SUSTAINABLE AVIATION FUELS (SAF)

WBA Factsheet

Summary

Sustainable Aviation Fuel (SAF) is a critical technology for decarbonising the aviation sector, which currently contributes about 2–3% of global CO_2 emissions. SAF is produced from a wide range of sustainable feedstocks, including used cooking oil, agricultural residues, municipal solid waste, woody biomass, and captured carbon, using approved conversion pathways such as HEFA, Fischer-Tropsch, Alcohol-to-Jet, and Power-to-Liquid. Compared to conventional jet fuel, SAF can reduce lifecycle greenhouse gas (GHG) emissions by 60–95%.

SAF is a drop-in fuel: it is chemically indistinguishable from conventional Jet A-1, requiring no modification to existing aircraft or airport fuelling infrastructure when blended up to approved limits. ICAO's Long-Term Aspirational Goals (LTAG) and major industry roadmaps project that SAF could provide 65–80% of the sector's CO_2 reductions by 2050. Global SAF production reached approximately 1 million tonnes in 2024, less than 0.5% of total aviation fuel demand of ~300 million tonnes per year.

Scaling SAF requires rapid expansion of feedstock supply chains, commercialisation of advanced conversion technologies, and enabling policy frameworks including blending mandates, tax incentives, and certification standards. The EU's ReFuelEU Aviation regulation, the US Inflation Reduction Act, and ICAO's CORSIA scheme are the principal policy drivers. Strong international collaboration, investment in first-of-a-kind projects, and harmonised global sustainability standards will be essential to close the gap between current production and the volumes needed for net-zero aviation by 2050.

Key Facts at a Glance

Indicator	Data
Global aviation CO_2 (2024)	~1 Gt/year (~2.5% of global CO_2; ~12% of transport CO_2)
Total jet fuel demand	More than 300 million tonnes/year
SAF production (2024)	~1 million tonnes (~0.53% of aviation fuel demand, EASA 2025)
GHG reduction vs fossil jet	60–95% lifecycle reduction depending on pathway & feedstock
ASTM-certified pathways (2025)	11 pathways; maximum blend typically 50% (Exception of 10% for HFS-SIP)

Dominant pathway today	HEFA, 81% of 2024 EU SAF supply from used cooking oil; 17% waste animal fats (EASA 2025)
Largest SAF producer	Neste (Finland, Netherlands, Singapore), ~1.5 Mt/year capacity
HEFA-SPK SAF spot price	Volatile in 2024–2025: ranged from ~$1,035/t to ~$2,350/t (Argus Media)
ICAO LTAG net-zero target	Net-zero international aviation CO_2 by 2050
EU ReFuelEU Aviation mandate	2% SAF (2025, now in force) → 6% (2030) → 20% (2035) → 70% (2050)
Asia-Pacific SAF demand 2030	0.4–5.9 Mt/year depending on policy implementation (Argus/ASAFA 2025)
ASAFA 2030 target	5% average SAF usage across Asia; 8 Mt SAF production capacity online
Required SAF by 2050 (NZE)	~300–400 Mt/year (IEA / Mission Possible Partnership)

1. Introduction

Sustainable Aviation Fuel (SAF) refers to non-fossil jet fuel that can be used in existing aircraft engines with little or no modification. SAF is crucial for decarbonising aviation, a sector that currently contributes about 2–3% of global CO_2 emissions and is one of the fastest-growing sources of greenhouse gases. Unlike conventional jet fuel derived from petroleum, SAF is produced from renewable or waste-derived feedstocks and can deliver significant lifecycle carbon emission reductions. ICAO's Long-Term Aspirational Goals (LTAG) and major industry roadmaps rely on SAF to provide approximately 65–80% of the sector's CO_2 reductions by 2050, making it an immediate and critical element of aviation's climate strategy.

Global aviation consumes roughly 300 million tonnes of jet fuel per year, producing nearly 1 billion tonnes of CO_2 annually, approximately 2.5% of global CO_2 emissions, and closer to 12% of transportation-related CO_2. Though aviation's share may appear modest, its climate impact is amplified by high-altitude non-CO_2 effects (contrails and NO_x) and by rapid traffic growth outpacing efficiency gains. If left unchecked, aviation's emissions could triple by 2050, consuming a large share of the remaining carbon budget for 1.5°C warming.

Unlike road transport, aviation cannot easily electrify for long-haul flights, making drop-in SAF the most viable near-term strategy. SAF can be blended with conventional jet fuel and used in existing aircraft and airport fuelling systems without operational penalties, enabling immediate lifecycle emissions reductions. In the long term, novel propulsion technologies (electric and hydrogen aircraft) may complement SAF, but these will not penetrate the market significantly until the mid-2030s and face range limitations. SAF is therefore likely to be indispensable for bridging the aviation decarbonisation gap in the critical next two to three decades.

2. Basics

What is Sustainable Aviation Fuel?

The International Civil Aviation Organization (ICAO) defines SAF as "renewable or waste-derived aviation fuel that meets defined sustainability criteria". In practice, SAF encompasses a variety of kerosene-type fuels derived from sustainable feedstocks, such as biomass, municipal waste, or captured carbon, which are refined to be chemically indistinguishable from conventional Jet A-1. Because SAF must meet the same stringent ASTM aviation fuel standards (ASTM D7566) for energy content, freezing point, and stability, it can be blended with fossil jet fuel and used by existing aircraft and airport fuelling systems seamlessly.

Current certified SAF is "drop-in", meaning up to a defined blend limit (typically 50%) can be used without any modification to aircraft. Boeing, Airbus, and engine manufacturers are testing 100% SAF operations, with successful demonstration flights completed in 2021–2022. By 2030, new aircraft are expected to be certified for 100% SAF use.

How SAF Differs from Conventional Jet Fuel

Chemically, neat SAF has lower aromatic content and virtually zero sulphur compared to petroleum jet fuel. These properties can reduce local air pollutants (particulate matter and SO_x) by approximately 90% and may also lessen contrail formation due to 50–70% fewer soot particles. On an energy-per-kilogram basis, SAF is like conventional jet fuel and delivers the same flight performance.

The key difference lies in the fuel's lifecycle carbon emissions: SAF's carbon is sourced from biomass waste or recycled CO_2, so when burned, the CO_2 released is offset by what was absorbed during feedstock growth or captured from other waste streams. In contrast, burning fossil jet fuel releases carbon that was locked underground for millennia. By replacing a portion of jet fuel demand, SAF achieves net greenhouse gas reductions without changing aircraft operations.

3. SAF Feedstocks and Production Pathways

As of 2025, seven pathways have been certified under ASTM D7566 for use in aircraft. Each pathway has an approved maximum blend limit and distinct feedstock requirements, technology readiness, and GHG reduction potential. Table 1 summarises the main certified SAF pathways.

HEFA, The Current Market Leader

HEFA converts lipid feedstocks such as used cooking oil, waste animal fats, and oil crops into synthetic kerosene via hydrotreating. HEFA is currently the most mature and widely deployed SAF technology, accounting for nearly all commercially available SAF today. Major producers include Neste (Finland/Netherlands/Singapore) and World Energy (USA). While scalable in the near term, HEFA faces feedstock constraints as global supplies of used cooking

Table 1: ASTM-Certified SAF Production Pathways and Key Characteristics (2025)

Pathway	Primary Feedstocks	Max Blend	Lifecycle GHG Reduction
HEFA (Hydroprocessed Esters & Fatty Acids)	Used cooking oil, waste animal fats, non-food oil crops	50%	74–84%
Fischer-Tropsch SPK (FT-SPK)	Woody biomass, municipal solid waste, agricultural residues	50%	66–94%
Alcohol-to-Jet (ATJ)	Sugarcane, corn, cellulosic ethanol, waste sugars	50%	50–80%
HFS-SIP (Fermented Sugars to Iso-Paraffins)	Sugars (farnesane production)	10%	Moderate (niche volumes)
CHJ (Catalytic Hydrothermolysis Jet)	Non-edible plant oils, algae oils	50%	Similar to HEFA
Power-to-Liquids (PtL / e-fuels)	Green hydrogen + CO_2 (direct air capture or biogenic)	50% (via FT)	~90% or near-neutral
Recycled Carbon Fuels	Industrial off-gases, MSW via fermentation / gasification	Varies	Significant (waste carbon diversion)

oil and waste fats are finite. Industry is exploring non-edible oil crops to increase the supply of feedstocks.

Fischer-Tropsch, Advanced Biomass Conversion

The FT-SPK pathway gasifies solid carbonaceous feedstock (biomass residues, municipal solid waste) into syngas, then catalytically converts it to liquid hydrocarbons. When using sustainable biomass or waste feedstocks, FT-SPK can cut GHG emissions by 66–94%. It remains less mature than HEFA, with several first-of-a-kind commercial projects currently being commissioned in the USA and Europe.

Alcohol-to-Jet, Leveraging Existing Ethanol Infrastructure

ATJ ferments sugar or starch feedstocks into alcohol (ethanol or isobutanol), then chemically converts the alcohol into jet-range hydrocarbons. ATJ fuel from crop and waste-based ethanol or other sustainable alcohols can yield 50–80% CO reduction. Two ATJ routes (from isobutanol and from ethanol) are ASTM-approved. The process is particularly attractive because it can leverage the large existing global ethanol industry to rapidly scale SAF production.

Power-to-Liquid, The Long-Term Frontier

Power-to-Liquid (PtL) SAF, also called electrofuels or e-kerosene, uses no biomass, it combines green hydrogen (from water electrolysis using renewable electricity) with CO_2 to synthesise hydrocarbon fuel via Fischer-Tropsch or methanol-to-jet processes. If renewable power and direct air capture (DAC) CO_2 are used, PtL SAF can achieve approximately 90% lifecycle CO_2 reduction or near-neutral emissions. The world's first commercial PtL SAF production unit began operations in Werlte, Germany, in 2022. Costs remain very high, making PtL primarily a post-2030 technology at commercial scale, with potential to become transformative if renewable power and DAC costs decline sharply.

Future Feedstocks

Methanol-to-Jet is viewed as the next promising pathway under ASTM approval. Ongoing R&D is expanding SAF feedstocks beyond today's waste oils and agricultural residues. Algae and microbial oils could provide lipid feedstock without competing for arable land. Lignocellulosic energy crops such as switchgrass and miscanthus could supply FT or ATJ pathways at scale if sustainably managed. In all cases, strict sustainability certification is needed to ensure feedstock production does not cause deforestation, food supply displacement, or other adverse impacts.

4. Environmental Benefits

4.1. GHG Emmisions Reduction

A key appeal of SAF is its lifecycle greenhouse gas (GHG) reduction compared to conventional jet fuel. SAF combustion emits CO_2 comparable to fossil jet on a per-kilogram basis, but the lifecycle emissions, including feedstock production, fuel processing, and supply chain, are substantially lower because the carbon is biogenic or recycled. Approximate lifecycle GHG savings by pathway can be seen in Table 1.

SAF also offers important co-benefits beyond CO_2 reduction. The 90% reduction in particulate matter and sulfur oxide emissions from SAF compared to fossil jet fuel creates direct public health benefits for communities near airports, where jet exhaust contributes meaningfully to local air quality degradation. Sourcing agricultural residues as SAF feedstocks can provide additional income to farming communities, while waste-to-fuel projects can reduce landfill methane emissions. These socioeconomic co-benefits are increasingly recognised in SAF policy frameworks and should be factored into holistic sustainability assessments alongside lifecycle carbon metrics.

Ensuring that claimed GHG savings are genuine requires robust lifecycle accounting. ICAO's CORSIA scheme establishes a minimum 10% lifecycle GHG reduction for eligible SAF. The EU's ReFuelEU Aviation regulation and the US Inflation Reduction Act both require a 50% minimum, steering the market toward higher-performance pathways. Certification schemes such as RSB and ISCC provide independent third-party verification of these claims.

Additionally, a growing body of research is refining the understanding of aviation's total climate impact, including the non-CO_2 effects of contrails, water vapour, and NO at altitude, which are estimated to roughly double aviation's effective climate warming compared to CO_2 alone. This creates both an obligation and an opportunity for SAF: its 50–70% reduction in soot particle emissions reduces ice nuclei for contrail formation, potentially providing climate benefits substantially greater than the lifecycle CO_2 reduction alone. The EU FORUM-AE project, NASA/DLR joint flight experiments, and ongoing ICAO CAEP research are refining the quantification of contrail climate impacts and developing new methodologies to credit SAF's non-CO_2 benefits in regulatory accounting frameworks.

Improved LCA methodologies are also addressing persistent uncertainties in land-use change (LUC) accounting, soil carbon dynamics, NO emissions from nitrogen fertiliser, and supply chain transport emissions. A 2025 peer-reviewed study in Energies confirms that PtL SAF can achieve lifecycle GHG reductions of up to 93% when using third-generation feedstocks and fully renewable electricity but also notes that real-world reductions have been limited due to technology rollout variability and feedstock inconsistencies. This underscores the importance of rigorous, regularly updated LCA standards that reflect actual production conditions rather than theoretical optima.

4.2. SAF's role in Decarbonisation Pathways

Every major aviation decarbonisation scenario positions SAF as the central lever for meeting the sector's climate obligations. Because practical alternatives for long-haul flight decarbonisation, hydrogen and battery-electric aircraft, will only contribute meaningfully after 2040 and face fundamental range and energy density constraints, SAF scales up as the primary near-term and medium-term solution to cut aviation CO_2. SAF's unique advantage is its drop-in compatibility: it works in today's aircraft, today's engines, and today's airport infrastructure, enabling immediate emissions reductions without waiting for the next generation of aircraft to enter the fleet. The following sub-sections examine the major international frameworks and scenarios that define SAF's expected role, the scale of deployment, and the implications for investment and policy action.

Industry Commitments and Airline Targets

The global Air Transport Action Group (ATAG) Waypoint 2050 report, the aviation industry's most comprehensive decarbonisation analysis, envisions SAF supplying 65–70% of aviation fuel by 2050 in a pathway consistent with limiting warming to 1.5°C. This single contribution from SAF exceeds all other measures combined, including new aircraft technology, air traffic management improvements, and market-based offsetting measures. IATA's net-zero 2050 roadmap similarly relies on SAF for approximately 65% of cumulative emissions abatement, with new propulsion technologies contributing around 13%, infrastructure/operational improvements around 3%, and carbon capture and offsetting making up the balance. Airlines have increasingly backed these commitments with concrete action. Between 2021 and 2023, virtually every major airline alliance, OneWorld, SkyTeam, and Star Alliance, announced collective SAF purchase commitments. Individual airlines, including United Airlines, Lufthansa, Delta, Singapore Airlines, and Japan Airlines, have signed multi-year offtake agreements totalling billions of litres. Boeing and Airbus have jointly committed to certifying all new commercial aircraft for 100% SAF use by 2030, removing the blend limit restriction that currently caps SAF at 50% of fuel uplift and unlocking the full emissions reduction potential of each litre of SAF produced.

ICAO Long-Term Aspirational Goal (LTAG)

In October 2022, at ICAO's 41st Assembly, Member States adopted a Long-Term Aspirational Goal (LTAG) of net-zero CO emissions from international aviation by 2050, a landmark commitment aligning the sector with the Paris Agreement. The LTAG analysis modelled four technology scenarios (A1 through B2) across a range of ambition levels. In the most ambitious scenario (A1), SAF could provide 96% of total international jet fuel by 2050, cutting aviation CO_2 by 81% versus a no-action baseline. Even in the more conservative intermediate scenarios, drop-in sustainable fuels remain the single largest contributor to emissions reduction, consistently accounting for more than 50% of cumulative abatement through 2050.

The LTAG report makes clear that non-biological SAF, particularly Power-to-Liquid e-fuels, will likely be essential to achieving such high substitution rates, given the physical limits on sustainable bio-feedstock availability globally. It also highlights that in high-SAF scenarios, fuel costs roughly double compared to a fossil-fuel baseline, underscoring that achieving these outcomes will require sustained and robust policy support to make SAF economically viable for airlines and passengers.

ASAFA 2030 Targets and the Asia-Pacific Investment Imperative

ASAFA has established five specific 2030 industry targets for Asia-Pacific:

- Achieve 5% average SAF usage across the region
- Promote 8 million tonnes of SAF production capacity online
- Advance all recognised SAF technology pathways
- Harmonise global, regional, and national frameworks for emissions tracking and SAF usage
- Support the establishment of a dedicated SAF expertise hub in Asia,

ASAFA and Argus Media joint analysis (APAC SAF Outlook 2025) projects Asia-Pacific SAF demand across a wide range depending on whether proposed mandates are enacted: a lower bound based on firm mandates only yields approximately 0.4 Mt by 2030, rising to 0.6 Mt by 2035; the upper bound, incorporating all proposed and discussed targets across Thailand, Japan, Singapore, Indonesia, South Korea, India, and Malaysia, yields approximately 5.9 Mt by 2030 and 7.2 Mt by 2035.

Regional Scenarios and National Targets

Regional decarbonisation roadmaps reinforce the central role of SAF. For example, the Europe's Destination 2050 roadmap, developed by Eurocontrol, ACI Europe, Airlines for Europe, ASD, and ERA, projects SAF providing 83% of total EU jet fuel by 2050 (approximately 32 million tonnes out of 38 Mt of demand), after a ramp-up from around 3 Mt in 2030.

Embedded in policy frameworks, national targets are emerging rapidly, as e.g. in the Asia-Pacific region, the world's fastest-growing aviation market. Table 2 shows a detailed list of current policy frameworks driving SAF adoption around the world.

The Required Scale-Up and Investment Gap

The gap between current SAF production and what is required under net-zero scenarios is the defining challenge of aviation decarbonisation. Global SAF production reached approximately 1 million tonnes in 2024, less than 0.5% of aviation fuel demand. The IEA Net Zero Emissions scenario requires SAF output to reach approximately 14 Mt by 2030 and 400 Mt by 2050: a 400-fold increase in under three decades. The Mission Possible Partnership estimates 300–370 Mt/year of SAF needed by 2050, requiring between 1,600 and 3,000 dedicated SAF production facilities worldwide, dwarfing today's global petroleum refining industry of approximately 700 refineries.

Only about 20–30 SAF projects had reached final investment decision globally by mid-2023. Even if all announced projects proceed without delays, SkyNRG analysis suggests global SAF capacity would reach only ~12.8 Mt by 2030, roughly one-third of what the IEA scenario requires. Bridging the remaining gap demands urgent action: streamlined project permitting, mobilisation of patient capital, expansion of sustainable feedstock supply chains, acceleration of ASTM certification for new pathways, and the development of international SAF trade frameworks. Without this coordinated effort, SAF supply in 2030 is likely to fall well short of what climate scenarios require, making the window for staying on a 1.5°C-compatible trajectory increasingly narrow.

5. Key Policy Frameworks Driving SAF Adoption

Policy is the primary driver of SAF market development. Blending mandates, tax incentives, carbon pricing, and demand-side requirements are being deployed across major aviation markets to stimulate production, reduce costs, and provide revenue certainty for producers. 2025 marked a pivotal year: ReFuelEU Aviation entered into force in January 2025, establishing the world's most ambitious SAF mandate regime. In response, Asian SAF exports to Europe increased almost five-fold in the first three quarters of 2025 as fuel suppliers scrambled to meet compliance needs. China's first SAF export quota was awarded in April 2025, facilitating the China-Europe trade route for the first time. The February 2025 European Commission assessment concluded the industry is on track to meet the 2025 2% target.

Table 2 outlines the key policy frameworks.

Table 2: Key SAF Policy Framewoks by Region (2025-2026)

Region	Policy Instrument	Key Details
ICAO (Global)	CORSIA	• Carbon Offsetting and Reduction Scheme for International Aviation. Mandatory phase begins 2027. • SAF eligible if meeting CORSIA Sustainability Criteria (minimum 10% lifecycle GHG reduction). • ASAFA survey: only 8% of APAC stakeholders fully ready for CORSIA 2027; 47% partially ready with major gaps. • CORSIA credit market tight: only 1 eligible project globally as of 2025 (J-REDD+ Guyana), with ~16Mt credits vs ~140Mt estimated Phase I demand. Buying interest $13–17/tonne CO_2.

European Union	ReFuelEU Aviation (in force Jan 2025)	• Mandatory SAF blending: 2% (2025, now in force), 6% (2030), 20% (2035), 34% (2040), 70% (2050). • E-fuel sub-targets: 0.7% (2030), 35% (2050). Flexibility mechanism allows averaged compliance across EU airports until 2035. EASA first annual report (Oct 2025): 81% of 2024 EU SAF was UCO-based; 25 fuel suppliers across 33 airports. • Non-compliance penalty: minimum twice the SAF price gap; shortfall must be made up the following year. Asian SAF exports to Europe up ~5× year-on-year in 2025.
United States	SAF Grand Challenge + Inflation Reduction Act	• Target: 3 billion gallons SAF/year by 2030; 35 billion gallons by 2050. • IRA blender's tax credit (45Z Clean Fuel Production Credit): $1.25–1.75/gallon based on lifecycle GHG reduction. • US DOE awarded $240M+ in SAF project grants in 2022–23. California LCFS provides additional ~$0.50–$1.50/litre for qualifying SAF. US producers seeking clarity on 45Z credit as it comes into force.
United Kingdom	Jet Zero Strategy + SAF Mandate	• SAF mandate from 2025 at 2%, rising to 9.5–10% by 2030 and 22% by 2040. • HEFA cap declining from 100% in 2025 to 42% by 2040 to drive advanced pathway investment. • £165M Advanced Fuels Fund. • UK Revenue Support Mechanism (CfD equivalent) under consultation. • Buy-out price: £5,875/t for main obligation, £6,250/t for PtL. • GHG savings requirement: minimum 40% vs fossil jet.
Japan	Green Innovation Fund + SAF Targets	• 10% SAF blending target by 2030 (all departing fuel suppliers). • Government capital subsidies for domestic SAF supply. • Green Innovation Fund supporting ATJ and eSAF R&D. ANA and JAL began using domestically-blended SAF on commercial flights for the first time in late 2024. • Several domestic SAF facilities announced including LanzaJet–Cosmo Oil ATJ project.
Singapore	SAF Levy (Law from Oct 2025)	• SAF Bill introduced September 2025, becoming binding law. • 1%Target SAF requirement from 2027, rising toward 5% by 2030 and 7–10% by 2035. • National SAF procurement agency formed late 2025 to coordinate government aviation fuel purchasing.
South Korea	Mandatory SAF Blending (from 2027)	• 1% SAF blending for all international departing flights from 2027, rising to 3% by 2030 and 7% by 2035. • International aviation fuel only. Policy enacted; among the firmest mandates in Asia-Pacific alongside Singapore.
Australia	Cleaner Fuels Programme	• A$1.1 billion (US$735 million) Cleaner Fuels programme announced September 2025, the first major Asia-Pacific government subsidy for SAF. • Ten-year fund supporting domestic biofuel and e-fuel production targeting operations from 2029. • Qantas and Airbus's SAFFA committed ~US$200M to global SAF projects. Jet Zero Council advising; A$250M LCLF grants also available. **No formal SAF blending mandate yet.**
Thailand	SAF Blending Roadmap	• Ministry of Industry and Trade issued directive promoting SAF. • Proposed: 1% from 2026, 3% by 2030, 5% by 2035. **Not yet binding law**; actively engaging aviation sector.

Indonesia	SAF Road-map (pro-posed)	• Government roadmap: 1% SAF from 2027, rising to 2.5% by 2030. Replaces previously enacted biogenic jet fuel policies. Under development; not yet fully law.
India	SAF Targets (under dis-cussion)	• Discussed: 1% from 2027, 5% by 2030, for international aviation fuel only. **No confirmed binding law**; policy support is growing.
China	SAF Pilot Programme	• 50,000 t SAF production target 2022–2025. 1% SAF at selected pilot airports. • First SAF export quota awarded April 2025, enabling China–Europe trade. • Targets beyond 2025 under discussion. Oriental Energy operating 1 Mt/year HEFA capacity.
Norway	SAF Man-date	• 0.5% SAF mandate from 2020, the world's first mandatory SAF blending requirement. Increasing ambition under national aviation climate strategy.

6. Current SAF Production and Projected Supply

Deployment of SAF is in its infancy globally, though 2025 marked a genuine inflection point. Total SAF production was approximately 0.1–0.2 million tonnes in 2022, growing to roughly 1 million tonnes by 2024, still far below 1% of jet fuel consumption. According to the EASA first annual ReFuelEU implementation report (October 2025), SAF accounted for 0.53% of global jet fuel in 2024 and was heavily concentrated: 25 fuel suppliers delivered SAF to 33 EU airports across 12 Member States, with five countries (France, Germany, the Netherlands, Spain, and Sweden) accounting for 99% of the EU supply. Almost all SAF used in 2024 was HEFA biofuel: 81% from used cooking oil and 17% from waste animal fats.

Additionaly, Asia-Pacific has emerged as a critical SAF production hub, increasingly serving both regional and European compliance markets. According to the ASAFA APAC SAF Outlook 2025, APAC SAF capacity is growing quickly and is projected to exceed 5 million tonnes by 2030. Table 3 summarizes the projected volumes for SAF production by 2030 and 2050, according to different climate scenarios.

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7. Techno-Economic Considerations

SAF's biggest challenge today is economic. Producing drop-in jet fuel from biomass or renewable power is significantly more expensive than refining fossil jet fuel, and this cost gap is the primary barrier preventing faster market uptake. Understanding the cost structure, capital requirements, and the trajectory toward competitiveness is essential for designing effective policy interventions and investment strategies.

7.1. Key Economic Barriers

Beyond headline production costs, several structural barriers impede SAF investment and commercialisation. Technology maturity remains a critical constraint: only HEFA is fully commercial at scale, while FT, ATJ, and PtL pathways carry significant first-plant risk that makes private project finance difficult without government backing. Feedstock supply chains for lignocellulosic and waste-derived feedstocks are largely undeveloped, creating logistics complexity and cost uncertainty. ASTM certification processes for new fuel pathways

Table 3: Global and APAC SAF Production/Demand Projections by Scenario

Scenario / Source	SAF Volume by 2030	SAF Volume by 2050
ICAO LTAG (net-zero by 2050)	~30 Mt/year	~30 Mt/year
IEA Net Zero Emissions Scenario	~14 Mt/year	~400 Mt/year
IATA Net-Zero Roadmap	~7 Mt/year (optimistic)	300-450 Mt/year
SkyNRG Announced Projects (if all proceed)	~12.8 Mt/year	-
Argus APAC Demand, Lower Bound (firm mandates)	~0.4 Mt/year (APAC only)	-
Argus APAC Demand, Base Case	~2.7 Mt/year (APAC only)	-
Argus APAC Demand, Upper Bound (all proposed targets)	~5.9 Mt/year (APAC only)	-
ASAFA APAC Supply Target	~8 Mt/year capacity (APAC only)	-
Current production (2024)	~1 Mt/year (global)	-

can take three to five years, delaying market entry for innovative producers. Finally, policy uncertainty, the risk that incentive structures will change before investors recover their capital, is frequently cited by SAF project developers as the single greatest barrier to reaching final investment decision.

The ASAFA APAC SAF Outlook 2025 Industry Survey, conducted across the SAF value chain, provides empirical validation of these barriers. The results of this survey, regarding key economic barriers, are shown in Figure 1.

The survey also reveals that 52% of APAC stakeholders believe only 2–5% SAF penetration is achievable across Asia by 2030 under current conditions, while 27% expect less than 2%.

7.2. Production Costs and Market Prices

Depending on the pathway and feedstock, SAF production costs are typically 2–6 times higher than conventional jet fuel per litre. HEFA from waste oils, the cheapest and most mature pathway, currently yields fuel at around $1.50–$2.00/litre, compared to fossil jet fuel that has

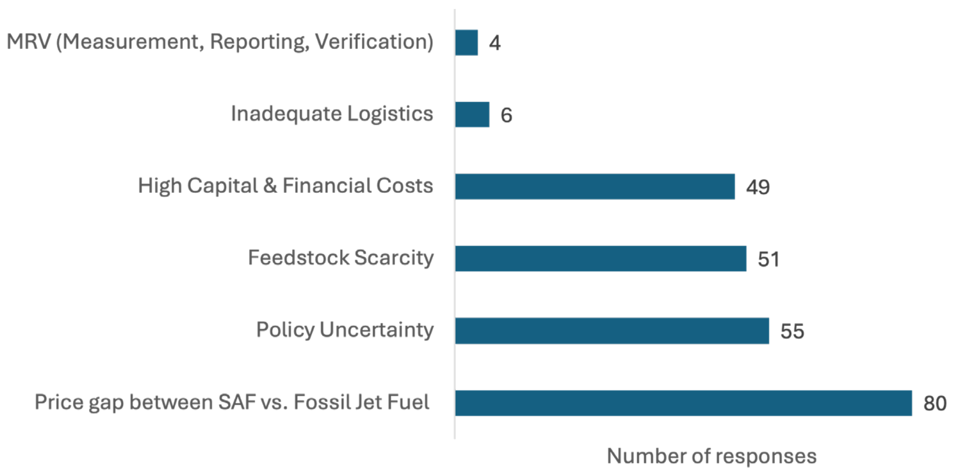


Figure 1. Key Economic Barriers for using SAF, mentioned by approximately 100 respondents in ASAFA APAC SAF Outlook 2025 Survey, multiple answers possible

averaged \$0.50–\$0.80/litre in recent years. More advanced pathways carry significantly higher costs: Fischer-Tropsch from biomass or MSW runs approximately \$2–\$4/litre for first-of-a-kind commercial plants, while Power-to-Liquid e-kerosene from current electrolysis and DAC technologies costs \$4–\$8/litre or more. The marginal abatement cost of SAF, the cost per tonne of CO_2 avoided, typically ranges from \$200 to \$400/tonne, far above prevailing carbon market prices. This cost premium ultimately flows through to airlines and passengers: a 5% SAF blend currently adds approximately \$3–\$8 to a short-haul return ticket, rising substantially at higher blend levels.

Historical experience from other renewable energy sectors, offshore wind, solar PV, lithium-ion batteries, demonstrates that consistent policy support and scaling can drive dramatic cost reductions that appear implausible in the early stages of deployment. SAF is expected to follow a similar learning curve. Bio-SAF production costs could fall 20–30% by 2030 and approximately 50% by 2040 through larger plant sizes, process optimisation, and improved feedstock logistics. PtL costs could decline even more steeply if renewable electricity reaches \$0.01–\$0.02/kWh globally and electrolyser costs continue to fall.

Carbon pricing provides an additional mechanism for narrowing the price gap. A CO_2 price of \$200/tonne, increasingly discussed as a necessary level for hard-to-abate sectors, would add approximately \$0.50/litre to the cost of fossil jet fuel, closing much of the current cost differential with HEFA SAF. The EU ETS, currently priced around 70–90/tonne for aviation, is already beginning to create this effect in European markets. Some analyses, including from the IEA, project that by 2050 the marginal cost of SAF could be within a few tens of cents per litre of fossil fuel if policy and technology levers are fully deployed, at which point mandates and incentives may no longer be necessary to sustain the market.

In terms of market pricing, global SAF was highly volatile in 2024–2025. HEFA-SPK SAF prices fell to record lows in 2024 as hydrotreated biofuels capacity expanded sharply, with several new HEFA plants coming online across Asia and Europe while European mandates had yet to take effect, keeping demand well below supply. In the first half of 2025, SAF remained oversupplied as the ReFuelEU flexibility mechanism allowed suppliers to average compliance over the calendar year, suppressing near-term physical demand. SAF prices ranged from approximately \$1,035/t to \$2,350/t (Argus HEFA-SPK assessment) across the 2024–2025 period. SAF was at times priced below HVO renewable diesel, an unusual market inversion. By Q4 2025, SAF prices recovered as European fuel suppliers accelerated purchases to meet the annual compliance deadline. ICE Argus HEFA-SPK SAF futures saw over 25,500

Table 4: Indicative SAF Production Costs and Abatement Costs by Pathway (2024-2025)

Pathway	Production Cost (\$/litre)	Abatement Cost (\$/tonne CO_2)	Maturity
HEFA (waste oils)	\$1.50–\$2.00	\$200–\$300	Commercial
Fischer-Tropsch (biomass/ MSW)	\$2.00–\$4.00	\$250–\$400	Eary commercial
Alcohol-to-Jet (ATJ)	\$1.80–\$3.50	\$200–\$350	Early commercial
Power-to-Liquid (e-kerosene)	\$4.00–\$8.00	\$500–\$900	Demonstration
Conventional Jet Fuel (Jet A-1)	\$0.50–\$0.80	-	Mature commodity

tonnes traded in Q2–Q3 2025, marking the emergence of a liquid hedging market.

7.3. Capital Expenditure and Investment Requirements

SAF production facilities are highly capital-intensive, and the need to prove new technologies at scale makes first-of-a-kind projects particularly expensive relative to eventual nth-of-a-kind costs. A single HEFA plant producing ~100 million litres per year may require $300–$600 million in capital investment. A cellulosic Fischer-Tropsch plant of similar output could cost $500 million to over $1 billion, reflecting the greater process complexity and technology risk. Power-to-Liquid plants integrating electrolysis, CO_2 capture, and FT synthesis at commercial scale are expected to cost $800 million to $2 billion+ for early installations.

Scaling SAF to meet net-zero aviation scenarios requires investment of a magnitude comparable to major energy infrastructure buildouts. Achieving approximately 40 Mt/year of SAF by 2030, the level required to be on track for net-zero, would demand an estimated $150–$200 billion of cumulative investment in new production capacity and supporting infrastructure. The Mission Possible Partnership estimates that 28–50% of all aviation decarbonisation investment through 2050 must flow into SAF production assets, potentially reaching into the trillions of dollars globally. Mobilising this capital requires long-term policy certainty, revenue guarantees, and de-risking instruments that private capital markets alone cannot provide.

7.4. Feedstock Costs and Supply Constraints

Feedstock represents a large and often volatile fraction of SAF operating costs. Used cooking oil (UCO) and waste animal fats, the primary feedstocks for today's HEFA plants, are increasingly scarce and price volatile as demand has grown rapidly across the renewable diesel, SAF, and oleochemical sectors. UCO now trades at hundreds of dollars per tonne, and concerns about fraudulent imports (particularly UCO from China) have led regulators in the EU and UK to impose certification and volume caps.

Lignocellulosic feedstocks (agricultural residues, forestry waste, dedicated energy crops) are generally cheaper on an energy basis but require undeveloped collection and preprocessing infrastructure, and their quality and moisture content can vary significantly, affecting conversion yields. For Power-to-Liquid, the dominant cost drivers are renewable electricity and CO_2: at current electricity prices of $0.04–$0.08/kWh and early-stage DAC costs of $300–$600/tonne CO_2, PtL SAF is extremely costly. However, with solar and wind electricity approaching $0.01–$0.02/kWh in favourable locations and DAC costs projected to fall to $100–$150/tonne by 2035, PtL economics

Notable SAF Projects and Initiatives

The SAF project landscape has evolved rapidly between 2023 and 2025, with several landmark milestones achieved and a new generation of projects reaching final investment decision across multiple geographies and technology pathways.

HEFA, Scaling the Incumbent Pathway

- Neste (Finland, Netherlands, Singapore)
- World Energy (USA)
- TotalEnergies & Eni, European Refinery Conversions
- DHL Group, Asia-Pacific Corporate SAF Leadership

APAC Airline Corporate SAF Programmes

- Cathay Pacific, Corporate SAF Programme
- All Nippon Airways (ANA), SAF Flight Initiative
- Japan Airlines (JAL), Corporate SAF Program
- Qantas, SAF Coalition

ATJ, First Commercial Plant Reaches Milestone

- LanzaJet Freedom Pines Fuels (USA, operational November 2025)
- LanzaJet Global Expansion

Fischer-Tropsch and Waste-to-Fuel

- Velocys Altalto (UK) and Bayou Fuels (USA)
- Gevo (USA, ATJ and FT)

Power-to-Liquid, From Demonstration to Early Commercial

- Atmosfair (Germany, operational 2022)
- Arcadia eFuels (Denmark, development
- Twelve (USA, CO Electrolysis)
- Synhelion (Switzerland, Solar Fuels)

could improve dramatically, potentially making it competitive with advanced bio-SAF pathways by the late 2030s.

Not all SAF developments in 2024–2025 have been positive. Several high-profile projects and companies encountered significant difficulties, underscoring the commercial risks facing the sector. For instance, Shell announced in 2025 a $600 million impairment and cancellation of its Rotterdam biofuels project, a significant signal that even major energy companies face economic viability challenges when scaling advanced biofuels without sufficient policy support or feedstock certainty. OMV (Austria) also announced a reduction in sustainable investments and a cut in annual capital expenditure targets in 2025, signalling a retreat from earlier renewable energy commitments. Fulcrum BioEnergy's MSW-to-FT plant in Nevada faced multi-year delays and financial difficulties, illustrating the challenges of first-of-a-kind Fischer-Tropsch deployment. These setbacks reinforce the case for robust, long-term policy instruments, including CfDs and production tax credits, to de-risk the private capital that SAF scale-up requires.

8. Infrastructure and Logistics Considerations

SAF supply chains are complex, often spanning multiple countries and involving several different operators, feedstock collectors, pre-processors, biorefineries, petroleum refiners for blending, logistics providers, and final airport fuel suppliers. However, one of SAF's most important advantages over other low-carbon aviation technologies is its compatibility with existing fuel infrastructure. SAF, once blended to specification, is fully fungible with conventional Jet A-1: it flows through the same pipelines, is stored in the same tanks, is dispensed through the same hydrant systems, and is pumped into aircraft through the same bowsers. No modification to airports, aircraft, or fuelling equipment is required at the point of use. This drop-in compatibility fundamentally de-risks infrastructure investment compared to alternatives such as liquid hydrogen, which would require an entirely new airport fuel ecosystem.

8.1. Blending and Fuel Certification

All current ASTM-certified SAF pathways require the neat SAF component to be blended with fossil Jet A-1 before aircraft delivery, up to a maximum blend limit (typically 50% for most pathways, 10% for HFS-SIP). Neat SAF, the pure, unblended fuel, is typically produced at a biorefinery and then transported to a petroleum refinery, fuel terminal, or tank farm where it is blended with conventional jet fuel to create a finished product meeting ASTM D1655 specifications. Only this blended product enters airport distribution systems and is uplifted into aircraft.

This blending requirement means SAF producers must establish relationships with petroleum refiners or fuel marketers who have access to blending infrastructure and the necessary quality testing equipment. In some cases, oil companies are co-processing biogenic feedstocks directly within their refinery hydrocrackers, a process that produces a renewable component already integrated into the conventional fuel stream, avoiding a separate blending step. Co-processing can handle up to approximately 5% bio-feedstock throughput at existing refineries, offering a lower-capital route to producing partially renewable jet fuel for the near term.

8.2. Transport and Distribution Logistics

SAF production is often geographically separated from the airports where it is consumed, creating logistical complexity. Neat SAF is transported by tanker truck, rail, or coastal/ocean shipping to blending sites or directly to major airport tank farms. The logistics cost of SAF transport is currently modest relative to the overall price premium, but it becomes more significant as SAF production scales up and supply chains lengthen to incorporate feedstock origins in rural or remote areas.

A specific logistical challenge for HEFA SAF, currently the dominant pathway, is that major producers such as Neste (Finland, Netherlands, Singapore) and World Energy (USA) are concentrated in a small number of locations, while aviation fuel demand is distributed across thousands of airports globally. Efficient multi-modal transport networks, including access to fuel pipeline systems that connect refineries to major airports, will be essential infrastructure investments as SAF volumes grow. For example, at San Francisco International Airport, SAF from World Energy is trucked to the airport tank farm, blended into the common fuel stock, and dispensed to all airlines without any separate handling, a model that works well at scale but requires logistical coordination among the producer, the terminal operator, and the airlines.

8.3. Airport Supply and the Book-and-Claim System

As of 2023, SAF has been physically uplifted at more than 50 airports worldwide, though often in small, infrequent batches rather than as a routine part of fuel supply. Airports that have moved toward regular SAF supply include Los Angeles International (LAX), San Francisco International (SFO), Oslo Gardermoen, Frankfurt, Amsterdam Schiphol, Singapore Changi, and Tokyo Narita. Oslo was the first airport in the world to implement a mandatory SAF blend, initially 0.5%, applicable to all airlines fuelling there.

Because physically delivering small SAF quantities to every airport is logistically impractical at current production volumes, a 'book-and-claim' accounting system has emerged as a bridging mechanism. Under book-and-claim, an airline or corporate buyer purchases a SAF certificate corresponding to a volume of SAF delivered into the fuel system at any airport in the network. The buyer claims the associated emissions reduction for their operations, even if the SAF was physically blended into fuel consumed by a different flight or at a different airport. Book-and-claim effectively decouples the physical supply chain from the environmental attribute, enabling corporate sustainability programmes and airline carbon reporting to begin benefiting from SAF investment before universal airport coverage is achieved.

ASAFA's APAC SAF Outlook 2025 industry survey found that 51% of Asia-Pacific stakeholders consider Book-and-Claim the most practical chain-of-custody model for scaling SAF in the region by 2030, compared to 37% favouring mass balance and only 5% supporting physical segregation. On registry infrastructure, 38% of survey respondents favoured regional or multilateral registries (such as an ICAO or ASEAN-coordinated platform) to issue and track SAF certificates, while 27% preferred national registries linked to government mandates. Only 3% trusted private industry-led registries alone, reflecting the need for sovereign or intergovernmental credibility in the SAF certificate market.

8.4. Infrastructure Investment and the Long-Term Vision

As SAF constitutes a growing share of aviation fuel, the supply chain infrastructure will need to evolve. Several strategic approaches are emerging. Locating SAF production close to major fuel pipeline networks or coastal ports reduces transport costs and improves supply reliability. Some airports are exploring 'airport bio hubs', dedicated biorefineries co-located with or adjacent to major airports, potentially incorporating waste-to-SAF or Power-to-Liquid production using locally available renewable power. Amsterdam Schiphol Airport has explored this concept for its 2030 planning horizon. Co-location eliminates inter-site transport costs and simplifies the supply chain, though it also requires substantial land, permitting, and capital investment.

The EU's ReFuelEU Aviation regulation includes a practical flexibility mechanism for the transition period: fuel suppliers are permitted to average their SAF delivery obligation across airports until 2035, rather than meeting the blending mandate at every airport individually. This means SAF is likely to be concentrated at major hub airports in the near term, with smaller airports receiving SAF coverage later as production volumes increase. Post-2035, a more geographically distributed supply will be required as the mandate tightens and SAF becomes a routine component of fuel supply at airports of all sizes.

Beyond blending and distribution, fuel quality monitoring, chain-of-custody documentation, and sustainability verification systems represent critical infrastructure investments that are currently underdeveloped relative to the scale of SAF deployment envisaged by the late 2020s. Digital platforms integrating production batch tracking, sustainability certification data, and book-and-claim registries will be essential to maintaining the environmental integrity of SAF markets as volumes grow.

9. Sustainability and Certification Considerations

Not all SAF is created equal. The climate benefit of any given litre of SAF depends critically on what feedstock was used, how it was grown or collected, what conversion process was applied, and how much fossil energy was consumed in production and transport. Robust sustainability criteria, independent certification schemes, and transparent lifecycle accounting are therefore foundational to SAF's credibility as a genuine climate solution.

9.1. Feedstock Sustainability and Land Use

The first and most fundamental sustainability requirement is that SAF feedstocks must not cause deforestation, peatland drainage, ecosystem destruction, or significant indirect land-use change (ILUC). ILUC (a predominantly EU centric policy framework) occurs when biomass demand in one location displaces agricultural production, which then expands into natural ecosystems elsewhere, effectively outsourcing the carbon debt to another region. The EU's Renewable Energy Directive (RED III) addresses this by prohibiting feedstocks with high ILUC risk from counting toward SAF mandates, and by limiting contributions from food and feed crops. Advanced feedstocks listed in RED III Annex IX, including crop residues, municipal solid waste, used cooking oil, algae, and woody biomass from sustainably managed forests, face much lower ILUC risks and are prioritised. It is critical to note that ILUC values are based on probabilistic models and are not measurable.

Feedstock eligibility rules vary by jurisdiction. Many countries outside the EU, including several in Asia and the Americas, permit the use of first-generation food-crop feedstocks (such as sugarcane ethanol for ATJ) for SAF production, provided lifecycle GHG thresholds are met. This reflects both different land-use contexts and different views on the social and economic trade-offs involved. The US SAF tax credits require a minimum 50% lifecycle GHG reduction versus fossil jet, effectively establishing a performance floor without restricting feedstock type. ICAO's CORSIA scheme similarly uses a performance-based approach, setting a 10% minimum GHG reduction threshold and relying on third-party certification to verify claims.

A particular concern for the near term is the sustainability of used cooking oil (UCO), which currently provides the dominant feedstock for HEFA production. Global supplies of genuine waste UCO are finite, estimated at approximately 6–10 Mt per year globally, and rapidly increasing demand from the renewable diesel and SAF sectors has driven price increases and, in some cases, fraudulent imports. Both the EU and UK have introduced annual caps on the contribution of UCO to renewable fuel mandates, and regulators are strengthening traceability and certification requirements to address fraud risks.

Asia-Pacific feedstock supply dynamics shifted significantly in 2024–2025, creating sharp price volatility across the region. On 8 January 2025, Indonesia paused exports of UCO and POME oil (palm oil mill effluent), immediately tightening regional waste oil supplies and pushing UCO and POME prices in Southeast Asia above palm oil for the first time. On 1 December 2024, China cancelled its VAT rebate for UCO exports, lowering feedstock costs for domestic Chinese producers, effectively keeping more UCO within China and redirecting it toward domestic HEFA production rather than export. These two policy changes combined to drive Asian feedstock prices to multi-year highs in September 2025 (Argus Media), with consequences for the economics of European HEFA plants dependent on Asian UCO imports.

Independent, third-party certification is the cornerstone of SAF sustainability assurance. The principal internationally recognised certification schemes include:

- RSB (Roundtable on Sustainable Biomaterials)
- ISCC (International Sustainability & Carbon Certification)
- CORSIA Sustainability Criteria

Regulators are increasingly working to harmonise these standards to reduce compliance costs for SAF producers operating across multiple markets. CORSIA and EU RED lifecycle values are being aligned; mutual recognition agreements between certification bodies are expanding; and IATA's Fuel Quality Requirements provide a common framework for airline fuel procurement specifications globally.

In terms of carbon accounting, several organizations, including the Rocky Mountain Institute, South Pole, and IATA, are currently exploring digital ledger technologies and blockchain-based certificate registries to improve real-time traceability and prevent emissions double-counting at scale under both the EU ETS and CORSIA.

10. Economic Instruments and Investment Incentives

Closing the cost gap between SAF and conventional fossil jet fuel is the central economic policy challenge for aviation decarbonisation. No single instrument is sufficient: a carefully designed portfolio of 'push' measures (reducing producer costs and de-risking investment) and 'pull' measures (increasing effective demand and buyer willingness to pay) is required. This section reviews the principal instruments currently deployed or under development across major SAF markets.

10.1. Production and Blender Tax Credits

Direct fiscal incentives tied to SAF production or blending are among the most effective near-term tools for narrowing the price gap. For example, the US Inflation Reduction Act (IRA) of 2022 introduced the Clean Fuel Production Credit under Section 45Z, which took effect on 1 January 2025 and initially provided a maximum credit of $1.75 per gallon for SAF (compared to $1.00 per gallon for other clean transportation fuels), with the actual credit value scaling with a fuel's lifecycle GHG emissions factor. The 45ZCF-GREET model, published by the US Department of Energy in January 2025, was designated as the primary lifecycle emissions methodology, with CORSIA Default and CORSIA Actual models also permitted for SAF.

This framework changed materially on 4 July 2025, when the One Big Beautiful Bill Act (OBBBA, Public Law 119-21) was signed

Table 5: SAF tax credits: US framework and 2025 modifications

IRA 2022 — Section 45Z Clean Fuel Production Credit (effective 1 Jan 2025)		
Max credit (SAF) $1.75/gal (prevailing wage) $0.35/gal (no wage compliance)	**Expiry / other fuels** Credit expires end-2027 Other clean fuels: $1.00/gal	**Lifecycle GHG method** Primary: 45ZCF-GREET (Jan 2025) Also permitted: CORSIA Default and CORSIA Actual
↓ OBBBA signed 4 July 2025		
One Big Beautiful Bill Act (OBBBA, PL 119-21) — four modifications to Section 45Z		
1. Credit rate cut (from 2026) $1.75 → $1.00/gal (prevailing wage) SAF premium over other fuels removed −43% reduction; many projects under review		**2. Credit extended by two years** New expiry: end-2029 (was end-2027) Provides additional investment runway
3. Feedstock origin restriction (from 2026) Eligible: feedstocks grown in US, Canada, or Mexico only Asian UCO and non-North American feedstocks excluded		**4. ILUC penalties removed** Indirect land-use change not counted in lifecycle GHG calculations / Corn ethanol, soy biodiesel now eligible
Section 6426(k) Blender's Credit — terminated		
Excise tax blender's credit for SAF ended for sales after 30 September 2025. IRS/Treasury proposed regulations published February 2026.		

into law. The OBBBA made four significant modifications to the 45Z credit as it applies to SAF, which are summarized in Table 5.

Against these changes, California's Low Carbon Fuel Standard (LCFS) continues to provide additional revenue for SAF with low carbon intensity, though credit prices have declined from their historical highs of $150-200/tonne and have traded in a lower and more volatile range in 2024-2025. Depending on a fuel's carbon intensity score and prevailing LCFS credit prices, qualifying SAF producers can still earn a meaningful additional per-litre premium, and the combination of 45Z and LCFS credits continues to improve HEFA SAF economics for California-served airports. Several other US states, including Washington, Illinois, and Minnesota, have introduced or are considering additional SAF incentive programmes, creating further stacking opportunities. However, the OBBBA's feedstock origin restrictions limit the extent to which non-North American producers can benefit from federal credit stacking, and the reduced 45Z SAF rate has narrowed the economic case for advanced pathway investment compared to the IRA's original framework.

Outside the US, Japan has approved direct capital subsidies for domestic SAF production facilities, targeting a 10% SAF blending rate by 2030. Korea, Singapore, and Australia are developing analogous fiscal frameworks. The design of these incentives varies; some are tied to GHG performance (like the US credits), while others are flat subsidies per litre or grants for capital investment, reflecting different policy philosophies and market contexts.

10.2. Grants, Loan Guarantees, and Capital De-Risking

First-of-a-kind SAF plants face a fundamental financing challenge: private capital markets are reluctant to lend at competitive rates to projects deploying technologies that have not yet been proven at commercial scale, even when the underlying technology is scientifically sound. Government grants and loan guarantee programmes address this 'valley of death' by providing non-dilutive capital and sovereign-backed credit enhancement that unlocks private co-financing. Some examples of awarded grants are listed in Table 6.

These grant and guarantee mechanisms are particularly important for advanced, non-HEFA pathways. HEFA projects can often attract commercial financing given the established technology and Neste's track record, though feedstock risk remains a constraint. FT, ATJ, and PtL projects face far greater first-plant risk and typically require government capital support to reach financial close. Without continued grant funding, the pipeline of projects needed to prove these technologies at commercial scale, and eventually bring costs down through learning, will stall.

Table 6: Indicative SAF Production Costs and Abatement Costs by Pathway (2024-2025)

Country/ Region	Issued from	Credit	Notes
USA	DOE Bioenergy Technologies Office (BETO)	$240 million	In SAF-related grants in 2022-23 through the SAF Grand Challenge and associated programmes
EU	EU Innovation Fund	€100 million	To individual advanced biojet projects, particular focus on non-HEFA pathways
UK	Advanced Fuels Fund	£165 million	To support UK SAF projects along multiple technology pathways

10.3. Contracts for Difference and Long-Term Revenue Guarantees

Contracts for Difference (CfDs), a policy instrument successfully deployed for offshore wind in the UK, the Netherlands, and Germany, are gaining serious attention as a mechanism for supporting SAF investment. Under a CfD, the government guarantees a 'strike price' per unit of SAF (or per tonne of CO_2 saved) for a period of 10–15 years. If the market price (including any existing tax credits and carbon revenues) falls below the strike price, the government pays the producer the difference. If the market price rises above the strike price, the producer repays the surplus. This two-way mechanism eliminates both upside and downside revenue uncertainty, providing the stable, long-term cash flow projections that project finance lenders require.

The UK government is actively developing a SAF CfD mechanism as part of its Jet Zero Strategy implementation, with the strike price likely to be set in terms of cost per tonne of CO_2 saved relative to fossil jet. The mechanism would be funded through a levy on aviation fuel or airline revenues. The EU is exploring similar instruments through its Innovation Fund and the Renewable and Low-Carbon Fuels Value Chain Alliance. CfDs are likely to be particularly valuable for capital-intensive, higher-risk pathways such as FT-SAF and PtL, where the technology risk premium in project finance is highest and where long-term revenue certainty is most important for reaching final investment decision.

10.4. Carbon Pricing and Emissions Trading

Carbon pricing provides an indirect but potentially powerful mechanism for SAF competitiveness by raising the effective cost of fossil jet fuel. The EU Emissions Trading Scheme (EU ETS) currently covers intra-European aviation, requiring airlines operating within the European Economic Area to surrender emissions allowances for their CO_2 emissions. At recent allowance prices of 70–90 per tonne CO_2, the ETS adds approximately 0.18–0.23 per litre to the cost of fossil jet fuel used on covered routes. As free allowance allocations are phased out under the EU's Fit for 55 package, this cost will increasingly be borne by airlines and, ultimately, by passengers through higher ticket prices.

CORSIA, ICAO's global carbon offsetting mechanism, began its voluntary pilot phase in 2021 and will become mandatory for most international airlines from 2027. While CORSIA's carbon credit prices have historically been low ($5–$20/tonne), the scheme creates a financial incentive for airlines to use SAF (which reduces CORSIA compliance obligations) and is expected to increase in stringency over time. Some policy analysts argue that CORSIA's effectiveness would be substantially enhanced by a minimum carbon price floor or by tightening the emissions baseline against which obligations are calculated.

A number of jurisdictions are exploring or implementing aviation-specific carbon taxes. Norway's CO_2 tax on aviation fuel, Sweden's air passenger tax, and the UK's Air Passenger Duty all create implicit pricing signals for lower-carbon fuels, though none are yet calibrated specifically to incentivise SAF at the scale required.

10.5. Demand Aggregation and Offtake Instruments

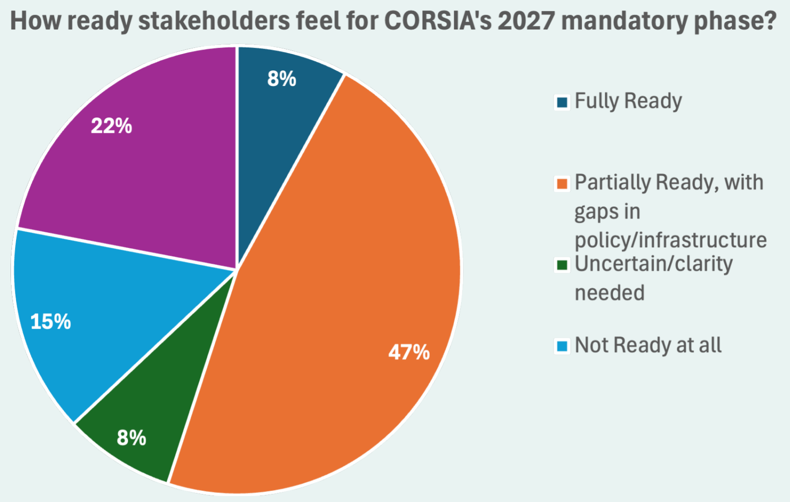
On the demand side, long-term purchase agreements and demand aggregation mechanisms provide SAF producers with the revenue certainty needed to secure project finance. Individual airline offtake agreements, committing to purchase a specified volume of SAF at a defined price over 5–15 years, are increasingly common. United Airlines' SAF investment fund, Lufthansa's multisupplier agreements, and Singapore Airlines' partnerships with Neste exemplify this approach. Alliance-level agreements have also emerged: oneworld's 2022 commitment covering 200 million gallons per year represents an important demand signal at scale.

Corporate buyers outside the aviation sector have become an increasingly important source of SAF demand through 'book-and-claim' purchasing. The Sustainable Aviation Buyers Alliance (SABA), formed by the Rocky Mountain Institute and Environmental Defense Fund, aggregates the purchasing power of large multinationals including Microsoft, Meta, JPMorgan, and Boston Consulting Group. SABA's collective transactions and SAF certificate frameworks lower transaction costs for corporate buyers, provide producers with a diversified customer base beyond airlines, and create demand signals that help de-risk investment in new production capacity.

CORSIA and the Carbon Offset Market, Current State

CORSIA's mandatory phase begins in 2027, covering all international aviation above 85% of 2019 emissions levels. As of 2025, the CORSIA credit market faces a severe supply bottleneck: only one project globally can offer eligible credits at scale, a J-REDD+ jurisdictional project in Guyana, which has issued approximately 16 million credits in total against an estimated Phase I demand of 140 million credits. Most eligible projects are early-stage, concentrated in Africa (clean cookstove projects in Madagascar, Rwanda, and Ghana), and face political and administrative barriers to obtaining host-country Letters of Authorization required for corresponding adjustment under Article 6 of the Paris Agreement. Around 95% of countries missed the February 2025 deadline to submit updated Nationally Determined Contributions (NDCs), meaning many host nations have not yet determined how many credits they can afford to grant Letters of Authorization for. Buying interest for guaranteed-structure CORSIA contracts currently hovers between $13–17/tonne CO_2 equivalent (Argus/ASAFA 2025). This is dramatically lower than the cost of abating the same emission through SAF use, making carbon offsets, while affordable, a significantly less transformative compliance mechanism than SAF.

A 2025 survey reveals that less than 10% of Asia-Pacific stakeholders feel fully ready for CORSIA's 2027 mandatory phase, and almost 50% still face major gaps in policy or infrastructure. In terms of compliance strategy, the same survey showed that around 35% of respondents remain uncertain about meeting CORSIA through SAF, other low-carbon fuels, or carbon offsets. This indicates that near-term CORSIA compliance in Asia-Pacific will be offset-dependent, reinforcing the need for accelerated SAF supply development and certification infrastructure ahead of the 2027 mandatory phase.



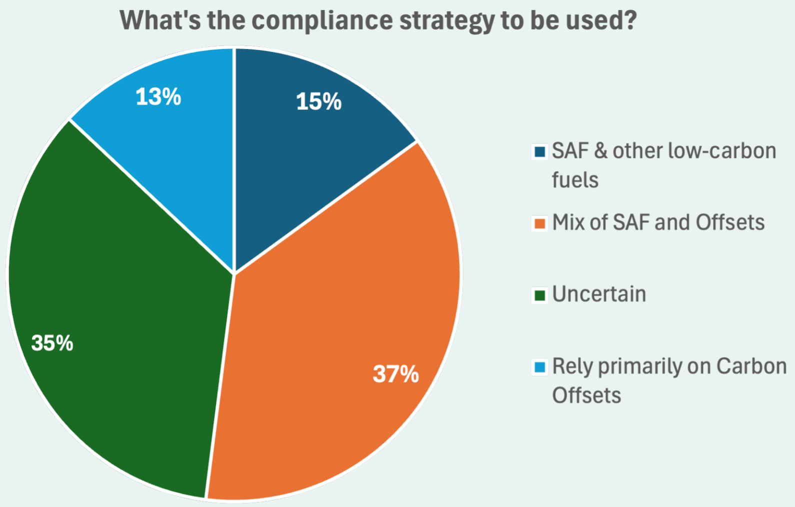


Figure 2 & 3. *Source: ASAFA APAC SAF Outlook 2025 Survey, multiple answers possible*

11. Emerging Technologies

The SAF innovation landscape has accelerated significantly in 2024–2025, moving beyond proof-of-concept in several key areas and entering a new phase where multiple next-generation pathways are transitioning from laboratory to early commercial deployment. A 2025 review published in the journal Energies characterises the current period as one where 'technology is outpacing policy', with ASTM approvals for new pathways accelerating and lifecycle analysis tools becoming more sophisticated than regulatory frameworks can absorb them.

11.1. Methanol-to-Jet, The Next ASTM Pathway

Methanol-to-Jet (MtJ) is widely regarded as the most imminent new addition to the ASTM D7566 certified pathway list. The pathway converts methanol, which can be produced from green hydrogen and captured CO_2 via Power-to-Liquid processes, or from biomass gasification, into jet-range hydrocarbons. The principal advantage of MtJ over conventional FT-PtL is its higher carbon yield and lower by-product formation, enabling more efficient conversion of CO_2 inputs into usable kerosene. Testing under ASTM D4054 has been progressing with volumes supplied by ExxonMobil, Haldor Topsoe/Topsoe A/S, and Honeywell-UOP. The pathway is expected to receive ASTM approval within the current decade.

MtJ is particularly attractive because it bridges bio-based and synthetic fuel production: the same conversion technology can process methanol derived from either biomass (giving it bio-SAF credentials) or renewable electricity and DAC CO_2 (giving it eSAF credentials eligible for the EU's synthetic fuel sub-mandate). This versatility makes MtJ a potentially important pathway for the post-2030 phase, when bio-feedstock constraints become binding and eSAF sub-mandates create premium-priced demand. Companies including TotalEnergies and Masdar demonstrated the potential of methanol as an aviation fuel blend at COP28.

11.2. Power-to-Liquid, Technology Acceleration in 2025

PtL SAF has seen meaningful technical progress in 2025, moving from a curiosity to a credible near-commercial technology. Three developments are particularly significant. First, innovations in Solid Oxide Electrolysis Cells (SOECs) are improving the overall energy efficiency of green hydrogen production, the critical and most expensive input for PtL. SOEC technology operates at higher temperatures than conventional alkaline or PEM electrolysers, enabling higher round-trip efficiency and the potential to integrate waste heat from industrial processes. Second, the integration of Direct Air Capture (DAC) with fuel synthesis units is gaining traction: several project developers are co-locating DAC modules with FT or MtJ synthesis units to reduce CO_2 supply chain costs and logistics complexity. Third, digital twins and AI-powered process control systems are being embedded in early PtL deployments to optimise real-time performance and reduce operational costs.

Twelve's CO_2 electrolysis approach represents a distinct and particularly innovative PtL variant. Rather than producing green hydrogen as an intermediate, Twelve's electrochemical process directly converts CO, water, and renewable electricity into carbon monoxide and hydrogen (syngas) in a single electrochemical step, which is then synthesised into jet fuel. The company claims this E-Jet® process uses up to 1,000 times less water and 30 times less land than bio-based SAF, and delivers up to 90% lifecycle CO_2 reduction. A first commercial-scale plant is under development. Meanwhile, Arcadia eFuels (Denmark) and Norsk e-Fuel (Norway) are advancing commercial-scale FT-based PtL plants designed to meet the EU's eSAF sub-mandate requirements from 2030.

11.3. Biomass with Carbon Capture (BECCS-SAF), Net-Negative Aviation Fuel

Coupling SAF production with bioenergy carbon capture and storage (BECCS) creates the theoretical possibility of aviation fuel with net-negative lifecycle emissions, the only pathway by which aviation could actively contribute to carbon dioxide removal rather than simply reducing its emissions rate. The mechanism works as follows: biomass absorbs CO_2 during growth; when converted to SAF via fermentation or gasification, a large fraction of the carbon is emitted as concentrated, near-pure CO_2 (at the fermentation vessel or gasifier flue) that can be economically captured and geologically sequestered. The SAF is burned and its CO_2 released into the atmosphere, but less carbon is emitted to the atmosphere than was removed from it, yielding a net negative outcome.

LanzaTech has proposed coupling its gas

fermentation technology with CCS to produce carbon-negative fuels. The US 45Q tax credit, providing $85/tonne for permanent geological CO_2 sequestration, provides financial support for such approaches. The UK's North Sea geological formations, and equivalent formations in Japan, Australia, and Southeast Asia, represent significant geological storage capacity that could underpin BECCS-SAF projects in those regions. If successfully demonstrated and scaled, BECCS-SAF could become an important tool for aviation to achieve net-zero or even net-negative emissions by 2050, providing both low-carbon fuel and a carbon removal service to offset residual emissions from flights that cannot be otherwise decarbonised.

11.4. Novel Feedstocks, Algae, CO_2-Derived Oils, and Agricultural Waste

Algae-based SAF continues to attract R&D investment despite previous commercial setbacks. Current research focuses on more productive strains, cultivation using waste CO_2 and municipal wastewater (avoiding competition for freshwater and nutrients), and genetic engineering of algae or yeast to produce hydrocarbons directly rather than triglyceride oils requiring a separate conversion step. The ASTM D4054 qualification process for algae-derived SAF via CHJ or HEFA is ongoing.

Agricultural and forestry residues represent the largest scalable near-term feedstock opportunity for advanced bio-SAF. Research is improving collection and preprocessing logistics for heterogeneous waste biomass, reducing cost and increasing the range of materials that can be cost-effectively processed. Haffner Energy's biomass gasification technology, designed to handle 'all types of biomass residues wet or dry, including agricultural and municipal waste', exemplifies this approach. When combined with LanzaTech's syngas fermentation and LanzaJet's ATJ conversion (the CirculAir technology chain announced in January 2025), it creates an integrated waste-to-SAF pathway applicable across diverse regional feedstock endowments, particularly in Southeast Asia, South Asia, and Africa.

11.5. Expanding the ASTM Pathway Framework

As of 2025, ASTM International has approved 11 SAF production pathways under D7566, up from 7 in 2020. Three additional co-processing pathways are covered under the petroleum-based Jet A-1 standard (D1655 Annex A1). Several further pathways are in the ASTM D4054 qualification pipeline, including MtJ, pyrolysis-based fuels, and novel aromatic blending components. The US Congressional Research Service has noted that the DOE estimates HEFA and ATJ will together account for approximately 89% of expected 2030 SAF production (HEFA at 66%, ATJ at 23%), with FT, PtL, and other pathways growing rapidly thereafter.

An important parallel development is the qualification of Synthetic Aromatic Kerosene (SAK), an aromatic blending component produced by Virent using a bio-based aqueous phase reforming process. SAK provides the aromatic content required for seal swell and energy density in aviation fuel, but from a non-petroleum source. The December 2022 Virgin Atlantic transatlantic flight on '100% SAF' used a blend of 88% HEFA-SPK and 12% Virent SAK, demonstrating that a fully fossil-free aviation fuel can meet all operational requirements when bio-based aromatics are combined with paraffinic SAF. Virent is near completion of ASTM approval for a new D7566 annex covering SAK, which would be a key enabler for true 100% drop-in SAF specification.

11.6. Hybrid Systems and Cross-Sector Integration

The most compelling near-term innovation opportunity lies not in single breakthrough technologies but in intelligent integration of existing processes. Power+Bio hybrid systems that add green hydrogen to biomass gasification increase carbon efficiency, converting more of the biomass carbon into useful fuel rather than CO_2, and reducing the feedstock requirement per litre of SAF produced. Several plants in Japan and Scandinavia under development plan to integrate on-site electrolysis hydrogen into biomass gasification or FT processes.

SAF production is increasingly being conceived as part of broader industrial symbiosis systems: co-located with biogas digesters (sharing CO_2 and waste heat), or co-located with industrial processes that produce waste CO (steel, cement, ethanol fermentation) that serves as feedstock for ATJ or PtL synthesis. Digital twin technology and AI-assisted process optimisation are improving real-time efficiency management of these complex, multi-input systems. These cross-sector integration approaches are likely to be as important as any single technology breakthrough in enabling the cost reductions needed to bring SAF to price parity with fossil jet fuel.

12. Conclusion

Sustainable Aviation Fuel is a cornerstone of global aviation's decarbonisation strategy. This factsheet has detailed how SAF offers a drop-in solution with significant lifecycle carbon savings, leveraging a variety of feedstocks and approved conversion technologies. The year 2025 marked a genuine inflection point: ReFuelEU Aviation entered into force in Europe, LanzaJet's Freedom Pines Fuels became the world's first commercial Alcohol-to-Jet plant, Australia committed A$1.1 billion to domestic SAF production, Singapore enacted its SAF mandate into law, and South Korea announced mandatory SAF blending from 2027. The global SAF market is no longer theoretical, it is real, expanding, and beginning to reshape aviation fuel trade flows.

The path forward requires every stakeholder group to move from observation to action. Policymakers must firm up proposed mandates into binding legislation, accelerate CORSIA readiness infrastructure, and design CI-based frameworks from the outset. Producers must scale up, diversify beyond HEFA, and lead on sustainability certification. Airlines must move from cautious pilot programmes to forward offtake commitments and corporate SAF partnerships. Investors must engage with blended finance mechanisms, back next-generation technologies, and treat SAF certificate markets as an emerging asset class. And corporate buyers must convert voluntary ESG commitments into structured, long-term SAF procurement.

With continued collaboration, across the industry alliances, regional associations, and national policy frameworks that are now coalescing around a shared vision, the goal of flights powered predominantly by sustainable fuels is increasingly achievable. Asia-Pacific, with the world's largest aviation growth market and vast feedstock resources, has a defining role to play. The next five years will determine whether the region becomes a global SAF leader or falls behind. The data, the technology, and the institutional capacity are emerging. What remains is the collective political and commercial will to act at the scale the climate demands.

WBA Position: A Coordinated Policy Portfolio for SAF Scale-Up

The World Bioenergy Association recognises that scaling SAF to the volumes required for net-zero aviation cannot be achieved through any single policy mechanism. A coordinated, long-term portfolio of complementary instruments is essential, combining supply-side incentives (production tax credits, capital grants, loan guarantees, CfDs), demand-side measures (blending mandates, carbon pricing, corporate procurement standards), and enabling infrastructure investments (feedstock supply chains, blending facilities, certification systems).

WBA calls on governments to:

1. establish long-term SAF blending mandates with clear, predictable escalation schedules to 2050, providing the demand certainty that underpins investment;
2. provide capital grants and production tax credits specifically targeted at advanced non-HEFA pathways (FT, ATJ, PtL) where technology risk is highest;
3. develop CfD or similar long-term revenue guarantee mechanisms to de-risk first-of-a-kind plants;
4. harmonise sustainability certification standards internationally and facilitate an interoperable SAF certificate registry, particularly in Asia-Pacific where fragmentation is a key barrier;
5. formally recognise Book-and-Claim as a valid compliance mechanism in national mandates during the supply scale-up phase;
6. evolve mandates from volume-based to carbon intensity-based frameworks to reward genuine GHG reductions;
7. ensure carbon pricing mechanisms provide a stable and rising incentive for lower-carbon fuel choices.

Stable, predictable policy over the full investment horizon of SAF projects (10–20 years) is as important as the level of support provided.

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Disclaimer

The findings, interpretations and conclusions expressed in this document are a result of a collaborative process facilitated and endorsed by the WBA but whose results do not necessarily represent the views of the WBA, nor the entirety of its Members, Partners or other stakeholders.

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