Smart Freight Centre

September 2025

SAF Insights – A Practical Guide for Freight and Aviation Stakeholders

Executive Summary

Sustainable Aviation Fuel (SAF) is a critical enabler for decarbonizing the aviation sector, especially in long-haul and cargo operations where alternative propulsion technologies remain out of reach for the foreseeable future. This publication provides a comprehensive, business-oriented overview of SAF – from its production and certification to its global policy landscape and practical integration into corporate greenhouse gas (GHG) accounting systems.

The guide begins by introducing the fundamentals of SAF and outlines the main production pathways, including HEFA, Fischer-Tropsch, Alcohol-to-Jet, and e-SAF. It explains how these fuels are certified and tracked through emerging SAF registries to ensure traceability and environmental integrity.

The following chapter examines how SAF deployment remains regionally fragmented, shaped by uneven policy support, feedstock access, and infrastructure maturity. Key obstacles to scaling up production are explored – such as high costs, limited feedstock availability, policy uncertainty, and underdeveloped supply chains – along with projections showing that SAF must grow from under 1% of aviation fuel today to over 60% by 2050. Meeting this challenge will require massive investment, coordinated regulation, and the commercialization of next-generation technologies beyond HEFA.
A special focus is placed on the evolving regulatory environment, with an overview of national and regional SAF mandates and incentives.

The document also introduces the Smart Freight Centre's MBM Framework, which offers companies a structured method for incorporating SAF into their emissions reporting, even without a physical link between fuel use and transport activity. Different chain of custody models such as Physical Separation, Mass Balance and Book & Claim are explained to help stakeholders make credible SAF claims in complex logistics systems.

Designed for cargo airlines, freight forwarders, and logistics stakeholders, this publication serves as a practical and strategic reference for understanding, deploying, and accounting for SAF in global supply chains.

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Smart Freight Centre (SFC) is an international non-profit organization focused on reducing the emission impacts of global freight transportation. Smart Freight Centre's vision is a zero-emission global logistics sector by 2050 or earlier, consistent with 1.5° pathways.

SFC's mission is to accelerate the reduction of logistics emissions by fostering collaboration within the global logistics ecosystem.

SFC's goal is to mobilize the global logistics ecosystem, particularly members and partners, to track and reduce its greenhouse gas emissions to achieve 1.5° pathways.

Clean Air Transport

Clean Air Transport aims to unite first movers on sustainable aviation in the freight sector, leveraging increased transparency of the GHG emissions to drive decarbonization measures across the air transport sector.

The CAT program works with strategic partners and members to further develop the GLEC Framework as well as to leverage increased access to primary data and their use to support decisions that reduce GHG emissions and to roll out practical book and claim guidelines that accelerate the use of SAF.

The goal is to support alignment in target setting within the air transport sector and exchange on measures and best practices taken to achieve such targets.

1 | Understanding Sustainable Aviation Fuel

Sustainable Aviation Fuel (SAF) is a liquid fuel that shares the same characteristics as conventional fossil jet fuel, allowing airlines to use it within existing aircraft technology and refueling infrastructure, often called "drop-in" fuel. Given the long service life of aircraft, often 20 to 30 years, using SAF as a drop-in fuel for the current fleet is critical, as it allows emissions reductions to begin immediately without waiting for long-term technological solutions that would require costly fleet replacements.

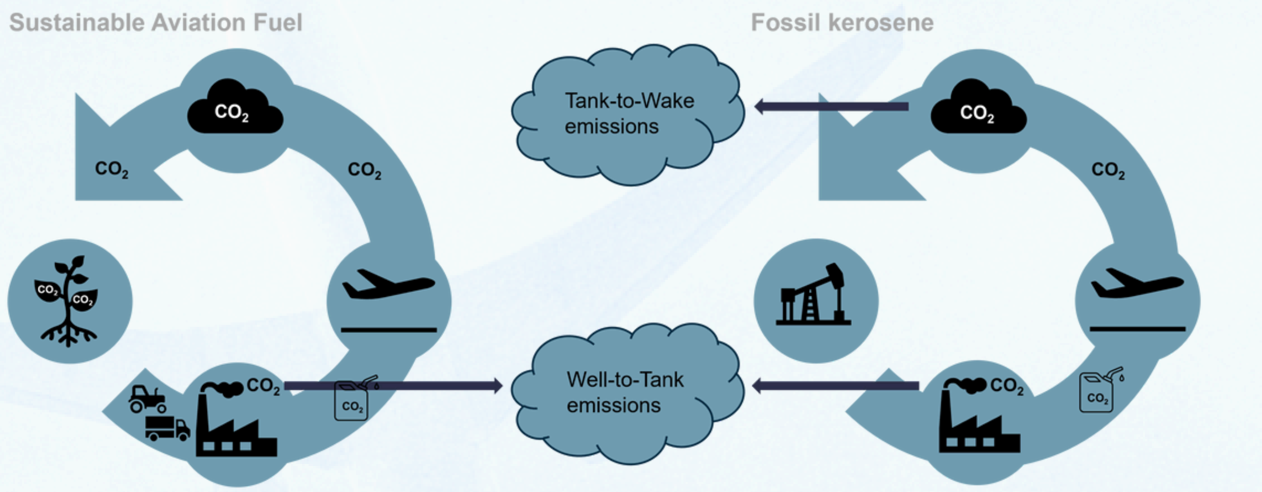
	2025	2030	2035	2040	2045	2050
Commuter & Regional	Electric or Hydrogen fuel cell & SAF	Electric or Hydrogen fuel cell & SAF	Electric or Hydrogen fuel cell & SAF	Electric or Hydrogen fuel cell & SAF	Electric or Hydrogen fuel cell & SAF	Electric or Hydrogen fuel cell & SAF
Short haul	SAF	SAF	SAF & potentially some Hydrogen	SAF & potentially some Hydrogen	SAF & potentially some Hydrogen	SAF & potentially some Hydrogen
Medium haul	SAF	SAF	SAF	SAF & potentially some Hydrogen	SAF & potentially some Hydrogen	SAF & potentially some Hydrogen
Long haul	SAF	SAF	SAF	SAF	SAF	SAF

Source: ATAG Waypoint 2050 (own illustration)

While electric and hydrogen propulsion technologies hold promise for the future of regional and short-haul aviation, their contribution to decarbonizing long-haul flights, which account for the majority of aviation GHG emissions, will remain limited for the foreseeable future. According to current projections, electric and hydrogen aircraft are not expected to be commercially viable for longer-range flight operations before the 2040s, and even then only in niche applications. In contrast, SAF is the only scalable solution available today that can directly reduce emissions from existing aircraft across all flight ranges, including international long-haul cargo routes. As such, SAF is expected to play the central role in decarbonizing global air freight, especially in the coming decades where other technologies cannot yet deliver the required range and energy density.

The overall carbon footprint of aviation fuels includes both indirect (Well-to-Tank, WTT) and direct (Tank-to-Wake, TTW) emissions. The direct emissions of conventional and sustainable fuels are similar due to their near-identical characteristics, including carbon content. However, the GHG emissions from SAF originate from biogenic carbon, which is balanced by the CO_2 absorbed from the atmosphere during the growth of the feedstock. Upstream emissions, on the other hand, vary between different SAF types and conventional fuels, influencing to what extent the fuel can achieve net emission savings on a Well-to-Wake (WTW) basis.

For SAF derived from biomass, the carbon released during combustion (TTW) is part of a biogenic cycle—it was recently absorbed from the atmosphere by the feedstock. This creates a closed loop, making the TTW carbon emissions effectively zero on a net basis. For fossil fuels, the carbon released is new to the atmosphere. The carbon intensity of SAF is determined by its upstream (WTT) emissions, which include feedstock cultivation, collection, transportation, and refining. These WTT emissions vary by SAF pathway and should be minimized to achieve the highest overall emission reduction on a Well-to-Wake (WTW) basis compared to fossil kerosene.



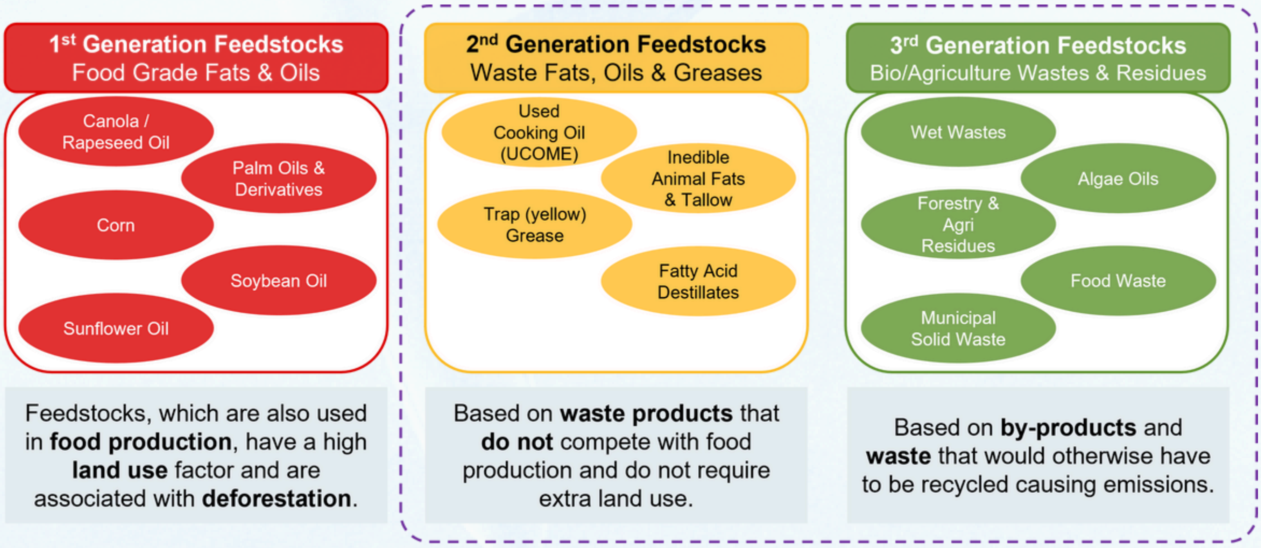
CO2 is sequestered from the atmosphere by plants. This means that CO2 is first removed from the atmosphere and then returned through combustion in the vehicle. The balance is therefore 0 and the tank-to-wheel emissions can be calculated accordingly.

There are three main groups of SAF with drop-in characteristics. The first group consists of biofuel derived from lipids, such as synthesized paraffinic kerosene from hydro processed esters and fatty acids (HEFA). The second group includes advanced biofuels produced through biochemical and thermochemical pathways. The third group comprises Power-to-Liquids (PtL) or e-kerosene, which use green electricity to produce hydrogen through electrolysis and combine it with carbon to synthesize hydrocarbons.

These SAF types differ in their emission footprints, technology readiness levels, production processes, equipment, costs, and feedstock availability. Currently, waste-based HEFA (based on used cooking oil) is the most commonly used SAF type, representing the most advanced and least expensive production pathway available today. However, the cost of HEFA SAF is approximately 2-4 times more expensive than conventional kerosene.

2 | SAF Production

Biofuels can be categorized into three generations based on their feedstock and sustainability. The first-generation biofuels are derived from feedstock commonly used in food production, such as corn and sunflower oil. These feedstocks often have a high land use factor, meaning the land could alternatively be used for food production or may contribute to deforestation. Consequently, the sustainability of first-generation feedstocks is subject to debate, as their use may compete with food production and can be associated with environmental concerns. The second-generation feedstocks, on the other hand, are derived from waste products like used cooking oils or animal fats. Third-generation feedstocks are also based on waste products; however, their main advantage is that they make additional feedstocks available for SAF. Examples include algae oils, food waste, and municipal solid waste, all of which can be converted into SAF.



Source: IATA SAF Handbook (2024)

Second and third-generation feedstocks are collectively known as advanced biofuels. They support land restoration and regeneration, enhance biodiversity, and develop sustainable supply chains at a regional level. These biofuels contribute to local income and employment and improve energy independence and security. The European Union's Renewable Energy Directive (REDII) recognizes only second and third generation feedstocks as truly sustainable biofuels, excluding those that compete with food production from the category of sustainable aviation fuel. Aviation biofuels produced from certain feedstock types listed in Article 4(5) RFEUA are explicitly "excluded" from the calculation of the minimum SAF shares (i.e. food and feed crops, intermediate crops, palm fatty acid distillate, palm and soy-derived materials and soap stock and its derivatives), unless listed in EU RED Annex IX.

2.1 SAF Production Pathways

SAF can be produced through several distinct technological pathways, each with its own characteristics and challenges. These production methods differ significantly in terms of the type of feedstocks they use, the technologies applied, their current level of commercial readiness, as well as their benefits and limitations. To ensure safety and performance in aviation, all approved SAF types must comply with ASTM D7566, the global standard for alternative jet fuels. The following section outlines the most relevant production methods, highlighting how they work, what they require, and where they stand in terms of market readiness. We distinguish between biogenic sustainable aviation fuel, where the raw material is based on biomass containing CO_2 that is returned to the atmosphere, and synthetic e-fuel, which is produced from energy and hydrogen.

	Feedstocks	Technology	Status	Benefits	Limitation
HEFA *Hydroprocessed Esters and Fatty Acids*	• Used cooking oil • Animal fats • Vegetable oils	Hydrogeneration	Most commonly used for commercial SAF production	• Low carbon intensity • Mature technology	Short feedstock availability
FT-SPK *Fischer-Tropsch Synthetic Paraffinic Kerosene*	• Biomass residues • Municipal solid waste	Gasification and Fischer-Tropsch synthesis	Pilot phase	• Availability of feedstocks • No competition with food production	High technology costs
AtJ-SPK *Alcohol-to-Jet Synthetic Paraffinic Kerosene*	• Sugar cane • Corn • Ethanol	Fermentation conversion	Early phase	• Availability of feedstocks • Uses existing ethanol infrastructure	High technology costs & low technology readiness
e-SAF *Power-to-Liquid*	• Green electricity • Hydrogen (H_2) • Carbon (CO_2)	Electrolysis and Fischer-Tropsch synthesis	Pilot phase to fulfill mandates starting soon	• Low carbon intensity • No competition with food production • **Scalable for net-zero**	High technology costs & green energy demand

Source: ITF (2023), IATA (2024), own illustration

HEFA (Hydroprocessed Esters and Fatty Acids) is currently the most widely used and commercially available SAF production pathway. It uses lipid-based feedstocks such as used cooking oil, animal fats, or vegetable oils. These oils are first pretreated and then hydroprocessed, a refining process that removes oxygen and saturates hydrocarbons to produce a synthetic jet fuel.

HEFA SAF offers significant lifecycle emissions reductions (between 70%-95% for waste-based HEFA and up to 60% for primary feedstock HEFA*) compared to fossil kerosene, depending on feedstock type and supply chain efficiency. Its major advantage is technical maturity and compatibility; however the availability of sustainable lipid feedstocks is limited, which constrains the long-term scalability of this pathway.

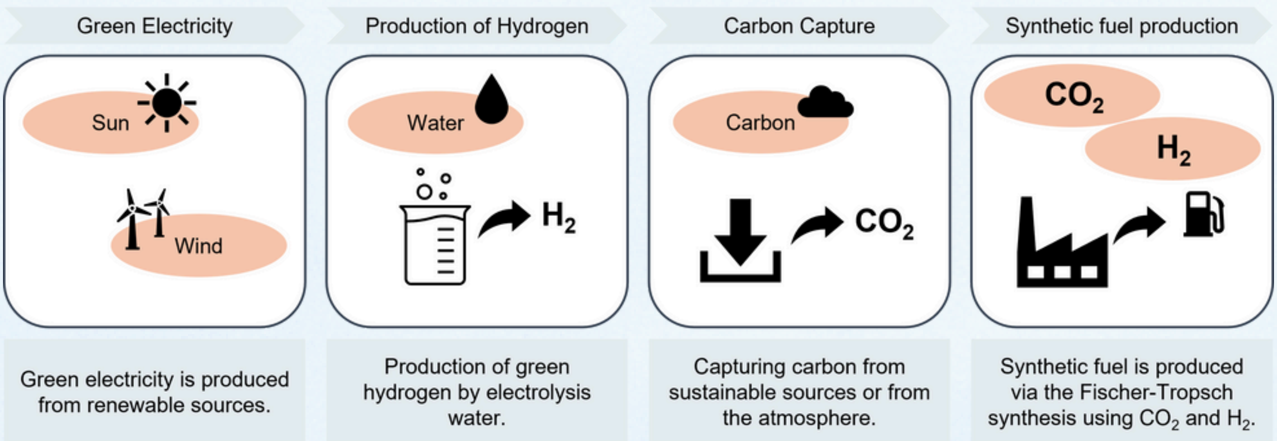
Fischer-Tropsch (FT) SAF is produced through a thermochemical process that converts solid or gaseous feedstocks, such as forestry residues, municipal solid waste, agricultural by-products, or renewable hydrogen and captured CO_2, into synthetic jet fuel. The process begins with gasification, where the biomass or waste is turned into syngas (a mixture of CO and H_2), followed by Fischer-Tropsch synthesis, which rearranges the gas molecules into liquid hydrocarbons suitable for aviation.

This pathway is particularly promising due to its flexibility in feedstocks and high fuel quality, but it is currently limited by high capital costs and technological complexity. Most FT-SAF projects are still in the demonstration phase, though several large-scale initiatives are under development. Up to 90% net emission savings* can be achieved using residues.

Alcohol-to-Jet (AtJ) SAF is produced by converting alcohols such as ethanol or isobutanol, which can be derived from sugar crops, agricultural residues, or industrial waste, into synthetic jet fuel. The process involves several steps: fermentation of biomass into alcohol, followed by dehydration, oligomerization, and hydroprocessing to produce hydrocarbons suitable for aviation.

AtJ is valued for its flexibility in feedstock sourcing and potential to leverage existing ethanol infrastructure. However, it is still in early commercial stages and faces challenges in terms of economic viability and process efficiency compared to more mature pathways like HEFA. AtJ-SAF can reach net emission savings between 25% and 70%,* compared to fossil kerosene.

Electric Sustainable Aviation Fuel (e-SAF), or Power-to-Liquid (PtL), is produced by combining green hydrogen and captured CO2 through a similar FT synthesis process. First, renewable electricity from sources like wind and solar power is used to split water into hydrogen via electrolysis. At the same time, carbon dioxide is captured either from the atmosphere or from sustainable industrial sources. In the final step, these two components, H_2 and CO_2, are converted into synthetic fuel, which can be used in today's aircraft engines with no technical modifications. The entire process enables a circular and low-carbon fuel pathway, with the potential for zero lifecycle emissions when powered by 100% renewable energy.



*Based on own calculations and CORSIA DEFAULT LIFE CYCLE EMISSIONS VALUES FOR CORSIA ELIGIBLE FUELS

The production of e-SAF remains significantly more expensive than fossil-based jet fuel, mainly due to the high energy demand and limited scale of current technologies. Producing e-SAF requires large amounts of renewable electricity to power electrolysis and synthetic fuel synthesis, both of which are still relatively inefficient and capital-intensive. In addition, the need for green hydrogen and captured CO_2 puts pressure on energy infrastructure and raw material supply, adding further to costs.

Another key factor is the lack of industrial scale. With only a few pilot plants operating globally, production volumes are too small to benefit from economies of scale. As a result, e-SAF can currently cost four to ten times more than conventional kerosene.

Reaching cost parity will require a combination of technological innovation, large-scale investment, and stable policy frameworks, including subsidies, carbon pricing, and clear long-term mandates. While electric and hydrogen-powered aircraft may emerge for short distances, e-SAF is the only viable option for long-range flights in the near and medium term. Most industry forecasts suggest that e-SAF could become economically competitive between 2040 and 2050, provided global infrastructure and renewable energy deployment accelerate significantly in the coming years.[2] In addition to the process for e-SAF, other production processes are currently being researched and tested, including Sun-to-Liquid (StL). This process uses high-temperature solar heat together with water and CO2 to produce SAF.

Excursion: What is Direct Air Capture?

Direct Air Capture (DAC) refers to various methods for capturing carbon dioxide (CO_2) directly from the atmosphere. To produce Power-to-X fuels, a carbon source is required, which, like biofuels, operates in a closed loop to ensure a neutral contribution to the atmosphere. DAC provides a regenerative approach to extracting CO_2 from the air and reintroducing it into the atmosphere through sustainable fuels. In addition to its use in fuels, this captured carbon can be stored to achieve a negative climate impact. Due to its global applicability and scalability, DAC has the potential to make a significant contribution to achieving climate goals in the long term.

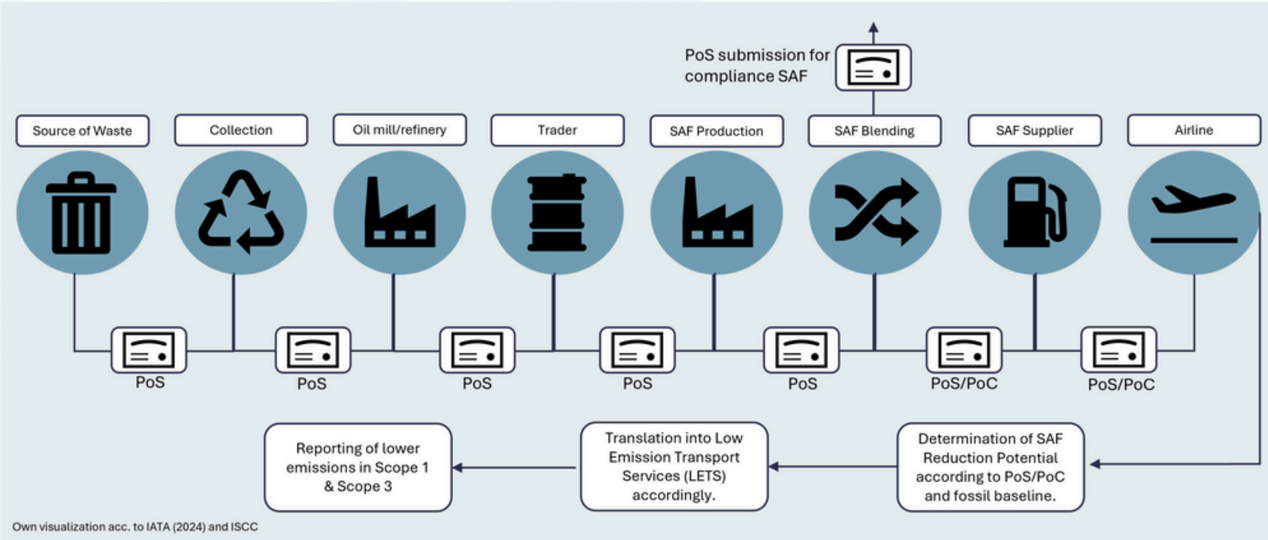
However, DAC is currently in its early stages of development, with only a small number of facilities in operation that produce only a fraction of the required amount of CO_2. The cost remains a major challenge, as processing large volumes of air to filter one tonne of CO_2 requires substantial amounts of renewable energy. To be commercially and economically viable for the production of PtL fuels in the long term, the cost of capturing one tonne of CO_2 must be reduced to $100, which would contribute approximately 25-30 cents per liter of fuel.

Ebner et al 2025, “Direct Air Capture”

[2] Royal Society of Chemistry (2024)

2.2 SAF Certification

Certification of SAF precisely determines and evaluates the environmental, social, and economic impacts of the production process for a specific unit of SAF. Given that SAF can be produced through different pathways and with various feedstocks, the impact varies significantly. Thus, the entire and often complex supply chain of a batch of SAF is tracked, and each participant is individually assessed and certified with their respective parameters. Each actor in the fuel supply chain provides a Proof of Sustainability (PoS) upon transfer, which documents the previous steps and the corresponding sustainability parameters. Ultimately, the airline that burns the fuel can claim the associated environmental attributes through the PoS and pass them along the Scope 3 chain. In the case of compliance SAF, which is used, for example, to fulfill the ReFuel EU Aviation Mandate, the PoS is used by the blender for fulfillment. A Proof of Compliance (PoC) is then created, which is passed further along the chain.



Regulations such as RED II or ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) set specific criteria for alternative fuel to be considered sustainable and used for regulatory compliance. Accordingly, the fuel must undergo a standardized certification process to ensure that the relevant sustainability criteria are met. The Roundtable on Sustainable Biomaterials (RSB) and the International Sustainability and Carbon Certification (ISCC) have developed corresponding certification schemes to meet these regulations and certify SAF for the voluntary market.

For more information see also: IATA, “Understanding SAF Sustainability Certification

2.3 SAF Registries

SAF registries are digital systems that track the production, transfer, and ownership of SAF and its associated emission attributes. They play a crucial role in ensuring transparency, avoiding double counting, and enabling credible climate claims especially when the physical use of SAF and the claiming entity are geographically or operationally separate – a chain of custody approach known as "Book and Claim".

When SAF is produced and certified under an approved sustainability scheme, a corresponding certificate can be issued in a registry. This certificate records key data such as volume, origin, sustainability compliance, and greenhouse gases associated—composing the "emissions profile" of the SAF. It can then be transferred through the value chain and eventually retired by the buyer to support emissions reporting, including through Book and Claim mechanisms (see section 5.4).

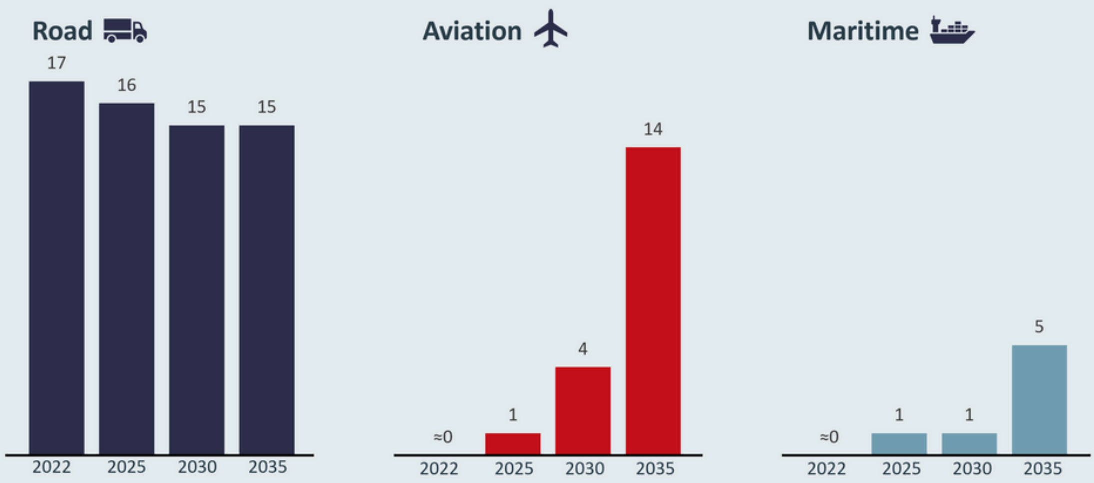
SAF registries are typically operated by independent bodies with expertise in sustainability certification and data verification. These operators ensure secure data handling and support flexible participation in SAF markets, enhance the credibility of carbon claims, and enable robust emissions accounting across Scope 1 and Scope 3. By providing trustworthy infrastructure, registries help scale SAF adoption and accelerate decarbonization in aviation.

3 | SAF Deployment

While global momentum behind SAF has accelerated in recent years, production volumes and deployment strategies remain highly uneven across regions and among airlines. These disparities reflect differences in policy maturity, market incentives, feedstock availability, and infrastructure readiness, leading to a fragmented global SAF landscape.

In high-income regions with targeted policy frameworks – such as the United States and the European Union – SAF production is scaling up rapidly, driven by financial incentives, mandates, and strong airline engagement. While projections for the European Union show that road transport's demand for sustainable liquid fuels will actually edge down slightly (from roughly 17 million tonnes of oil equivalent (Mtoe) in the EU in 2022 to 15 Mtoe by 2035), aviation's requirement will leap from virtually zero to around 14 Mtoe over the same period. Maritime demand also grows, albeit more modestly to about 5 Mtoe by 2035.[3] This stark shift underlines that aviation is set to become the fastest-growing segment of the sustainable-fuels market by far – nearly matching today's road-fuel volumes – and therefore must be prioritized when allocating finite refinery slots and lipid-based feedstocks.

Expected EU sustainable liquid fuel demand by sector, 2022-2035, million tonnes of oil equivalent



Note: Aviation includes EU-27 international and domestic air traffic, maritime includes EU international and domestic shipping, covering all reported monitoring, reporting and verifying (MRV) emission and fuel data, for example 100% of emissions and fuels on voyages between EU ports, 100% at-berth and 100% of voyages between an EU port and one outside the EU.

[3] Financing sustainable liquid fuel projects in Europe: Identifying barriers and overcoming them

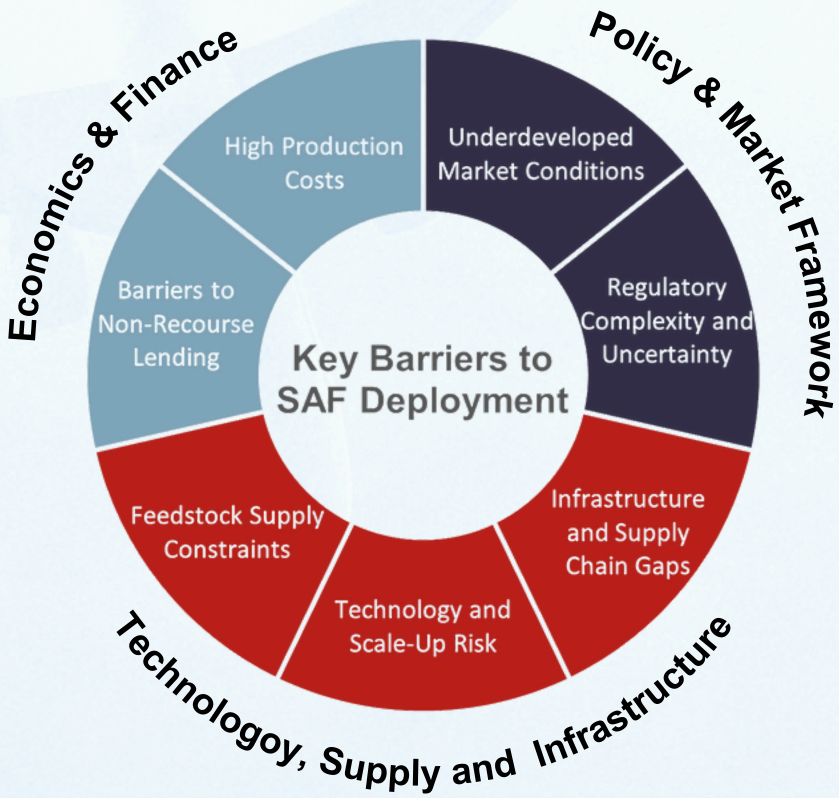
In contrast, many emerging and developing economies remain in an exploratory or pilot phase, lacking the regulatory clarity, technical infrastructure, and investment flows needed to establish viable SAF supply chains. This divergence poses a significant challenge to achieving the scale and geographic diversity of SAF production required for aviation's global decarbonization.

The role of airlines is equally differentiated. Carriers headquartered in regions with strong policy support have entered into multi-year offtake agreements and are engaging directly in SAF project development. For example, some airlines are not only sourcing SAF but also co-investing in new production facilities. Conversely, airlines in less-incentivized regions – particularly in parts of Asia, Africa, and Latin America – tend to limit their SAF involvement to isolated demonstration flights or depend on international partnerships and voluntary mechanisms such as book-and-claim.




3.1 Key Barriers to SAF Deployment

The European Investment Bank (EIB), in its 2024 report on financing sustainable liquid fuel projects in Europe, identifies seven major barriers that are impeding investment and scale-up across the sector[4]. While the study's geographic scope is Europe and its technological focus spans a range of sustainable liquid fuels (not only SAF, many of its findings are broadly applicable to SAF deployment worldwide – with regional variations in policy, infrastructure, and market maturity. The following is a condensed summary of the EIB's insights, interpreted in the context of SAF:



[4] Financing sustainable liquid fuel projects in Europe: Identifying barriers and overcoming them

Economics & Finance

Barrier	Description
High Production Costs	SAF production remains significantly more expensive than fossil jet fuel. Without sufficient carbon pricing or targeted support mechanisms, investors face an unattractive cost differential ("green premium"). This issue is exacerbated in regions without SAF mandates or price supports.
Barriers to Non-Recourse Lending	According to the EIB, most SAF projects fail to meet the criteria for non-recourse project finance due to high risk, lack of long-term offtake contracts, and limited creditworthiness of buyers and sponsors. This is especially challenging for independent developers – both in Europe and globally – who often lack the capital to bridge development stages without tailored financial instruments.

Policy & Market Framework

Barrier	Description
Underdeveloped Market Conditions	The SAF market remains in an early stage, lacking spot markets, consistent standards, and liquid trading platforms. Long-term offtake agreements are rare, and supply chains are fragmented. This market immaturity increases transaction costs and risk for investors and developers.
Regulatory Complexity and Uncertainty	Although the EU has introduced strong SAF policy signals (e.g. ReFuelEU Aviation), overlapping and evolving regulations (such as RED III, ETS, and tax directives) create uncertainty. The lack of harmonization across jurisdictions and limited visibility beyond 2030 undermine long-term investment planning—a trend also seen in other global regions.

Technology, Supply and Infrastructure

Barrier	Description
Feedstock Supply Constraints	Bio-based feedstocks are limited, unevenly distributed, and in high demand from other sectors. Advanced feedstocks (e.g. algae, agri-residues) remain underdeveloped, while e-fuel inputs like green hydrogen and renewable electricity face scalability and cost hurdles. These constraints are not unique to Europe.
Technology and Scale-Up Risk	Most SAF pathways beyond HEFA remain pre-commercial. Multistep production chains (e.g., PtL) introduce integration risks, and limited deployment history makes it difficult for investors to assess reliability and performance. Similar concerns are echoed in global markets with nascent SAF industries.
Infrastructure and Supply Chain Gaps	The geographic separation between optimal production sites (e.g., Iberia, Scandinavia) and SAF demand hubs (e.g., major airports) poses a major logistical challenge. Midstream infrastructure, including hydrogen pipelines, CO_2 transport, and blending facilities, remains underdeveloped – an issue mirrored in other continents.

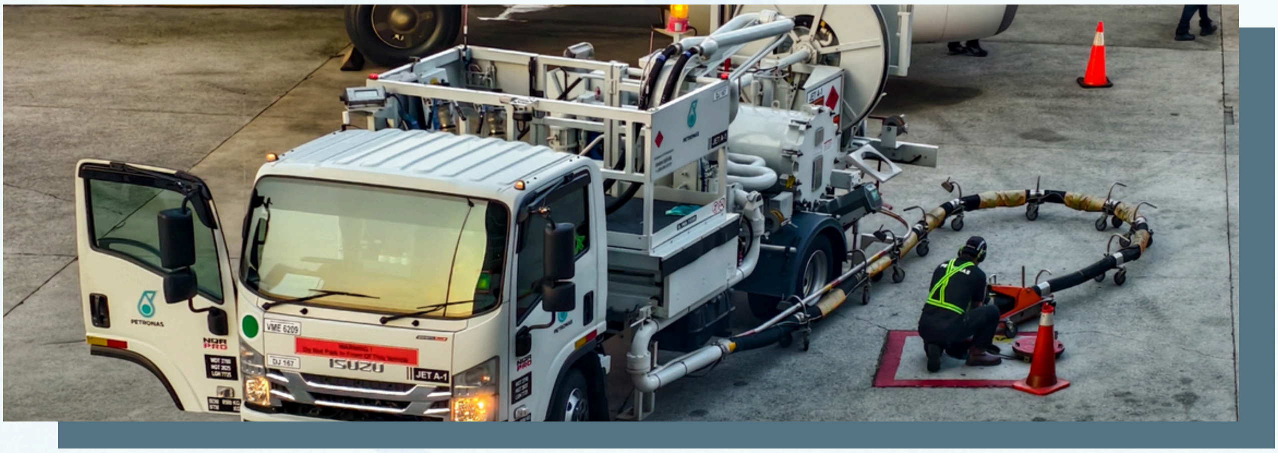
The EIB's findings highlight that SAF scale-up is constrained by a web of financial, regulatory, and technical barriers – most of which apply well beyond Europe and extend across the broader sustainable liquid fuels landscape. Addressing these barriers requires a globally coordinated approach, including stronger public-private risk-sharing, harmonized regulations, and targeted investment in feedstocks, infrastructure, and early-stage project support. In this context, Book and Claim mechanisms are promising means to help overcome infrastructure and market maturity barriers by enabling SAF purchases independent of physical supply chains, thereby bridging the gap between remote production sites and demand centers, while also creating early market signals and transactional volume needed to build confidence, reduce risk, and accelerate investment in SAF production and distribution.

3.2 Future Outlook

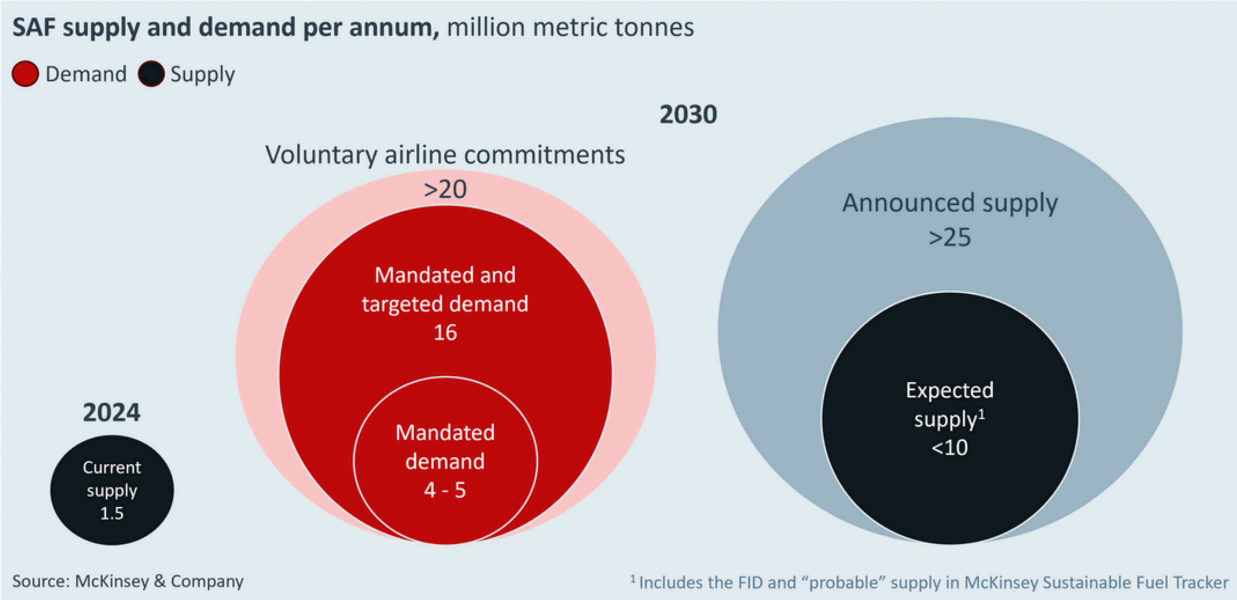
By 2050, sustainable aviation fuels (SAF) are expected to deliver the lion's share of aviation's carbon reductions when compared to its reference year. IATA projects that SAF will supply roughly 65% of the emissions cuts needed for net-zero CO_2 by mid-century. In their net-zero roadmap, SAF far outweighs other measures: only 13% comes from new electric/hydrogen tech, 3% from operations, and 19% from offsets.[5] Today, SAF is nearly negligible in the fuel mix (~0.5% of total jet fuel produced in 2024), so reaching 65% by 2050 means an immense production ramp-up. In practical terms, aviation will need on the order of hundreds of millions of tonnes of SAF per year by 2050. For example, the Air Transport Action Group's (ATAG) Waypoint 2050 analysis indicates aviation could require roughly 330-445 million tonnes of SAF annually by 2050, produced at 5,000-7,000 new refineries worldwide.[6] In short, production capacity must grow by orders of magnitude. This will only happen if all stakeholders along the supply chain and governments act together now to scale facilities and supply chains.

Scaling up Production

Building nearly a trillion liters of SAF per year will be a multi-stage process. In the near term (to 2030), dozens of projects are under development: McKinsey estimates **200+ SAF projects** worldwide, which could yield about **11-25 million tonnes** per year of capacity by 2030.[7] SkyNRG and ICF project that global SAF production capacity will reach 18.1 Mt by 2030.[8] However, demand will most probably be higher: mandated blending requirements and airline pledges already target about 4.5 million tonnes per year by 2030 (mandated) and up to 16–20 million tonnes if voluntary targets are met.[9]



5 IATA - Fly Net Zero
6 Aviation: Benefits Beyond Borders
7 Securing a sustainable fuel supply: Airline strategies | McKinsey
8 SAF Market Outlook 2025, available here: Sustainable Aviation Fuel Market Outlook 2025
9 Securing a sustainable fuel supply: Airline strategies | McKinsey



A World Economic Forum/Kearney study warns that even with announced projects, supply will fall short: about **4.4 Mt** will be in production by end-2024, plus **6.9 Mt** from committed expansions, yet an **additional ~5.8 Mt** capacity must come online by 2026 just to stay on track for 2030 demand.[10]

- **Current vs. future volumes**: SAF is under 1% of fuel today. To reach IATA's net-zero scenario (~65% by 2050), production must expand many-fold – roughly a 10–15x jump by 2030, then a further 10–20x by 2050. ATAG estimates aviation will need 500 to 700 Mt of SAF per year by 2050.

- **Investment and timing**: Meeting these targets requires massive investment and speed. The WEF/Kearney report finds that **$19–45 billion** of capital is needed by 2030 (depending on technology mix), and that policy certainty and financing innovation are crucial. Given the scale of capital required, the long lead times of new facilities, and the need for a reliable demand signal, it is hard to imagine such investment materializing without mandates that ensure sustained SAF uptake. The voluntary market can play a supportive role, but only the combination of binding requirements and voluntary action is likely to give investors the confidence needed for an industrial-scale ramp-up.

However, in the run up to 2030 the market is likely to outpace actual offtake mandates and voluntary offtake, creating a period of oversupply. This poses a threat, as this surplus could depress returns, prompting project delays, cancellations or capacity reductions. Ironically, these near term retrenchments would leave the industry even less prepared for the steep ramp up required after 2030, when blending mandates and airline commitments will drive demand well past available capacity.

[10] WEF_Financing_Sustainable_Aviation_Fuels_2025.pdf

The rapid scale-up needed to meet future SAF demand can only occur with coordinated global policy. IATA and industry groups emphasize that aviation fuel regulations should be **technology-neutral and harmonized** across markets. Key policy enablers include:

- **Blending mandates and incentives**. Robust SAF mandates (e.g. national blend targets) and incentives (e.g. tax credits and subsidies) signal long-term demand and help reduce risk for investors. As SAF supply is initially limited, mandates must be part of a broader strategy of subsidies and R&D support.

- **Stable, long-term frameworks**. Consistent regulations and carbon pricing give confidence to finance long-lived SAF facilities. The WEF study stresses "long-term policy consistency" and feedstock security as preconditions for attracting the needed $45B investment by 2030. Similarly, IATA notes that government action (aligned across countries) is instrumental to scale SAF and meet net-zero goals.

- **Public-private collaboration**. Governments, airlines, fuel supplier, and investors must collaborate to de-risk SAF projects. While some aircraft operators and fuel suppliers are taking early steps – such as signing offtake agreements and forming joint ventures – these remain limited to select front-runners. Given SAF's significantly higher cost relative to fossil jet fuel and the uncertain nature of many production technologies, most projects are still considered too risky for widespread private investment. Public support in the form of grants, concessional loans, loan guarantees, or framework conditions (such as corporate accountability under CSRD) is therefore essential to make early projects financially viable and to crowd in larger-scale private investment. At the same time, private actors must ultimately absorb the resulting green premium by committing to purchase SAF at higher cost, ensuring that demand materializes once public de-risking has reduced investment barriers.

In summary, policy alignment – nationally and internationally – will be as critical as physical technology. Without it, even strong SAF projects could stall. This need has been recognized by ICAO (the UN's aviation body), IATA, SFC, Clean Air Transport, coalitions like Clean Skies for Tomorrow, and private airlines, all of which are urging cohesive global measures (including supportive mandates and blending goals) to jump-start SAF markets.

Technological Innovation

Emerging fuel pathways will play a key role in reaching scale. Today, most SAF comes from waste fats and oils via the HEFA process, which until 2030 will remain the dominant pathway for SAF production, accounting for approximately 82% of expected global SAF production capacity.[11] However, the availability of sustainable oils and fats – which are also in demand from other sectors – is limited and therefore a constraint to HEFA's mid- to long-term scalability. According to SkyNRG and ICF, the tipping point (where demand will exceed availability of HEFA feedstocks) could be expected as early as in 2030.

Therefore, **next-generation routes** must be proven and scaled. However, emerging pathways beyond HEFA face some steep technological hurdles before they can pick up the slack once waste oils and fats run out around 2030.

Power to Liquid can theoretically yield net-zero fuel, but must overcome the high cost and energy intensity of green hydrogen and direct air capture, plus integrate these steps at scale with reliable CO_2 sourcing.

Several companies have demonstrated commercial **Alcohol to Jet** plants. However, the pathway needs further breakthroughs in low cost, high yield fermentation (especially from cellulosic feedstocks), plus more efficient dehydration and upgrading catalysts to drive down capital and operating expenses.

Gasification Fischer Tropsch projects demand robust, high-throughput gasifiers and long-life catalysts, and are best sited close to large biomass resources. While they offer greater flexibility in feedstock type and tolerance to contaminants compared to HEFA or alcohol-to-jet processes, they still face complex logistics due to the low energy density, seasonal availability, and dispersed nature of biomass, which complicate collection, transport, and storage at the scale required. Permitting challenges can further add to development complexity.

In each case, rapid research and development, process intensification, and supportive policy will be essential to drive down costs, unlock new feedstocks bring these pathways to commercial maturity to ensure a diversified, scalable supply beyond HEFA's limits.

[11] SAF Market Outlook 2025, available here: Sustainable Aviation Fuel Market Outlook 2025

4 | SAF Mandates and Policies

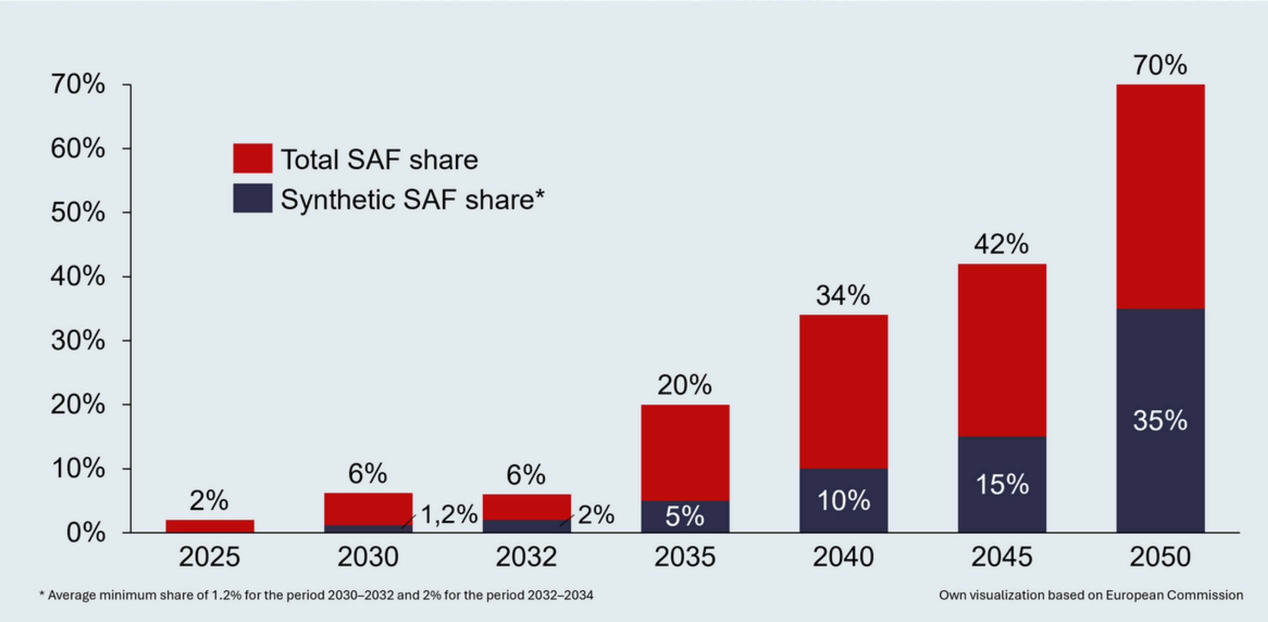
As the aviation industry needs to scale up its decarbonization efforts, governments around the world are introducing mandates and incentives to promote the use of SAF. These policies play a crucial role in shaping the future availability, cost structure, and strategic importance of SAF – especially for cargo operators seeking to reduce their carbon footprint.

The table below offers an overview of existing and planned SAF policies by country or region. It is important to note that the structure and ambition of these mandates vary significantly. Some countries have introduced legally binding blending quotas, while others rely on voluntary targets, financial incentives, or tax credits. In many cases, policy frameworks are still under development or undergoing public consultation.

This is a fast-moving policy space. We recognize that national strategies and regulations evolve rapidly, and this overview may be updated periodically to reflect key developments relevant to cargo and commercial aviation stakeholders.

4.1 Purpose and Mechanisms of Mandates and Policies

The European Union's ReFuelEU Aviation regulation, part of the "Fit for 55" package, mandates a progressive increase in the use of SAF at EU airports. Starting with a 2% SAF blend in 2025, the requirement escalates to 6% by 2030, 20% by 2035, and reaches 70% by 2050. Additionally, there's a sub-target for synthetic SAF, beginning at 1.2% in 2030 and increasing to 35% by 2050. Under the regulation, the SAF blending obligation is placed on fuel suppliers, not on airlines, ensuring a harmonized supply-side mandate across EU airports without imposing direct obligations on air carriers. The aim is to provide a clear demand signal, encouraging investment in SAF production and infrastructure across member states.



Complementing ReFuelEU Aviation, the EU Emissions Trading System (EU ETS) has been revised to further incentivize SAF uptake. This cap-and-trade mechanism sets an overall limit on GHG emissions from key sectors, including aviation within the European Economic Area. Airlines must hold allowances for their emissions, creating a financial incentive to reduce fuel use and invest in low-carbon solutions like SAF. From 2024 onwards, SAFs that meet strict sustainability and emissions criteria can benefit from zero-rated emissions under the EU ETS, effectively lowering an airline's compliance costs. In addition, the EU is allocating 20 million free allowances (Fuels Eligible for ETS support – FEETS) specifically to support the cost differential of SAF, creating a financial incentive for early adoption. Together, these measures strengthen the business case for SAF and ensure a coherent regulatory framework that aligns climate ambition with market signals.

The UK's SAF mandate requires fuel suppliers to blend 2% SAF into jet fuel by 2025, increasing to 10% by 2030 and 22% by 2040 taking a linear approach. A distinctive feature is the inclusion of a Power-to-Liquid (PtL) sub-target, starting at 0.5% in 2028 and rising to 3.5% by 2040. The mandate also incorporates a cap on the use of HEFA-based SAF to promote diversification of feedstocks.

Singapore is pursuing a hybrid policy model, combining a mandated SAF blending requirement with a SAF levy on tickets to close the cost gap with conventional jet fuel. Starting at 1% blending in 2026, the target rises to 3-5% by 2030, depending on market conditions. The SAF levy mechanism is unique: airlines will pay a fixed fee per passenger or freight unit, which is used to subsidize the higher price of SAF. This cost-sharing model aims to ease the financial burden on carriers while maintaining price transparency and encouraging sustainable practices. The dual structure shall ensure that Singapore remains competitive as a global aviation hub while actively advancing climate goals.

Rather than mandates, the U.S. employs financial incentives to promote SAF adoption. The Clean Fuel Production Credit, effective from 2025 to 2027, offers tax credits ranging from $1.25 to $1.75 per gallon of SAF, depending on lifecycle greenhouse gas reductions. Additionally, the SAF Grand Challenge aims to produce 3 billion gallons of SAF annually by 2030 through coordinated efforts in research, development, and infrastructure investment.

Japan has set a target for domestic airlines to replace 10% of their jet fuel consumption with SAF by 2030. The government is also exploring the development of advanced SAF production technologies, including alcohol-to-jet and synthetic fuel pathways, to diversify and strengthen its SAF supply chain.

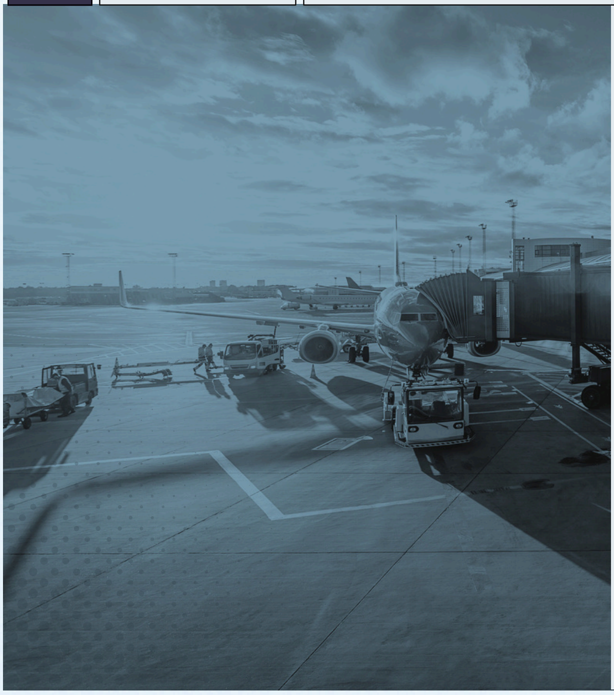
4.2 Global Overview of SAF Mandates and Policies

Sustainable Aviation Fuel (SAF) is a critical solution for reducing greenhouse gas emissions from the aviation sector. Governments worldwide are introducing mandates, subsidies, and incentives to accelerate its adoption. This map highlights existing and planned SAF policies by country and region, showcasing blending targets, fiscal incentives, and regulatory frameworks that are shaping the future of sustainable air travel.

Mandate | Subsidies | State-Level Subsidy | Mandate (planned) | Mandate + Levy (planned)

	Country (Region)	Description	Source
1. Mandate	European Union (EU)	ReFuelEU Aviation: SAF blending mandate starting at 2% (2025), 6% (2030), 20% (2035) rising to 70% (2050), sub-target for synthetic aviation fuel from 2030	EASA
2. Subsidies	European Union (EU)	20 million ETS allowances for SAF price bridging; tax incentives discussed	EU Commission
3. Mandate	United Kingdom (UK)	SAF mandate with a linear increase: 2% (2025), 3.6% (2026), 5.2% (2027), 6.8% (2028), 8.4% (2029), 10% (2030), 22% (2040), Power-to-Liquid sub-target from 2028, includes a cap on the amount of HEFA SAF used to meet obligations	UK Government
4. Mandate	Norway	Since 2020: 0.5% SAF blending requirement; applies to all aviation fuel suppliers – not airlines.	Norwegian Government
5. Subsidies	United States (Federal)	Clean Fuel Production Credit (2025–27): SAF tax credit: \$1.25–\$1.75/gal, depending on fuel emission factor (<51 gCO_2e/MJ – 1.75\$, 51-75 gCO_2e/MJ – 1.25-1.65\$, >75 g CO_2e/MJ – no credit)	U.S. Internal Revenue Service
6. Subsidies	United States (Federal)	SAF Grant Challenge: Target of 3 billion gallons SAF p.a. until 2030 through R&D, Financial Incentives, Infrastructure & Scaling, Regulatory Coordination	US Government
7. State-Level Subsidy	United States (Illinois)	\$1.50/gal tax credit for SAF (2023–2033) applicable to commercial aviation use and in addition to federal credit	The Illinois Department of Revenue

	Country (Region)	Description	Source
8. State-Level Subsidy	United States (Washington)	SAF price incentive starting at ≥50% lower lifecycle GHG emissions than fossil jet fuel, increasing by 1% increments up to $2/gal.	Port of Seattle
9. Mandate (planned)	India	1% (2027), 2% (2028) for international flights	Indian Government
10. Mandate (planned)	Japan	10% SAF by 2030 of domestic airline's jet fuel consumption	InfluenceMap
11. Mandate (planned)	South Korea	SAF mandate: 1% (2027) for international flights; increasing share planned; tax breaks for biofuel producers	Korean Ministry of Culture, Sports and Tourism
12. Mandate + Levy (planned)	Singapore	SAF mandate: 1% (2026), 3–5% by 2030 (depends on SAF availability, costs and market conditions); funded by a fixed SAF levy on tickets used to cover the cost difference with conventional fuel	Singapore Government
13. Mandate (planned)	Indonesia	SAF mandate with gradual increase: 1% (2027), 2.5% (2030[AS1]), 5% (2035), 12.5% (2040), increasing to 50% by 2060 for international aviation	Indonesian Government
14. Mandate (planned)	Brazil	SAF quota: 1% (2027) increasing by 1% per year to 10% by 2037; part of 'Fuels of the Future' legislation	Brazilian Government
15. Mandate (planned)	Malaysia	SAF blending goal: 1% (2027) rising to 47% by 2050	Malaysia, Ministry of Economy
16. Mandate (planned)	Turkey	SAF blending target: 5% by 2030 for international flights; public consultation ongoing	Directorate General of Civil Aviation
17. Mandate	Switzerland	Implements ReFuelEU Aviation	Swiss Government



The global momentum for Sustainable Aviation Fuel (SAF) is growing, but reaching ambitious decarbonization goals will require coordinated action across governments, industry, and supply chains.

The overview does not claim to be exhaustive, and we welcome information on new (planned) mandates and updates.

Ready to Take the Next Step?

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4.3 Airport-Level SAF Incentives

In addition to national mandates and government subsidies, several airports across Europe have introduced their own SAF incentive schemes to accelerate adoption. These programs are typically targeted at airlines operating at specific hubs and aim to bridge the price gap between SAF and fossil jet fuel through direct subsidies, rebates, or fee discounts.

For example, Heathrow Airport operates a rebate system funded by NOx-related aeronautical charges, rewarding airlines that uplift SAF. Airports such as Düsseldorf, Stuttgart, and Brussels offer fixed per-tonne subsidies, while Munich Airport provides free storage and throughput services for SAF deliveries. Some airports, including Eindhoven, and Swedavia-operated airports in Sweden, have introduced or piloted annual incentive funds dedicated to SAF cost compensation.

Additionally, several airports in France and the UK, including Lyon, Gatwick, and Edinburgh, apply a “bonus-malus” model, adjusting landing fees based on carbon efficiency, including the use of SAF. Although the financial impact is currently capped (e.g., at ±5% of total charges), it reflects a growing trend of embedding climate performance into airport pricing models.

Together, these airport-level schemes play a complementary role to national policies, offering location-specific incentives that support early SAF deployment and stimulate demand from airlines.

5 | SAF Accounting & Market Based Measures

After learning about SAF as a key lever for decarbonizing air transport, we now turn to the question of how SAF can be adopted via a variety of “chain of custody” approaches and focus on the accounting perspective within companies. The main focus will be on presenting the current standards for calculating aviation emissions and the basic principles of emission accounting behind SAF before introducing Smart Freight Centre’s Voluntary Market Based Measures Framework for Logistics Emissions Accounting and Reporting (MBM Framework). This Framework provides a clear and credible structure to help organizations integrate SAF into their emissions reporting via any chain of custody approach. It supports both direct (i.e., physical) SAF use and indirect SAF use via more flexible chain of custody models such as Mass Balance and Book and Claim. The MBM Framework defines how environmental benefits can be calculated, allocated, and transparently claimed by multiple organization types in the transportation value chain. This is especially relevant in aviation logistics, where SAF availability, traceability, and accounting integrity are major challenges.

5.1 Aviation Emissions Accounting according to the GLEC Framework and ISO 14083

Accurate and consistent accounting of aviation emissions is essential for tracking climate performance and preparing for the integration of SAF into corporate decarbonization strategies. Several internationally recognized standards and frameworks define the methodologies for calculating and reporting aviation emissions:

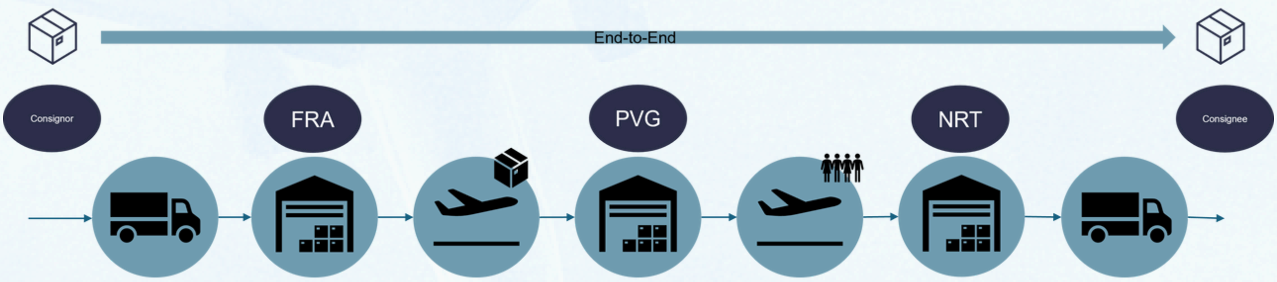
- ISO 14083: the global standard for quantifying and reporting greenhouse gas emissions from transport chains, including aviation. It applies to both Scope 1 and Scope 3 emissions.

- Global Logistics Emissions Council (GLEC) Framework: provides practical guidance for implementing ISO 14083, including default emission intensities and standard emission factors for transport fuels.

- International Air Transport Association (IATA) Standards: widely used by airlines, with Recommended Practice (RP) 1678 for cargo emissions and RP 1726 for passenger flights for reporting in Scope 1.

Under ISO 14083, emissions are calculated across the entire transport chain end-to-end, with each shipment being broken down into legs between handling points, so-called Transport Chain Elements (TCEs). For example, a shipment from Europe to Japan might include a truck transport to Frankfurt (FRA), a long-haul freighter flight to Shanghai (PVG), a passenger aircraft leg to Tokyo (NRT), and final delivery by truck. Between the transport legs there are transshipments at so-called “hubs” where cargo is handled and (re)bundled. Each TCE is assigned to a Transport Operation Category (TOC), or a Hub Operation Category (HOC), defined by similar operational characteristics such as aircraft type or (comparable) load factor, or airport vs. cargo handling terminal of a logistics hub, to apply for the emission calculation of this specific part of the transport chain. Especially the TOC types directly influence emissions.

For example, in our scenario, a 777 full freighter aircraft is used with a certain cargo capacity and average load factor. These factors are reflected in the TOC and included in the emissions calculation accordingly. Consistency in TOCs over 6–12 months is recommended to average out seasonal variations, weather impacts, and other external factors, enabling robust tracking over time.



The actual fuel consumption, which is directly linked to emissions using fuel emission factors, can either be modeled or provided by airlines through data sharing of primary data. The global emission factor for fossil JET A/A1 is based on ICAO’s default WTW value (e.g., 89 g CO_2e/MJ) which is also endorsed by IATA’s and Smart Freight Centre’s emission factors (3.18 kg CO_2e TTW/kg fuel, 3.84 kg CO_2e WTW/kg fuel).

To assess the environmental performance of a TOC, emissions are related to the transport activity, which is expressed in tonne-kilometers (transported weight multiplied by the distance). This value can then be used to calculate the shipments transported with this TOC. In addition, the value can be used as a fossil baseline for any SAF adoption.

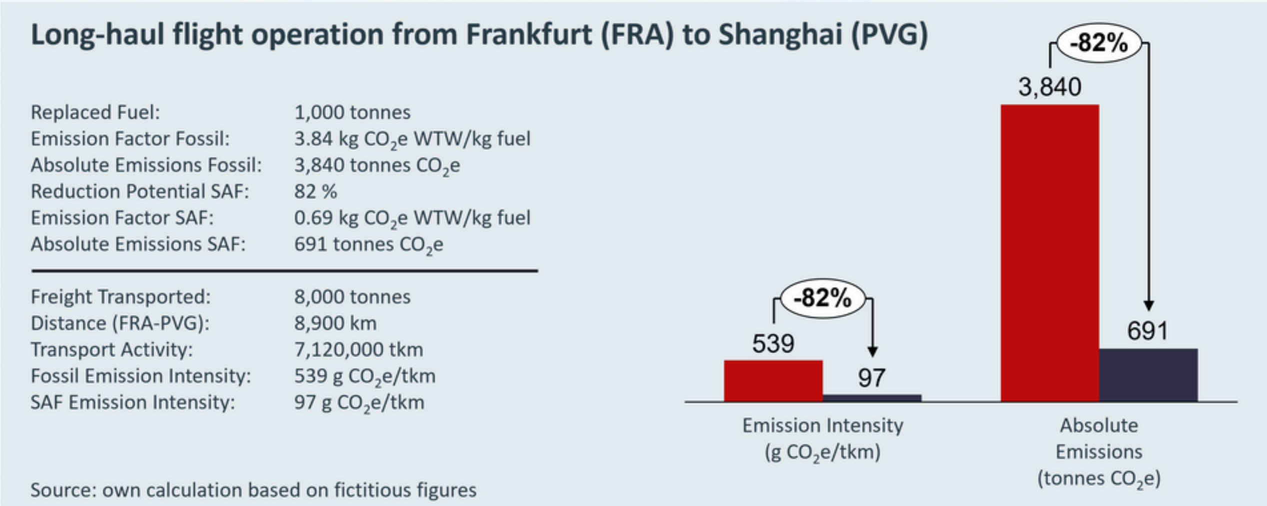
Energy Carrier	Lower heating value MJ/ kg	Density kg/l	GHG emission (operational/TTW) g CO2e/MJ	GHG emission (total/WTW) g CO2e/MJ	GHG emission (operational/TTW) kg CO2e/kg	GHG emission (total/WTW) kg CO2e/kg
Jet Kerosene (Jet A1 and Jet A)	43.1	0.802	73.9	89.0	3.18	3.84

Source: GLEC Framework V3.1

The environmental benefits of SAF are always assessed using a fuel life cycle approach (WTW) that includes all emissions along the value chain of the fuel, including the upstream process like production and transportation, as specified in ISO 14083 and the GLEC Framework. The lower emission profile is calculated by comparing the WTW emissions factor of SAF to that of conventional aviation fuel (CAF), based on the purchased or consumed mass or volume adjusted for fuel energy content. The difference, expressed as the impact of SAF, is then applied against a fossil baseline to quantify the total emission savings.

In order to allocate SAF to a specific transport of which emissions are to be lowered, it is attributed to a specific TOC leading to a lower emission intensity of this TOC, respectively, thereby applicable to all flights within such TOC. This allows all directly or indirectly involved parties to apply the lower emission profile in their balance sheets using SAF linked to actual transport activity.

Let's take the example of a flight between Frankfurt and Shanghai again. An airline replaces 1,000 tonnes of kerosene with SAF on this TOC, which has a reduction potential of 82%. This means that the fossil emission factor of 3.84 kg CO_2e/kg fuel can be reduced by 82% to calculate the emission impact of SAF. The next step is to calculate the impact on the transport activity flown. Due to the efficiency of this TOC, we are able to transport 8,000 tonnes of freight between Frankfurt and Shanghai (8,900 km) with a fuel capacity of 1,000 tonnes, resulting in a transport activity of 7,120,000 tkm. Using this value, one can then calculate the fossil and SAF emission intensity, which has been reduced from 539 to 97 g CO_2e/tkm on this route/TOC. This value can now be applied to the corresponding shipments that were transported as part of the total 8,000 tonnes on this route/TOC.



IATA’s CO2 Connect tool now provides primary airline data to Scope 3 reporters, improving accuracy for target setting and offering a reliable fossil baseline for SAF integration. Where available, primary data, which is based on actual measured energy use, should be prioritized over modeled data, as recommended by ISO 14083. High-quality, consistent data ensures that SAF adoption can be credibly reflected in emission inventories, forming a strong foundation for the next step: applying market-based measures to claim reductions.

5.2 What does “Market Based Measures” mean?

Market-based measures (MBMs) are voluntary mechanisms that enable companies to address growing GHG emissions by supporting low-emission transportation services (LETS) and products (e.g. fuels), even though they are not directly used to move their own freight. There is precedent for the market-based approach. The term “market-based” is also used in the electrical sector where such approaches are both approved by GHGP and under revision within current stakeholder feedback of their Corporate Standard. This approach is especially valuable in hard-to-abate sectors like aviation, where sustainable solutions such as SAF are often more expensive, not yet widely available, and where SAF is nearly universally compatible with existing fuel infrastructure and may be treated as a commodity. Here, the term market-based is to communicate that the emissions profile of the fuel or service is allocated disproportionately or disconnected from a purely physical allocation.

Therefore, SFC’s MBM Framework offers a structured approach to GHG accounting and reporting for voluntary low emission transportation actions. It provides language to describe these efforts and enables companies such as cargo airlines and freight forwarders to cooperate and financially support SAF use and credibly claim the associated emissions benefits in their own carbon inventories - e.g., the lower emission profile of the fuel and the lower-emission intensity of the transportation services.

5.3 How can SAF be adopted under the MBM Framework?

SAF can be integrated into the MBM Framework as a recognized low emission procurement option for reducing transport-related carbon footprints. The Framework allows companies to engage with SAF either through direct use or by purchasing its environmental attributes. This flexibility opens up opportunities for organizations to participate in climate action with more flexibility to where or how the SAF is actually deployed. To make this possible, the Framework introduces two important concepts: the low emission solution (Solution) and low emission transport service (LETS).

A Solution is a product, such as SAF, that has a lower GHG emissions profile compared to conventional options. It is not a transport activity, but a material (e.g., SAF) with verified attributes that can be used in transport logistics. By using this solution in a vehicle, a transport service can be provided.

A **Low Emission Transport Service (LETS)** is a freight transport activity (e.g. a cargo or passenger flight) that is carried out using a Solution. A LETS does not necessarily mean it has been booked or claimed. In fact, a purely physical supply chain without specific marketing can also be considered a LETS. It combines a transport operation with the use of a low-emission input and has a calculatable, lower GHG impact.

- Solution = the low emission input (e.g. SAF)
- LETS = the transport activity generated when using the Solution (e.g. flights conducted using SAF)

To ensure robust and transparent GHG accounting, the Framework details how the emission attributes of a Solution are converted into a LETS as the fuel is utilized to conduct transportation activity, mirroring the fundamental elements of transportation emissions accounting in traditional supply chains. Focusing on the service ensures that the benefit is tied to a specified unit of transport activity (e.g., tonne-kilometer), creating credible in-value-chain climate action and increasing fungibility with physical accounting and traditional inventories. This approach helps organizations account for the lower emission profile of a SAF, regardless of their role in the value chain, and avoid accounting for "reductions" like an offset. By preserving the link to actual transport activity, the climate benefit remains attached to the logistics system and helps avoid inconsistencies and double counting. This structure provides companies with a reliable basis for reporting on low emission measures in logistics, while maintaining environmental integrity.

5.4 Different chain of custody systems

A key focus of the MBM Framework is between direct (physically-linked) and indirect (non-physically-linked) Solutions and LETS. For example, in a direct LETS, the SAF is used in airline A's aircraft, but in an indirect LETS, the SAF is utilized by another airline B's aircraft but claimed for airlines A's services. This may be for many reasons, most basically that the SAF was not available at their actual airport of call. The carrier generates a "Direct LETS" and an "Indirect LETS" in these respective scenarios.

The same logic and terminology applies to a cargo owner who is procuring a LETS via a market-based chain of custody approach. When the fuel is used directly in the aircraft transporting a company's goods, they are procuring a direct LETS. Without the physical link, the company is supporting SAF use elsewhere, claiming an indirect LETS. When an air carrier generates an indirect LETS (i.e., from SAF procured through a registry), then the cargo owner has procured an indirect LETS with the associated carbon intensity. The offering party, a carrier or an LSP, shall specify if it is market-based when offering.

The MBM Framework enables such a flexible approach, providing the language for the involved organizations to make valid claims and accurately describe their approaches, provided they follow specific "integrity measures" and constraints on such claiming to ensure the SAF use is voluntary and emissions claims are of high integrity. Verification of B2B reporting and/or end-of-year inventory to the MBM Specification is highly recommended.

Four chain-of-custody models are outlined below, detailing how emission attributes from SAF can be transferred and claimed within logistics systems:

1. **Physical Separation**

- The Solution (e.g. SAF) is kept physically separate from conventional fuels throughout the supply chain
- The low emission profile is directly attributed to the organization using the product
- Highest traceability, limited scalability
- Consideration of legal blend ceiling limits, e.g., HEFA: max 50%
- Theoretically possible, but impractical due to shared airport fuel infrastructure

2. **Mass Balance fuel supply**

- Low-emission and conventional fuels are mixed (e.g., in an airport fuel farm), but the volume of the sustainable input is tracked and can be claimed by one organization
- Allows for some physical mixing while maintaining a verified balance of inputs and outputs
- Widely used in fuel systems but introduces verification complexity

3. **Mass Balance SAF uplift**

- SAF and SAF blends are tracked across physical uplifts in an airline's network and are allocated to specific transport services to create corresponding LETS.
- Allows Book and Claim (see below) within an airline's network but excludes separate SAF ownership between physical uplifting Airline and SAF purchasing and selling airline.

4. **Book and Claim**

- Physical product and emission attributes can be separated. A buyer can claim the GHG emission attributes without using the fuel physically.
- An internal ledger (or tracking within a registry) of book and claim units and required third-party verification is necessary to track ownership and prevent erroneous double counting in case the LETS has been allocated to specific users. (remaining supply chain actors uses residual mix)
- Requires a clear communication by parties involved, including airlines who actually uplift fuels but cannot claim the fuel for themselves and their passengers/clients
- Leverages the commodity quality of both SAF and the air cargo service to deliver the emission attributes (the lower emission profile) to the procuring cargo owner, even if not physically connected.

5.5 Adopting the MBM Framework in aviation in 5 Steps

There are multiple ways of procuring a LETS. Generally, it is clearer to procure LETS from existing relationships, from carriers and LSPs.

If you are a cargo owner and interested in securing your own solution profile, you must take care of calculating the LETS correctly. To ensure accurate and secure SAF integration into accounting systems, the following steps can help ensure accurate and secure integration if followed by Scope 1 (carriers) and Scope 3 reporting companies across the transport chain:

- **Step 1**: Identify a transport service based on the mode of transport, vehicle type, its fuel needs, and the corresponding transport activity performed.

- **Step 2**: Calculate emissions using the fossil emission factor for kerosene and the emission intensity, relating absolute emissions to the transport activity in tonne-kilometers (tkm).

- **Step 3**: Create a Low Emission Transport Service (LETS) by implementing a solution-here, SAF. It is crucial to understand the reduction potential of SAF compared to conventional kerosene and the corresponding emission factor of such.

- **Step 4**: Calculate the absolute emissions based on the fuel needs identified in Step 1 and the replacement of kerosene with SAF. Relate the emissions again to the performed transport activity to determine the new emission intensity of the LETS.

- **Step 5**: The new absolute and relative emissions are compared to the baseline to determine the delta. The lower emission profile from the LETS can then be included in the overall carbon accounting of the company reporting in Scope 3. The attribute of the transportation had the service been fossil kerosene is the “reference case” that is provided to non-participants of the decarbonized transport (the LETS).

Meticulous accounting, along with clear guidance and oversight, is required to protect the validity of customer claims and to ensure that both absolute and relative emissions reductions from fuel substitution are accurately reflected, especially when claimed by multiple Scope 3 stakeholders across the value chain.

5.6 Conclusion

The MBM Framework enables the use of SAF in emissions accounting, even when companies are not physically operating the aircraft that uses the fuel. It introduces the key concepts of the low emission solution (Solution) and low emission transportation service (LETS) to give language to the most common places in the value chain where a "market-based" approach is applied to help organizations procure as-close-as-possible to their standard procurement and to ensure that environmental benefits can be tied to the transport supply chain no matter the organization type. Four chain-of-custody models—physical separation, mass balance for fuel supply and for fuel uplifts, and book and claim—offer practical pathways for integrating SAF into procurement and decarbonization strategy. A five-step approach guides companies through emissions calculation, SAF application, and credible Scope 1 and Scope 3 reporting.

In addition to these core elements, the MBM Framework provides detailed guidance on voluntary claiming rules, emission integrity, registry systems, and how to avoid double counting, and the MBM Specification provides the auditable structure to verify market-based reporting. A "market-based" approach is a valuable tool for any logistics or aviation stakeholder seeking to take real, reportable climate action, today.

Initiatives like the Book and Claim Community are essential for accelerating the adoption of SAF. They establish a unified and trustworthy ecosystem for this market-based accounting approach. The community's main goal is to act as a central hub, bringing together diverse stakeholders to avoid duplicated efforts and fast-track the creation of credible book and claim systems across the industry.

Publications from the Community, such as the Principles and Best Practices for Book and Claim Systems in Heavy Transport have been vital to this effort. This document captures real-world lessons and sets agreed-upon principles for building effective book and claim systems. By clearly defining these best practices, the community provides a roadmap for implementation, identifies remaining gaps, and offers resources to guide stakeholders. This emphasis on clear principles and a shared narrative makes it easier for various organizations to credibly report their climate actions within a verified framework, such as the MBM Framework. This, in turn, boosts market confidence and speeds up the decarbonization of hard-to-abate sectors.

6 | Further Reading & Useful Links

The world of SAF is evolving rapidly, with new research, initiatives, and tools emerging every year. To help readers continue their learning journey, this section brings together a selection of useful resources, including training opportunities through the SFC Academy and links to trusted websites covering key aspects of SAF production, policy, deployment, and sustainability. These materials provide a starting point for deeper exploration and staying up to date with the latest developments in aviation decarbonization.

6.1 SFC Academy & Publications

The SFC Academy is Smart Freight Centre's global learning platform designed to support organizations at every stage of their decarbonization journey. It provides free educational resources across all modes of transport, alongside in-depth trainings for beginners through to advanced practitioners. For aviation, the Academy hosts live online webinars on key topics such as Book and Claim and aviation emission calculation in line with industry standards and frameworks – see for example the "Aviation Emission Calculation in Practice" course. Organizations can also benefit from customized trainings tailored to their specific needs, ensuring that knowledge directly supports their sustainability strategies. By joining the SFC Academy, stakeholders gain the tools and expertise to take meaningful action on freight decarbonization.

SFC Publications

You can explore the following publications as well as additional resources on freight decarbonization topics in the Smart Freight Centre Library, which houses frameworks, guides and other media developed by SFC:

Global Logistics Emission Council (GLEC) Framework v3.1

This globally recognized methodology for calculating and reporting logistics emissions guides and supports companies in implementing transparency on the efficiency of their supply chains and logistics. It offers an easy-to-use approach to an ISO 14083-compliant calculation of GHG emissions from transport, covering the transport itself as well as logistics hubs and the emissions from the energy supply to them both.

Market Based Measures Accounting Framework

Application of a market based accounting approach to the quantification and reporting of transportation greenhouse gas emissions. It is based on and supplements the fundamental transportation GHG accounting principles described in the GLEC Framework.

Market Based Measures Specification for Logistics Emissions Reporting

Provides organizations with an opportunity to transparently document, report and independently assure their in-value chain, market based activities.

6.2 Useful Links to External Resources

This chapter provides a curated selection of links to practical publications and reference materials on Sustainable Aviation Fuel (SAF). The resources are intended to help industry professionals navigate market developments, access reliable data, and apply recognized standards and frameworks in practice.

1. Market Development Trackers, Dashboards and Calculators

Boeing SAF Dashboard

Interactive tool aggregating announced global SAF production projects. Visualizes capacity by region, technology, and timeline, highlighting gaps between supply and demand. Useful for gauging the future supply landscape.

ICAO Global Framework (GFAAF) Portal

Includes a Live SAF Feed showing flights fueled with SAF and an Airport Map of SAF availability. Also hosts ICAO's SAF Guide and other official documents, making it a central global reference.

U.S. SAF Grand Challenge Dashboard (DOE)

Tracks U.S. SAF production (current and projected) against national targets. Includes fact sheets, metrics dashboards, and reports outlining the path to 3 billion gallons by 2030.

Mission Possible Partnership – Global Project Tracker

Maps the global pipeline of net-zero-aligned industrial plants, including SAF and aviation projects. Can be filtered by sector, geography, and project status. Useful to place SAF development in the wider context of industrial decarbonization.

AIR SAF Reduction Calculator

Online calculator for estimating CO_2 reductions from SAF blends. Also includes an Airport Map (business aviation focused) showing SAF availability by location.

SkyNRG SAF Market Outlook
Periodic reports on global SAF market developments. Includes demand forecasts, policy updates, and analysis of announced production projects. Provides a clear picture of where the SAF market is heading and the policy drivers shaping it.

Transport & Environment – SAF Observatory
Tracks SAF production and deployment worldwide, including which airlines and airports are using it. Ranks airlines and airline groups on their use of and commitment to SAF, and highlights developments in e-SAF. A useful accountability and benchmarking tool.

2. SAF Deployment, Certification and Registries

RSB Book & Claim Registry
A digital registry for SAF credits based on the Roundtable on Sustainable Biomaterials (RSB) standards. Tracks issuance and retirement of Book & Claim Units (BCUs), ensuring credible SAF sourcing claims.

SAFc Registry (RMI)
Public registry for Sustainable Aviation Fuel Certificates, launched at COP28. Standardizes SAF certificates for transparent trading, enabling companies to support SAF use even when physical supply isn't available.

IATA – Understanding SAF Sustainability Certification
Explains the requirements, criteria, and processes for SAF sustainability certification. Provides practical guidance to airlines and buyers on navigating certification schemes and ensuring credible claims.

3. Handbooks and Guides

IATA SAF Handbook (2024)
Guidance document explaining the main challenges airlines face when buying SAF. Covers contracting, pricing models, fuel quality standards, and sustainability claims. Tailored for practical application by airlines and procurement teams.

ICAO Sustainable Aviation Fuels Guide
Comprehensive reference on SAF pathways, feedstocks, technical specifications, costs, and policies. Still widely used for introductory and regulatory guidance.

Air Transport Action Group – Waypoint 2050
Industry strategy laying out pathways for the global aviation sector to reach net-zero emissions by 2050. Provides scenarios, milestones, and the role of SAF in decarbonization. A key reference for long-term planning.

7 | Glossary

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Biofuels

Renewable fuels derived from organic materials, such as plants, algae, or waste products. Biofuels are produced through various processes that convert biomass into usable forms of energy, including liquid fuels, gas, and electricity. They are considered a key part of the transition to sustainable energy systems because they can help reduce greenhouse gas emissions compared to fossil fuels, especially when produced from renewable feedstocks and when used as a substitute for conventional fuels in transportation and energy generation.

Biomass

See Feedstock

Blending Facility

An industrial site where Sustainable Aviation Fuel (SAF) is mixed with conventional Jet A or Jet A-1 fuel to create a certified drop-in blend that meets aviation standards. Blending is typically done near refineries or distribution hubs and is essential for SAF compliance under ASTM D7566, which specifies blending limits (typically up to 50%). Proper blending ensures fuel safety, traceability, and adherence to performance requirements.

Book & Claim

A chain-of-custody model in which the environmental attributes of SAF are decoupled from the physical fuel. This enables fuel users—like airlines or corporations—to purchase SAF certificates and claim associated benefits, even if the actual SAF is used at a different location. Book & claim helps drive investment in SAF production and creates market access for stakeholders unable to physically access SAF.

Carbon Capture (and Utilization) – CC(U)

A set of technologies and processes designed to **capture carbon dioxide (CO_2)** emissions from various sources, such as industrial processes, power plants, or directly from the atmosphere. The captured CO_2 can be stored underground (carbon sequestration) or utilized in various applications, such as the production of **e-Fuels** (e.g., synthetic fuels like **e-diesel**, **e-methanol**, **e-jet fuel**), chemicals, or construction materials (e.g., carbonated concrete). There are two main types of carbon capture:

1. **Point-Source Capture**: CO_2 is captured directly from the exhaust streams of power plants, industrial facilities, or other large emitters, where it is separated from other gases.
2. **Direct Air Capture (DAC)**: A technology that captures **CO_2 directly from the atmosphere**, using chemical processes that absorb or adsorb CO_2 from ambient air.

Both are crucial concepts in the fight against climate change, with Point-Source Capture addressing ongoing emissions and Direct Air Capture tackling CO_2 that has already been released into the atmosphere.

Captured CO_2 can be used as a feedstock for **e-Fuels**, where it is combined with **renewable hydrogen** to produce **synthetic hydrocarbons** like **e-diesel**, **e-jet fuel**, or **e-methanol**. Alternatively, captured CO_2 can be stored underground in geological formations to permanently reduce atmospheric CO_2 concentrations.

Carbon Credit

A marketable unit representing one metric ton of CO_2-equivalent avoided, reduced, or removed from the atmosphere. Airlines and other actors can purchase carbon credits to offset their residual emissions as part of voluntary or compliance carbon markets. While SAF use reduces emissions directly, carbon credits may be used to complement SAF when full decarbonization is not yet feasible.

Carbon Intensity (CI)

A measure of the amount of greenhouse gas emissions per unit of energy produced, typically expressed as grams of CO_2-equivalent per megajoule (gCO_2e/MJ). CI is a core metric in evaluating and comparing the environmental performance of SAF vs. conventional jet fuel. Fuels with a lower CI contribute less to climate change and may receive incentives or credits under systems like LCFS or ETS.

Carbon Sequestration

The process of **capturing and storing carbon dioxide (CO_2)** to prevent its release into the atmosphere, thereby reducing the impact of greenhouse gases on global warming and climate change. Carbon sequestration can occur in both **natural** and **artificial** systems and is a critical strategy for mitigating climate change. There are two primary types of carbon sequestration:

1. **Geological Sequestration**: CO_2 is captured from industrial processes or the atmosphere and injected deep underground into geological formations, such as depleted oil and gas reservoirs or deep saline aquifers, where it can be stored for centuries.
2. **Biological Sequestration**: CO_2 is absorbed and stored by natural processes in forests, soils, oceans, and other ecosystems. Plants, for example, absorb CO_2 during photosynthesis and store it as biomass.

Conversion Process

The industrial method used to transform raw feedstocks (like waste oils, biomass or CO_2) into Sustainable Aviation Fuel. It is a key step in SAF production pathways, determining fuel yield, quality, and emissions. Common processes include:

- **HEFA**: Hydrotreating esters and fatty acids
- **Fischer-Tropsch (FT)**: Converting syngas from gasified biomass
- **Alcohol-to-Jet (ATJ)**: Upgrading alcohols (e.g., ethanol)
- **Power-to-Liquid (PtL)**: Synthesizing fuel from CO_2 and green hydrogen

Each process varies in technology maturity, cost, and lifecycle emissions.

Drop-In Fuel

A type of fuel that is chemically and physically compatible with existing infrastructure, engines, and fuelling systems without requiring significant modifications. Drop-in fuels can be used interchangeably with conventional fuels, such as fossil-based jet fuel, diesel, or gasoline, in existing equipment and transportation systems. The ability of drop-in fuels to work with current engines, pipelines, and fuelling stations makes them an attractive solution for reducing carbon emissions without needing costly or time-consuming infrastructure upgrades. All certified Sustainable Aviation Fuels (SAFs) approved under ASTM D7566 are currently drop-in fuels. These SAFs are designed to blend seamlessly with conventional jet fuel (typically up to 50% by volume) and meet all necessary specifications for use in commercial and military aircraft.

Emissions Trading System (ETS)

A market-based climate policy tool that sets a cap on total emissions and allows regulated entities (such as airlines) to **buy or sell allowances** to meet their emission targets. SAF use can help reduce an airline's compliance burden under systems like the **EU ETS**, where only fossil fuel-derived emissions are counted. Increasing SAF uptake can therefore reduce the number of allowances an airline needs to purchase.

Feedstock

A raw material or input used in a production process to create **fuels**, **chemicals**, or **other products**. In the context of **e-Fuels** and **sustainable fuel production**, feedstocks typically refer to materials like **carbon dioxide (CO_2)**, **water (H_2O)**, **biomass**, and **renewable hydrogen**, which are converted into usable energy or fuel through various chemical processes. Common feedstocks include:

- **Carbon Dioxide (CO_2)**: Captured from the atmosphere or industrial processes, used in the production of **e-Fuels** via **Power-to-Liquid (PtL)** or **Power-to-Gas (PtG)** processes.
- **Water (H_2O)**: Split into hydrogen and oxygen via **electrolysis**, with hydrogen being used in the synthesis of **e-Fuels**.
- **Biomass**: ·Organic materials, such as agricultural residues or wood, which can be converted into **syngas** or liquid fuels through thermochemical processes such as **gasification**. Biomass gasification can also produce renewable hydrogen through partial oxidation followed by a water-gas shift reaction.
- **Hydrogen**: ·A critical feedstock for synthesizing e-Fuels from CO_2. It can be produced renewably via electrolysis using green electricity, or from biomass as noted above. Hydrogen derived from natural gas with carbon capture and storage (CCS), often called **blue hydrogen**, may serve as an interim solution during the transition to fully renewable pathways.

Feedstocks play a central role in the sustainability and carbon intensity of the final product. When renewable feedstocks are used, such as CO_2 from the atmosphere or hydrogen from renewable electricity, the process can contribute to carbon-neutral fuels.

Jet Fuel

Jet A and **Jet A-1** are types of **conventional fossil-based aviation turbine fuel** used to power commercial and military aircraft equipped with gas-turbine engines.

- **Jet A** is primarily used in the **United States**.
- **Jet A-1** is the **international standard** and is widely used outside the U.S.

The two fuels are nearly identical in composition, with the main difference being the freezing point:

- **Jet A**: Freezing point of −40°C.
- **Jet A-1**: Freezing point of −47°C, providing better performance in colder climates and at high altitudes.

Jet A and Jet A-1 serve as the **baseline fuels** for blending with **Sustainable Aviation Fuel (SAF)** under standards like **ASTM D7566**. Once blended, SAF must meet the same specifications as Jet A or Jet A-1 to ensure safety, compatibility, and performance in existing aircraft and fueling infrastructure.

Life-Cycle Assessment (LCA)

A methodological framework for assessing the **environmental impacts** associated with all stages of a fuel's life cycle—from **raw material extraction** or cultivation through production, distribution, use, and disposal. In the context of SAF, LCA is used to determine the **carbon intensity** and sustainability performance of a fuel and is required for eligibility under policies like **CORSIA** and **LCFS**.

Pathway
A defined production route for converting a specific type of feedstock into Sustainable Aviation Fuel (SAF), encompassing the full sequence from feedstock sourcing through fuel conversion and final blending. A SAF pathway includes:

- **Feedstock type**: e.g., waste oils, agricultural residues, municipal solid waste, CO_2.
- **Conversion process**: e.g., HEFA, Fischer-Tropsch, Alcohol-to-Jet.
- **Fuel upgrading and certification**: Ensuring compliance with ASTM D7566 specifications for aviation use.

Each pathway has a unique **lifecycle GHG emission profile**, influenced by feedstock origin, process efficiency, energy inputs, and co-products. Pathway-specific performance also determines eligibility for regulatory incentives (e.g., CORSIA, EU ETS, LCFS).

Power-to-Liquid (PtL)
A sustainable fuel production pathway that synthesizes liquid hydrocarbons, such as Sustainable Aviation Fuel (SAF), by using renewable electricity to convert carbon dioxide (CO_2) and hydrogen into liquid fuels. The process typically involves:

- **Electrolysis**: Using renewable electricity (e.g., solar, wind) to split water into hydrogen (H_2) and oxygen (O_2).
- **CO_2 Capture**: Capturing CO_2 from the air or industrial emissions.
- **Synthesis**: Combining hydrogen and CO_2 through chemical processes (e.g., Fischer-Tropsch synthesis) to produce hydrocarbons that can be refined into SAF.

PtL offers a route to producing **carbon-neutral** or even **carbon-negative fuels**, depending on the source of CO_2 and the use of renewable electricity. It is considered a **long-term, scalable solution** for reducing aviation emissions and enabling a transition to low-carbon air travel.

Sun-to-Liquid (StL)
Sun-to-Liquid (StL) technology uses high-temperature solar heat, along with water and CO_2 (for example, captured from the atmosphere) to produce SAF. An entirely solar-driven thermochemical process that differs from conventional Power-to-Liquid (PtL), which relies on renewable electricity, along with water and CO_2, to generate syngas that is then converted into fuel through standard industrial processes.

Sustainable Aviation Fuel (SAF)

The definition of SAF is set out in Article 3(7) of the ReFuelEU Aviation regulation. It includes drop-in aviation fuels that meet the sustainability criteria of the **Renewable Energy Directive (RED)**.

SAF are defined as:

(a) Synthetic aviation fuels made from renewable hydrogen and captured carbon (as defined in Article 2(36) of the RED and limited to liquid drop-in fuels);

(b) Advanced biofuels produced in particular from waste and residues (from the raw materials listed in Annex IX Part A within the meaning of Article 2(34) of the RED);

(c) biofuels produced in particular from oils and fats (e.g. from the feedstocks listed in Part B of Annex IX within the meaning of Article 2(33) of the Renewable Energy Directive). Renewable Energy Directive);

d) Recycled carbon aviation fuels within the meaning of Article 2(33) of the Renewable Energy Directive.

Tank-to-Wake (TTW) Emissions

The emissions produced **during the combustion** of aviation fuel in an aircraft engine. TTW does **not** account for upstream processes such as feedstock production, processing, or transportation. While fossil jet fuel has high TTW emissions, SAF can have lower or similar TTW values, depending on composition—but its environmental advantage is often in **lower upstream emissions**, captured in **WTW** or **LCA** analysis.

Well-to-Wake (WTW) Emissions

A **life-cycle assessment** approach that measures all greenhouse gas emissions from the initial extraction or cultivation of feedstocks ("well") to the final combustion of the fuel in an aircraft engine ("wake"). WTW includes **upstream** (e.g., farming, processing, transport) and **downstream** emissions and is the basis for calculating the total climate impact of aviation fuels, including SAF.

Smart Freight Centre

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Smart Freight Centre (SFC) is a globally active non-profit organization for climate action in the freight sector. Our goal is to mobilize the global logistics ecosystem, in particular our members and partners, in tracking and reducing its greenhouse gas emissions. We accelerate the reduction of logistics emissions to achieve a zero-emission global logistics sector by 2050 or earlier, consistent with 1.5° pathways.

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