO, 2023f). Achieving the LTAG will rely on national programmes to support the SAF sector and other measures that reduce aviation emissions. ICAO members report related activities in biannual ICAO State Action Plans, and forthcoming editions will provide further information on programmes to support the LTAG through SAF deployment (ICAO, 2023g).

Principle design elements of sustainable aviation fuel policies

SAF could potentially be the greatest driver in necessary emission reductions for the aviation sector, allowing the sector to become carbon neutral by 2050. The ICAO LTAG set this important target for programmes that reduce emissions from international aviation. Its successful implementation will rely on individual member states' action from to promote SAF. Several advanced SAF strategies predate the ICAO LTAG, but the LTAG created additional momentum in the sector.

Governments that support SAF have a common objective, yet programme designs and ambitions vary. Three basic design elements for policies are:

- SAF deployment targets
- regulatory frameworks to mandate SAF supply or use (stick approach)
- economic incentives for SAF supply or use (carrot approach).

SAF deployment targets are often the first step for a comprehensive policy package and set the level of ambition for the sector. SAF deployment targets establish a market-share percentage or an amount of SAF that should be in use by a specific year. Markets that have adopted explicit targets for SAF deployment include EU members, India, Indonesia, Japan, Norway, the United Kingdom and the United States. However, SAF deployment targets may prove ineffective if they are not coupled with frameworks that promote investment in SAF.

Economic incentives for SAF supply or use are similar to those in other sectors that have successfully brought low-carbon technologies into the market, including road transport and the power sector. ITF (2023b) presents available policy designs, ranging from mechanisms that assist investors in accessing finance to direct subsidies for SAF production and deployment. Support instruments can come in at different market stages to support R&D activities or close the production cost gap between producing SAF and conventional kerosene. Many markets incentivise activities that can advance SAF. These include tax incentives for SAF production in the United States, funding for R&D and plant investments in European countries, and research programmes in the United Arab Emirates.

Regulatory frameworks to mandate the supply or use of SAF come as fuel blending mandates or LCFS. A fuel blending mandate requires fuel suppliers or users to meet blending quotas of SAF with conventional fuel, either as a blending share or in absolute quantity, over given periods. LCFS prescribe a decreasing carbon intensity for fuel sold in the market that suppliers can meet by producing eligible low-carbon fuels or purchasing credits from suppliers that overachieve their quota. Fuel blending mandates and LCFS are effective at bringing a determined quantity of alternative fuels into the market but do not offer price certainty. Overly ambitious policy targets may outstrip supply and lead to high fuel prices, while low requirements fall short of stimulating large investments in production. ITF (2023b) discusses the advantages and shortcomings of these policy designs in more depth. The policy frameworks of the EU and the United Kingdom deploy regulatory frameworks to mandate SAF use.

As of 2023, the most elaborate SAF policy frameworks and proposals cover the EU, UK and US markets. These same regions also produce the most SAF, indicating that policy frameworks stimulate production. The US policy follows a carrot approach, with tax incentives for production. The EU and UK programmes also support R&D and plant investments, but mandatory blending requirements lie at their core. Blending mandates are effective in reaching a desired deployment level, yet the aviation industry warns that they must be accompanied by production incentives to prevent sharp price increases (IATA, 2023e). Instruments that buffer against unreasonable price fluctuations, such as the buyout mechanism in the UK policy proposal, can address these concerns.

Finding ways to make varied policies compatible will be a priority to ease compliance for companies that operate in multiple jurisdictions. As mentioned above, the emission reduction threshold for eligible SAF types under the EU (65%), US (50%) and UK (50%) frameworks are significantly stricter than under the global SAF definition of the ICAO CORSIA (10%). The low emission reduction criteria under ICAO CORSIA are more inclusive, yet stricter thresholds may channel policy support to technologies that can best deliver on aviation's net-zero objective.

Additional regions, especially Asia and Oceania, are expected to adopt supportive policy frameworks soon. Almost all announced SAF production capacity additions until 2025 are in OECD countries (World Bank, 2022). This uneven distribution of announced capacity additions mirrors that policy frameworks in developing countries tend to be less advanced than in Europe and North America, despite a high feedstock potential in many developing countries (ICF, 2023). Building capacity and attracting investments for production facilities are priorities for these markets to overcome concerns of high costs and limited production facilities for SAF. Despite these challenges, several countries consider opportunities for local SAF production, including Argentina, Kenya and Burkina Faso (ICAO, 2018a; ICAO, 2018b; ANAC, 2021). India already produces SAF domestically (Gevo, 2023).

Many markets look to sustainable aviation fuel to reduce emissions

The Aviation Common Interest Group is a sustainable aviation fuel (SAF) policy forum under the auspices of the International Transport Forum, with experts from 19 governments and 14 companies. The group convened four times in 2021 and 2022, and members shared insights on strategies to support SAF. This section summarises the SAF policies of some countries that joined project activities. The information comes from a survey with partner governments, presentations at Aviation Common Interest Group meetings and original research. The section considers official targets for SAF deployment and strategies to promote these fuels, either through incentive programmes or fuel mandates. ECAC (2023) presents policy information for additional European countries.

Table 2. Policy designs deployed by selected sustainable aviation fuel programmes

	Argentina	Canada	European Union	France	Germany	India	Indonesia	Japan	Norway	Spain	Sweden	Türkiye	United Arab Emirates	United Kingdom	United States
Official SAF target			■	■	■	■		■	■	■	■			■	■
Regulatory framework			■	■	■	■		■	■	■	■			■	
Incentive programmes		■	■	■	■		■	■	■	■	■		■	■	■

Note: The figure provides an overview of deployed policy designs in selected SAF programs. Shaded areas indicate that a country's policy features the design element in question.

Argentina

Argentina recognised SAF as a measure that can reduce emissions from aviation in its 2021 Action Plan for Reducing CO_2 Emissions in Aviation (ANAC, 2021). There is no regulatory or incentive framework to promote SAF use and investments. Initiatives reach back to 2011, when the government and industry agreed to study domestic SAF production opportunities. Today there is no significant SAF deployment despite opportunities to promote a domestic SAF industry.

Canada

Economic programmes that promote SAF include a CAD 227.9 million Low Carbon Fuel Procurement Program for SAF and Renewable Diesel and a CAD 1.5 billion Clean Fuels Fund to support investment in low carbon transport fuels (Government of Canada, 2022a; Government of Canada, 2022b). The government also awarded CAD 5 million to innovative SAF producers under its Sky's the Limit Challenge (Government of Canada, 2022c). There is no official SAF deployment target nor a framework with regulatory requirements to deploy SAF. British Columbia's Low Carbon Fuel Standard does not include the aviation sector.

European Union

ReFuelEU Aviation is a regulatory framework by the European Commission to scale up SAF proposed in 2021 and confirmed in 2023. A SAF blending mandate will apply to aviation fuel suppliers at 2% in 2025, 6% in 2030, 20% in 2035, 34% in 2040, 42% in 2045, and 70% in 2050. There are sub-targets for PtL aviation fuel, and 1.2% of supplied SAF must come from this advanced pathway by 2030. The sub-target will increase to 5% in 2035 and 35% in 2050. ReFuelEU Aviation excludes feedstock that can be used for feed or food. (European Parliament, 2023)

The EU Renewable Energy Directive (RED) lists eligible feedstock in Part B of Annex IX. The emission reduction threshold for eligible biofuels under RED is 65% (EU, 2018). The blending mandate would apply to fuel uptake at all EU airports. A ten-year transition period will offer flexibility to meet blending requirements as an average across airports. Aircraft must take up at least 90% of fuel needs at the origin airport to prevent airlines from fuel tankering, i.e., carrying excess kerosene on inbound flights from non-EU airports without a blending mandate (European Council, 2023).

Non-compliant parties will face penalties, and collected fines would contribute funding to a Renewable and Low-Carbon Fuels Value Chain Industrial Alliance, a programme to support SAF research and production. The blending mandate for synthetic aviation fuels (e-fuels) considers renewable hydrogen, renewable electricity and renewable fuels of non-biological origin. (European Council, 2023; ITF, 2023b)

EU members that adopted national SAF programmes before the ReFuelEU Aviation framework's confirmation may harmonise provisions to avoid a fragmented policy landscape.

France

As an EU member, France will adopt the ReFuelEU Aviation provisions. In addition, France mandated that 1% of aviation fuel would be SAF as of 2022 (Ministère de la Transition écologique, 2020). The 2021 National SAF Deployment Roadmap called for research and demonstration projects to apply for funding, targeting SAF from advanced bioenergy and hydrogen-based fuels (Ministère de l'Économie et des Finances, 2021).

Germany

As an EU member, Germany will adopt the ReFuelEU Aviation provisions. A national policy framework promotes power-to-liquid (PtL) in aviation (Federal Government of Germany, 2021). A confirmed blending mandate foresees 0.5% PtL in aviation by 2026 and 2% by 2030 (~200 000 tonnes of fuel by 2030). The early market scale-up aims at closing the cost gap between PtL and other advanced SAF.

Funding programmes for renewable fuels have EUR 1.54 billion available for 2021-2024. Proposed instruments targeting PtL in aviation include a funding guideline for supporting plants with >10 000 tonnes of annual production capacity. Support programmes focus on domestic projects and foresee deployment in other countries with high renewable energy potential as the technologies commercialise.

India

Increasing the use of bioenergy is a pillar in India's strategy to become a carbon-neutral economy by 2070. Existing policy frameworks in India to promote bioenergy in transport focus on the road sector, including a 20% ethanol blending target for gasoline by 2023 (Government of India, 2022). A 2020 policy revision admitted surplus production and damaged grain as eligible feedstock (Government of India, 2021), which could increase feedstock supply for SAF production. The government is exploring a 1% SAF blending mandate for domestic flights for 2025 (Reuters, 2023). Domestic fuel production has started with agricultural waste feedstock (Gevo, 2023).

Indonesia

The government promotes SAF as part of a broader strategy to scale up bioenergy in all transport sectors, focusing on palm oil as feedstock. The national oil company Pertamina has several SAF pilot projects underway that use palm oil as feedstock (DGCA Indonesia, 2022). Indonesia adopted SAF blending targets in 2015, aiming to reach 5% by 2025 (IEA, 2021). However, deployment remains nascent and will not meet this target. SAF projects in Indonesia currently focus on fulfilling technical specifications. Sustainability criteria for SAF are yet to be specified.

Japan

In 2023, the Japanese government announced a 10% SAF blending mandate for 2030 (NIKKEI Asia, 2023). Economic support programmes are in place to support the objectives of the Green Growth Strategy, a document that outlines the country's SAF plans (METI, 2021). It prioritises the SAF pathways of biomass gasification with Fischer-Tropsch synthesis, alcohol-to-jet, and algae-based fuels. Programmes also invest in R&D for technologies and processes deployed in the PtL pathway. The government aims to reduce SAF production costs through economic measures and has adopted a target price of JPY 100 (~USD 0.8) per litre SAF by 2030, which would close the price gap with conventional jet fuel.

Norway

A 0.05% SAF mandate for domestic and international flights took effect in 2020. The government aims to raise the blending rate to 30% by 2030 (EUROCONTROL, 2022). In 2020, SAF volumes reached 2.5 million litres, compliant with the 0.5% target. However, the Covid-19 crisis kept that year's absolute aviation demand low. The SAF supply comes from hydroprocessed esters and fatty acids (HEFA), with waste oils sourced in Europe as feedstock.

Spain

As an EU member, Spain will adopt the ReFuelEU Aviation provisions. At the national level, the Law on Climate Change and Energy Transition stresses the importance of promoting advanced bioenergy and PtL SAF (Goverment of Spain, 2021).

Sweden

As an EU member, Sweden will adopt the ReFuelEU Aviation provisions. At the national level, the country adopted a SAF blending mandate of 1% in 2021 with the goal of reaching 30% in 2030 (EUROCONTROL, 2022).

Türkiye

Türkiye's Ministry of Industry and Technology collaborates with the EU on promoting SAF under the project Integrated Biorefinery Concept for Bioeconomy Driven Development (INDEPENDENT). This project uses algae feedstock (Lo, 2022). There is no official target for SAF deployment.

United Arab Emirates

The United Arab Emirates (UAE) supports SAF through several R&D and demonstration projects exploring alternative SAF types' potential for local production. Demonstration projects include SAF production with feedstock from halophytes plants that grow under local conditions and from gasification of MSW and Fischer-Tropsch synthesis.

The UAE has not adopted a formal SAF target, and the industry has no regulatory requirement to scale up. However, the country has pledged to become a carbon-neutral economy by 2050 and, in 2023, released a

National Sustainable Aviation Fuel Roadmap (UAE Ministry of Energy & Infrastructure, 2023). The UAE airline Etihad Airways has pledged to reduce emissions by 50% until 2035 (from 2019 levels) and to become carbon neutral by 2050 (Etihad, 2020).

United Kingdom

The United Kingdom's sustainable aviation fuel mandate policy proposal combines a regulatory framework mandating SAF supply with several incentive programmes to encourage production using innovative pathways through advanced bioenergy and PtL. The government is conducting a public consultation on policy design with two phases in 2021 and 2023. The government has confirmed a SAF mandate for fuel suppliers at 10% from 2030. At the moment, the target share for 2025 and years after 2030 are unconfirmed.

The policy design employs a system of tradeable certificates. Fuel suppliers must purchase enough SAF certificates from producers to meet the blending target. Tradeable certificates represent an amount of SAF measured in energy content. Certificate calculations consider a carbon intensity factor. Fuels that reduce emissions by more than 70% compared to an 89 gCO_2/MJ baseline (representing fossil fuels) receive additional certificates. The policy sets a 50% emission reduction threshold for eligible fuels – considerably stricter than CORSIA's 10% (DfT, 2023). The policy excludes feedstock from feed and food crops and proposes a ceiling for HEFA in aviation to protect existing HEFA uses in the road sector from supply bottlenecks and price increases.

A sub-target for e-kerosene is under consideration to support this more advanced fuel. There are four proposed trajectories for PtL blending rates, of which the proposed medium and high ranges are similar to the PtL sub-targets in ReFuelEU Aviation.

The policy proposal features a mechanism to buy out from blending obligations to prevent price shocks in case of supply shortfalls. The proposed buyout price is GBP 2 per litre for bioenergy SAF and GBP 2.75 per litre for PtL SAF. These prices reflect pessimistic production cost expectations of the most expensive production pathway in the respective fuel family (bioenergy and PtL) minus the expected cost for fossil fuel (DfT, 2023).

Once adopted, the policy will be a stand-alone policy promoting SAF uptake with more targeted support than offered by the existing Renewable Transport Fuel Obligation (RTFO), which currently includes aviation fuel.

United States

The US government announced the SAF Grand Challenge in 2021. This policy aims to accelerate the scale-up of SAF by reducing its production costs, increasing production volumes and strengthening its environmental performance. The policy's objective is to shift the majority of aviation fuel demand to SAF by making it cost-competitive with conventional jet fuel.

The SAF Grand Challenge adopts deployment targets of 10% for 2030 (3 billion gallons) and 100% for 2050 (40 billion gallons). For a SAF to be eligible, it must reduce emissions by at least 50% compared to conventional jet fuel. An implementation plan, the SAF Grand Challenge Roadmap, was released in 2023 and outlined the necessary steps to reach deployment targets (DoE, DoT, USDA, 2022). The SAF Grand Challenge focuses on economic incentive programmes with blender and production tax credits to stimulate SAF supply. The 2022 Inflation Reduction Act (IRA) is a central mechanism to assist several sectors in decarbonising. It offers incentives of up to USD 1.75 per gallon SAF. The SAF Grand Challenge does not specify a sub-target for PtL SAF. However, tax incentives for renewable electricity and low-carbon hydrogen production in the IRA will also benefit PtL production, whereby incentives for hydrogen production reach up to USD 3 per kg (Wood Mackenzie, 2022; Webster, 2022).Integrating sustainable aviation fuel policies with transport decarbonisation strategies

Promoting domestic industrial development and strengthening energy resilience are important policy objectives of SAF programmes in addition to reducing aviation emissions. SAF production is more decentralised than fossil fuels because production facilities tend to be smaller and near production resources. This holds especially for facilities using advanced bioenergy feedstock and PtL. Investing in domestic fuel production can boost the local economy through employment opportunities, increase energy supply resilience and reduce dependence on fuel imports. The UK sustainable aviation fuel mandate policy proposal mentions both energy security and job creation as programme objectives (DfT, 2023).

SAF frameworks are often part of wider decarbonisation strategies encompassing multiple sectors. For example, the US 2022 Inflation Reduction Act offering incentives for SAF production covers many sectors of the economy, and the EU ReFuelEU Aviation programme will support the broader Fit for 55 packages of the European Green Deal. (European Council, 2023; Wood Mackenzie, 2022)

Biofuel programmes for road transport predate SAF programmes in many markets and offer important lessons to policy makers seeking to promote SAF. Biodiesel and SAF from HEFA use the same production technology, and plants that produce both fuels can optimise processes to maximise the output of either. Existing policy frameworks tend to offer more support to biodiesel, thus prompting plants to optimise production for road fuels (IRENA, 2021). Taking a cross-sectoral perspective when designing programmes can optimise resource allocation between sectors and prevent unintended impacts. An important consideration is that low-carbon drop-in fuels are the only decarbonisation option for most flights. This is different for many road transport segments, where electrification is a more energy-efficient option with higher emission savings than biofuels or synthetic fuels.

Governments can maximise emission reductions and energy savings across the economy by directing available drop-in fuels to hard-to-decarbonise sectors, including aviation, while promoting alternative, energy-efficient decarbonisation technologies in sectors where they are available. For example, electrifying road vehicles may reduce the sector's reliance on biofuels and unlock feedstock for SAF production in some contexts. Strategies should acknowledge that road transport's reliance on drop-in fuels continues despite increasing EV sales in many markets in legacy fleets or segments not ready for electrification. Strategies to divert drop-in-fuel feedstocks to aviation while the road sector still relies on them could cause unintended consequences. For example, aviation and road biofuels are directly competing for feedstock supply. The competition could increase abatement costs in the road sector, which poses important questions on equity because aviation users tend to be a small, rich group within society (IEA, 2020). The UK sustainable aviation fuel mandate policy proposal's HEFA cap offers insights into strategies to prevent unintended consequences. It aims to avoid diverting feedstocks from road transport, where they are still needed during the transition to zero-emission road vehicles (DfT, 2023).

Reaching the ICAO LTAG for net-zero emissions by 2050 requires a robust scale-up of SAF. Several governments have adopted support frameworks to that end. However, governments must increase the reach of existing frameworks. Frameworks that mandate or incentivise fuel production and deployment concentrate on only a few leading markets. Without additional policy ambition, the sector risks falling short of reaching international climate objectives.

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Sustainable Aviation Fuels
Policy Status Report

The aviation sector has pledged to become climate neutral by 2050. Sustainable Aviation Fuels (SAFs) are the only available low-carbon fuel technology for air travel today. They are thus indispensable for the sector to reach its climate targets. This report presents recommendations to promote the production and deployment of SAFs, which can replace conventional, fossil aviation fuel to reduce carbon dioxide emissions from aircraft. The insights come from discussions in the ITF's Decarbonising Aviation Common Interest Group, an expert forum on SAF policies bringing together government and industry representatives.

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