

Green Fuel for Blue Skies

Charting the Course for Sustainable Aviation Fuels



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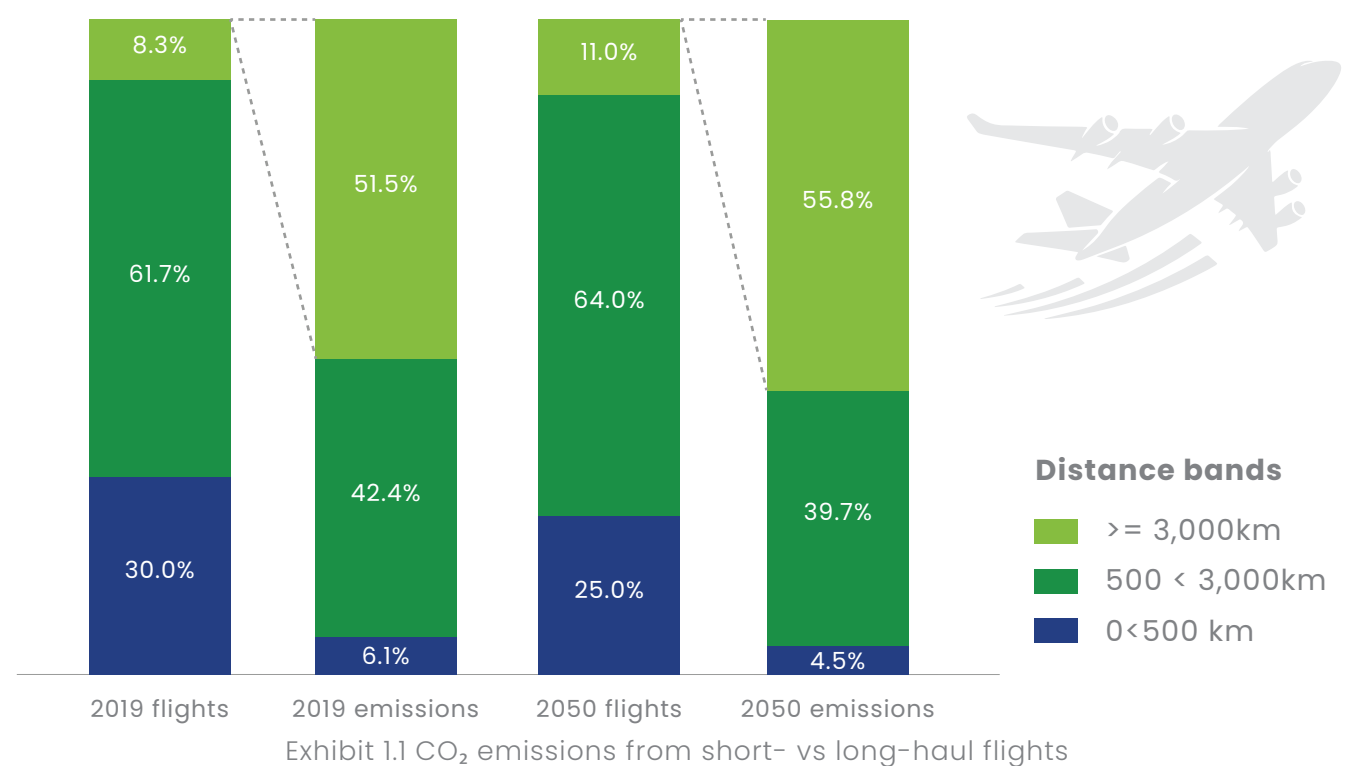
Chapter 1: Overview of Sustainable Aviation Fuels

The commitment to limit global warming to 1.5°C above pre-industrial levels, as enshrined in the Paris Agreement, demands deep and rapid emissions reductions across all sectors by mid-century. The Intergovernmental Panel on Climate Change (IPCC) estimates that global CO₂ emissions must fall by roughly 45% by 2030 from 2010 levels and reach net-zero around 2050.

Aviation remains one of the fastest-growing and hardest-to-abate sectors, led by intrinsic dependence on high-energy-density liquid fuels, long assets lifetimes, and a post-pandemic rebound in passenger demand. Commercial aviation today accounts for roughly 1 billion tonnes of CO₂ or ~2.5% of global energy-related CO₂ emissions, but climate impact is significantly higher when non-CO₂ effects like contrail formations are included. Including impact from such effects, estimates suggest that aviation could contribute up to 4% of total anthropogenic warming to date, though science is still unclear on the exact contribution.

If left unchecked, the Air Transport Action Group projects that passenger aviation could generate nearly 2 billion tonnes of CO₂ emissions by 2050, more than twice the industry’s 2019 levels . This underscores the urgency for the sector to undergo an accelerated transition far earlier than its current trajectory suggests.

The challenge is particularly acute for long-haul flights. For instance, in Europe, long-haul flights constitute less than 10% of total departures, however account for over half of aviation’s CO₂ emissions. Globally, long-haul flights contribute to 40% emissions . Although promising advances are being made in electric and hydrogen propulsion, their technical limitations confine them largely to short-haul or regional operations for the foreseeable future. For long-haul flights, no zero-emission alternative exists today that can match the range, payload, and energy density of conventional jet fuel; and even if such technologies emerged today, scaling them to commercial maturity and building the necessary global infrastructure would still take decades.



Recognizing this urgency, in 2022 the International Civil Aviation Organization (ICAO) adopted a Long-Term Global Aspirational Goal (LTAG) of achieving net-zero CO₂ emissions from international aviation by 2050, in line with the Paris Agreement.

The relative contribution of different decarbonization levers, ranging from operational efficiencies and fleet renewal to the widespread adoption of SAF, is illustrated below in exhibit 1.2. SAF refers to jet fuel produced from non-fossil,

renewable, or waste-derived sources, and meeting rigorous technical and sustainability standards. As the exhibit shows, aircraft and operational efficiency improvements are expected to deliver roughly one-third of the required emission reductions, while SAF adoption of around 450–500 Mt annually^{iv} accounts for nearly two-thirds of the total abatement needed to reach aviation's 2050 net-zero target.

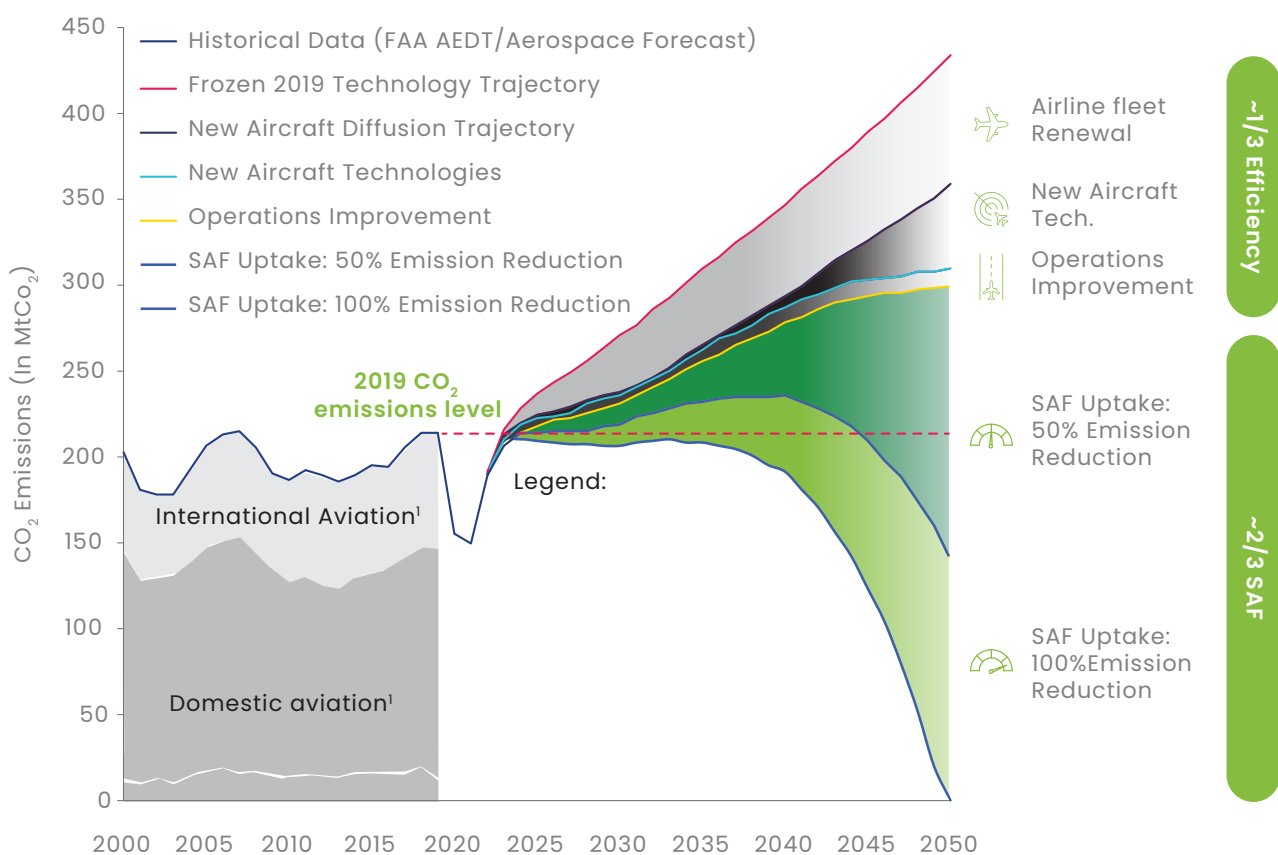


Exhibit 1.2: Role of SAF as a key lever to decarbonize aviation

The versatility of SAF lies in its ability to be produced from a wide variety of feedstocks and conversion pathways. Depending on regional resource availability, technologies can convert waste oils, agricultural residues, lignocellulosic biomass, municipal solid waste, renewable electricity, or captured

CO₂ into jet fuel that meets stringent aviation standards. Exhibit 1.3 provides an overview of these production routes, highlighting their respective commercial readiness levels from mature, at-scale processes such as HEFA (Hydroprocessed Esters and Fatty Acids) to emerging options like Fischer–Tropsch and

SAF represents a more proactive mitigation lever, reducing emissions at the source rather than offsetting them after combustion.



Exhibit 1.3: Detailed overview of SAF feedstock and production



The effectiveness of SAF in decarbonizing aviation is best understood through four defining features as outlined below:



Exhibit 1.4: Key features of SAF

Compatibility with the Existing Infrastructure

A key advantage of SAF is its ability to integrate seamlessly into today's aviation system. As a certified drop-in replacement for conventional jet fuel, SAF can be blended up to 50% under current ASTM standards, without requiring any modification to aircraft engines, airport infrastructure, or distribution networks. This compatibility avoids the long lead times and capital costs associated with next-generation aircraft technologies, e.g., developing the entire supply chain and infrastructure for low-carbon Hydrogen.

Strong Trajectory for Ecosystem Development

The global SAF ecosystem, spanning feedstock supply, refining capacity, certification, and policy support, has advanced rapidly over the past decade. While most production technologies remain in early commercial or pilot stages, the sector's coordinated progress has established a credible platform for large-scale deployment. Governments are introducing supportive frameworks, technology developers and fuel producers are scaling commercial refineries, and airlines are entering long-term offtake agreements, all of which are accelerating market confidence.

High Emission Reduction Potential

The principal climate benefit of SAF lies in its ability to achieve deep life-cycle greenhouse gas savings. Across certified pathways, SAF typically reduces emissions by 60–80% relative to fossil jet fuel, depending on feedstock type and production efficiency. These savings are calculated on a well-to-wake & Life Cycle Assessment (LCA) basis, covering all stages from resource collection to combustion. By substituting fossil-derived fuel with renewable or waste-based alternatives, SAF prevents additional carbon from entering the atmosphere, enabling in-sector decarbonization. SAF can also help reduce non-CO₂ climate impacts, such as contrails, by lowering soot and sulfur emissions that contribute to their formation.

Broader Economic and Environmental Benefits

By converting agricultural residues, municipal waste, and used cooking oil into high-value fuels, SAF supports circular economy principles, reducing waste and creating productive uses for underutilized materials. The growth of SAF value chains stimulates local employment and investment, generating income for farmers, waste aggregators, and small enterprises involved in feedstock supply.



In developing and emerging economies, SAF production also enhances energy independence by reducing reliance on imported fossil fuels and attracting green capital into new industrial infrastructure.

Collectively, these benefits position SAF not only as a tool for decarbonization, but as a catalyst for just, inclusive, low-carbon economic growth.

Chapter 2 Rising Global Momentum for SAF

In just a few years, SAF has evolved from an experimental concept to a cornerstone of the aviation sector's decarbonization strategy. Around the world, governments are embedding SAF within long-term energy and climate frameworks that collectively define the next phase of market growth and investment.

Global Alignment on Net-Zero Aviation

The seeds of global alignment around SAF were sown in 2016, when the ICAO launched the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), a first-of-its-kind global framework to curb emissions from international flights. Building on this foundation, 193 countries came together under ICAO in 2022 and agreed to pursue the LTAG of achieving net-zero for the aviation sector by 2050.

Designed to address the sector's rapidly growing carbon footprint, CORSIA was structured in two main phases: a voluntary phase (2021–2026), allowing early participation by willing countries, followed by a mandatory phase (2027–2035), under which majority international flights will be covered. Airlines can comply through CORSIA-eligible emissions units or CORSIA-eligible fuels, including SAF.

While CORSIA represents a landmark in global aviation governance, it still leaves open questions about the post-2035 landscape. The scheme currently ends in 2035, with no clearly defined roadmap for the period beyond. This uncertainty has prompted growing calls for ICAO to develop a successor framework that sets explicit SAF blending or uptake targets to complement carbon offsetting.

Many industry stakeholders expect that after 2035, ICAO may evolve CORSIA into a more comprehensive emissions-reduction regime – one that integrates clear, quantitative goals for SAF adoption,

providing longer-term policy certainty to global investors and airlines alike.

From Commitments to Concrete Mandates

Following ICAO's lead, governments around the world began to craft their own SAF mandates that airlines or fuel suppliers blend a minimum share of SAF into jet fuel. These mandates are fast proliferating, signaling not only environmental intent but also industrial opportunity.

Europe emerged as the first major region to translate ambition into regulation. Norway was the pioneer, mandating 0.5% SAF in all aviation fuel from 2020, followed by Sweden and France, which set progressively higher targets through to 2030. France's approach stands out for coupling mandates with state-backed funding and investments in next-generation "Power-to-Liquid" fuels, demonstrating how regulation can drive innovation.

The European Union has consolidated this leadership through the ReFuelEU Aviation Regulation, adopted in 2023. It creates a rising, bloc-wide SAF requirement starting with 2% in 2025 and escalating to 70% by 2050. Crucially, it builds a comprehensive compliance system that penalizes non-adherence, incentivizes higher-abatement fuels, and ensures fair competition through anti-tankering rules. By embedding sustainability guardrails and connecting with the EU's emissions trading system, ReFuelEU establishes one of the most ambitious and integrated SAF policy frameworks in the world.

Post-Brexit, the United Kingdom has also crafted its own version of a SAF mandate, starting at 2% in 2025 and reaching 10% by 2030. Complementing this is a robust financial ecosystem of price guarantees, funding for SAF plants, and a national clearinghouse to speed up certification.

01: USA

- Renewable Fuel Standard (RFS)
- Inflation Reduction Act (IRA CFPC 45Z)
- LCFS State-level Incentives (California, Illinois, Minnesota and Washington)
- State-level tax credits for SAF (Hawaii, Illinois, Minnesota, Nebraska, Washington)
- SAF Grand Challenge – 9 Mt/y produced by 2030 (non-binding)

02: Norway

SAF mandate: 0.5% in 2020, considering 30% by 2030

03: France

1% SAF blend since 2022

04: Sweden

0.8% reduction mandate in 2021
Rising to 27% in 2030

05: Switzerland

Alignment with ReFuelEU

06: UK

- 2% SAF blend in 2025
- 10% SAF blend by 2030 (0.5% eSAF)
- 22% SAF blend from 2040 (3.5% eSAF)

07: UAE

General Policy for SAF (Dec 2023)
– 1% locally produced SAF to UAE airlines at UAE airports, by 2031

Significant uncertainty regarding climate policies persists across regions

08: EU 28 (ReFuel EU Aviation)

- 2025: 2%
- 2030: 6% (1.2% e-fuels)
- 2035: 20% (5% e-fuels)
- 2040: 34% (10% e-fuels)
- 2045: 42% (15% e-fuels)
- 2050: 70% (35% e-fuels)

09: Indonesia

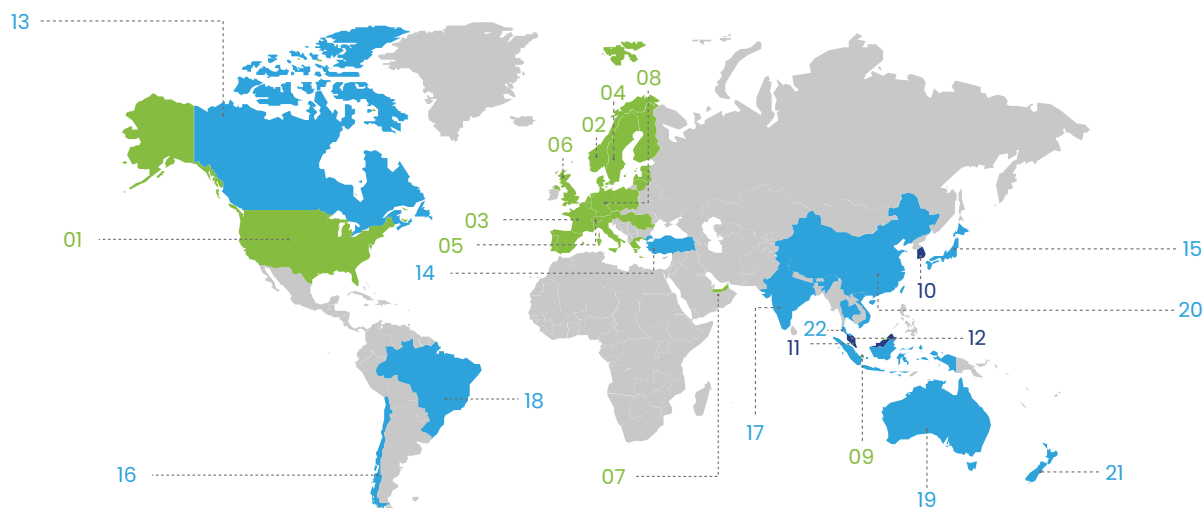
SAF roadmap: 1% in 2027 50% by 2060

10: South Korea

1% SAF mandate proposed starting in 2027

11: Singapore

SAF mandate: 1% by 2026 (3–5% by 2030), SAF levy proposed



12: Malaysia

Roadmap for SAF mandate: 1% in 2026 (47% by 2050)

13: Canada

Clean Fuel Standard since 2022, aspirational 10% SAF by 2030 (under discussion).
British Columbia agreed on 1% SAF blend by 2028, rising to 3% by 2030

14: Turkey

SAF mandate proposal: 5% SAF blend by 2030

15: Japan

SAF mandate proposal: 10% by 2030 (incl. SAF levy)

16: Chile

Clean Flight government program (roadmap)

17: India

Indicative SAF mandates: 1% SAF blend by 2027
2% SAF blend by 2028
(5% by 2030 proposed)

18: Brazil (Fuel of the Future law)

- 1% emission reduction by 2027
- 10% emission reduction by 2037

19: Australia

Jet Zero Council aspiration: ≥10% SAF in 2030 (no mandates currently)

20: China

- ETS expansion to aviation expected
- SAF mandates expected by 2030 in the 2–10% range
- Hong Kong to set SAF cons. target in '25

21: New Zealand

Sustainable Biofuels Mandate
Currently not including SAF

22: Thailand

2024 draft: 1% in 2026, 8% by 2036

ICAO CORSIA offsetting targets will become binding starting in 2027 for all members' international flights (exceptions apply)

■ SAF policies implemented

■ Soon to be implemented mandates

■ Proposed/Under discussion

Sources: ICAO, Argus, EU Commission, ACI, IEA, Eurocontrol, Biomass Magazine, S&P Global, Press search

Exhibit 2.1: Global SAF policy landscape

The UK's model illustrates how regulatory certainty and financial stability can jointly de-risk investment in new fuel production.

Across the Atlantic, the United States has opted for an incentive-driven approach rather than hard blending mandates. Through the SAF Grand Challenge and the Inflation Reduction Act, the US government has introduced generous tax credits tied to carbon performance, encouraging private-sector innovation and domestic production. Layered with state-level Low Carbon Fuel Standards in California, Oregon, and Washington, these policies together create one of the most powerful economic pull mechanisms for SAF globally.

Momentum is not confined to the transatlantic corridor. Across Asia, governments are now moving decisively to catch up. Singapore will become the first in the region to enforce a SAF requirement starting with 1% in 2026 under its Air Hub Blueprint. South Korea, Malaysia, and Indonesia have all announced mandates starting by 2027, signaling an accelerating policy convergence across the region.

Large emerging economies are also stepping forward. India has outlined an indicative plan beginning in 2027, while Japan, Canada and Brazil have published detailed SAF roadmaps aiming for 5–10% usage by 2030. Even oil-producing nations like the UAE are joining the movement, setting voluntary targets and supporting domestic production of SAF. These announcements, though varied in design and ambition, highlight a growing recognition that investment in SAF can stimulate domestic industry, create skilled jobs and strengthen energy security.

This accelerating policy landscape is already translating into tangible market demand. By 2030, global SAF demand is projected to reach nearly 10 Mt, driven by a combination of binding mandates, production incentives, and early market signals from aviation industry. When combined with voluntary airline

commitments, the momentum suggests a rapidly expanding baseline for SAF adoption. Exhibit 2.2 illustrates the projected demand trajectory through the end of the decade and shows that mandated demand makes up the largest share, led by Europe's regulatory push. North America follows with a mix of incentive-driven and voluntary demand. The projection for North America will update as the impact of changes to United States incentive policy becomes clearer. Emerging markets contribute smaller but steadily growing volumes. Together, these regional dynamics underscore how policy ambition is beginning to shape the geography of future SAF consumption.

Increasing commitment from airlines

As governments accelerate SAF adoption through mandates and incentives, airlines are translating their decarbonization commitments into tangible action. In 2021, the International Air Transport Association (IATA) member airlines formally voted in aAs governments accelerate SAF adoption through mandates and incentives, airlines are translating their decarbonization commitments into tangible action. In 2021, the International Air Transport Association (IATA) member airlines formally voted in a resolution committing the industry to reach net-zero carbon emissions by 2050. This consensus at the global industry level has cascaded to airline boards and strategy meetings everywhere. Many carriers now articulate ambitious environmental targets, sometimes expressed as percentage goals for SAF in their fuel mix.

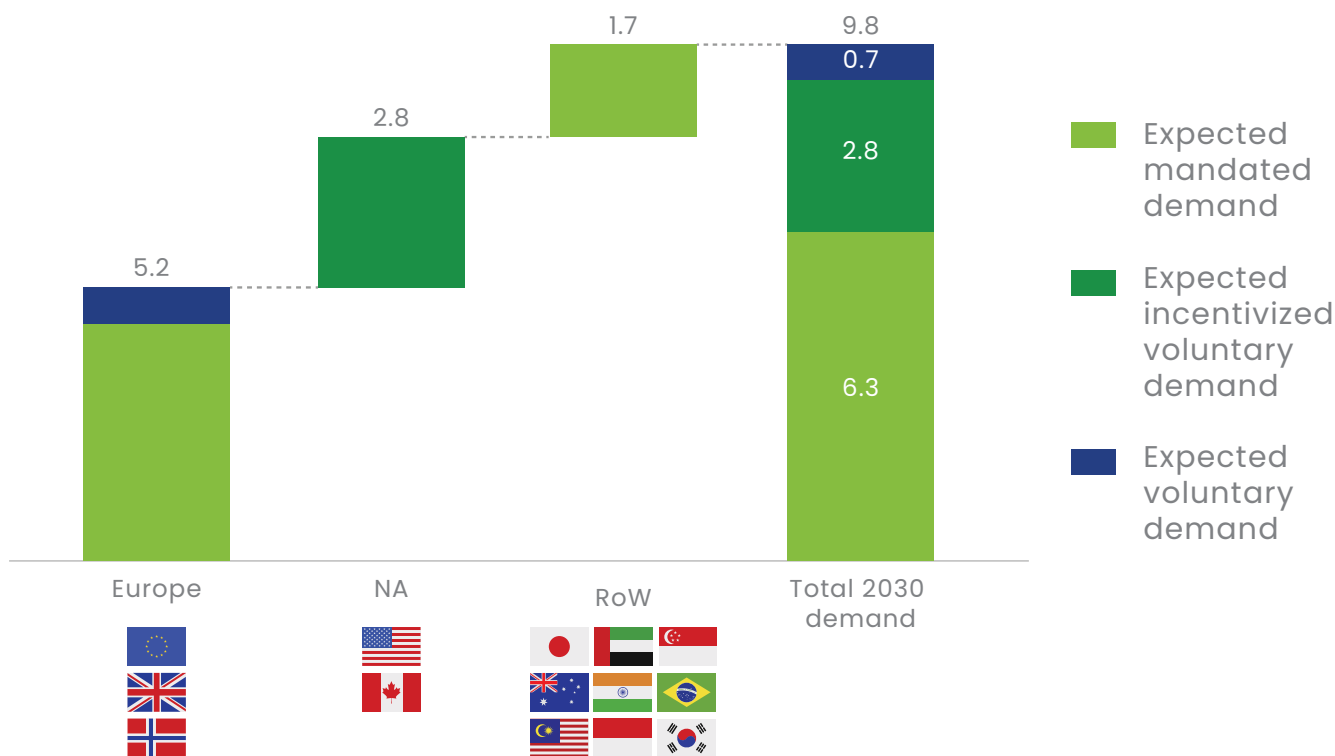


Exhibit 2.2: Rising SAF demand driven by regulations and voluntary airline demand



Exhibit 2.3: Voluntary SAF commitments by airlines

Across the globe, leading airlines are taking early steps to operationalize this transition. In the US, United Airlines Holdings, for instance, has built one of the world's largest SAF portfolios around 2.9 billion gallons under offtake or investment and uses millions of gallons annually at its hubs. American Airlines has committed more than 620 million gallons of low-carbon fuel purchases, fulfilling roughly 20% of the airline's goal to replace 10% of jet fuel usage with SAF by 2030.

In Europe, the International Airlines Group (IAG), parent to British Airways and Aer Lingus targets 10% SAF use by 2030. It has committed about US \$3.5 billion to offtakes and used more than 160 Kt of SAF in 2024 alone. Lufthansa Group has signed a memorandum of understanding with Shell for offtake of up to 1.8 Mt between 2024 and 2030, while Air France-KLM has long-term agreements totaling more than 2.5 Mt with Neste and TotalEnergies. These moves demonstrate how European airlines are securing supply chains well ahead of the region's tightening blending mandates.

Momentum is equally visible in Asia-Pacific and the Middle East. Qantas plans to replace 10% of its jet fuel with SAF by 2030 and 60% by 2050, supported by co-investments in Australian production projects and an AU\$200 million SAF fund with Airbus. Singapore Airlines Group has set a 5% SAF target by 2030, backing it with offtake agreements from Neste and World Energy and the upcoming SAF levy scheme at Changi airport. Japan Airlines and All Nippon Airways are also targeting a 10% SAF blend by 2030, forming domestic partnerships with ENEOS and other refiners to build local capacity. In the Gulf, Qatar Airways and Emirates Airlines have begun SAF uplift at major European hubs and have relayed commitment to scaling usage as regional supply grows in future.

These commitments are not just responses to regulatory requirements, many of them are largely voluntary offtakes designed to accelerate market formation. Airlines are deliberately over-contracting relative to current mandates to de-risk their supply

chains, send credible demand signals to developers, and gain reputational leadership.

Airlines are also investing directly in SAF startups and projects which help new technologies reach scale and secure early capacity. A few examples include United Airlines investing through its venture fund in Alder Fuels, Dimensional Energy and Cemvita, and Southwest Airlines investing thirty million dollars in LanzaJet.

Collectively, these actions mark a fundamental shift in aviation's decarbonization journey. Airlines are no longer passive consumers but active architects of the SAF economy, shaping markets through forward contracts, joint ventures, investment funds, and ecosystem partnerships.

Despite visible progress and a growing diversity of initiatives, the market signal has weakened even as supply still lags far behind demand. After the strong momentum in 2021 and 2022, new SAF offtake activity has slowed. Relative to 2022, newly contracted volumes fell by around 45% in 2023 and then by a further 80% in 2024, which is more than 90% below the 2022 peak, and deal counts also declined. At the same time, current SAF production remains negligible compared to overall jet fuel demand. In 2024-25 SAF accounted for roughly 0.7% of global supply. Even with announced and planned projects, production is expected to meet only 2% to 4% of demand by 2030, which remains well short of what a net-zero pathway requires, with the IEA Net-Zero Scenario calls for at least 10% SAF by 2030.

The slowdown in SAF deployment reflects financing constraints more than a lack of projects or technology. After the surge of activity in 2021-2022, new offtake volumes fell significantly in 2023-24 as developers struggled to secure the long-term purchase agreements needed to unlock project finance. Many projects remain technically and environmentally ready, but without creditworthy offtakers or predictable price support, few can reach final investment decision.



This widening gap between ambition and adoption underscores the scale of the challenge ahead. The next phase of the SAF transition will hinge on overcoming

constraints in cost, policy stability, technology readiness, and infrastructure, issues explored in the following chapter.

Chapter 3: Challenges in SAF adoption

As highlighted in the previous chapter the narrative around SAF has shifted from possibility to implementation. However, this rising wave of commitment now meets a complex set of practical and systemic hurdles that threaten to slow its translation into real-world deployment.

A reinforcing loop appears to be holding back SAF adoption. High premiums and unclear price trajectories keep airline

demand tentative, which weakens offtake signals and slows new investment. Capacity then fails to scale, learning effects are muted, and costs remain elevated, so confidence in alternative pathways builds more slowly. Policy uncertainty and gaps in financing, standards, and data amplify each step in the loop, turning caution into inertia as demonstrated in exhibit 3.1.

SAF cost premium

SAF costs are 2-5x of jet fuel

Low visibility on when prices are expected to streamline

Weak demand signal

Buyers hesitant to commit at current price differentials

Low voluntary corporate demand with lack of consensus on Book & Claim

Low maturity of pathways apart from HEFA

Overreliance on HEFA pathway

Low tech maturity of alternate pathways

Limited scale-up of production & supply

Lack of credible demand weakens investor confidence

High Capex and long payback period

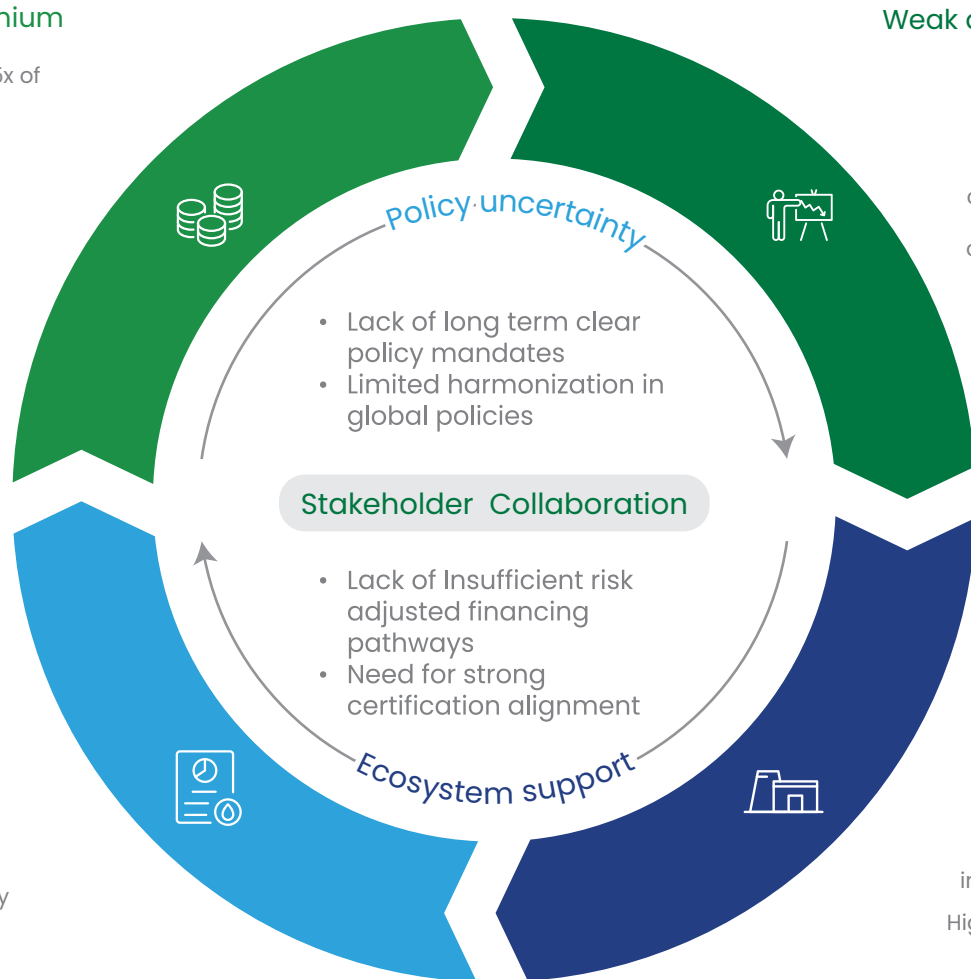


Exhibit 3.1: Challenges in SAF Adoption

Sidenote Solar PV industry

From the 2000s through the early 2010s solar PV was trapped in a vicious cycle. High module costs suppressed demand, and weak demand kept factories small, leading to incremental research and high costs. However, solar emerged from this vicious cycle and from a global capacity of about 40 GW in 2010, it expanded to about 1.8 TW by the end of 2024, with additions of 451GW in 2024 alone.

The break came from policy and ecosystem design that created bankable demand and scale. In the United States a 30% Investment Tax reduced effective project costs and catalyzed finance. Germany used feed-in tariffs that guaranteed offtake and accelerated early deployment. India's National Solar Mission and subsequent guidelines from the Government of India shifted procurement to tariff based competitive bidding with standardized documents, which disciplined prices and improved project bankability. Together these policy and ecosystem tools converted sporadic purchases into predictable pipelines that manufacturers could scale against and that investors could underwrite with confidence.

Scale and learning then created a virtuous cycle. Average module prices fell from around \$2/watt in 2010 to near record lows around \$0.2/watt in 2024 based on global spot and market averages. Falling costs enabled ever larger projects and higher efficiency cell architectures. The result is a feedback loop in which policy created demand lowers costs and lower costs unlock more demand. Rising demand justifies factory and supply chain expansion and scale plus innovation drives another round of cost reductions. Within about fifteen years PV moved from a niche technology to a mainstream market that now adds hundreds of gigawatts each year.

SAF cost premium

SAF today costs roughly two to three times more than conventional jet fuel, largely

because of high feedstock prices and limited production capacity. For an industry like aviation that already operates on thin margins, with fuel accounting for 25% to 30% of total operating costs, such a premium is difficult to absorb. With a pass-through model to preserve airline margins, ticket costs could increase by 3–6% for SAF costs of 2x to 3x compared to conventional jet fuel considering blending ratio of 10% only. In the absence of broad market adoption or strong policy support, any airline choosing to use SAF risks eroding its competitiveness, either by passing the additional cost to consumers or absorbing it within its balance sheet.

When airlines first set out their decarbonization strategies, many expected SAF prices to decline steadily through this decade as production scaled. Those expectations have not materialized. Global SAF output remains below 0.7% of total jet fuel demand. Even though more than 60 airlines have signed offtake agreements with producers such as Neste, World Energy, and Aemetis, these commitments cover a minute share of projected 2030 demand for SAF.

Low demand signal

With little forward price visibility and no clear path to cost parity, airlines remain cautious about entering long-term offtake contracts, especially through voluntary commitments. The absence of stable, clearly defined blending mandates and enforceable penalties limits airlines' ability to commit to long-term offtakes. This weak demand signal slows investment, keeping supply limited and reinforcing today's price premium

Consumer demand adds another layer of constraint. Awareness of SAF among passengers remains limited, and willingness to pay a premium for lower-carbon travel is uncertain. Corporate flyers have been more proactive on this front, with several large companies committing to reduce their Scope 3 emissions through SAF purchases or book-and-claim schemes. Initiatives such as the Sustainable Aviation Buyers

Alliance and First Movers Coalition have created early momentum by aggregating corporate demand and facilitating transparent SAF procurement. However, this segment still represents only a limited share of total passenger traffic, and on routes with limited corporate participation, such models are difficult to replicate.

As a result, current demand for SAF is supported primarily by a narrow set of voluntary initiatives and pilot programs rather than broad, sustained market pull. Unlocking wider adoption will depend on mechanisms that share costs more evenly across the aviation value chain and create predictable, long-term demand signals for producers. Firm demand signals in terms of Offtake commitments are further discussed in Chapter 4, Section 3, “Establishing long-term offtake agreements”.

Limited scale-up of production & supply

Expanding SAF supply depends on resilient feedstock, logistics infrastructure and commercial scale production facilities. Output is still dominated by HEFA and scaling is constrained by the need to secure sustainable lipids over the life of each plant. Changing sustainability criteria have also dampened investor appetite for new HEFA capacity. HEFA's dependence on lipid-based feedstocks also exposes it to availability and price constraints. The broader feedstock challenge and its implications for scaling are explored in Chapter 4, Section 1, “Feedstock limitation for HEFA”. Supply chains for used cooking oil and waste fats are relatively established, whereas agricultural and forestry residues and municipal solid waste for emerging pathways lack organized collection systems. Scaling these facilities requires local aggregation hubs, robust quality control, and dedicated transport that can provide reliable long-term supply.

High capital expenditure requirements add further complexity. Building a commercial-scale SAF plant demands

significant upfront investment, and uncertainties around feedstock sourcing and long-term policy signals often make these projects difficult to finance. Although investment in blending and storage infrastructure is relatively modest compared with plant construction, it remains a necessary enabler for scaling physical SAF deliveries. This is further explored in chapter 4, Section 4: “Establishing SAF supply infrastructure”.

Developers also face information gaps when identifying viable project locations. Reliable, granular data on feedstock availability, collection costs and transport logistics over extended periods are often scarce, especially in the Global South, increasing the time and effort required for site assessment. Establishing open, data-driven mapping of feedstock resources could help reduce these early-stage risks and guide investment toward the most suitable regions.

Building a robust SAF supply ecosystem will therefore require a coordinated approach, without which production growth will continue to face systemic bottlenecks, slowing the sector's ability to expand at the pace required for meaningful decarbonization. Without coordinated action, scaling stalls and the virtuous cycle required for cost reduction cannot take hold.

Low maturity of pathways beyond HEFA

Current SAF production remains heavily concentrated in a single technology with HEFA accounting for the majority of global output today. Co-processing of bio-feedstocks alongside fossil crude in existing refineries is also expanding, but the approach is limited by ASTM certifications that typically allow a maximum blend of around 5%. While these routes have proven the technical feasibility of SAF, they cannot deliver the scale needed for deep decarbonization highlighting the need to accelerate the commercialization of new technology

pathways. Processes such as gasification followed by Fischer–Tropsch synthesis, alcohol-to-jet, and power-to-liquid fuels have all demonstrated technical viability, but few have progressed beyond pilot or demonstration plants so far. Although gasification and Fischer–Tropsch technologies have been proven at scale in different applications, their integration for SAF production remains complex. The limited scale-up of these alternatives has begun to affect investor confidence, as timelines lengthen and capital intensity remains high.

Even within existing technologies, significant investment is required to reduce both capital and operating costs through process optimisation, improved catalysts and supply chain efficiencies. Establishing regulatory sandboxes for emerging SAF pathways can accelerate certification and market entry, enabling next-generation technologies to scale faster once current HEFA capacity reaches its limit. At the same time, stronger collaboration between technology developers, refiners and research institutions will be essential to accelerate learning, share performance data and bridge the gap between demonstration and deployment. Without such progress, SAF innovation risks remaining confined to a narrow set of mature pathways, constraining the sector’s ability to grow at the pace required for aviation’s net-zero transition. Diversifying pathways reduces feedstock risk and supports the scale required to bend costs down over time. These themes have further been explored in Chapter 4, Section 2: “Technology readiness of alternative pathways”.

Policy uncertainty

With the current economics of SAF, policy remains the single most important lever determining the scale and pace of deployment, especially in this nascent phase of the industry. While several governments have introduced frameworks to support SAF, few provide long-term visibility or certainty. This poses

a challenge for investors planning new facilities, as developing and commissioning a commercial SAF plant can take five to seven years. To undertake projects of this scale, developers need predictable incentives and mandates for at least a decade beyond commissioning. The lack of durable and clearly defined policy horizons has therefore made it difficult for offtakers to make long-term binding agreements and for producers to reach final investment decisions.

As these policy frameworks are still nascent, regulatory parameters and implementation guidelines continue to evolve. Ambiguity around incentive eligibility, blending targets, qualification criteria and documentation often delays support. Over the last few years, governments have revised feedstock eligibility, sustainability criteria and LCA methodologies often altering project economics mid-development. The transition from RED II to RED III in the European Union and ongoing clarification on the incentives in the United States illustrate how such changes can unsettle investors. Each adjustment introduces uncertainty over which technologies or feedstocks will qualify for incentives.

The challenge is compounded by limited harmonization across jurisdictions. As a global industry, aviation must navigate differing definitions of sustainability, inconsistent LCA methodologies such as CORSIA, EU RED and GREET, and fragmented certification regimes. This increases the cost and complexity of compliance, constraining cross-border trade and hindering the emergence of a cohesive global market for SAF.

Policy is therefore a critical enabler for accelerating SAF uptake, shaping both demand creation and supply expansion. Its role, and the emerging models of effective policy design, are examined in

Ecosystem support

Beyond technology and supply chains, the wider ecosystem that supports SAF

production and deployment remains nascent. The sector still needs to mature on several fronts which are explored below:

- **Sustainability alignment:** Countries differ in their eligibility lists, LCA methods and treatment of indirect Land-Use Change (iLUC), creating uncertainty for producers operating across markets on what counts as “sustainable”. This lack of consensus raises compliance costs and reduces interoperability of global SAF supply chains. Further, scaling of certification agencies and capacity building has not kept pace with potential for developing feedstock supply chains in Global South. Many producers face delays due to skill shortages and the limited presence of accredited agencies in these regions, impacting potential development of feedstock hubs. This is further explored in chapter 4, Section 6:” The Role and Purpose of Certification in SAF”
- **Financing:** SAF projects remain capital intensive and high risk, requiring patient capital and early-stage de-risking. Yet few blended-finance and insurance instruments, guarantees or concessional facilities are tailored to the sector. The bankability concerns are further extended by policy uncertainty and limited demand visibility which deter private investors.

- **Carbon market signals.** Underdeveloped carbon markets offer little financial incentive for SAF deployment. Credit prices remain low, liquidity limited, and accounting methodologies inconsistent, leaving producers uncertain about how to value emission reductions. A more transparent and predictable carbon pricing framework could help channel finance toward SAF production and close part of the cost gap with conventional jet fuel.

While international bodies such as ICAO, IATA and ISO are developing complementary frameworks, there is no unified mechanism to align Policy, certification and investment priorities across stakeholders. This fragmentation slows industry learning and adds to transaction costs, underscoring the need for more structured platforms for collaboration and joint planning.

These challenges are significant and overcoming them is essential given the important role of SAF in the aviation sector’s transition to net-zero. Global SAF production needs to scale more than 100x by 2050 to achieving the sector’s 2050 net-zero target. Bridging this gap demands sustained progress across policy, technology, infrastructure and markets. The next chapter explores six key levers that can drive this scale-up, each of which will be critical to unlocking the next phase of SAF growth.

Chapter 4 | Section 1: Feedstock limitation for HEFA

HEFA SAF Feedstocks: Availability, Limitations, and Opportunities

To produce SAF, there are several technology pathways that convert different types of renewable materials into jet fuel. Among all available routes, the Hydroprocessed Esters and Fatty Acids (HEFA) process has emerged as the most technically advanced and commercially established option. It is currently the backbone of global SAF production, accounting for over 90% of current and planned SAF production capacity.

The price premium over conventional jet fuel remains the principal barrier to SAF adoption, and under the HEFA pathway feedstock costs account for a significant share of that premium. Lowering feedstock costs and widening sustainable supply are the most near term ways to reduce prices and increase production.

The HEFA process depends heavily on lipid-based feedstocks, which can broadly be grouped into three main categories that together define the potential and limitations of this pathway:

- **Waste and residual oils:** This includes used cooking oil (UCO) from restaurants and households, waste animal fats (tallow), grease and trap oils from industry, and other recycled oils. These waste lipids are attractive due to their low carbon footprint and avoidance of land-use impacts.
- **Virgin vegetable oils:** 1G vegetable oils from crops such as soybean, rapeseed (canola), palm, sunflower, etc. These were traditionally used for biodiesel and can also be processed via HEFA into jet fuel.
- **Novel vegetable oils (NVOs):** Emerging second-generation oilseeds (e.g., carinata, camelina, pennycress) that can be cultivated as rotational or cover crops, generating feedstock for HEFA-type fuels without displacing

food production. These are often classified as “low-input” crops, as they typically require less irrigation, fertilizer, and pesticide use, and can grow on marginal or lower-quality land, improving soil health and reducing iLUC risks compared to conventional oilseeds.

Dominant Feedstocks Today: UCO and Plant Oils

In practice, used cooking oil and other waste oils, along with some virgin vegetable oils, currently dominate HEFA SAF production. Refiners prefer waste-based feedstock whenever possible because of policy incentives and sustainability advantages. For example, UCO and tallow earn stronger credit value compared to vegetable oils under most incentive schemes, making them economically attractive feedstocks.

Virgin plant oils are also used today (especially where waste oils are scarce), but they are less sustainable than waste oils and risk driving iLUC. Many governments have highlighted risks relating to such feedstocks, for instance, the EU’s Renewable Energy Directive places caps on food crop-based biofuels and both EU and UK SAF regulations do not allow the use of food and feed crop-based SAF.

Stage		Low	Medium	High	Assumptions	What can unlock this stage
 Theoretical UCO potential	Annual global waste-lipid pool that could, in principle, be generated	31 Mt	35 Mt	38.0 Mt	31 Mt projected by S&P, 38MT Projected for 2030 by Global data	Not much can be done to expand the global generation of UCO
 Collected UCO	Material collected from restaurants/ food processors/ households	20% → 6.2 Mt	50% → 17 Mt	80% → 30.4 Mt	Wide dispersion of collection rates today (e.g., Japan 21–37%, Malaysia 30–45%, China 60–80%, Korea 76–92%)	Mandated take-back for food businesses; household drop-off schemes; city level collection mechanisms; reduce illegal use; price signals to small generators
 UCO routed to biofuels	Allocation across competing sinks (UCOME/RD vs SAF)	80% → 4.9 Mt	90% → 15.3 Mt	95% → 28.9 Mt	Estimates suggest 80% of the total UCO is relayed for biofuels production	Guaranteed SAF demand, airline offtakes, and refinery configurations that prioritize jet.
 HEFA renewable liquids	Total hydrocarbons produced per t UCO (mass basis)	0.85 yield → 4.2 Mt	0.92 yield → 14.5 Mt	0.95 yield → 27.4 Mt	TEAs/LCA show high liquid yields from lipids (order 0.85–0.95 depending on slate & process)	Feedstock pretreatment for better yield, Catalyst Performance improvement, and steady-state operations
 SAF share of liquids	Jet fuel fraction in the product slate	15% → 0.63 Mt SAF	30% → 4.3 Mt SAF	55% → 15.1 Mt SAF	Default HEFA favors diesel; >15% jet requires extra processes and raises cost; 30% is a realistic midpoint with 50–65% as the upper end with higher costs	“Max-jet” operations tuned by reactor severity and fractionation; Dedicated catalyst campaigns

Exhibit 4.1.1: Projected UCO-based SAF potential by 2030

The above model analyses three hypothetical scenarios to assess UCO-based SAF availability. Beginning from the low scenario, each subsequent scenario assumes more favorable conditions for UCO availability for SAF production via HEFA. However, as the table illustrates, once the entire supply chain is traced from theoretical availability to actual collection and conversion, the effective SAF yield from waste oils is far more limited. Competition from other biofuel uses, collection inefficiencies, and conversion losses along

the HEFA pathway all constrain the ultimate volume of jet fuel that can be produced. Even in a balanced, medium-case scenario, the SAF output from UCO would still fall significantly short of the expected demand of ~10 Mt by 2030, highlighting that it cannot support large-scale growth over the long-term. Nevertheless, it remains critical to maximise the use of UCO and other waste oils in the near term, as they are essential to help HEFA scale as the only commercially proven pathway capable of meeting immediate SAF deployment goals.

Used cooking oil and other waste lipids have inherent scaling limitations

1. The total obtainable quantity of UCO-derived HEFA is relatively small compared to the enormous fuel demand of aviation. Global UCO generation is a fraction of the 360 Mt of jet fuel used annually in 2024.
2. Collecting these dispersed waste streams is challenging, especially from households. Much of the potential UCO is not being captured due to inefficient or nascent collection systems. For example, India is estimated to collect only 13–19% of its theoretical UCO potential. Many other countries similarly collect only a small share of available used oil, with the remainder often ending up in sewers, informal reuse (e.g. illicit “gutter oil”), or simply discarded. Improving collection infrastructure and awareness is a slow, region-by-region process.
3. Another constraint is competition from other biofuel sectors. UCO and tallow have been popular feedstocks for marine biofuels, biodiesel and renewable diesel producers for years. Road transport biofuels, which are already a mature market, consume a large portion of the waste oils that are collected. With climate policies promoting low-carbon fuels in trucking and marine transport as well, these sectors vie for the same limited waste lipid.
4. Even when waste oils are available, the HEFA refining process has technical limitations on how much jet fuel it produces per unit of oil. Under normal operating conditions, a HEFA refinery produces predominantly heavy hydrocarbon products akin to diesel. In fact, only around 15% of the liquid output is jet fuel (HEFA-SPK) unless additional cracking steps are applied. It is technically feasible to increase the jet fuel yield in HEFA through more severe hydrocracking and fractionation, but this comes at a cost. Studies show that by redesigning and operating the process to maximize jet-range output, the jet fraction could reach roughly 50% of the total product.

As a result, HEFA SAF producers face feedstock supply bottlenecks and rising input costs. Industry reports note that overall waste oil supply is “curtailed by the reliance on industrial waste streams and by competition from other transport sectors”.

Opportunities to Improve Waste Oil Utilization

Improve collection efficiency:

Governments and industry can invest in better systems to gather used cooking oil and waste grease, especially from diffuse sources like small restaurants and households. Regions like China, India, and Southeast Asia have significant uncollected UCO potential that could be realized with stronger incentives and logistics. Programs to certify and buy UCO from food businesses, community drop-off points for household oil, and public awareness campaigns can all increase the volumes captured. Some cities have begun installing collection bins for used cooking oil (for example, Seattle’s biodiesel programs), offering a template that could be replicated globally. Higher collection rates directly translate to more feedstock for HEFA without land expansion, however, any expansion must account for higher carbon emissions and procurement costs from a larger catchment area.

Policy incentives to prioritize SAF use:

Currently, a large share of collected UCO is consumed by the bio-based diesel alternatives for road transport due to longstanding blending mandates and double-counting credits for waste-based biofuels in some regions. New policies could carve out a portion of these waste oils specifically for aviation.

Process optimization for higher SAF yield:

Refineries can invest in equipment and catalyst upgrades to increase the fraction of jet fuel produced from each barrel of

Improve collection efficiency:

Governments and industry can invest in better systems to gather used cooking oil and waste grease, especially from diffuse sources like small restaurants and households. Regions like China, India, and Southeast Asia have significant uncollected UCO potential that could be realized with stronger incentives and logistics. Programs to certify and buy UCO from food businesses, community drop-off points for household oil, and public awareness campaigns can all

Expanding Novel Oilseed Crops for HEFA

A major opportunity to scale HEFA production lies in cultivating sustainable, non-food oil crops to expand HEFA feedstock supply. Unlike first-generation oilseeds grown on prime farmland, these strategies aim to produce oil without displacing food or causing land-use change. Two main approaches are emerging:

Dedicated non-food oil crops:

Plants like *Jatropha*, *Camelina* and *Carinata* have the potential to unlock HEFA scalability while preserving sustainability, as they thrive on fallow, degraded, or semi-arid lands where food crops struggle. They also tend to require relatively low inputs; for example *Camelina* grows with minimal fertilizer or irrigation and can even help restore soil health. Large-scale deployment, however, will depend on developing seeds and supply chains thereof, partnerships across the value-chain, agronomic expertise and farmers training, pilot and demo programs, and market incentives and policy support.

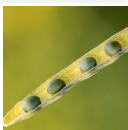
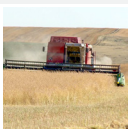
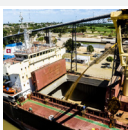
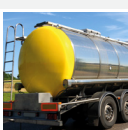
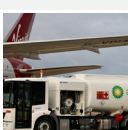
Integrating oilseed cover crops into existing agriculture:

Oilseeds crops like Pennycress, Winter *Camelina*, *Brassica Carinata* can be planted as intermediary cover crops between food crop cycles in a variety of climates. One way to achieve this can be

through crops that grow over winter, protecting and enriching soil, and are harvested in spring for oilseed before the next food crop. This “second crop” model adds feedstock without expanding farmland, while delivering environmental co-benefits such as erosion control and carbon sequestration.

Looking ahead, these novel oilseed systems could substantially expand the pool of sustainable oils available for SAF. Unlike existing waste streams, purpose-grown feedstocks can scale with demand if cultivated responsibly on idle and degraded land, or through rotational cycles.

Adoption of such systems requires dedicated efforts and may still feel “new” for the ecosystem. Early on, farmers weigh seed costs and the uncertainty of trying an unfamiliar crop. But these are practical, solvable hurdles, and extensive development of seeds and testing and piloting cycles in real-world conditions can help mitigate risks and reduce uncertainties to a certain extent. Clear price signals and simple offtake agreements can reduce risk, extension support can build on-farm confidence, and local aggregation with basic quality assurance can make the first mile work. As buyers show up reliably and pay on time, the economics can settle for acreage to follow.

Key value chain activities		Hypothesis: responsible player ¹	Key challenges
 Seed development & production	 Seed co	Find seed developer with opportunity to partner	
 Farmer recruitment	 Seed co	Remuneration for incentives; De-risking crop switch	
 Seed sales	 Seed co	Seed pricing mechanism (can include seeds w/o charge to farmer)	
 Growing & harvesting	 Farmer	Level of farmer's risk taken	
 Crop logistics & storage	 Crushers	n/a	
 Crushing	 Crushers	Relationship with crusher; Readiness of crusher to accept novel feedstock	
 Feedstock marketing and sales	 Aggregators/ Traders	Cost of shipping seed oil if crusher not near biofuel refinery	
 Biofuel refining	 SAF producers	Seed oil pricing mechanism	
 SAF sales & distribution	 Producers/ Fuel suppliers	n/a	

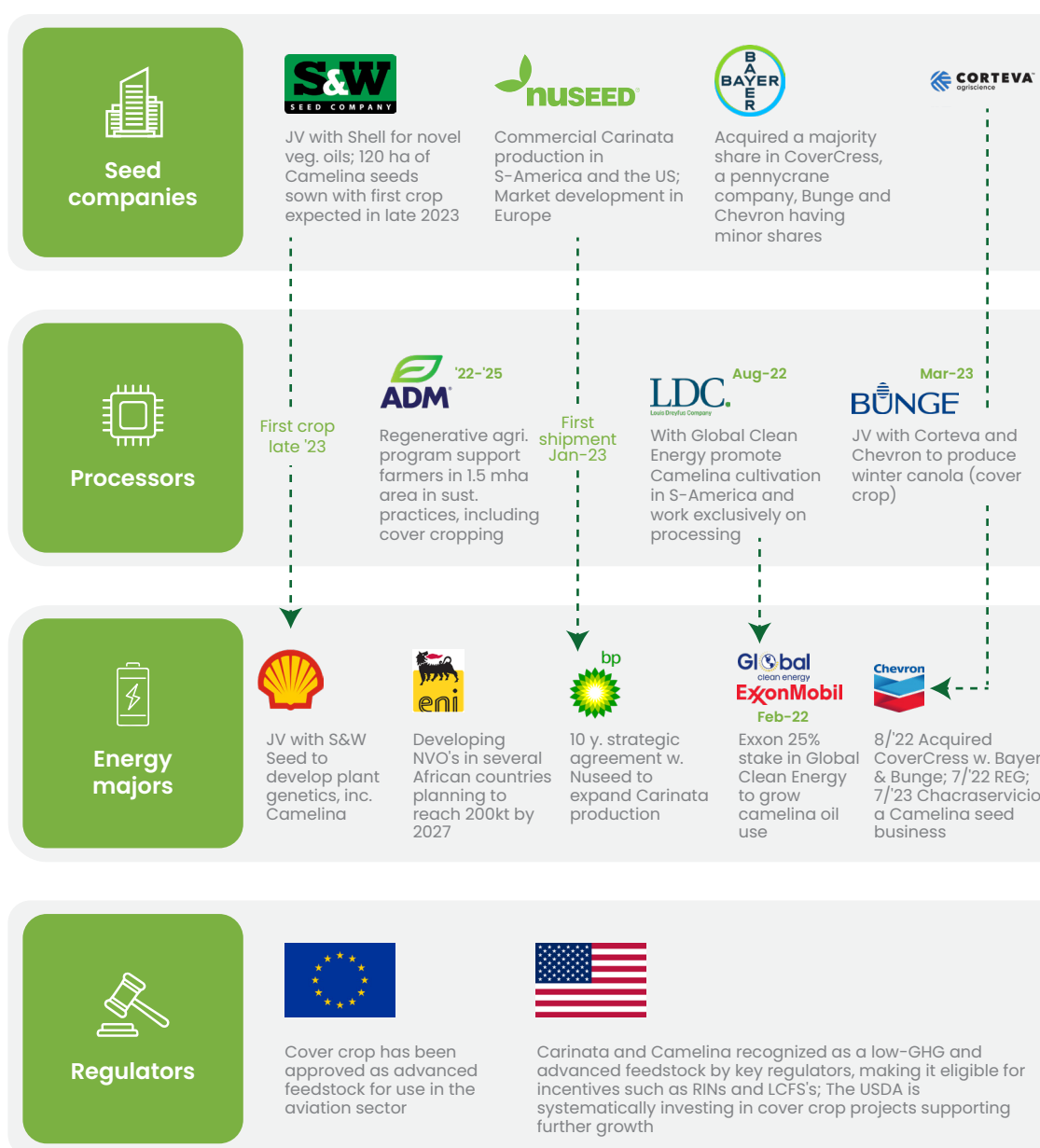
1. Responsible may mean executing player, or may mean subcontracting of specific activities

Exhibit 4.1.2: Challenges in adoption of Novel vegetable oils

Unlocking the full potential is also about changing habits, not just technologies. When planting windows, rotations, and payment cycles are made easy and when farmers see trusted neighbors succeed, adoption accelerates. Co-ops and offtakers that provide seed, advisory, and guaranteed purchase, while recognizing soil-health improvements, create a flywheel of trust. With that alignment, growers can integrate these crops at scale and sustainably, and with lasting benefits

to both farm incomes and SAF supply.

Even once the agronomic potential is proven, establishing economically viable supply chains at scale will remain a major hurdle. Early-stage deployment is likely to face high collection, aggregation, and logistics costs, with limited processing capacity making coordinated investment and policy support essential to reach commercial viability



1. EU Renewable Energy Directive 2. Common Agricultural Policy
Source: European Commission; US EPA; USDA; Press releases; BCG analysis

Exhibit 4.1.3: Stakeholders across the NVO landscape

Exhibit 4.1.3 outlines some of the existing partnerships building the NVO supply chain. Seed companies, processors, and energy majors are forming partnerships to improve crop genetics, secure offtake, and expand cultivation of promising species like Camelina and Carinata. Companies have already invested in pilot programs across Africa and South America to test seeds, assess yields, validate economics, and strengthen aggregation and logistics models, demonstrating that this transition is already underway rather than theoretical. At the same time, regulators in the EU and US are recognizing these crops as low-carbon, advanced feedstocks eligible for renewable fuel incentives. Together, these coordinated initiatives signal a shift from experimentation to early commercialization and an ecosystem increasingly aligned to make NVO a reliable and scalable feedstock for future SAF production.

Expanding SAF potential through feedstock diversification

Beyond waste lipids, bio-SAF scale can come from diversifying feedstocks through alternative pathways such as Alcohol-to-Jet (AtJ) and Gasification-Fischer-Tropsch (GFT). Lignocellulosic residues like agricultural straw, bagasse, corn stover, rice husk, forestry by-products and sorted municipal solid waste are abundant and geographically distributed. The feedstock base for these alternate pathways is far broader than HEFA and tapping vast 2G sources has large potential to unlock SAF production.

Case in point: Non-grain-based feedstocks dwarf UCO in scalable potential

India's non-grain feedstock base including agricultural residues (rice/wheat straw, cotton stalks, bagasse), animal manure, forest residues, and sorted MSW is vastly larger than UCO. The GBA assessment estimates only ~3.5 MMT of UCO versus >2000 MMT of sustainably available excess non grains based biomass, with clear geographic concentrations mapped

across states and seasonal availability by residue type. This highlights the availability of non grain based biofuels at national scale and their potential to be mobilized with the right systems.

The same report highlights that unlocking non grain based feedstocks depends on improving collection efficiency, pre-treatment/logistics, and enabling policy/finance rather than on absolute resource size. In short, feedstock availability is not the constraint for non grain based pathways, however, it needs the production technology to advance.

Key Takeaways:

- HEFA is the dominant SAF production pathway today, but growth is capped by limited sustainable lipid-based feedstock and sourcing constraints.
- Waste lipid feedstocks are finite and contested however, they can be optimized via better collection, allocation, and higher refinery jet yields to meet near-term demand.
- Novel vegetable oils can expand HEFA sustainably, but need seed R&D, new agricultural practices, farmer support, and supply-chain pilots.
- To truly scale SAF, essential to diversify beyond HEFA into alternate pathways like AtJ and GFT which can utilise abundant residues and waste-based feedstock.

Chapter 4 | Section 2: Technology readiness of alternative pathways

Need for Innovation Beyond HEFA

Meeting net-zero trajectories will require over 500 Mt of SAF each year compared with about 2 Mt expected in 2025. To achieve true system-wide decarbonization, the industry cannot rely solely on HEFA production pathway. Reducing the cost premium requires much larger volumes and a broader mix of feedstock. Scaling production can drive learning, improves utilization, and efficiency, which together lower unit costs.

Exhibit 4.2.1 below illustrates this critical shift. Each emerging SAF pathway, from HEFA and AtJ to GFT and PtL (e-SAF), draws on distinct feedstock bases, expanding the carbon and hydrogen resource pool available for aviation fuel production. This diversity is what will enable regional specialization and long-term scalability in a net-zero aviation system by tapping into abundant resources specific to each region.

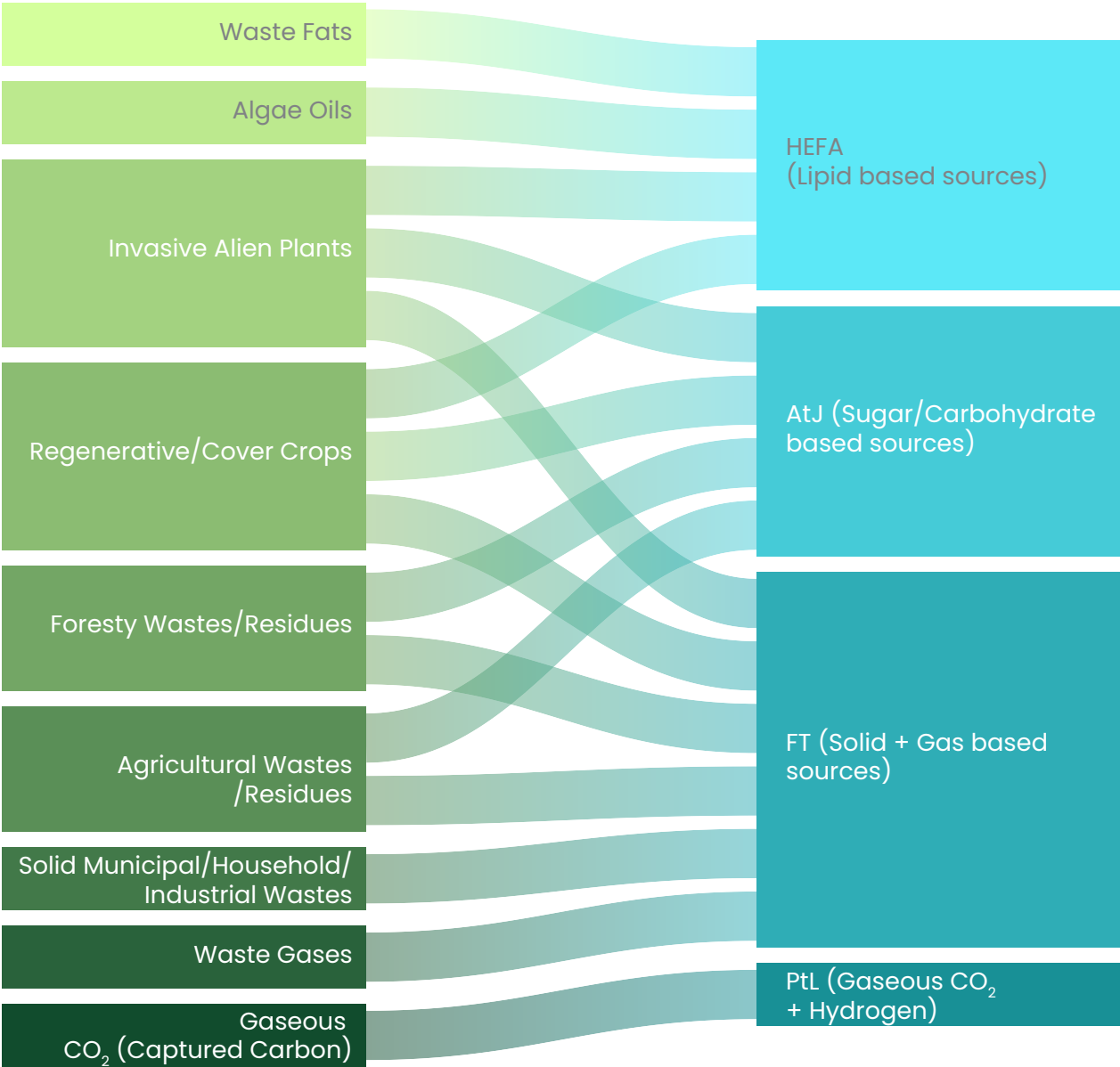


Exhibit 4.2.1: Feedstock mapping to production pathways (Not Exhaustive)

While HEFA continues to dominate near-term deployment, early investment trends already reflect a transition toward a more diversified technology landscape.

As shown in Exhibit 4.2.2, upcoming SAF projects to scale rely on HEFA with small facilities for AtJ and GFT coming up.

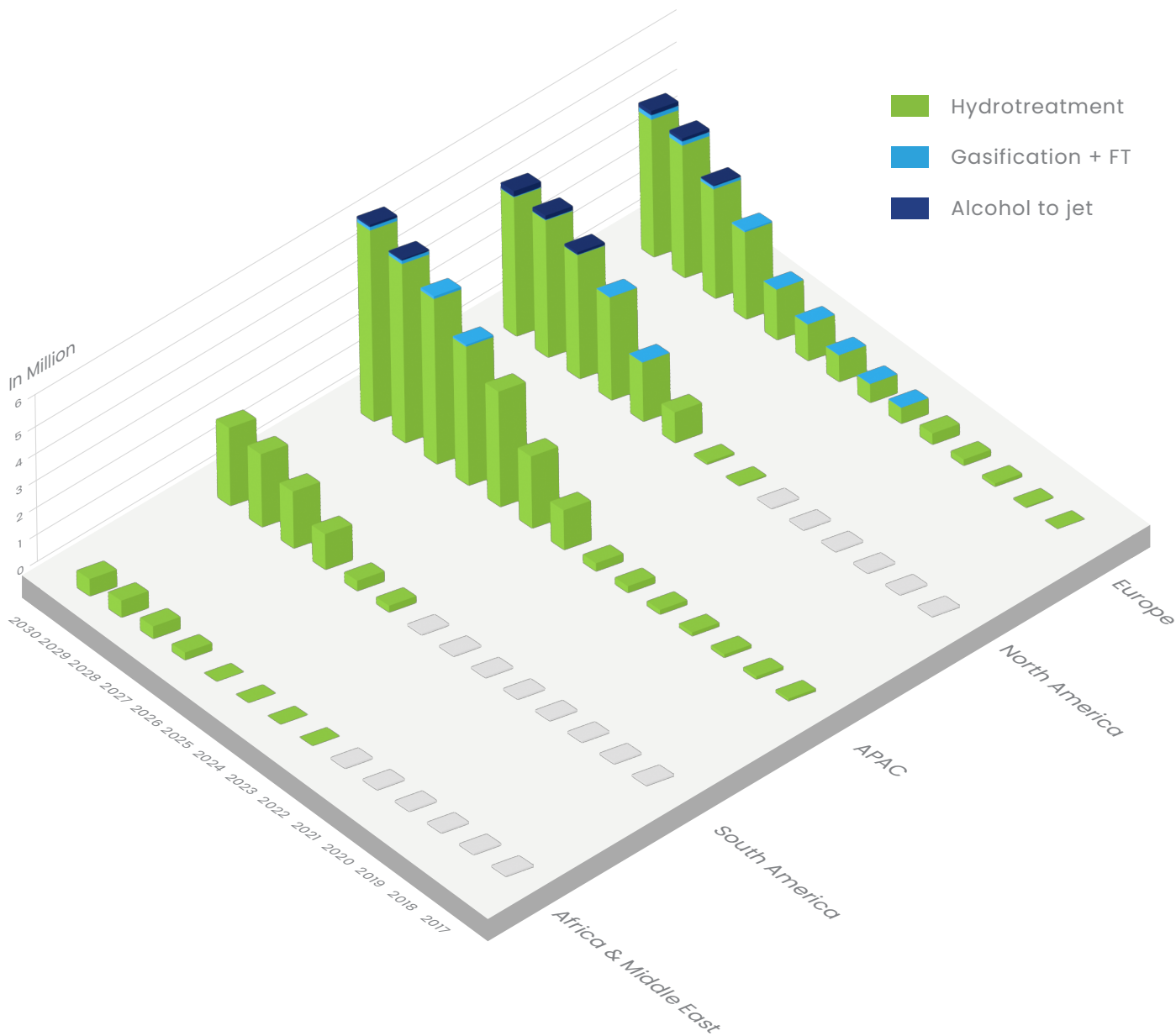


Exhibit 4.2.2: Projected SAF production capacity across region by technological pathways (in Mt) (Source: BCG Analysis)

*SAF capacity based on announced or expected nameplate figures, assuming ramp-up at 50% (year 1), 75% (year 2), and 100% (year 3+). Actual supply may be lower due to capacity utilization <100% and potential production shift from SAF to HVO Renewable Diesel (market-driven).

This diversification can enable regional production tailored to local resource strengths, and drive down prices through innovation and competition. Ultimately, scaling SAF to meet global net-zero goals will depend on how effectively the industry can nurture, de-risk, and commercialize multiple technological routes.

Prominent alternatives

To achieve this diversification, ASTM International has expanded its certification framework, approving nine synthetic aviation fuel pathways under ASTM D7566 (Standard certification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons) as of 2025 and co-processing pathways under ASTM D1655 (Standard certification for Aviation Turbine Fuel). Each pathway defines specific feedstocks and conversion processes capable of producing drop-in jet fuels compatible with existing aircraft and infrastructure.

Among these, three emerging technologies stand out as the most mature alternatives to HEFA:

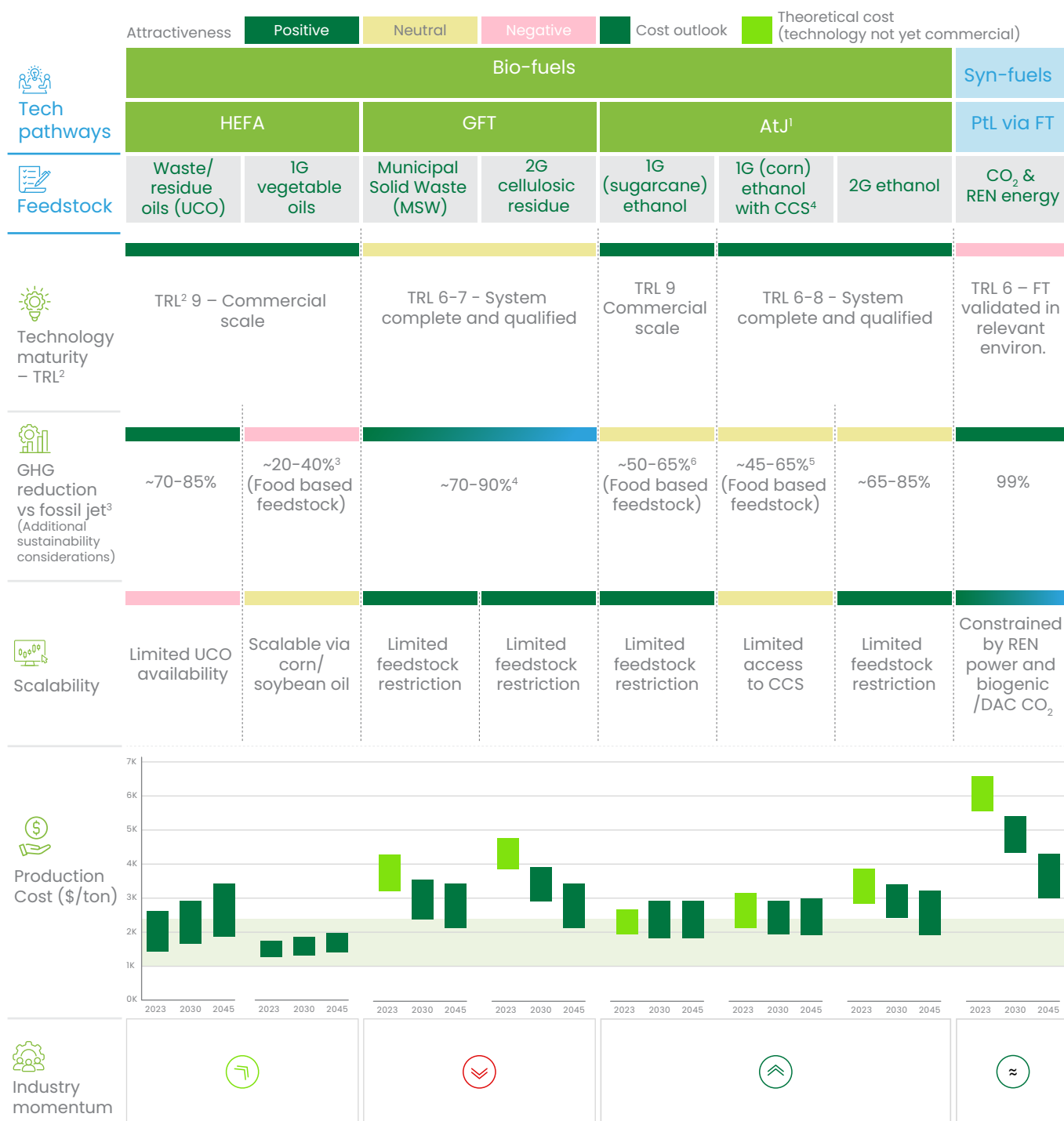
- **AtJ:** Converts ethanol and other alcohols into olefins and then (mostly paraffinic) hydrocarbons like Renewable Diesel and SAF
- **GFT:** Transforms biomass and waste into sustainable fuel through syngas production and chain-growth to longer hydrocarbon molecules, often including waxes on top of kerosene/diesel range and naphtha

- **PtL:** Synthesizes jet fuel from renewable hydrogen and captured CO₂ through Fischer Tropsch or Methanol synthesis followed by Methanol-to-Jet (MTJ).

Together, these routes expand the usable carbon and hydrogen resource base and represent the next frontier for scaling SAF to meet net-zero aviation goals.

Most of these pathways have advanced meaningfully in recent years, supported by pilot and first-of-a-kind commercial demonstrations. Yet, all continue to face technical, operational, and economic barriers that limit near-term scalability from conversion efficiency and feedstock logistics to capital intensity and product certification.

Exhibit 4.2.3 below provides a comparative snapshot of these major SAF production pathways. It highlights how HEFA remains the most mature technology today but is feedstock-constrained, while AtJ, GFT, and PtL represent the next generation of scalable solutions that need continued innovation and policy support to achieve full commercial deployment.



1. Assuming an integrated ethanol production and ATJ conversion design; 2.TRL – Technology readiness level; 3. GHG reduction compared to conventional jet fuel (89gCO₂ eq/MJ). Based on ICAO LCA incl. ILUC figures except for 1 ethanol CCS; GHG reductions shown in the analysis are indicative, they can be further optimized by measures such as renewable energy sourcing, supply chain decarbonization etc.; 3. Assuming vegetable oils such as rapeseed, soybean 4. MSW GHG reduction dependent on non-biogenic carbon in the MSW mix; 5. Assuming corn-based ethanol (47–60 gCO₂e/MJ) with CCS during fermentation (~31gCO₂e/MJ). Based on GEVO figures, excluding energy efficiency measures or renewable electricity; 6. Sugarcane-based ethanol CI 25–30 gCO₂e/MJ, AtJ 8–14 gCO₂e/MJ
Source: ICAO, BCG Analysis

Exhibit 4.2.3: Overview of prominent SAF production pathways

Alcohol-to-jet (AtJ) :

AtJ fuels are produced by converting alcohols such as ethanol or isobutanol, into jet-range hydrocarbons via dehydration, oligomerization, and hydrogenation. AtJ - synthetic paraffinic kerosene (SPK) was first certified in 2016 from isobutanol and in 2018 from ethanol

with a 50% blend limit. This pathway can leverage widely available alcohol as feedstock, including existing ethanol production infrastructure. Countries like Brazil, India and US have massive ethanol industries that could supply feedstock for AtJ, potentially yielding billions of gallons of SAF.

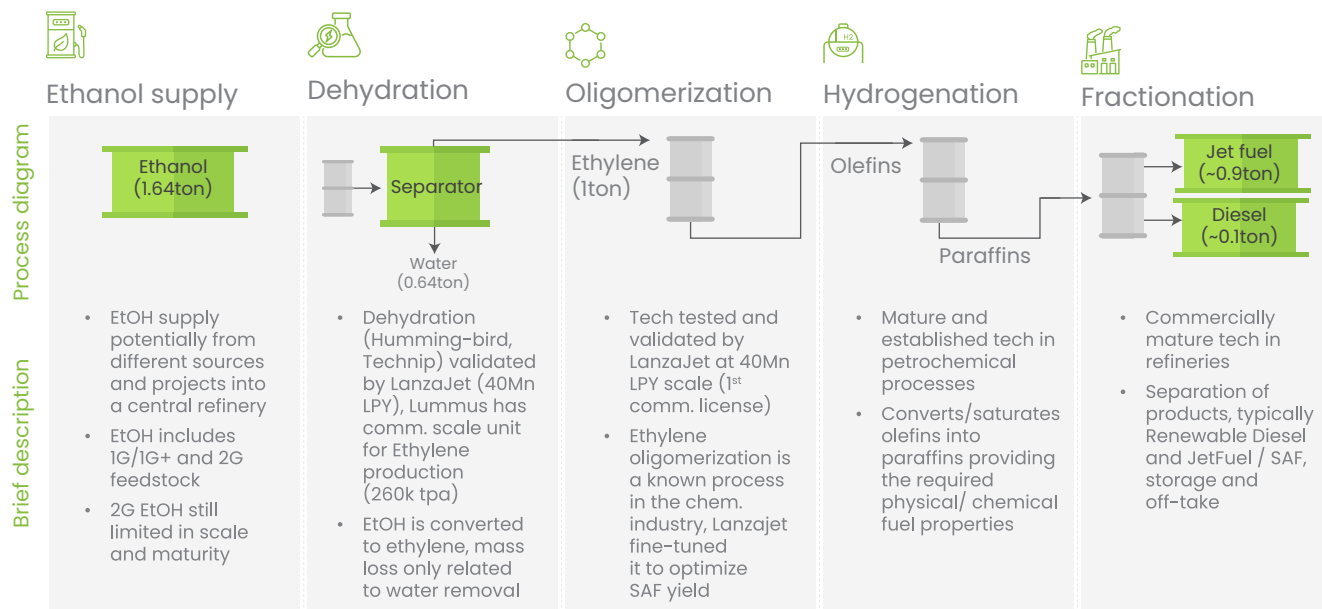


Exhibit 4.2.4: Technical Diagram of Alcohol to Jet pathway

The pathway offers notable advantages. The feedstock base is broad, encompassing sugars, starches, and lignocellulosic residues. The technology also supports a “hub-and-spoke” deployment model which decouples alcohol production from jet fuel upgrading, allowing distributed, low-cost feedstock conversion at the periphery and centralized, capital-intensive fuel synthesis at scale. This configuration can provide a high degree of flexibility and hedging in terms of ethanol feedstock sourcing.

From a process standpoint, AtJ can offer high carbon yield and selectivity toward jet fuel, achieving life-cycle carbon intensity reductions of up to 80% when using low-carbon ethanol feedstocks. The conversion operates under mild process conditions, resulting in comparatively lower capital and operating costs relative to more complex thermochemical pathways like GFT. These advantages

make AtJ a commercially promising routes for scaling SAF production in the near to medium term.

Few early pilot and demonstration plants have validated the technical feasibility of the AtJ process. Gevo’s Luverne plant in Minnesota has successfully demonstrated isobutanol-to-jet conversion under continuous operation, while AtJ Japan, a national demonstration project has tested ethanol-based AtJ fuel at smaller scale for domestic aviation use. These projects illustrate growing confidence in the pathway’s potential to scale.

The LanzaJet Freedom Pines Fuels facility marks a major step forward in commercializing the AtJ pathway. The project secured diversified financing from the US Department of Energy, Microsoft’s Climate Innovation Fund, and Breakthrough Energy, while offtake agreements with IAG airlines, British

Airways and All Nippon Airways ensured long-term market demand. By prioritizing low-carbon ethanol sourcing, the plant demonstrates the pathway's ability to achieve meaningful life-cycle emissions reductions.

Although commissioning has faced some teething issues, this is not uncommon for First-Of-A-Kind (FOAK) technology integration at commercial scale. These early hurdles provide valuable operational insights that will strengthen process reliability and accelerate learning for the next generation of AtJ projects.

Despite strong momentum, AtJ still has a few practical hurdles to clear, with current cost ranging from 4-5x of jet fuel. Multi-step processing and hydrogenation keep energy use and unit costs elevated today, and feedstock cost typically makes up over 50% of total AtJ fuel cost so access to low-CI ethanol remains important. However, the outlook is fairly positive, as projects move from FOAK to NOAK, catalysts and integration improve, supply chains mature, and plants are sited for optimal utilities and logistics, overall costs are expected to decline and carbon intensity to improve.

While AtJ is one of the most commercially advanced non-HEFA pathways, its large-scale deployment will depend on continued cost reductions and sustained reliability of integrated operations demonstrated at the first generation of commercial plants.

Gasification + Fischer-Tropsch (GFT):

The GFT pathway converts solid cellulosic feedstocks into SAF by first gasifying the feedstock into synthesis gas ($\text{CO} + \text{H}_2$), then running the Fischer-Tropsch catalytic synthesis to produce hydrocarbons, followed by upgrading to jet fuel. GFT fuel was one of the earliest approved SAF types, receiving ASTM certification in 2009 with eligibility for 50% blend. This pathway can theoretically use a wide range of feedstocks including municipal solid waste, agricultural, forestry residues, and other biomass as well as fossil resources like natural gas and coal with carbon capture. This versatility and the large potential volume of waste/biomass feedstocks make GFT a crucial pathway for long-term SAF supply.

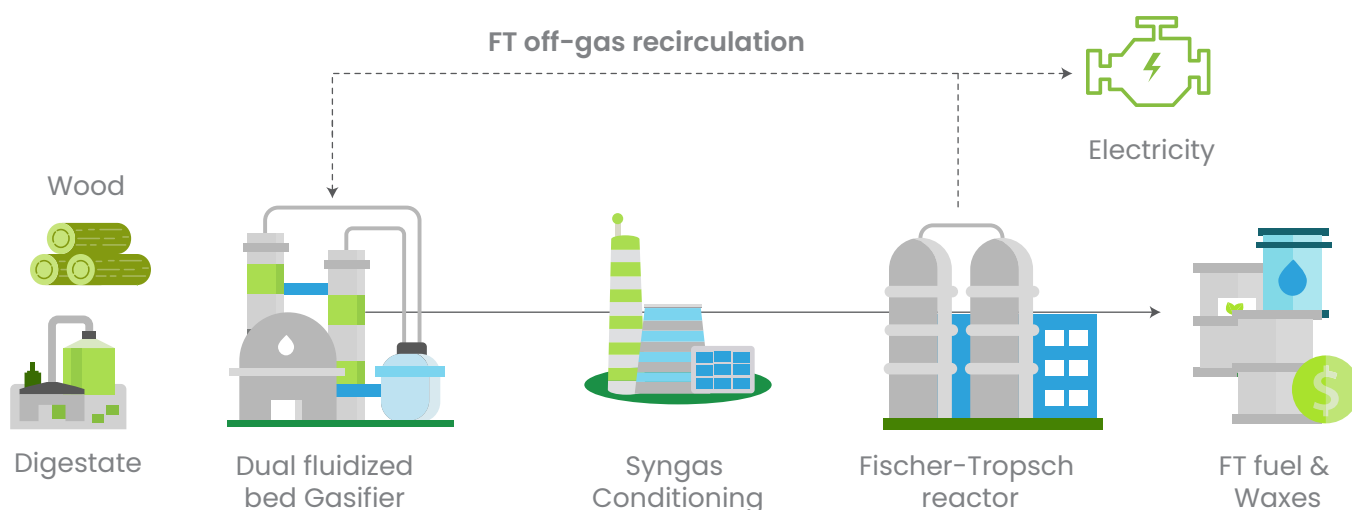


Exhibit 4.2.5: Technical Diagram for Gasification Fischer-Tropsch production pathway

The GFT pathway's major advantage lies in its feedstock flexibility and scalability. It can utilize a wide spectrum of low-cost, non-food waste materials, making it one of the few SAF technologies capable of tapping into vast, underused carbon streams such as municipal waste, or agricultural and forestry residues. Its technical maturity is rooted in decades of FT use in coal- and gas-to-liquid industries means that the chemistry is well understood. However, integration of FT with gasification of biomass has not been successfully proven at commercial scale so far. For countries with abundant biomass or waste resources, GFT offers a potential route to large-scale, regionally anchored SAF supply.

The pathway requires significant capital for gasification, syngas cleanup, and Fischer-Tropsch synthesis. Biomass and waste feedstocks need careful preparation and quality control, since variation in particle size, moisture, composition, and heating value can affect gasifier stability and syngas quality. Fischer-Tropsch produces a wide hydrocarbon slate that includes heavy waxes that then need hydrocracking and upgrading, which adds units and cost. The central task is consistent integration of feedstock preparation, gasification, cleanup, synthesis, and finishing to deliver stable

runs at scale. As designs standardize and projects move from FOAK to repeat builds, both reliability and economics are expected to improve.

While scale-up and integration challenges have surfaced, market signals are positive: private capital is being deployed, partners are tightening designs and contracts, and teams are actively working to resolve the known technical hurdles.

While the Fischer-Tropsch process is technically proven in fossil applications, demonstrating continuous, commercial-scale operation using sustainable feedstocks remains the key hurdle along with a high-cost premium of 5-6x of jet fuel. If upcoming projects can achieve steady-state production and reliable economics, GFT could become a cornerstone of large-scale SAF supply in the 2030s.

Power-to-liquid (PtL):

Power-to-Liquid SAF, also called synthetic electrofuel or e-kerosene, is produced by combining hydrogen with carbon dioxide to synthesize hydrocarbon fuels. The process typically begins with the electrolysis of water using renewable electricity to generate hydrogen, paired with the capture of CO₂ from biogenic sources (such as biomass processing or biogas plants), industrial emissions, or directly from the air. The captured CO₂ is

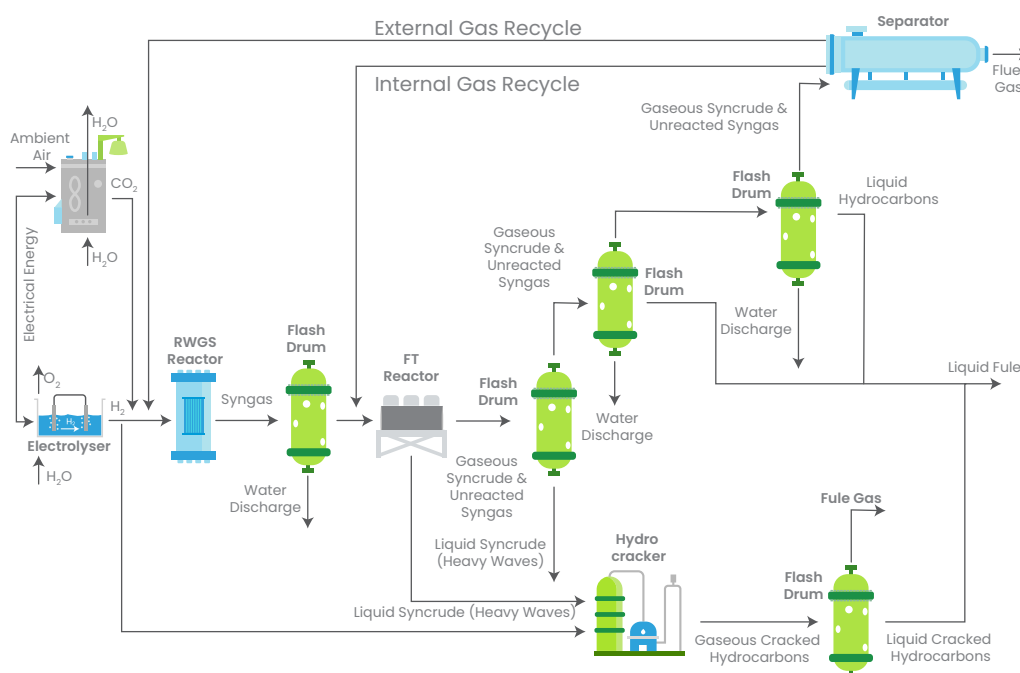


Exhibit 4.2.6: Technical Diagram of Power to Liquid production pathway

then converted to carbon monoxide, often through a reverse water–gas shift reaction, and combined with hydrogen to produce liquid hydrocarbons via Fischer–Tropsch or methanol synthesis pathways. The result is a drop-in jet fuel produced from air and water, with very low life-cycle emissions, especially if the input energy is renewable.

The main advantage of PtL lies in its virtually unlimited feedstock potential biogenic and captured CO₂, water, and renewable power making it a long-term cornerstone for aviation decarbonization once costs decline and its very low life-cycle CI when powered by 100% renewable energy.

Few pioneering projects have demonstrated PtL's technical feasibility. The Atmosfair e-kerosene plant in Werlte, Germany, inaugurated in 2021, was the world's first dedicated PtL facility for aviation fuel, integrating Siemens Energy electrolyzers, INERATEC's modular FT system, and biogenic CO₂ from a biomethane plant. Norsk e-Fuel in Norway is developing a 50 Mn-liter-per-year facility using renewable hydropower and captured CO₂, while US-based Infinium is constructing a FOAK pre-commercial plant, the Roadrunner PtL demo facility in Texas, supported by Breakthrough Energy Catalyst and airline offtake agreements. These early projects represent crucial first steps toward proving the pathway at scale.

The pathway requires substantial energy and capital due to the need for large volumes of renewable electricity and the deployment of electrolyzers, carbon dioxide capture, and synthesis units leading to high-cost premium of 8–9x of jet fuel prices. At current scales, levelized costs are higher than HEFA and AtJ because most facilities are FOAK with limited operating hours and incomplete learning curves. Early pilots focus on sustained on-spec production and on improving catalyst performance and system integration. As projects advance toward larger units with better heat and water integration and longer continuous

runs, costs and reliability are expected to improve, positioning Power to Liquid as an important long-term option for deep aviation decarbonization.

While PtL remains in its infancy, it represents one of the few truly scalable routes for deep decarbonization of aviation. Its success will depend on steady technological learning, declining renewable electricity costs, and patient, staged investment in first-of-a-kind facilities.

Co-processing in hydrocarbon refineries

As an interim step toward large-scale SAF deployment, petroleum refineries are increasingly starting to co-process renewable feedstocks such as used cooking oil, animal fats, or FT biocrudes alongside conventional crude oil. This approach produces a blended jet fuel containing a renewable fraction without the need for a dedicated SAF production plant.

Co-processing is an approved pathway under ASTM D1655 and ASTM D7566 Annex A9 for producing jet fuel with a renewable content. However, the process is currently limited to a maximum of 5% biogenic input, primarily due to differences in feedstock properties and the need to maintain consistent product quality. Despite this constraint, co-processing offers a practical near-term route to leverage existing infrastructure, logistics, and workforce capabilities.

Unlike standalone SAF production (e.g., HEFA or AtJ), there's no physical separation between renewable and fossil molecules in the output. This means you can't directly measure how much of the jet fuel portion is "renewable." Instead, the renewable fraction must be calculated and attributed using tracing methods like mass and carbon balance approach.

Several traditional refineries worldwide such as Eni's Venice and Gela plants in Italy, Neste's Porvoo refinery in Finland, and

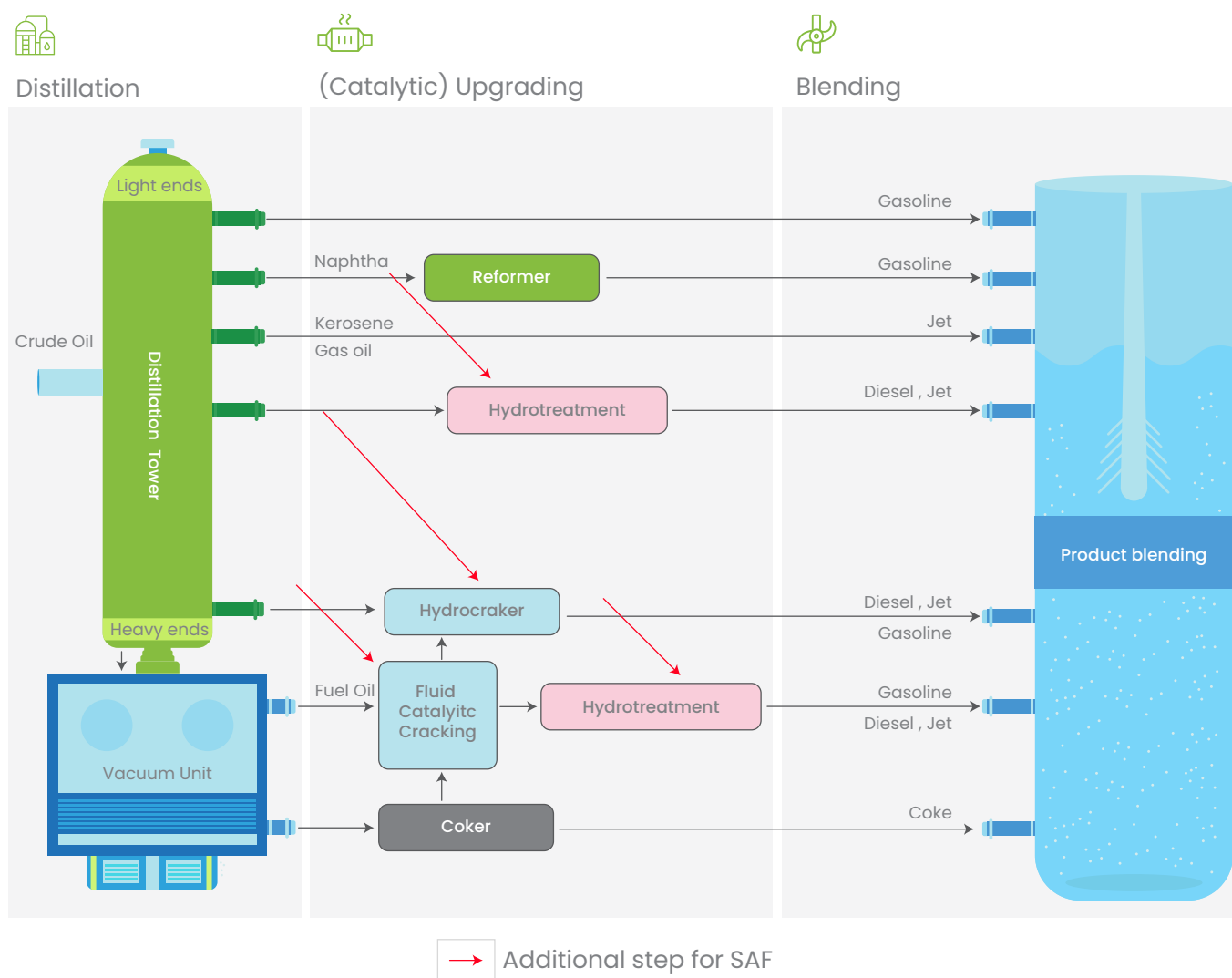


Exhibit 4.2.7: Technical diagram of co-processing SAF with Fossil fuel

TotalEnergies' facilities in France have begun co-processing small percentages of used cooking oil or other renewable intermediates into their crude units to produce jet fuel blends. While not a standalone solution for large volumes, co-processing can serve as a bridge technology, providing operational experience, early emission reductions, and a pathway to expand renewable input ratios as refinery technologies and standards evolve.

Other Emerging Pathways

Besides the major routes above, several other SAF pathways are in various stages of development:

Catalytic Hydrothermolysis (CHJ):

A process that mimics petroleum formation by using high-pressure water and catalysts to convert triglyceride oils into a biocrude, which can be upgraded to jet fuel. This was certified in 2020 for up to 50% blend via the ARA "ReadiJet" process. CHJ can use similar lipid oily feedstocks as HEFA but potentially with shorter processing time. A key advantage is that CHJ biocrude can be processed in existing refineries. A few pilot projects are underway, but like HEFA, its scale is going to be ultimately determined by lipid feedstock availability.

Methanol-to-Jet (MTJ):

The MTJ pathway converts renewable methanol, produced either from green

hydrogen and captured CO₂ or via biomass gasification, into jet-range hydrocarbons through methanol-to-olefins (MTO) and subsequent oligomerization and upgrading steps. The resulting fuel, known as MTJ-SPK, is currently under ASTM certification review, but has been demonstrated at pilot scale in US and Europe, including the SAFari MTJ facility led by Fraunhofer ISE in Germany. Several large scale projects have been announced, including a 250ktpa facility in EU by Power2X. MTJ offers a versatile alternative to Power-to-Liquid routes, using methanol as an energy-dense intermediate that simplifies fuel synthesis, storage, and transport.

Pyrolysis and Hydrotreated Depolymerized Cellulosic Jet (HDCJ):

This pathway converts lignocellulosic biomass such as forestry residues, agricultural wastes, or algae into a bio-oil via fast pyrolysis, which is then hydrotreated and upgraded to produce jet-range hydrocarbons. While not yet ASTM-certified as a standalone SAF pathway, pyrolysis offers significant scalability potential due to its broad feedstock flexibility and modular design. Several technology developers, including BTG Bioliquids, Fortum, and Envergent Technologies, are advancing pilot and demonstration-scale facilities. However, technical challenges remain in stabilizing, deoxygenating, and upgrading the highly oxygen-rich bio-oils to meet jet fuel quality and performance specifications.

Synthetic Iso-Paraffins (SIP):

This pathway, also known as the Direct Sugar to Hydrocarbon route, ferments sugars to produce farnesene, which is then hydrotreated to farnesane, a C₁₅ iso-paraffin. SIP fuel was approved at up to 10% blending with technology pioneered by Amyris. It has seen limited use due to high feedstock (sugar) costs and competition with other biochemical products.

Observed Levers to enable SAF Commercial Readiness:

Scaling SAF production technologies from the lab to the runway requires more than breakthrough science – it demands a structured, system-wide approach to innovation, finance, regulation, and collaboration. Much like solar PV, offshore wind, and hydrogen before it, SAF technologies face the challenge of crossing the “valley of death” between promising R&D and commercially bankable projects.

To bridge this gap, countries and industries can deploy phase-appropriate levers that evolve across the technology maturity curve from early incubation to global replication. The following framework outlines available policy levers and collaboration models which can accelerate SAF technology readiness through four sequential phases.

Building on this framework, experience from SAF pilots and adjacent renewable technologies points to a common set of benchmarks that can guide progress from early research to commercial scale. Applied phase by phase, these practices can align technology readiness with finance, policy and market development to keep execution tight and risk contained. The next section highlights real-world examples that show how targeted actions across innovation, investment, regulation and collaboration can accelerate learning, improve bankability and build a clearer path from the lab to large-scale industrial production.

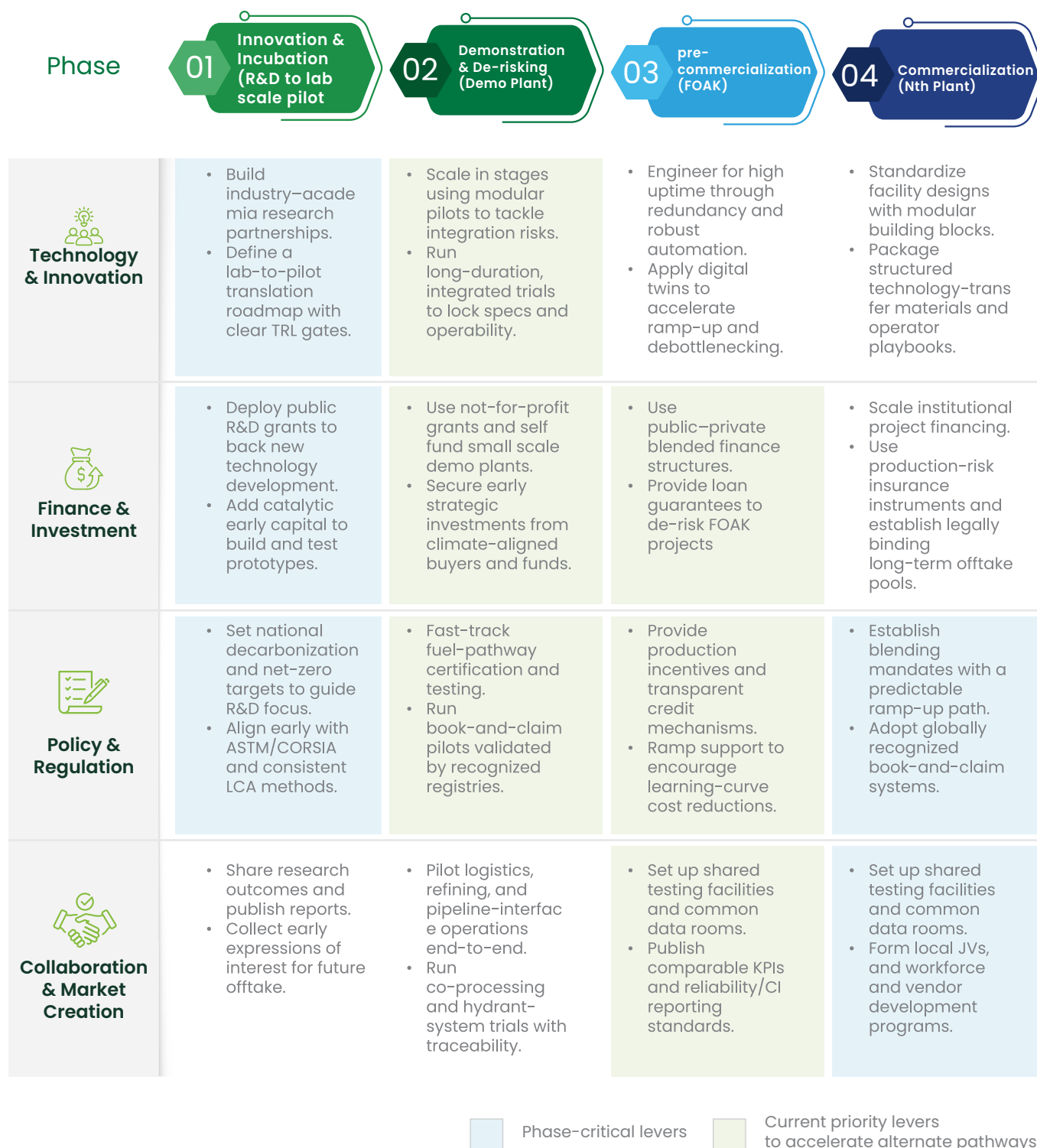


Exhibit 4.2.8: Levers to support phased technology advancement

Phase 1: Innovation & Incubation (R&D → lab-scale pilot)

Technology & Innovation: Industry-academia Partnerships

The Alcohol-to-Jet pathway pioneered at PNNL and commercialized by LanzaTech's LanzaJet shows how research institutions and industry accelerate R&D, public labs perfected ethanol-upgrading chemistry while LanzaJet steered certification and scale-up, converting laboratory insights into a commercial fuel pathway.

Finance & Investment: Public and International R&D Grants

Public research programs such as DOE's Bioenergy Technologies Office and Horizon Europe provide grants that seed diverse SAF routes such as AtJ, gasification-FT, and PtL helping academic breakthroughs form spinouts, secure equipment access, and reach pilot readiness with techno-economic and life-cycle baseline. Another example can be observed as Breakthrough Energy Fellows' Explorer grants back earlier-stage, higher-risk climate solutions in university labs or research entities, overseen part-time by faculty/researchers before company formation.

Policy & Regulation: National decarbonization targets

National climate commitments such as the EU Climate Law and the UK's net-zero target can anchor public portfolios and guide private research priorities, signaling durable demand for low-carbon aviation fuels and aligning early SAF R&D with future certification, policy, and market expectation.

Phase 2: Innovation & Incubation (R&D → lab-scale

Technology & Innovation: Staged Scale-Up

The Hywind floating wind program demonstrated how new technologies can

be scaled following a staged model. It began with a single 2.3 MW unit that proved the spar concept. It progressed to a small array that validated multi-unit operations in open water. It then expanded to an industrial scale site that established supply chain, logistics, and operations and maintenance practices at scale. Each step was deliberately sized to reveal integration risks and operational constraints before larger capital was committed.

Finance & Investment: Climate -aligned fund

Climate aligned investors can underwrite early demonstration plants. Breakthrough Energy Ventures has committed more than 3.5 billion dollars across more than 110 companies, financing, launching, and scaling deep decarbonization technologies from seed to growth and helping demonstration scale projects cross the risky pre bankable gap.

Policy & Regulation: Fuel Pathway Certification and Testing

New SAF pathways must be approved under ASTM D7566 before they can be used in aviation. The approval process advances once pilot plants produce fuel for coordinated ASTM D4054 evaluations with aircraft and engine manufacturers, and the results are replicated at scaled demonstration sites. For example, AltAir's Paramount facility, California produced early HEFA-SPK batches that were used for extensive engine and flight testing with OEMs like Boeing, Pratt & Whitney, Rolls-Royce. These data supported the ASTM D7566 Annex A2 approval for HEFA-SPK in 2011.

Phase 3: Commercialization (FOAK)

Finance & Investment: Blended finance

Blended finance instruments help bridge the gap between first-of-a-kind projects and commercial scale. In Australia, early large-scale solar projects combined Australian Renewable Energy Agency grants and Clean Energy Finance

Corporation concessional loans with private developers for construction and operations . The projects shared standardized templates that lowered financing costs and sped up delivery, turning initial public support into repeatable models for future investments. Similarly, the European Investment Bank has extended major loans to advanced biofuel facilities, such as €285 million for Cepsa's Andalusia SAF/HVO plant and €430 million for Galp's Sines refinery upgrade, reinforcing how public finance can unlock private capital for emerging clean fuel industries.

Policy & Regulation: Production Incentives and credit mechanism

In the United States, the SAF Blenders' Tax Credit helped close the price gap between SAF and fossil jet fuel by giving a set payment for every gallon of SAF blended into aviation fuel. This then shifted to the Section 45Z Clean Fuel Production Credit, which rewards producers for making fuels with lower carbon emissions. Together, these incentives give early projects the stability they need to reach commercial scale while pushing the industry toward cleaner production over time. In Europe, carbon pricing systems like the EU Emissions Trading System make airlines pay for their emissions through tradeable allowances. Using SAF helps airlines cut those emissions and lower their compliance costs, creating another financial reason to use cleaner fuels.

Collaboration & Market Creation: development/testing Data sharing

Centralized testing and data-sharing platforms can speed up certification and reduce costs. For example, the UK's Offshore Renewable Energy Catapult helped shorten turbine certification cycles by providing shared facilities and standardized testing for multiple companies. A similar model for SAF involving producers, regulators, and investors where they can access common testing data, could harmonize fuel certification protocols, avoid duplication, and build confidence in new pathways

more quickly.

Phase 4: Commercialization (Nth plant)

Policy & Regulation: Blending Mandates and demand drivers

ReFuelEU Aviation's escalating mandate, coupled with the US SAF Grand Challenge volume target, establishes predictable demand signals across key markets, enabling long-term contracting, portfolio financing, and infrastructure planning that are essential for replicating commercial plants at meaningful global scale.

Collaboration & Market Creation: International Technology Transfers

Italy's Enilive began producing SAF at the Gela biorefinery in January 2025 using the Ecofining process co-developed with Honeywell UOP, which converts biogenic feedstocks into jet fuel. This shows how core technology deployment and process know-how was developed in US was transferred and embedded in an Italian site to create large-scale SAF supply.

Technology innovation is a key lever to unlock the future of SAF. Achieving net-zero will depend on progress across AtJ, GFT, PtL and co-processing routes that widen the feedstock base and bring production to scale. The focus now must move from proving technical feasibility to building reliable and affordable systems. If technology brings costs under control other challenges become easier to solve. Investment will follow, policies will gain traction and markets will grow. With continued innovation and steady cost reduction, SAF can move from limited pilots to a global industry that powers aviation toward net-zero.

Key Takeaways:

- As technologies like ATJ GFT and PtL progress from pilot to demo and FOAK, Teething issues are expected, which as showcased by other technologies, are addressable.

- Multiple policy and ecosystem levers are available to support scale up of technologies from R&D to commercialization.
 - Targeted policy support and bankable long-term offtake agreements are essential to create strong demand signals to accelerate production.
 - Costs are expected to decline from FOAK to nth-plant as the technologies mature.
-

Chapter 4 | Section 3: Playbook on long-term offtake agreements

Why offtakes are essential

The scale up of SAF is constrained by its price premium over conventional jet fuel and by the absence of durable demand at higher price points. Premiums are expected to moderate as technology improves and scale efficiencies emerge, but early projects need clear support to trigger commercial build out and unlock cost reductions and market momentum. Firm offtake agreements provide the demand signal required to enable technological advancement and expanded production.

Long-term bankable offtake commitments anchor project revenues and reduce risk for lenders and investors. They unlock investment in capital intensive conversion technologies, feedstock logistics, and large-scale facilities by providing price and volume certainty. This new capacity can improve supply learning and utilization leading to lower per unit cost reinforcing a strong growth cycle.

For fuel suppliers and airlines, offtakes secure multi-year access to SAF and gives clearer price visibility in a new market. Since airlines usually contract fuel for short periods, they perceive real risk in committing to long-term offtakes without clear price formation, firm delivery arrangements, and credible rules for environmental attributes. Policy regimes in major markets are introducing blending and emissions accounting obligations for suppliers and airlines, which increases the need to lock-in molecules and certificates ahead of compliance timelines. Early commitments reduce the risk of shortfalls, smooth compliance costs, and support a reliable transition to higher blend levels.

As global policy dynamics continue to evolve, it is prudent for airlines and fuel suppliers to secure their SAF supply chains early and for producers to use offtakes to develop projects that are ready for

investment, even though securing buyer commitments remains difficult as airlines weigh long-term price and delivery risk.

Current offtake trends

After an initial surge of momentum, global SAF offtake activity has showcased signs of moderation. According to ICAO data, as highlighted in Exhibit 4.3.1, cumulative offtake volumes have expanded rapidly since 2019 reflecting strong early confidence in scaling commercial production, yet new agreements in 2023–2024 have trended lower than the 2022 peak. Since the first commercial offtake in 2013, airlines have publicly launched more than 150 SAF deals across 81 carriers, and nearly 40% of these airlines have signed multiple agreements indicating that offtakes are a critical part of their decarbonization strategy rather than a one-off sustainability gesture.

Many of these contracts continue to rely on the established HEFA pathway, but around 40% now support emerging routes such as GFT, AtJ, and PtL reflecting a deliberate effort to diversify the supply base and signal long-term technology neutrality. A significant share may still be contingent on project development progress, enabling policy support, or the timely achievement of technology milestones, indicating that diversification beyond HEFA is not yet underpinned by firm contractual and financial commitments.

The surge between 2021 and 2022 marked a clear inflection point with more than 90 new agreements announced representing over 30 billion litres of contracted SAF. Activity has since moderated as airlines paused to recalibrate amid policy uncertainty, persistent green premiums, and uneven production ramp-up. Fuel suppliers also act as counterparties in many agreements, and in the European Union the blending obligation sits with

Volume (Bn l)

Count

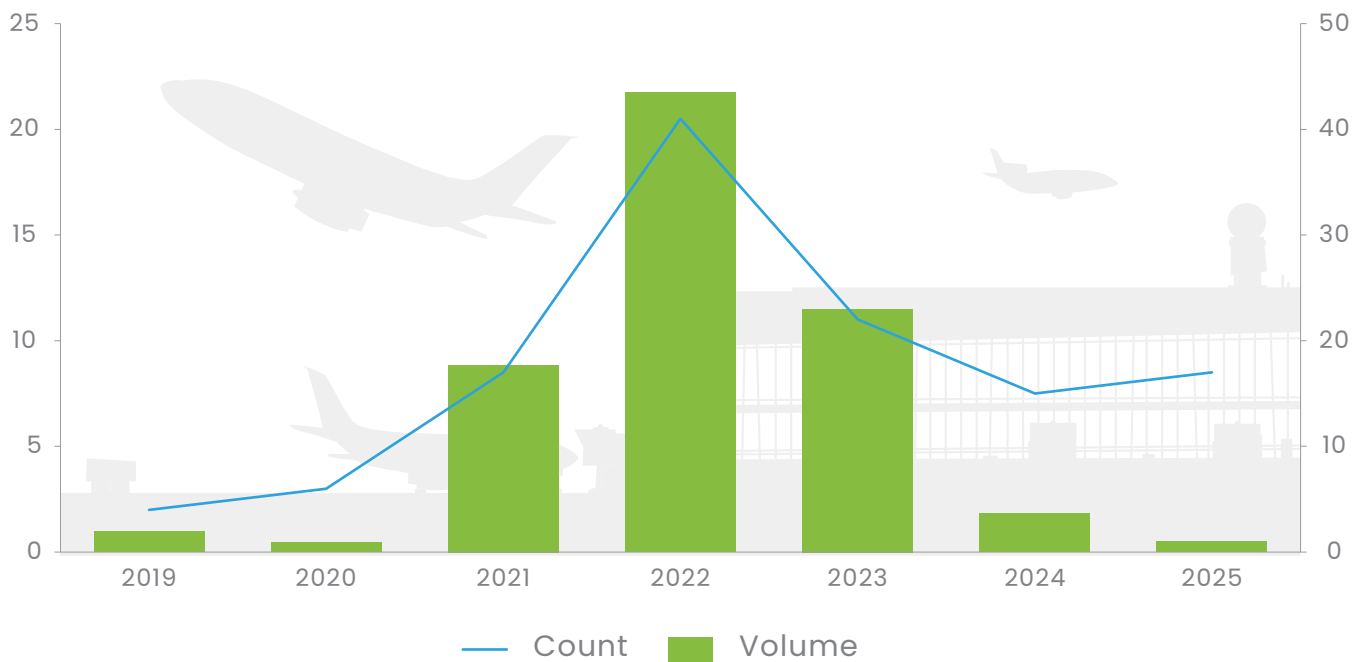


Exhibit 4.3.1 Current trend in SAF offtakes

suppliers who must deliver SAF to covered airports.

Despite year-on-year variations, the average offtake size has remained stable at around 376 million litres per deal while the median contract size is around 74 million litres indicating that most transactions remain relatively small suggesting that producers and large buyers continue to sign sizeable multi-year contracts that reflect sustained confidence in medium term demand

growth. This is also backed by the fact that the top 25 offtake deals represent more than 80% of total volume. A key feature of existing offtake agreements is that over half of all agreements have durations shorter than four years highlighting a market still in transition toward longer and more bankable commitments as observed in Exhibit 4.3.2.

Further, the SAF offtake landscape remains concentrated and geographically uneven. Nearly 60% of total contracted volume till

SAF offtake volume (million liters) Vs duration of contract

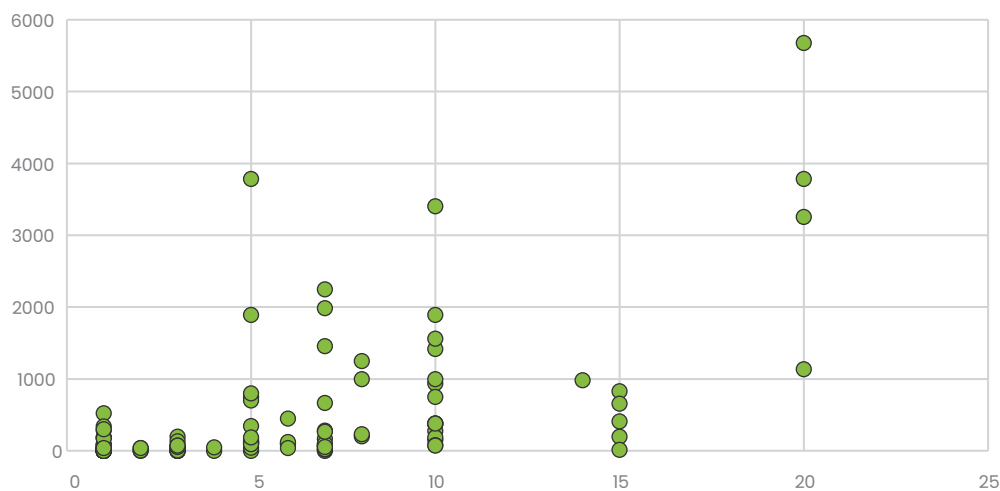


Exhibit 4.3.2: Analysis of existing offtake agreements

Oct 2025 originates in the United States supported by production incentives under the Inflation Reduction Act and state-level Low Carbon Fuel Standards, while Europe accounts for roughly 30% driven by compliance mandates under ReFuelEU Aviation.

A notable recent development in the SAF offtake landscape is the rise of innovative partnerships involving corporates that are seeking to reduce their Scope 3 emissions from business travel and supply chains. One example is the partnership between Citi and American Airlines, which jointly committed to offtake SAF from Infinium's Project Roadrunner in Texas, an e-fuels facility supported by Breakthrough Energy Catalyst. Through this agreement, Citi will help finance and claim part of the Scope 3 emissions reductions associated with the fuel used by American Airlines, demonstrating how corporate buyers can play an active role in scaling SAF supply while advancing their own decarbonization targets.^{xxviii}

What makes them bankable

Offtake agreements sit at the core of the project-finance equation for new SAF facilities. Developers aim to secure multi-year, legally binding offtakes before reaching FID, as they provide lenders with the revenue visibility and credit assurance essential for financing. Pre-FID offtakes convert technical readiness and policy momentum into demonstrable demand certainty, effectively bridging the gap between project feasibility and bankable cash flows.

The credibility of both counterparties is a critical prerequisite for a bankable offtake agreement. For producers, demonstrating proven technology readiness, operational reliability, and compliance with recognized sustainability standards is essential to establish lender confidence. Lenders and offtakers require assurance that the facility can consistently deliver certified, on-spec fuel volumes over the contract term, translating technical capability into predictable commercial performance.

On the buyer side, creditworthiness and financial stability are equally important. Airlines, fuel suppliers, or corporate offtakers must demonstrate strong balance sheets or provide guarantees to ensure payment obligations are met over multi-year tenors. In addition, lenders and producers increasingly assess the buyer's creditworthiness in the context of regulatory obligations such as SAF blending mandates, quotas, or emission reduction targets which effectively create a "policy-driven demand floor." Entities subject to such mandates are often viewed as more reliable offtakers, given their compliance requirements and lower likelihood of demand erosion.

Refiners and oil marketing companies often enhance the credibility of an offtake arrangement through their established trading infrastructure, logistics networks, and policy compliance experience. Unlike independent developers, many integrated oil and gas companies finance SAF projects directly on balance sheet rather than through project finance, reducing lender exposure and perceived risk. Their participation can therefore substitute for external credit enhancement, improving the overall credibility and bankability of the offtake structure.

What does it entail and how to enhance bankability:

For SAF offtakes to unlock investment at scale, they must provide cash flow certainty for producers and delivery confidence for buyers. The below exhibit showcases that bankability depends on two pillars, robust commercial structure, and strong contract integrity and risk management. This builds on a foundation of a strong policy and standards ecosystem, enforceable contracts, and a stable policy ecosystem.

The below sections deep dive into each feature of the pillars and highlight case studies on how these can be made more bankable:

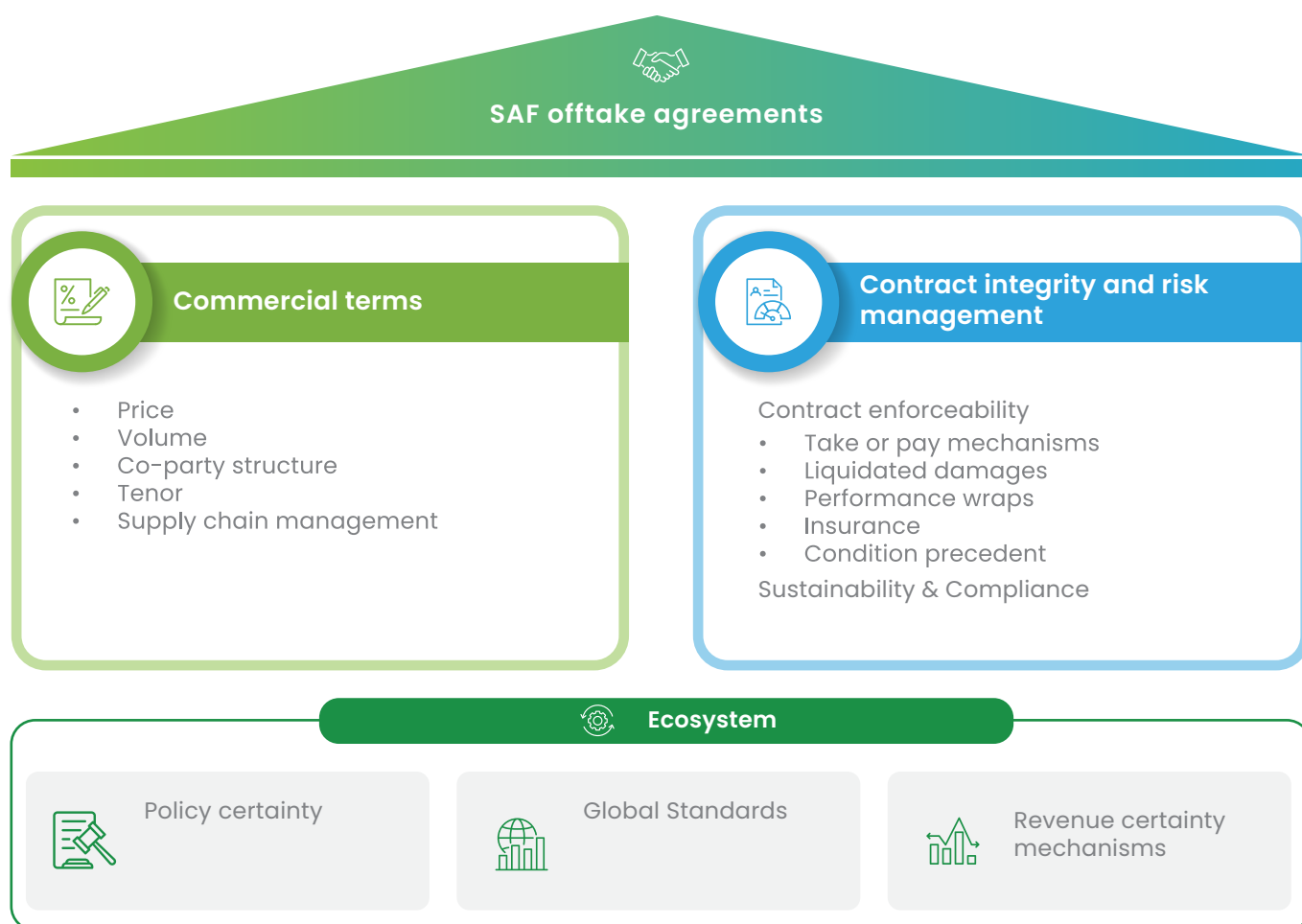


Exhibit 4.3.3 Bankability Blueprint for SAF Offtakes

Commercial terms

Price:

Pricing mechanism and benefit allocation

Price formation is central to the bankability of offtake agreements, determining how value and risk are shared between producers and buyers. Because SAF production costs remain significantly higher than fossil jet fuel, pricing structures must bridge the “green premium” while preserving commercial viability for both sides.

As shown in Exhibit 4.3.4, SAF offtakes today rely primarily on four pricing models. Each mechanism distributes cost and risk differently, indexed model tends to balance exposure more evenly, while cost-plus and tolling structures favor producers and market-driven pricing

favors buyers. As policy incentives and compliance frameworks mature, hybrid models that blend these approaches may become the norm, providing both price stability and transparency across the SAF value chain. SAF offtake agreements often involve a range of policy incentives and environmental attributes to support their economics. Incorporating these benefits in offtakes can materially reduce the green premium between SAF and fossil jet fuel, making offtakes financially viable.

What makes them bankable

For producers, a bankable pricing mechanism is one that ensures stable and predictable revenues over the contract term and outlines clear allocation of available incentives between various parties in the value chain, regardless of market volatility. Linking SAF prices to

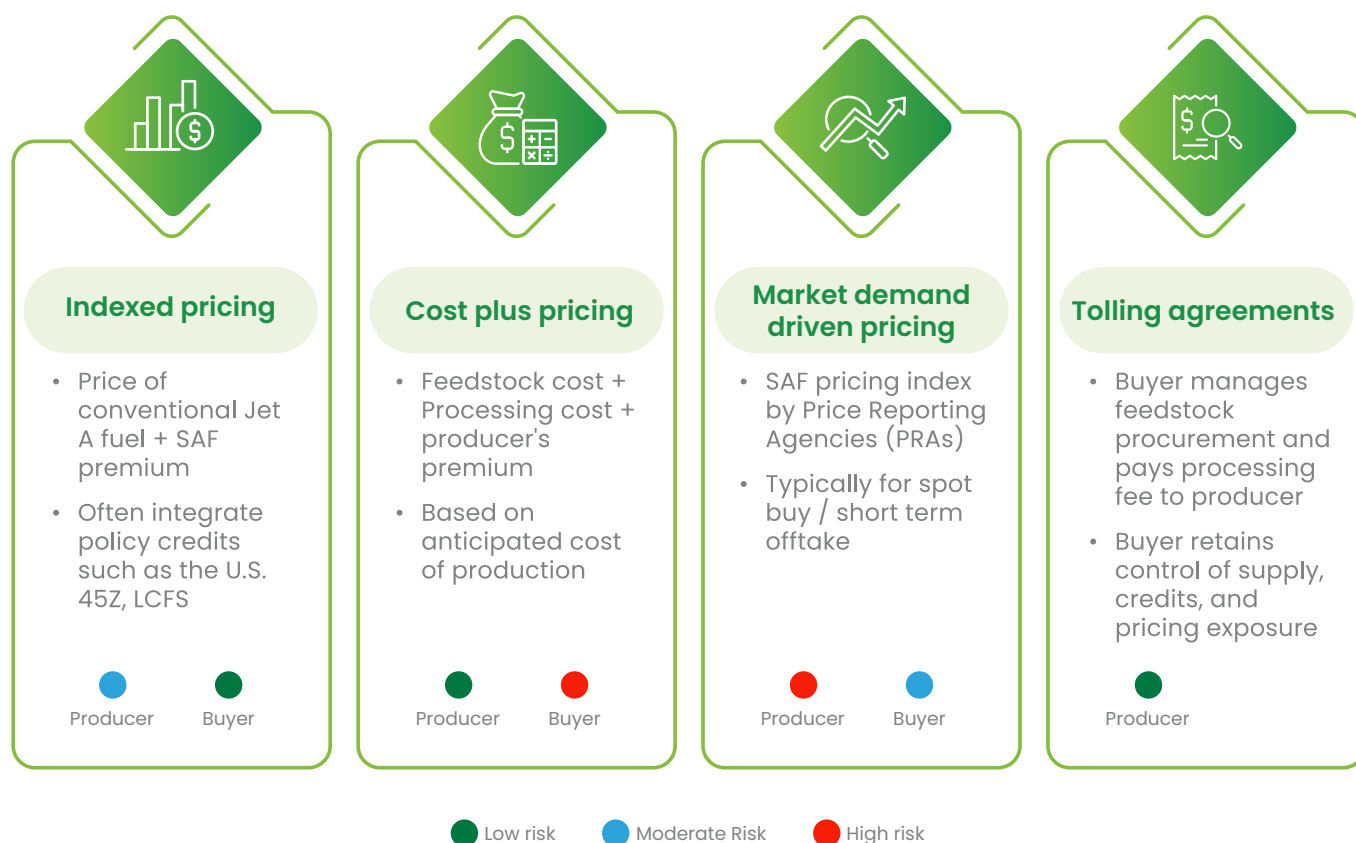


Exhibit 4.3.4 : Types of pricing mechanisms

Price:

Pricing mechanism and benefit allocation

Price formation is central to the bankability

of offtake agreements, determining how value and risk are shared between producers and buyers. Because SAF production costs remain significantly higher than fossil jet fuel, pricing structures must bridge the “green premium” while

Case in point:

Cedar LNG – Tolling Agreement for Liquefied Natural Gas (LNG)^{xxix}



Context

Cedar LNG, a Haisla Nation and Pembina Pipeline Corporation, led project in British Columbia backed First Nation by the adopted a tolling agreement model to commercialize its proposed floating LNG facility. Under this structure, Cedar LNG provides liquefaction, storage, and loading services to upstream natural gas suppliers without directly taking title to the gas or LNG produced.



Offtake structure

Customers supply their own feed gas and pay a fixed liquefaction fee for converting it into LNG. Cedar LNG's tolling model locks in long-term revenue through capacity-based charges, independent of fluctuating global LNG prices. This approach transfers commodity price risk to the customers while ensuring predictable cashflows for the project operator but may result in potentially lower returns.



Why it worked

- Fixed liquefaction tolls provide stable, contractually guaranteed revenue streams suitable for project finance.
- Separating commodity ownership from processing allows Cedar LNG to focus on operational efficiency rather than price exposure.

Volume:

For producers, securing fixed-volume offtake agreements is essential to create a predictable revenue stream and to match commitments with the designed capacity of the plant. Producers can anchor on any of the following three archetypes available to cover their output profile, which may depend on the pathway as detailed in exhibit 4.3.5:

1. Integrated sale: Selling the entire slate of products such as renewable diesel and naphtha to Fuel suppliers
2. Disaggregated sale: Separate offtake or marketing agreements for SAF, renewable diesel, and other co-products.
3. Hybrid sale: Long-term SAF offtake agreement with airlines or suppliers while selling other co-products as a bundle to traders, marketing companies or fuel suppliers

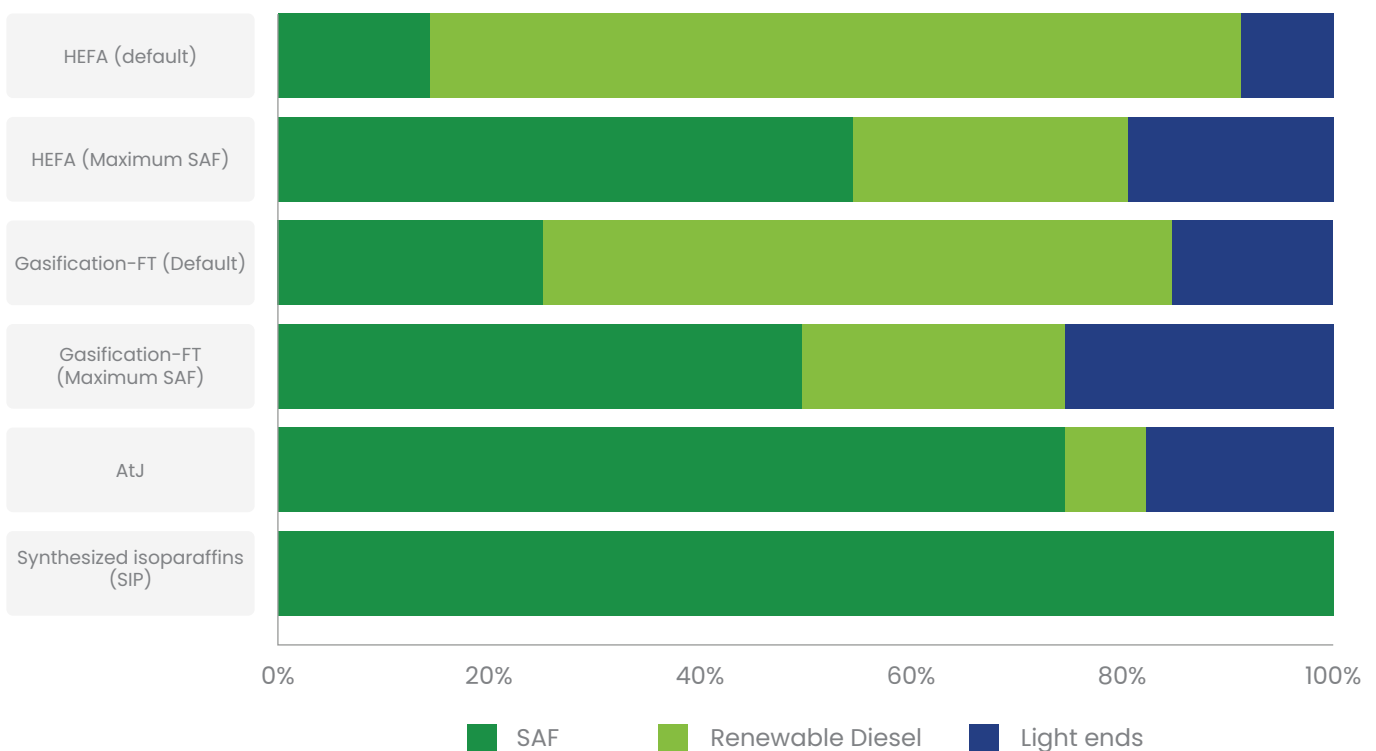


Exhibit 4.3.5 Production slate of SAF production pathways

What makes them bankable

From a financing perspective, the volume commitment is the anchor of any bankable offtake. Lenders look for firm, multi-year purchase obligations that secure a substantial share of the plant's

output, typically covering at least 60–80% of projected production during the debt tenor. Where buyers hesitate to lock-in full volumes, a portfolio of partial agreements across credible counterparties can collectively deliver the same assurance.

Case in point:

Enilive (Eni) SAF: refiner-led offtake that “clears the whole slate”



Context

Enilive commissioned its first SAF facility at Gela, leveraging existing refinery logistics, storage, and product-slate flexibility.



Offtake structure

Refiner/marketer-anchored: molecules, credits, and co-products flow through the refiner's systems rather than bilateral, airport-specific airline liftings.



Why it worked

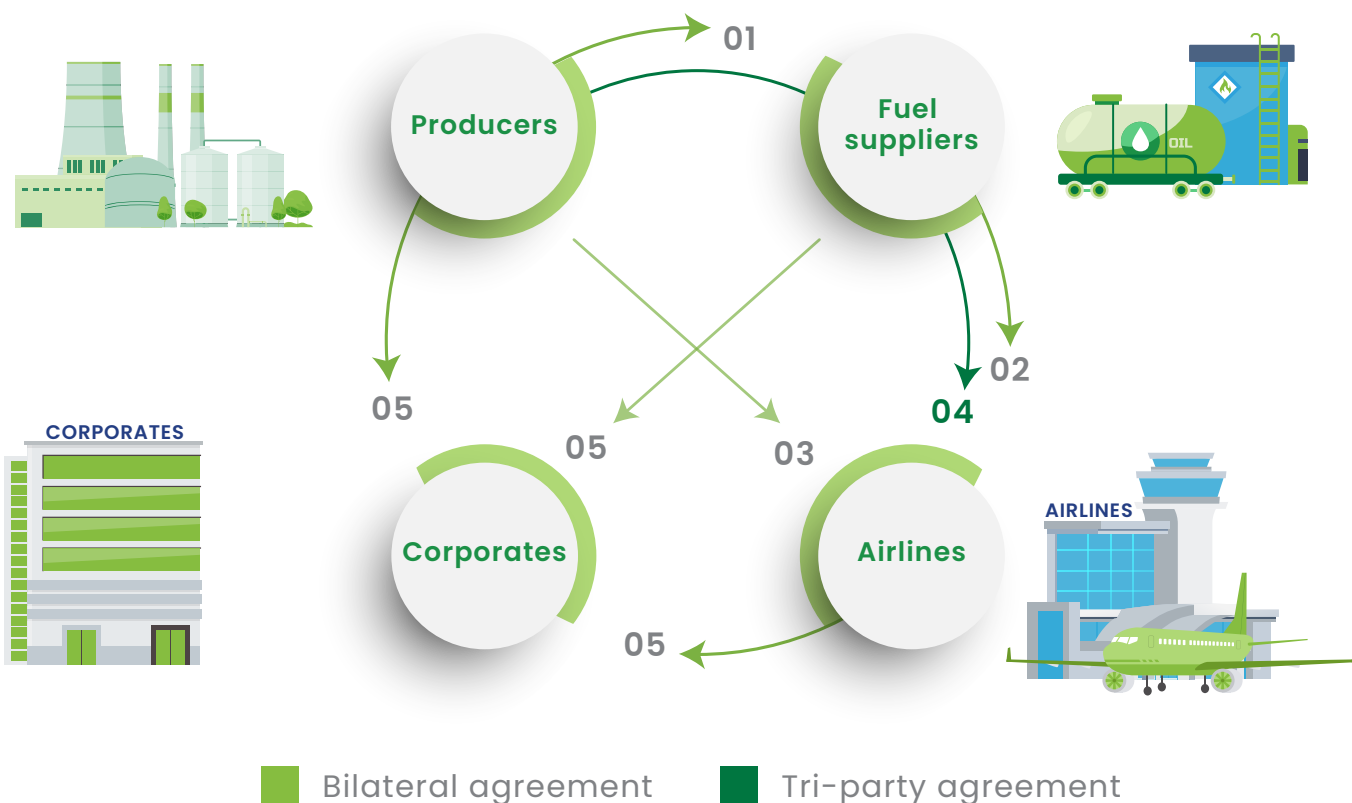
- Refiner can absorb volatility (storage/blending/hedging) and monetize credits cleanly.
- Whole-slate optimization (SAF + RD + naphtha/LPG) stabilizes plant margins vs. “SAF-only” buyers.
- Brownfield logistics leading to lower execution risk and faster commissioning.

Parties participating in contract

SAF offtake structures are evolving beyond traditional bilateral deals into a spectrum of partnership models that balance risk, liquidity, and operational control across the value chain. The choice of counterparties, whether fuel suppliers, airlines, or corporate buyers, determines how volumes, pricing, and logistics are managed, and how effectively each participant can capture value. Alliances or consortia can also pool demand of multiple carriers, aggregating volumes large enough to secure better pricing and longer terms with producers or fuel suppliers. This can especially help smaller airlines access supply at better terms.

What makes them bankable

From a bankability standpoint, the structure and composition of participating parties are as critical as the contract itself. Deals anchored by established fuel suppliers or investment-grade airlines provide higher assurance to financiers on credit quality. Tripartite models can further enhance confidence by blending supply security with assured offtake and technical competence. Depending on the contractual terms, direct producer airline contracts may face scrutiny over demand concentration and tenor uncertainty, particularly when airline priorities are often dynamic. Adding corporate buyers to offtake agreements can also strengthen contracts and their bankability.



Co-party structure	Highlights
01 Producers <> Fuel Suppliers	<ul style="list-style-type: none"> Fuel suppliers can absorb and optimize the entire product slate and manage supply ecosystem. Limited upside potential driven by multiple sources of revenue
02 Fuel suppliers <> Airline	<ul style="list-style-type: none"> Airlines purchase SAF/ SAF credits Provides stable and scalable SAF access to airlines with established partner Access to operational expertise of established fuel suppliers
03 Producers <> Airline	<ul style="list-style-type: none"> Model observed in multiple offtake deals Lenders may be concerned about demand volatility and contract duration
04 Tripartite agreements	<ul style="list-style-type: none"> Combines supplier's scale and logistics ecosystem with airline demand pull Provides a hedge for producers and airlines with an established player as part of contract
05 Corporate demand	<ul style="list-style-type: none"> Purchase SAF certifications from airlines/ suppliers/ producers Potential to aggregate multi-year commitments from different parties

Exhibit 4.3.6 Offtake ecosystem

Case in point: SABA multi-year SAFc purchase agreements



Context

The Sustainable Aviation Buyers Alliance announced the largest collective SAFc purchases to date. Corporate members committed nearly US\$200 million over five years, covering ~50 million gallons of SAF. In 2023 Bank of America, Boston Consulting Group, JPMorgan Chase & Co., Meta, and few others together purchased SAF certificates for nearly 850,000 gallons of high-integrity SAF produced by World Energy, helping fuel JetBlue flights.



Offtake structure

Corporates buy SAF certificates through SABA's program; fuel is produced and blended elsewhere, while SAFc are issued and retired in a registry to confer the associated emissions reductions to the buyer



Why it worked

- Registry-based tracking underpins no double counting and transparent CI claims.
- Enables credible Scope 3 reduction claims for corporates even where physical SAF supply is not yet available on their routes.

Tenor

Short-term agreements of 1-4 years have dominated SAF offtakes to date, with many lasting a single year. This mirrors conventional jet fuel contracting and is often used to test feasibility, meet early compliance needs, or bridge the period till production ramp-up.

Long-term agreements of 5-20 years are important for scaling supply especially for advanced SAF and emerging pathways, because they provide revenue certainty that supports project finance. Buyers may also secure preferential pricing or volume options. These agreements commonly

include ramp-up clauses to reflect the transition from commissioning to steady state and extensions that align with facility lifetimes.

What makes them bankable

From a financing perspective, tenors of around ten years or more enhance bankability by aligning with project debt profiles and creating predictable cash flow over the operating life of the plant. For advanced pathways with higher upfront capital requirements and longer ramp-up periods, longer tenors further distribute risk over time and improve the attractiveness of the project to lenders and investors.

Case in point:

Gevo <>Oneworld alliance offtake^{xxx}



Context

Oneworld members including Alaska Airlines, American Airlines, British Airways, Finnair, Japan Airlines, and Qatar Airways announced plans to purchase up to 200 million gallons per year of SAF from Gevo.



Offtake structure

A collective agreement spanning multiple airlines, structured for a five-year term with deliveries beginning in 2027.



Why it worked

- Pooling volumes through an alliance gave the producer a scale commitment attractive to lenders.
- Multiple carriers could access SAF supply under the same umbrella agreement. Diversification across multiple airlines reduced single-buyer risk.

Supply chain management

Feedstock sourcing

Feedstock sourcing shapes both the cost, sustainability and the reliability of SAF production. The type, quality, and consistency of feedstock influence fuel yield, conversion efficiency, and life-cycle carbon intensity. Building stable, traceable, and certified supply chains helps keep input costs predictable and output quality consistent over the life of the plant.

What makes it bankable

Bankability improves when feedstock contracts align with offtake agreements in both duration and committed volumes. Long-term supply with identified fallback providers or aggregators maintains continuity at transparent prices even when markets shift. When feedstock availability is matched to offtake obligations, lenders can model steady margins and cash flow with greater confidence.

Case in point:

TotalEnergies Biorefinery (Normandy) + Quatra UCO supply



Context

Total Energies Normandy biorefinery (including SAF/HVO) secured a 15-year UCO supply with Quatra and offtake supply to KLM Airlines^{xxx}



Why it worked

- Long-tenor feedstock contracts de-risk the producer's price basis
- Integrated refiner can route molecules across products and geographies as market spreads shift.

Contract integrity and risk management

Contract Enforceability

Take-or-pay agreements

Take-or-pay clauses require buyers to pay for contracted volumes even if they do not physically lift the fuel. This ensures that producers maintain stable cash flow, shielding

them from demand fluctuations or operational disruptions. Deficiency payments are typically applied to compensate for unpurchased volumes, creating predictable revenue for debt servicing. These clauses allow projects to reach financial close with confidence in repayment capability.

Case in point:

Delta Air Lines × Gevo: SAF take-or-pay (75M gal/yr, 7 years)^{xxxiii}



Context

In March 2022, Gevo announced a take-or-pay agreement to supply Delta with ~75 million gallons of SAF annually for seven years (replacing a 2019 deal), estimated at about \$2.8 billion in revenue over the term. Deliveries were indicated to begin mid-decade.



Offtake structure

A binding, multi-year take-or-pay contract where Delta airlines commits to pay for contracted volumes regardless of physical uplift, with terms referencing environmental attribute value alongside fuel sales



Why it worked

- Bankability: Predictable cashflows from take-or-pay obligations support project finance for new SAF capacity.
- Scale & tenor: 75 M gal/yr over seven years gives sufficient volume and duration to underwrite investment and offtake logistic

Liquidated damages:

Liquidated damages are pre-agreed financial penalties triggered by delays, delivery shortfalls, or underperformance. They define a clear remedy framework that avoids lengthy legal disputes and compensates buyers for potential losses. LDs incentivize on-time delivery and operational reliability, demonstrating the producer's confidence in their technology and execution. Predefined remedies reduce counterparty and operational risk, strengthening lender and buyer confidence in project performance.

Performance wraps:

Performance wraps provide contractual guarantees that the plant will meet defined technology performance targets, e.g., yield, throughput, quality, efficiency, uptime, etc. They are typically offered by the EPC contractor, the technology licensor, or the parent sponsor and are verified through acceptance testing such as a performance guarantee test run. These guarantees create measurable remedies and give lenders confidence that operating risk is managed, which supports longer tenors and smoother ramp from commissioning to steady state.

Case in point:

HOLBORN Hamburg + Topsoe HydroFlex: licensor PGTR guarantees^{xxxiii}



Context

HOLBORN is converting capacity to produce SAF/HVO using Topsoe HydroFlex (2024). After commissioning, a Performance Guarantee Test Run confirms the unit meets guaranteed yield/quality followed by continued service to support ramp-up.^{xxxiv}



Why it worked

- a. Bankability improves because lenders can rely on licensor-backed PGTR to validate guaranteed operating metrics.
- b. Shorter ramp: Direct licensor involvement reduces ramp-up uncertainty.

Insurance

Third party insurance can complement wraps by turning operational risk into an insured claim. This coverage is especially important for lower maturity technologies where yields, availability, and carbon intensity can fluctuate during scale-up. Common products include delay in

start-up insurance that covers losses from commissioning delays and performance shortfall insurance that compensates when production or quality falls below contracted levels. By providing clear payout triggers and independent claims administration, insurance strengthens credit assessment and protects project cash flow.

Case in point:

Ariel Green: long-term output insurance^{xxxv}



Context

Ariel Green (insurance provider) offers long-term output cover of up to fifteen years and start up repair cover for bio conversion and biofuels. The cover guarantees output at an agreed attachment level and is designed to protect debt service during under performance and commissioning issues.



Why it worked

- a. Bankable tenor: Up to 15 years, aligning with debt and offtake windows.
- b. Debt service focus: Explicitly designed to keep lenders protected if the plant under-delivers.

Conditions precedent

Before an offtake agreement becomes effective the supplier must demonstrate regulatory compliance and operational readiness. Technical certification, including ASTM requirements is the first requirement, to ensure compatibility with existing aircraft and infrastructure. Delivery timings and terms should also be clearly laid out in the contract. Agreements need to state the expected commercial operation date and the start window for deliveries with a practical ramp from commissioning to steady state. These are critical conditions precedent and if they are not met the contract would become void.

Sustainability & Compliance

Sustainability performance determines both eligibility for policy incentives and the market value of the fuel. Contracts can specify carbon intensity targets and the method used to measure life-cycle emissions. Lower carbon intensity generally support higher credit values and can meet growing buyer expectations for measurable decarbonization.

Compliance with recognized sustainability standards and certification from recognized bodies ensures traceability and credibility. Contracts often also set requirements for feedstock origin and type, CoC, and ongoing monitoring so that credits are protected and certified output can be sustained for the full term

.What makes them bankable

Bankability improves when carbon intensity metrics and measurement methods are defined in the contract, and certification is maintained under recognized schemes. These elements reduce regulatory and supply risk, and allow lenders to model cash flow with confidence.

Ecosystem

Policy certainty

A stable and predictable policy environment enables bankable SAF offtakes, covered in depth in chapter 4, Section 5 on policy ecosystem. Without policy certainty, agreements remain exposed to sudden shifts that weaken their economic foundation. Durable and well defined policies anchor demand and revenues and allow lenders to underwrite long-term contracts with lower regulatory risk.

Global standards

Harmonised standards ensure fungibility and credible claims across markets. Sustainability frameworks such as CORSIA, ISCC, and RSB can verify life-cycle carbon reductions and prevent double counting, which supports cross border recognition and participation in registries. Shared standards create uniformity and credibility so value is retained across jurisdictions and policy credit and corporate reporting remain valid.

Revenue certainty mechanisms

Revenue certainty mechanisms can convert volatile market prices into predictable cash flow that supports investment decisions. They reduce exposure to price swings by setting clear revenue outcomes that hold through cycles. Governments have explored providing fixed price for biofuels and are also exploring Contracts for Difference (CfD) as eligible mechanisms. CfDs are administered by a central counterparty and set a fixed strike price and compare it to a reference index/ discovered price. In each settlement period the scheme pays a top up when the reference price is below the strike and collects a payback when it is above. This allows producers to see stable net revenue for longer terms, improving credit assessment, and lowering the cost of capital.

Case in point:

United Kingdom SAF Revenue Certainty Mechanism^{xxxvi}



Context

The United Kingdom is planning to introduce a SAF specific CfD style program to de risk investment in new capacity. It will be administered by a government owned counterparty modelled on the company used for power sector Contracts for Difference.



Offtake structure

Producers compete in reverse auctions by bidding the lowest strike price they are willing to accept. Contracts are awarded until the round budget or volume cap is met. Successful bidders sign private law agreements with the government backed counterparty. The contract guarantees settlement to the strike price through top ups when the market is lower and repayments when the market is higher.



Why it worked

The mechanism allocates support efficiently, channels funding toward the most cost competitive projects, and provides predictable cash flows that underpin financing.

Taken together, these elements show that a bankable offtake agreement requires multiple aspects to fall in place. Currently, short term contracts dominate the market, the industry requires long-term certain demand with price certainty to invest higher capital into the sector.

Key Takeaways:

- Firm, long-term and clear demand signals are essential to unlock project finance
- Bankable offtakes need credible counterparties, transparent pricing and clear allocation of policy credits, revenue certainty,

- Risk tools strengthen bankability including take-or-pay clauses, liquidated damages, performance guarantees and third party insurance to protect cash flow from delays or shortfalls
- Aggregating airline demand and corporate purchases can boost bankability and scale of offtake agreements

Chapter 4 | Section 4: Establishing SAF supply infrastructure

As production scales, SAF must be integrated into existing fuel supply chains so that molecules reliably reach the wing. Because SAF is a certified drop-in fuel, the core airport infrastructure that handles Jet A today can also handle ASTM-approved SAF blends.

The challenge is to add selective capacity and control points, not to build an entirely new system. In practice, this means providing dedicated storage for neat SAF, accurate blending through certified metering, routine quality testing, and digital tracking for custody and sustainability certification.

This integration builds on the existing standards framework. Neat SAF, known as a synthetic blending component under ASTM D7566, is blended with conventional jet fuel up to a pathway-specific limit as per approved ASTM pathways. Once the blend meets all performance and safety parameters, it is reclassified under ASTM D1655 as standard jet fuel. From that point onward, it can be stored, transported, and dispensed exactly like conventional fuel.

The following section outlines how SAF integrates into the existing aviation fuel ecosystem, from how blending works in practice to how custody and sustainability claims are tracked. It also examines the infrastructure upgrades required to support large-scale adoption, the financial implications of these investments, and optimal locations for blending and storage within the current supply chain. Together, these elements illustrate how SAF can scale efficiently through existing logistics networks with required additions while maintaining full compliance, transparency, and operational continuity.

Financial implications

From a cost standpoint, the infrastructure upgrades required to supply SAF are modest compared to production costs,

considering both CapEx and OpEx. The cost of blending, storage and handling jet fuels generally contributes 2-3% of the cost per barrel currently. Incremental infrastructure investment typically represents about 5-10% of total SAF project capital expenditure. Building a greenfield blending facility with 4-tank structure could cost USD 20-25 million for a 15-20k barrel capacity. Whereas refurbishing tanks and associated infrastructure at terminals can cost USD 3-10 million per site, depending on capacity, while refinery or terminal integration is often achieved within existing utility and logistics footprints. These figures underscore that infrastructure is not the cost barrier, the heavy lift lies in production financing, not blending and storage.

How blending works in practice

Blending SAF is a controlled, standard fuel operation. Neat SAF and Jet A are stored separately, then combined via in-line injection or in a dedicated tank to the approved blend ratio as shown in exhibit 4.4.2. Terminals choose from feasible methods based on operations and preferences. Most commonly, SAF and Jet A are blended in a third tank, certified, and if needed moved to a fourth tank for storage.

A second, less common option injects SAF directly into a Jet A tank more economical for small volumes but typically requiring dedicated infrastructure (EI, 2022).

Tank-mixing equipment ensures homogeneity and offsets density differences. Once blended, the fuel uses the same pipelines and trucks as conventional jet fuel.

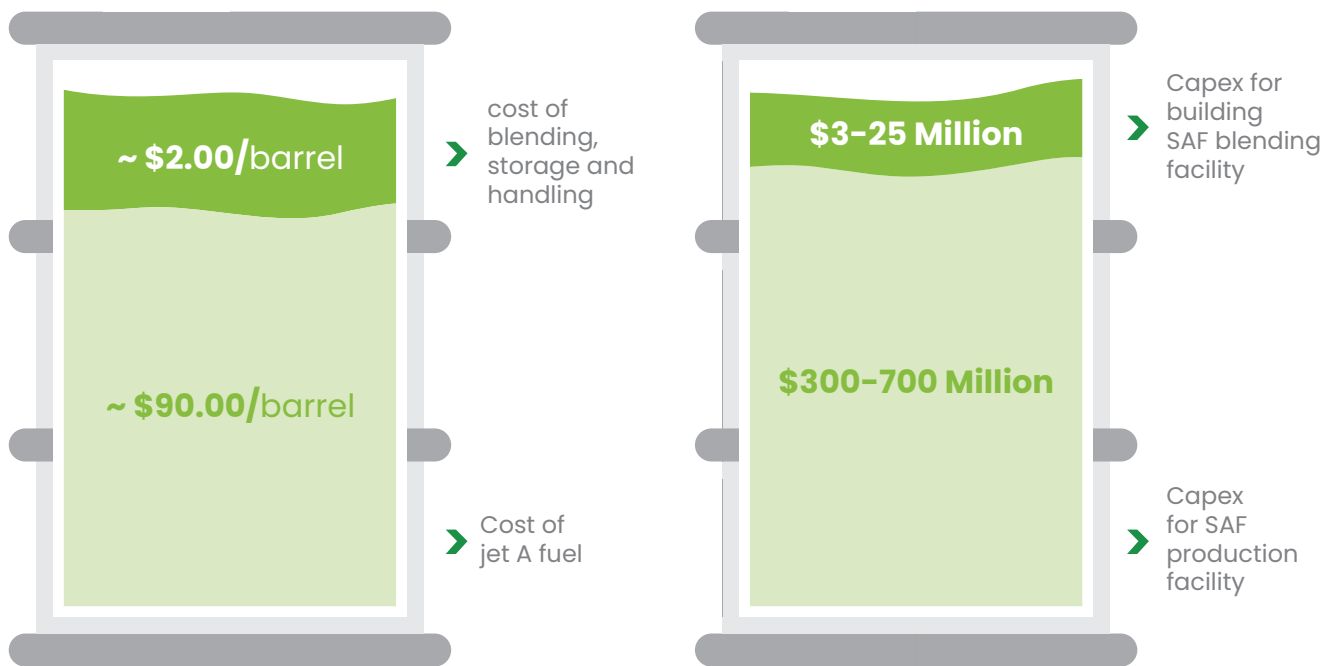


Exhibit 4.4.1: Financial implications of supply infrastructure for SAF

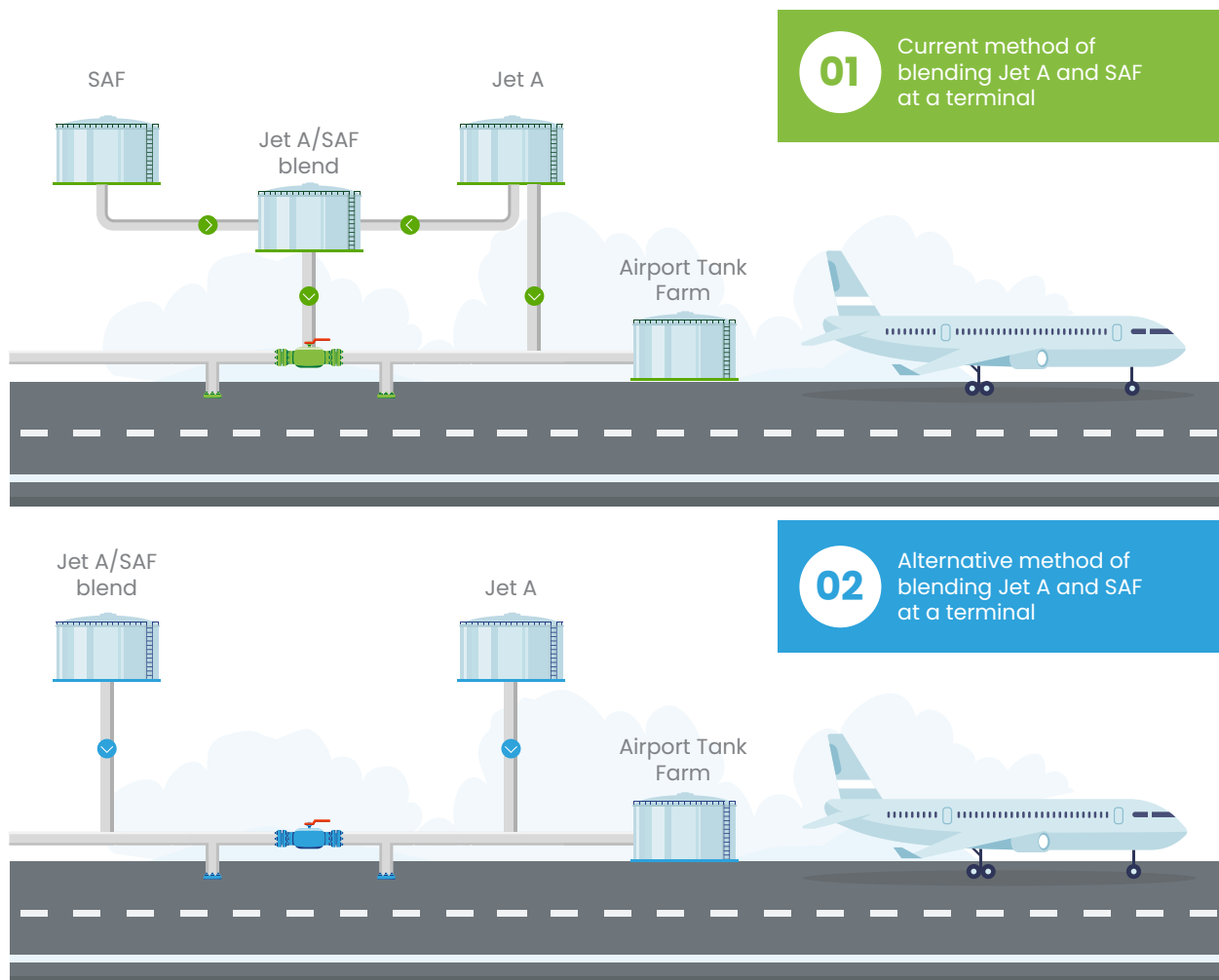


Exhibit 4.4.2: Methods for SAF blending with Jet A (Source NREL)^{xxxvii}

Infrastructure upgrades required

While blended SAF can be handled within existing supply infrastructure, targeted upstream infrastructure is required to bring neat SAF to the blend point and into that network. Key elements include reliable transportation from production sites to terminals, segregated storage for neat SAF

and finished product, accurate, metered blending to pathway limits, rigorous testing and quality assurance. With the following enhancements, SAF integrates seamlessly into current operations from terminal to wing:

Generic SAF supply chain

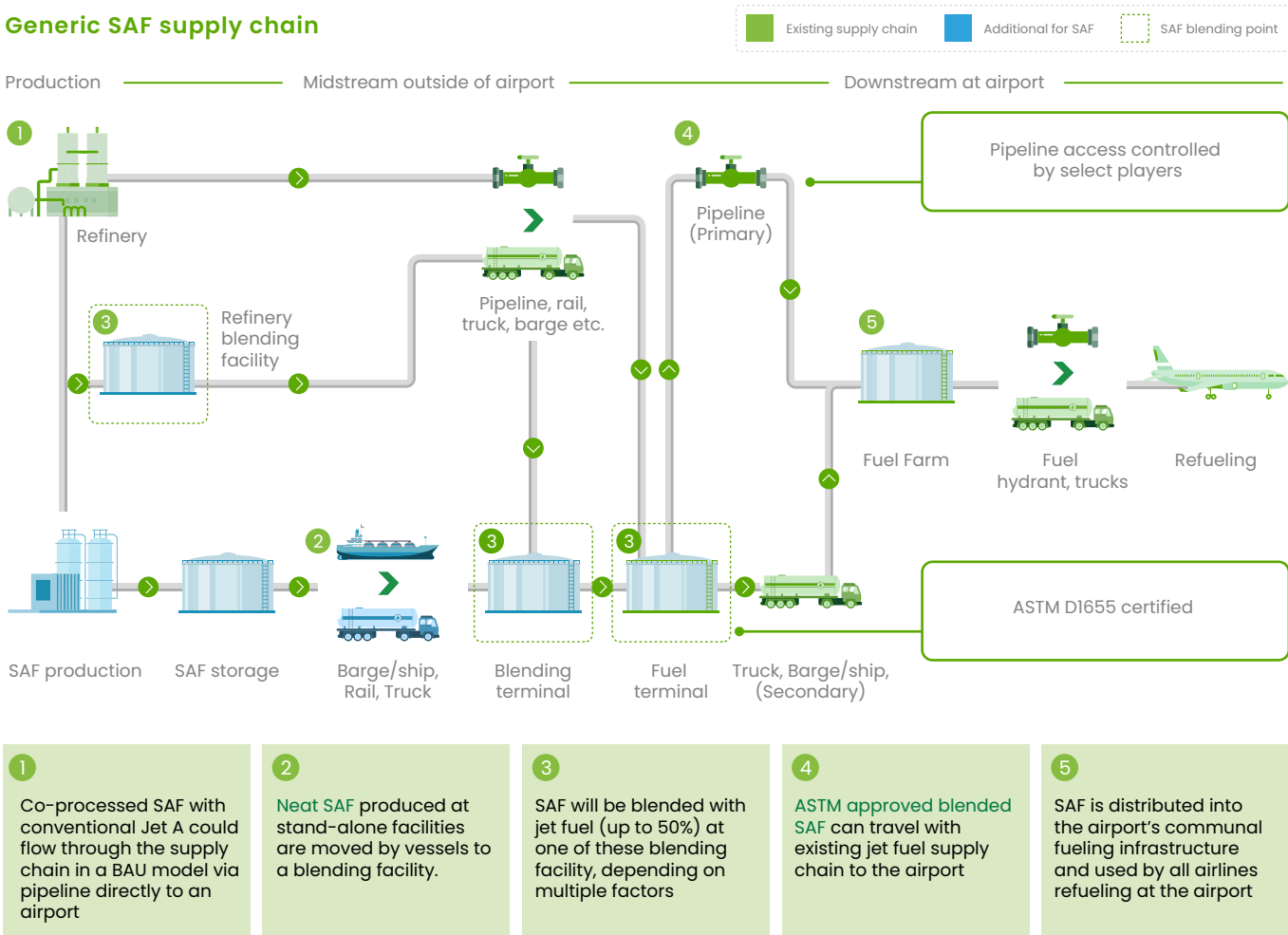


Exhibit 4.4.3: SAF supply infrastructural map

Transportation from production to blending sites

Neat SAF must be moved from production sites to blending hubs via road, coastal tankers, or barges, maintaining product integrity through sealed loading, inerting, and custody documentation to prevent contamination or data loss.

Storage for neat SAF and blended jet fuel

Operators may use 3 to 4 tanks to blend and store jet fuel, though in-line blending can reduce this need . Current regulations do not allow SAF from different pathways to be commingled in the same tank before blending with Jet A. This requirement, along with variations in aromatic content across SAF sources, influences how many

tanks a site must maintain.

A blending system with accurate metering

SAF blending uses in-line or tank systems with fiscal metering and digital controls to ensure precision within pathway limits. Automated monitoring and batch records create an auditable trail supporting CoC and verified carbon accounting.

Testing and compliance

Quality control mirrors conventional jet fuel, with sampling before and after blending, laboratory analysis for key parameters, and a Certificate of Analysis issued only when ASTM compliance is met.

These infrastructure requirements are incremental, not bespoke, yet they are decisive. By placing storage, metering, and QA capacity thoughtfully, suppliers can enable scale without re-plumbing supply.

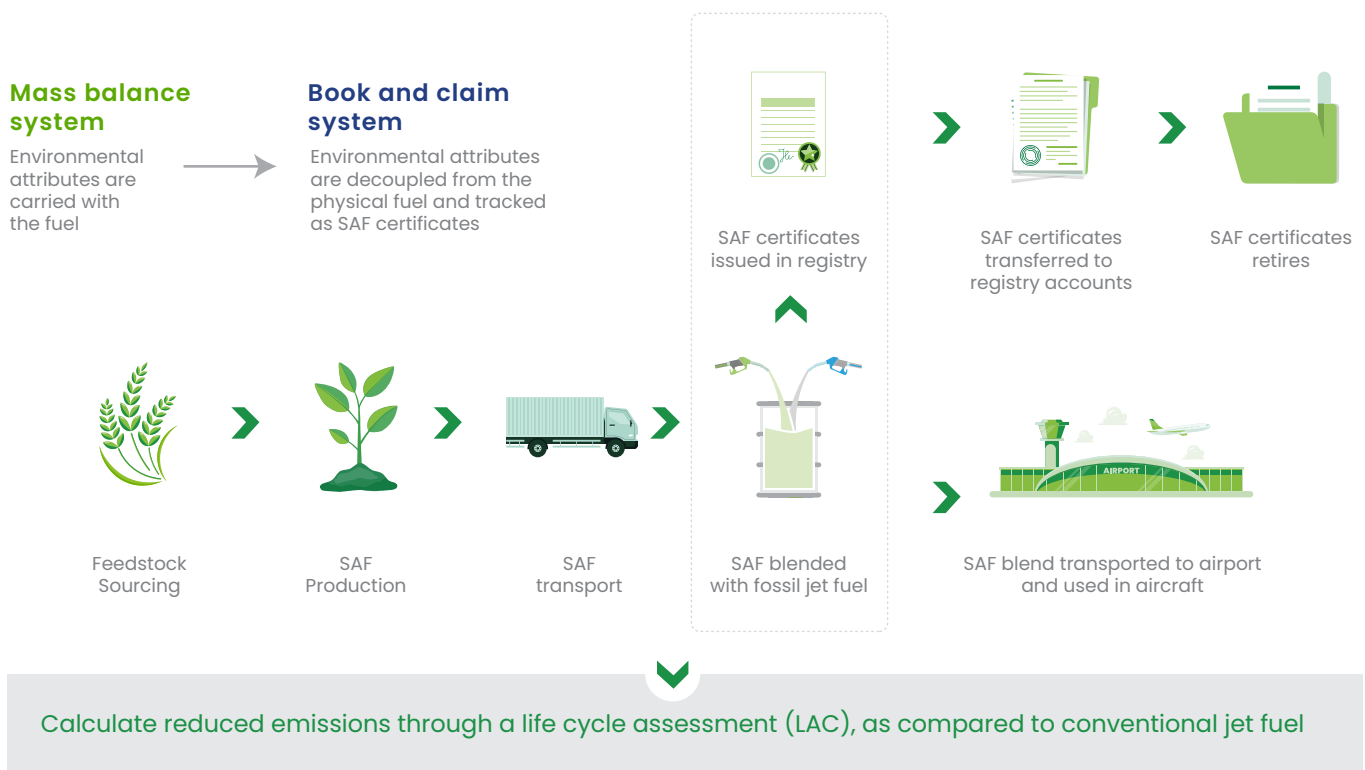


Exhibit 4.4.4 Mass balance vs. Book-and-Claim mechanism

Chain-of-Custody(CoC): mass-balance and where book-and-claim fits

Within the blending system, SAF use can be tracked in two main ways. The first is mass balance, where the SAF share is traced within a defined system boundary such as a refinery, terminal, or airport and proportionally allocated to outgoing fuel. The second is book-and-claim, where the physical fuel and its environmental attribute are separated.

Most SAF still moves physically through the network after blending, in parallel, book-and-claim offers a flexible accounting route. In this model, a supplier blends and

delivers blended fuel into the system at one location and issues serialized certificates that record details like pathway, blend ratio, batch ID, energy content, and life-cycle carbon intensity. An airline or corporate user at another location can later retire these certificates to claim the associated emission reduction. The fuel they physically uplift may be conventional jet, but the environmental benefit is transparently transferred through the registry.

Both methods protect fuel quality and safety. The choice depends on logistics and market structure, not on how physical fuel is handled. Because the blended fuel is already certified as standard jet, book-and-claim removes the

need to trace individual molecules.

Where to locate blending

There is no single “right” location; multiple nodes can work, and choices often evolve with supply and demand. Three common models are:

At refineries

When a refinery operates an SAF unit or sits near an SAF producer, refinery-based blending can be efficient. Refineries already have tankage, distribution system, certified meters, labs, and QA systems, limiting the incremental steps to blend and certify SAF-jet. Co-location, when possible, tends to integrate blending infrastructure most seamlessly.

Example – IndianOil (Panipat, India): Indian Oil Corporation Limited (IOCL) has been certified to produce SAF at its Panipat complex and plans a UCO-to-SAF revamp on site with target ~30–35 kt/yr in early phases. Crucially, Panipat is already tied into IOC’s product pipeline network including a dedicated ATF line from Panipat to IGI Delhi airport, leveraging existing jet logistics.

At regional blending hubs

Independent terminals, especially those designed for multi-mode receipts (truck/rail/barge) can aggregate volumes from multiple SAF producers and serve a broader airport catchment. They can add required infrastructure and support third-party “blending-as-a-service” models. This hub approach offers flexibility as supply scales and pathways diversify.

Mobile blending stations

A recent innovation is containerized/mobile SAF blending station that can be dropped into a hub (or even near-airport) to create certified, on-demand D1655 product without building a full rack. Because they’re built as modular, containerized skids, capacity can be right-sized by adding or removing units, and the entire package can be managed flexibly.

For example, FlyORO’s “AlphaLite” is a 40-ft modular unit designed for last-mile blending, deployable pre-airport or on-airport. FlyORO

recently announced partnerships to scale this approach globally. This gives terminals a lower-CapEx, relocatable way to add blending capacity as flows shift.

Off-airport-served terminals

Where space allows and production is nearby, upgrading an airport-adjacent terminal can shorten logistics and ease last-mile constraints.

Example – San Francisco Airport (SFO) via off-airport terminal & pipeline:

Neste established pipeline deliveries of blended SAF into SFO, using refurbished off-airport storage and the existing multi-product pipeline to the airfield. Operations at the airport fuel farm remained “business as usual” because the fuel arrived as D1655 jet fuel.

Supply infrastructure is not a fundamental barrier to scaling SAF. The essential systems to store, blend, certify, and distribute jet fuel already exist and can be adapted with targeted, incremental investments. What is needed is stronger coordination among producers, terminals, and airports to locate blending and storage capacity where it delivers the greatest efficiency, to build the technical and institutional capacity to manage growing SAF and certificate trades, and to digitize custody and sustainability systems for transparent carbon accounting across the supply chain.

Key Takeaways

- SAF is a true drop-in fuel and can use existing tanks pipelines trucks and hydrants with added storage blending and testing where needed
- Infrastructure is not the cost barrier since blending and storage upgrades are modest compared to production CapEx
- Book-and-claim lets SAF be supplied via the nearest terminal without long distance physical movement by transferring the environmental attribute
- Blending can happen at existing refineries or intermediate blending terminals with no changes required at the airport end

Chapter 4 | Section 5: Policy & Regulatory landscape

Breaking the vicious cycle of high prices, low demand and limited production requires policy support as the central lever. Durable policy creates predictable demand, lowers investment risk and recognizes verified carbon benefits, providing the scaffolding for market formation. Consistent frameworks with strong sustainability guardrails build confidence and allow learning and scale to translate into lower costs over time.

As SAF moves from demonstration to deployment, governments are constructing a mix of mandates, fiscal incentives, and carbon accounting rules to close the cost gap and build confidence across the value chain. Yet ambition alone does not guarantee delivery. Lessons from other clean-energy transitions show that investors, refiners, and airlines commit only when the policy environment is stable, consistent, and easy to navigate.

Before examining specific measures, it helps to view the policy landscape through the models that have taken shape. The European Union relies on clear blending mandates increasing over time, the United States favors incentives driven production and the United Kingdom blends both approaches with price-stability mechanisms designed to protect investors from volatility. Together, these frameworks demonstrate the diverse policy pathways to stimulate demand, attract investment, and safeguard sustainability. The following sections trace how these approaches have evolved and what they reveal about the practical levers for scaling SAF globally.

Evolving policy and regulation: impact on SAF adoption

While policy frameworks for SAF have expanded rapidly, the pace of evolution has also created planning risk across the value chain. Policymakers have often made adjustments to sustainability criteria, eligibility rules, and crediting pathways, making it harder for producers

and investors to commit capital with confidence and equally challenging for airlines and technology developers to align long-term plans. Each revision, though aimed at improvements, adds a layer of uncertainty about future standards and incentives which can ripple through the ecosystem, and weaken the momentum that strong policy is meant to create.

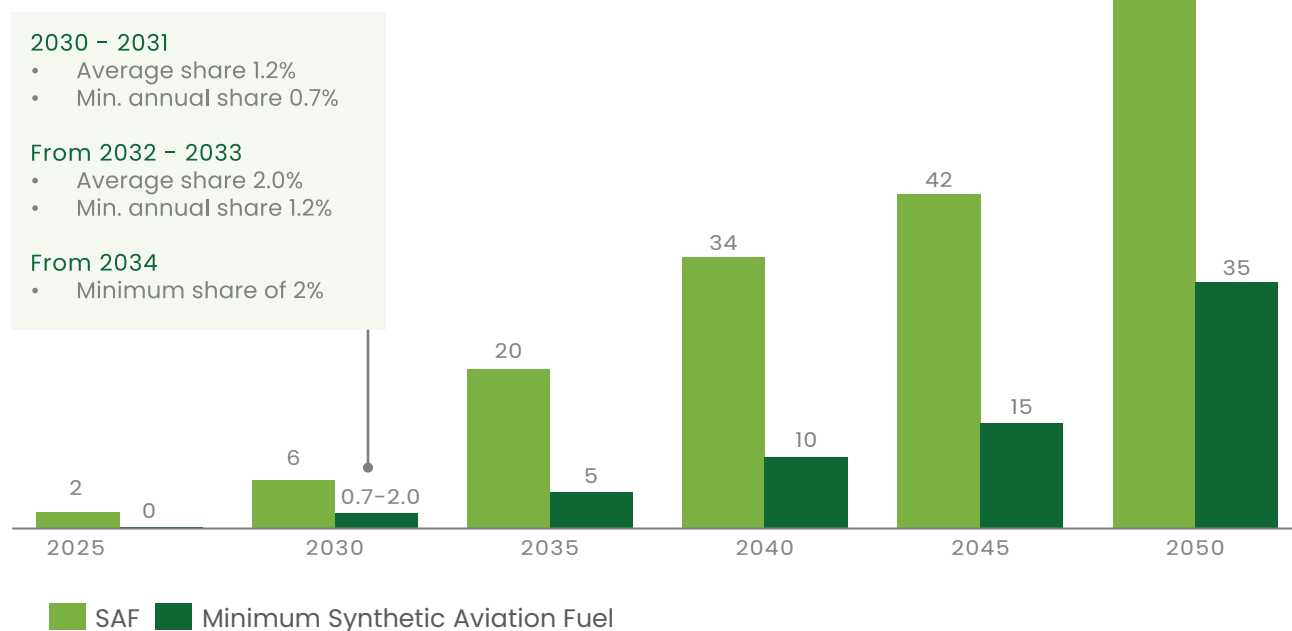
Changing policy on biofuels in Europe is a prime example

Over the past two decades, the European Union's renewable fuel policy has steadily evolved from encouraging basic biofuel blending to enforcing a far more rigorous and sustainability-driven framework. What began with broad goals to cut emissions through any renewable substitute has gradually transformed into a system that rewards the cleanest, most traceable, and least land-intensive fuels. Each revision of the Renewable Energy Directive has tightened greenhouse-gas thresholds, narrowed eligible feedstocks, and raised the expectations for verification and reporting, reflecting the EU's increasing ambition under the Green Deal and "Fit for 55" climate agenda.

The policy shift also marks a clear move away from crop-based biofuels toward advanced and waste-derived alternatives. Early programs that relied heavily on food and feed crops are now being phased down, while incentives and mandates focus on residues, lignocellulosic materials, and emerging synthetic options such as e-fuels. EU also introduces Annex IX which defines the "green list" of preferred feedstocks, Part A for truly advanced materials, and Part B for limited waste oils and fats, which underpins the long-term sustainability pathway for biofuels and SAF in Europe. This progression signals their broader intention to ensure that every liter of alternative fuel delivers verifiable and durable climate benefit.

EU deep dive | New targets for aviation decarbonization through sustainable fuels introduced

New targets for SAF
(min. volume share in EU airports, as % of fuel mix)



Highlights of the ReFuelEU Aviation regulation

Proposed Regulation apply to aircraft operators, EU airports, and suppliers of aviation fuel

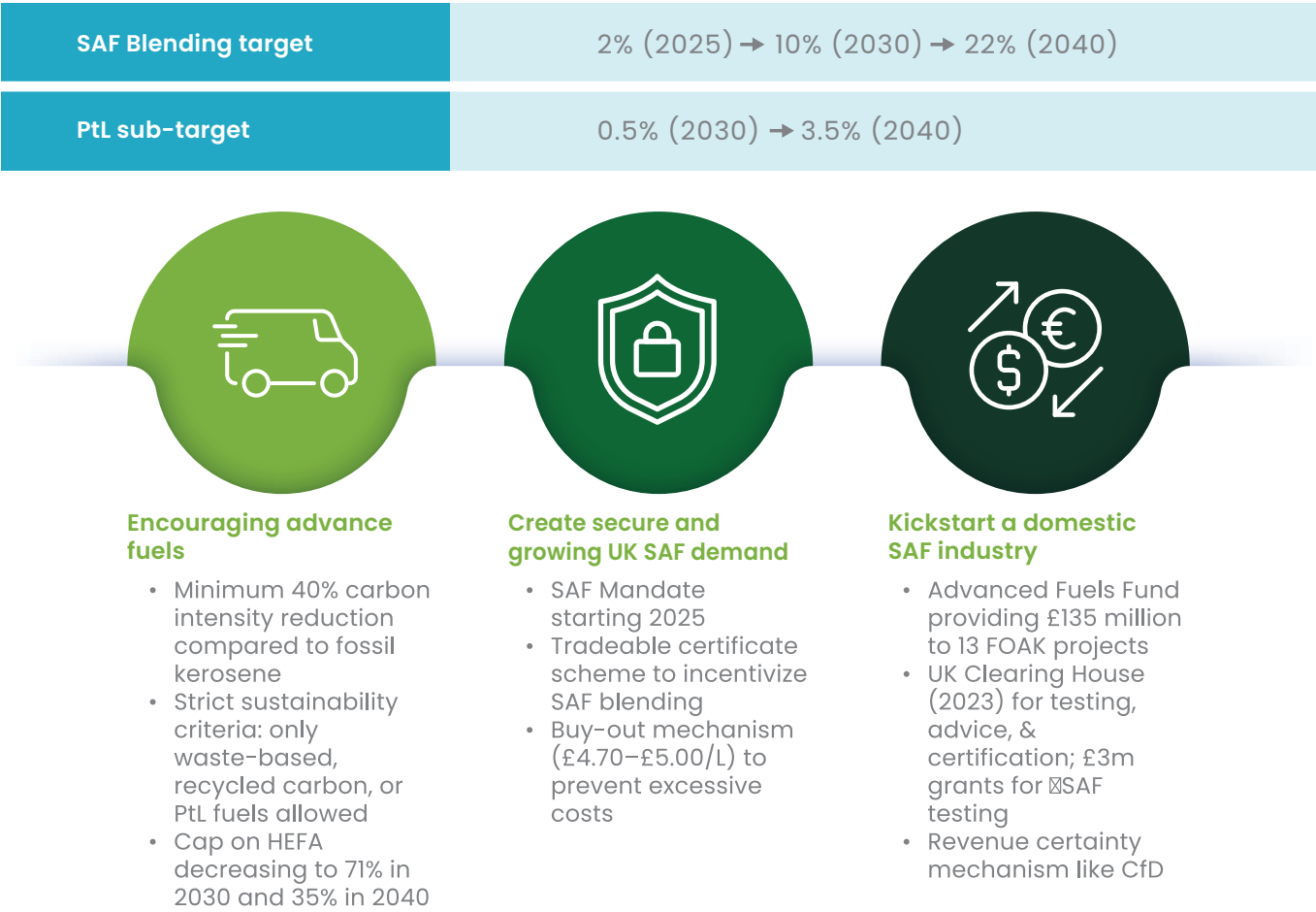


Note: Sustainable Aviation Fuels means drop-in aviation fuels that are either synthetic aviation fuels, advanced biofuels as defined in Article 2, 2nd paragraph, point 34 of Directive (EU) 2018/2001, or biofuels produced from the feedstock listed in Part A of Annex IX to that Directive. SAF produced from feedstocks included in "part B" will be limited to a maximum of 3%

Source: European Commission; Proposal 2021/0205 ReFuelEU Aviation – sustainable aviation fuels; Proposal 2021/0207 Revision of the EU Emission Trading System for Aviation; Proposal 2021/0204 Carbon Offsetting and Reduction Scheme for Int. Aviation. Trilogue discussions

Exhibit 4.5.1: Overview of EU SAF Policy

UK deep dive | Driving SAF Adoption through demand mandates & production incentives like



Contracts for Difference (CfD)

How it works

Government sets a “strike price” that guarantees revenue per unit of SAF
Allocated via reverse auctions: lowest acceptable strike prices win until the round’s budget/volume cap is met
If market price < strike, producer gets a top-up; if market > strike, producer pays back the difference
Contracts are time-bound (multi-year) and settled against an agreed market reference.

How does it help?

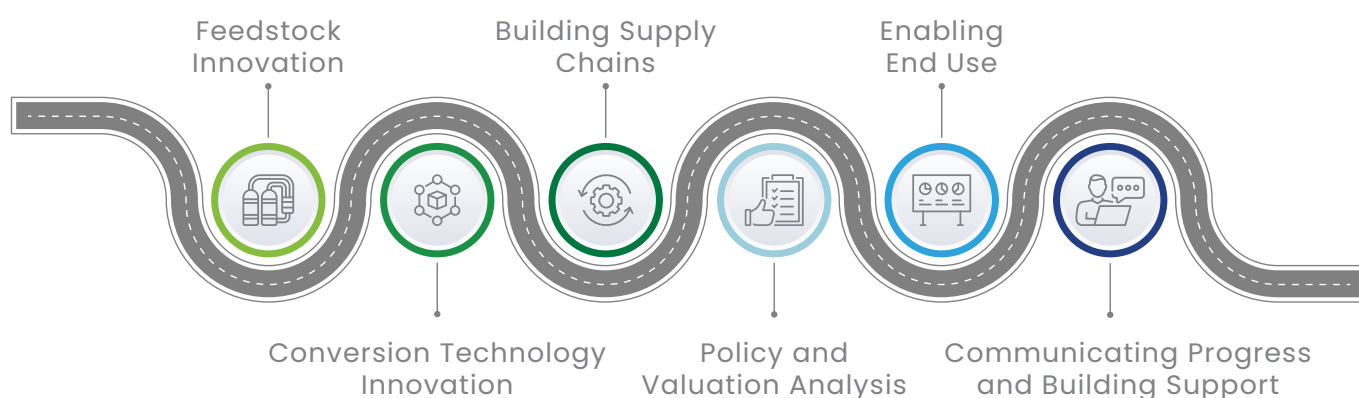
01	Producers: Bankable, predictable cashflows → unlocks project finance/FID
02	Airlines/OMCs: More long-term offtake capacity at lower, steadier premiums
03	Lenders/investors: Reduced price risk, clearer downside protection

Exhibit 4.5.2: Overview of UK SAF Policy

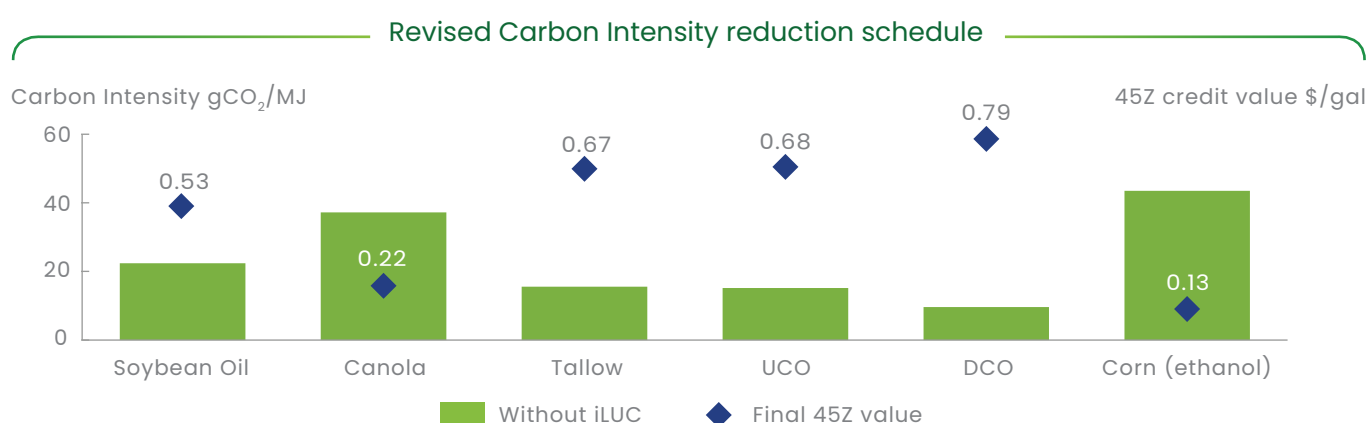
USA deep dive | SAF Grand Challenge

Target for SAF production	Produce 3 billion gallons/year by 2030 → ~35 billion gallons/year by 2050
Eligibility	SAF must cut lifecycle GHG ≥50% vs. fossil jet

- Led by Department of Energy (DOE), the U.S. Department of Transportation (DOT), the U.S. Department of Agriculture (USDA)
- The roadmap lays out six action areas spanning all activities with the potential to impact the SAF Grand Challenge objectives of expanding SAF supply and end and reducing the cost of SAF:



45Z Clean Fuel Production Credit



	Federal producer credit for fuel made in the U.S. and sold in 2025–2029
	For the rest of 2025 (before the 2026 rules start): <ul style="list-style-type: none"> • Imported used cooking oil (UCO) is ineligible under the 45Z GREET pathway • Other foreign feedstocks remain eligible till end of 2025
	From 2026 (fuel made after Dec 31, 2025): <ul style="list-style-type: none"> • Feedstocks must be North American (U.S./Canada/Mexico). Clifford Chance • ILUC is removed from lifecycle carbon (CI) calculations. Clifford Chance • Credit is capped at \$1/gal (with prevailing wage), so SAF no longer has the \$1.75/gal upside. Clifford Chance • Negative-emission CI scores are banned, except for fuels from animal manure (e.g., RNG)

Source: Argus, BCG analysis

Exhibit 4.5.3: Overview of US SAF Policy

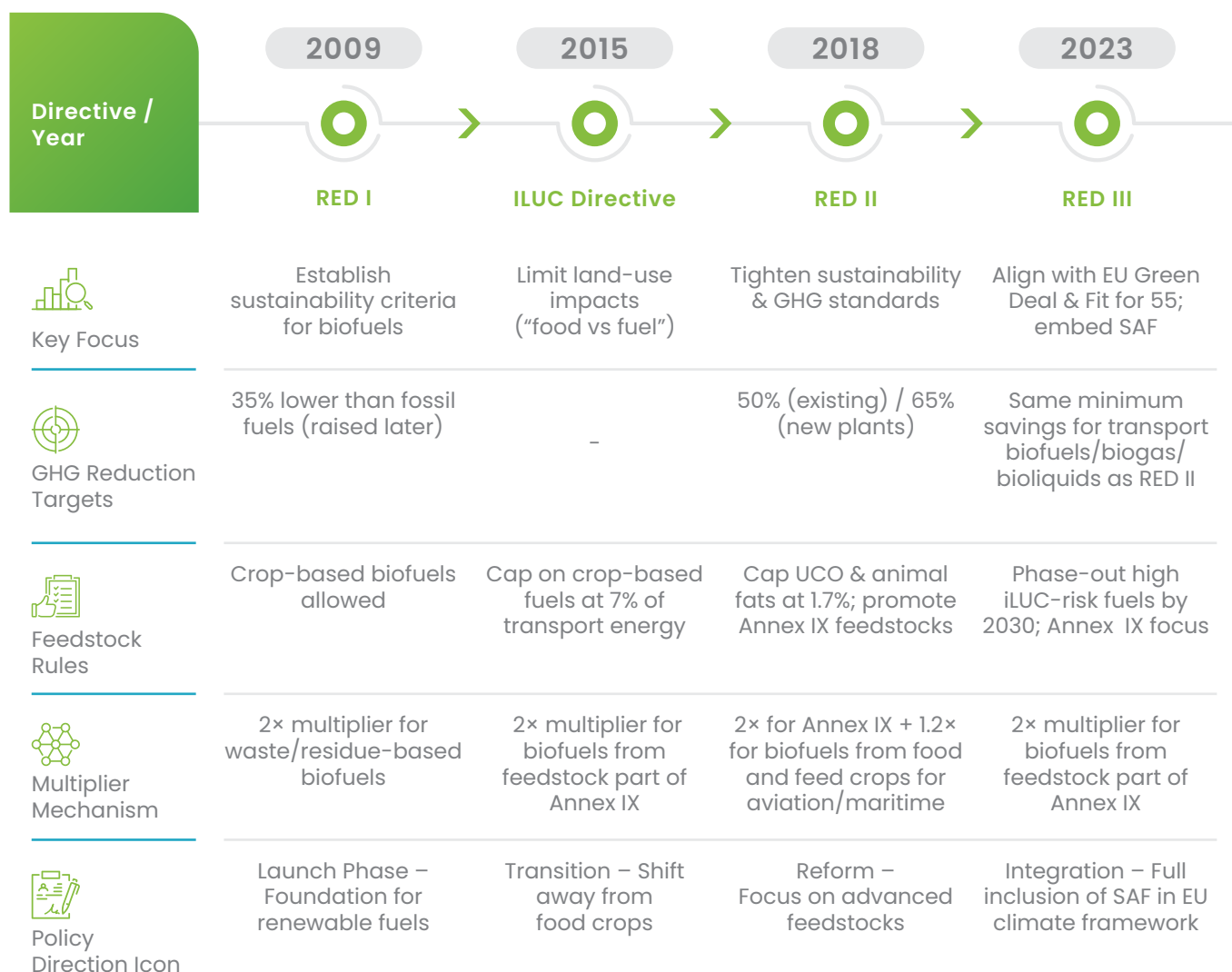


Exhibit 4.5.4: Evolution of EU SAF policies

A Similar Evolution Has Been Observed for the UK

The UK's approach to SAF policy has evolved through adjustments, initial proposals set a 60% emissions-saving threshold later revised to 50% and ultimately reduced to 40% after repeated consultations, aiming at an effort to widen eligibility but one that also revealed the struggle to balance ambition with feasibility. These revisions and shifting targets have also impacted investor confidence and create ambiguity for

producers, impacting FIDs. While the inclusion of a sub-target for Power-to-Liquid fuels shows intent to push next-generation pathways, the simultaneous cap on HEFA fuels has created new uncertainty around near-term supply and feedstock choices, given the low commercial maturity and higher costs of alternative technologies to present.

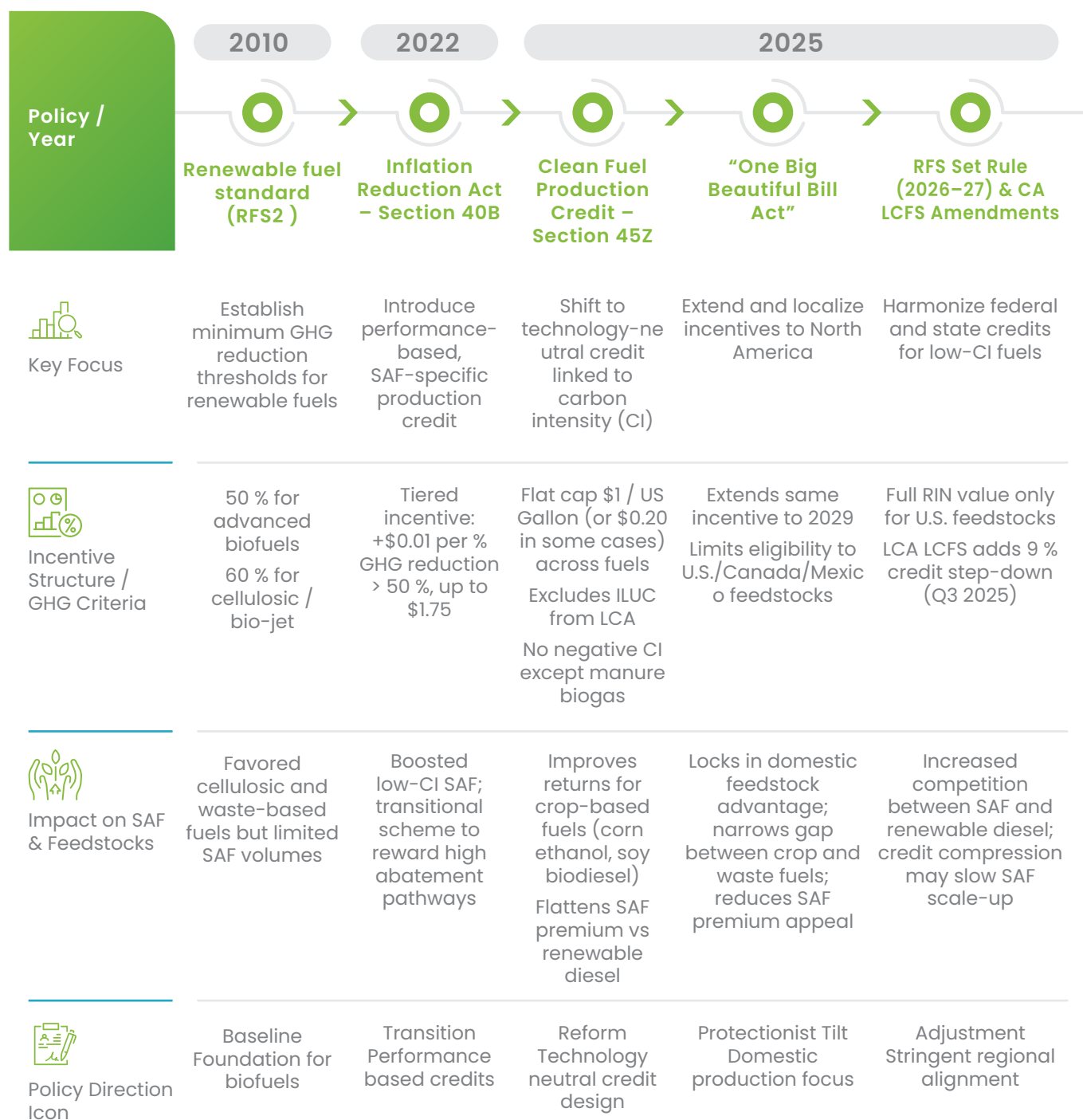


Exhibit 4.5.5: Evolution of US SAF policies

Policy Incentives In the US Observed Likewise Evolution Over Time

Over the past decade, US fuel policy has shifted from sustainability-based eligibility to performance-based incentives, and more recently toward a domestically focused and technology/fuel-agnostic regime. Renewable fuel standard 2 (RFS2) set the early guardrails with minimum GHG thresholds, but the Inflation Reduction Act moved the center of gravity to production credits tied to carbon intensity, rewarding deeper abatement regardless of technology. With 45Z, that logic broadened and flattened one credit design for many fuels reinforcing a technology-neutral, CI-linked approach while narrowing the distinct premium for SAF.

These changes have clear market effects with time-limited credits and evolving rules, this creates planning pressure for stakeholders across the entire value chain. The policy mix also compresses the “green premium,” improving near-term economics for several pathways and narrowing the competition between SAF and other low-carbon fuels like renewable diesel. Stronger preference for North American feedstocks and tighter state-level rules further tilt incentives toward domestic supply. In practice, credits tied to carbon performance can drive near-term scale, but lasting SAF

Model-gaps & Inconsistencies Across Policies:

A unique aspect of aviation is that it operates as an inherently global network, with international routes, shared aircraft models, and standardized operational systems. Because flights cross jurisdictions daily, consistency in fuel quality, safety standards, and emissions accounting is essential. SAF policy currently is a web of mandates, market instruments and carbon-accounting rules that shape real investment decisions and airline cost curves. Four “policy macro-regions” can be sketched:

1. ICAO’s CORSIA framework as the global floor, relatively flexible and not particularly ambitious or restrictive with its rules
2. The EU/UK supply mandates with linked penalties/buyouts and carbon-market/CfD type of support
3. The North American uncertain, credit-driven demand pulls, like the federal RFS program and the IRA 45Z in the US, and national LCFS schemes in CA/OR/WA and Canada’s British Columbia
4. The big, fragmented Rest of the World (RoW), with a mosaic of approaches and regions progressing at different paces with the development of SAF blending mandates, some -like Brazil, Singapore, South Korea and Japan- potentially faster than others.

The transition to SAF requires globally aligned and clearly defined policies, ensuring that sustainability measures are recognized and implemented uniformly across markets.

Inconsistencies Across the Policy Landscapet

While macro-regions point towards decarbonizing aviation, they do so with different levers, boundaries and eligibility rules. That divergence is where both the opportunity and the friction currently lie – key differences can be observed across different regimes as illustrated in Exhibit 4.5.6.

Current Gaps In SAF Policy

Despite rapid progress, several policy ambiguities still impede bankable offtake and timely FIDs. The points below highlight where clearer rules or guidance would materially reduce risk:

REGIME	FOSSIL BASELINE (CO ₂ e/MJ)	ELIGIBILITY THRESHOLD	IMPLIED CI THRESHOLD (gCO ₂ e/MJ)	MANDATE TYPE	SYN-SAF SUB-TARGET	FEEDSTOCK SCOPE SUMMARY	ILUC TREATMENT
CORSIA (ICAO)	81.9	≥10% reduction	≤73.71	Global offsetting framework; no SAF blending mandate	No	Broad; LCA-based eligibility	Default iLUC values; low-iLUC risk certification possible
EU / UK	94	≥65% reduction (installations ≥ 2021)	≤32.90	Blending mandates (ReFuelEU/UK), penalties (EU) and buy-outs (UK)	Yes – starting 2030 (EU) and 2028 (UK)	Annex IX A/B ¹ , RCAF ² , LCAF ³ , RFNBO ⁴ ; food/feed crops excluded; palm/soy material & PFAD/ soap-stock excluded unless added to Annex IX	1G SAF excluded for mandate; high-iLUC biofuels to be phased out by 2030 under RED III
NORTH AMERICA (US / CANADA)	Program specific	US §45Z ≤~47.4 gCO ₂ e/MJ	Program specific	No US federal SAF blending mandate; credit-driven (RFS/RINs, 45Z, LCFS); Canada CFR & LCFS	No	Broader set incl. some food-based crops; origin-based rules favor domestic	§45Z currently excludes iLUC (program-dep endent elsewhere)
REST OF WORLD	Varies	Varies	Varies	Select countries exploring mandates and incentives	Limited – no explicit targets	Varies by jurisdiction	Varies

1. Annex IX (EU RED II/III) – EU list of eligible advanced and waste/residue feedstocks (Part A/B) for renewable fuel

2. Recycled Carbon Aviation Fuel

3. LCAF – Low-Carbon Aviation Fuel

4. Renewable Fuels of Non-Biological

5. RIN – Renewable Identification Number, the tradable compliance credit in the U.S. RFS

Exhibit 4.5.6: Evolution of US SAF policies

GEOGRAPHY / LAYER	RULE-SETTER / INSTRUMENT	FRICTION POINT	BANKABILITY RISK	FOCUS AREA
US	IRA §45Z tax credit; federal RFS program (RIN credits); state-level LCFS (e.g., California)	<ul style="list-style-type: none"> Credits arise at different points of the value chain (production, blending, withdrawal) Support is short-sighted and subjected to adjustments. 	<ul style="list-style-type: none"> Disputes over value attribution (who owns the value and when) timing/price friction. Complex market predictability due to lack of long-term targets and support. 	<ul style="list-style-type: none"> Define waterfalls (who gets the value first), revision triggers and pass-throughs clauses Include the flexibility to switch to alternative credit stacks.
EU	ReFuelEU Aviation; EU ETS; RED III; Union Database for Biofuels (UDB)	<ul style="list-style-type: none"> Claims across multiple schemes; national rules aren't fully harmonized (high fragmentation) learning curve on UDB use (no official mandatory implementation deadline). 	<ul style="list-style-type: none"> Risk of double counting, claims being invalidated, or delivery hiccups. 	<ul style="list-style-type: none"> One-batch/one-claim" rule; proof of retirement in a recognized registry List which certificate registries are going to be contractually accept and what are the remedies if something goes wrong
GLOBAL	ICAO/CORSIA	<ul style="list-style-type: none"> The exact same batch can be scored differently vs EU/US/RoW Sequencing of claims is tricky. 	<ul style="list-style-type: none"> Claims can be mis-routed; Value associated with products can disappear due to different rules Risk of fraud heavier audit exposure. 	<ul style="list-style-type: none"> A clear hierarchy for which scheme gets to claim first Robust batch ID tracking and retirement procedures.
RoW	Country-specific mandates/incentives, customs and tax rules.	<ul style="list-style-type: none"> Domestic markets and supply chains are still maturing; risk of high exposure if projects depend only on exports – especially in a world dominated by high geopolitical tensions. 	<ul style="list-style-type: none"> Sudden changes in netbacks (realized prices) or shipping routes (due to changing physical markets), with logistic impacts. 	<ul style="list-style-type: none"> Delivery optionality (alternate delivery points/markets), political-risk triggers, and rights to redirect to alternative markets.
VOLUNTARY MARKETS	B&C registries and voluntary standards	<ul style="list-style-type: none"> Documentation and recognition vary across schemes and regions 	<ul style="list-style-type: none"> Reputation/audit risk; Claims may not be fungible across programs/regions 	<ul style="list-style-type: none"> Strong single-use tracking; transparent disclosure that lines up across parties Price adjustments if recognition differs.

Exhibit 4.5.7: Policy Gaps and friction points

Reflection on Biofuel Policy Performance

Over the past two decades, global biofuel policies have provided important lessons in translating ambition into outcomes. Many initiatives were launched with strong political backing and high expectations for emissions reductions, yet their results often fell short of original targets. In several cases, changing market conditions, evolving sustainability priorities, dynamic political environment and regulatory adjustments led to outcomes that differed from initial plans. This experience underscores the complexity of scaling new energy systems and the importance of stable, adaptive, and well-coordinated policy frameworks.

For the SAF industry, this legacy serves as both context and caution. Policymakers and market participants remain mindful of the challenges faced in earlier biofuel programs and are therefore more measured in setting timelines and targets. Ensuring that new SAF policies are durable, clearly enforced, and financially viable will be essential to maintaining investor confidence, promoting investments in the near term and sustaining long-term industry growth. For instance, many countries set blending targets for biofuels and adjusted those targets later in response to supply and market dynamics, such as the renewable fuels volume target set by US under RFS or China's E10 blending mandate, or Brazil's biodiesel mandate. At the same time, we have seen countries achieve and exceed their mandates in

other biofuels, for example Brazil and India's ethanol blending mandates, US's ethanol blending targets and Indonesia's biodiesel blending mandate.

Overall, the mixed performance of earlier biofuel initiatives highlights how critical policy stability, clarity and coordination are for SAF. As governments refine new frameworks, drawing on these experiences can help build programs that are both ambitious and achievable anchoring confidence across the aviation value chain and accelerating the industry growth.

Best Practices and Path Forward For Global SAF Policies

As we saw in earlier sections, some countries have a head start on the path for aviation decarbonization; however, as the policy environment remains nascent, firm long-term and possibly harmonized policies across the world will be required to scale SAF.

The following framework outlines best practices for policymakers based on 10+ leading SAF and biofuel policies across different regions. However, each country has its own unique context such as feedstock availability, resource base, industrial maturity, and policy priorities and hence the following levers may need modification to suit national circumstances. Exhibit 4.5.8 following the four pillars outlines available levers for policymakers along with benchmarks for scaling SAF.

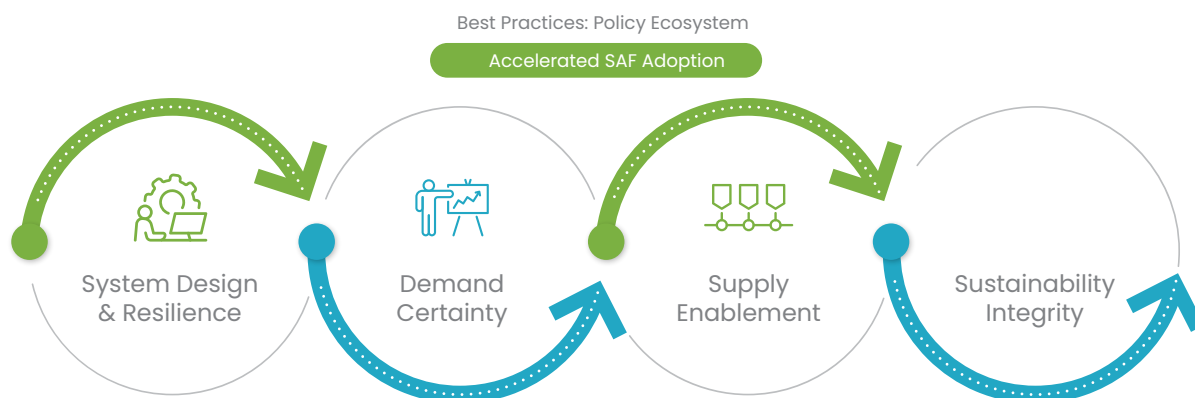


Exhibit 4.5.8: Policy support levers for global SAF adoption



Observed practices



Description



Case in point

Clear, escalating blending mandates	<ul style="list-style-type: none"> Rising schedules with advanced/e-fuel sub-targets Mandate compliance via tradable credits Defined non-compliance treatments 	<ul style="list-style-type: none"> India: Ethanol blending mandate targeting E10 by 2022 and E20 by 2025 Brazil: RenovaBio program establishing a national ethanol blending. South Korea: 1% SAF blending mandate announced for implementation by 2027
Demand-pull via levies	<ul style="list-style-type: none"> Small, route-based levies earmarked for SAF Distance/class differentiation used to moderate impacts. 	<ul style="list-style-type: none"> Singapore: SAF levy (from 2026) supporting ~1% initial blend, ramping toward 3–5% by 2030
Public procurement & anchor offtake	<ul style="list-style-type: none"> Early state purchases (military, government travel) providing bankable offtake and market signal. 	<ul style="list-style-type: none"> Germany: Military procurement of 3.8M liters SAF for air force fleet India: Delhi Metro Rail Corporation long-term solar power purchase agreement
Production incentives & credits (CI-linked)	<ul style="list-style-type: none"> Incentives indexed to lifecycle CI, narrowing the cost gap and guiding investment. 	<ul style="list-style-type: none"> US: IRA §45Z carbon-intensity-linked SAF tax credit with stackable LCFS credits. Canada: Clean Fuel Regulations (CFR) life-cycle carbon-intensity reduction requirements with a federal credit market
Revenue certainty mechanisms (price stabilization)	<ul style="list-style-type: none"> CfD/price-floor style tools used to stabilize margins and support diversification beyond HEFA. 	<ul style="list-style-type: none"> UK: SAF Revenue Certainty Mechanism using Contracts for Difference (CfD),
Capital support for production	<ul style="list-style-type: none"> Grants/loans/guarantees applied to FOAK and early commercial plants to lower financing hurdles. 	<ul style="list-style-type: none"> EU: Innovation Fund grants totaling €3.6 billion for First-of-a-Kind SAF projects Norway: Nordic Electrofuel ~€40M PTL specific grant
Infrastructure & logistics development	<ul style="list-style-type: none"> Co-investment in terminals, blending, storage, QA, and airport logistics to ease bottlenecks. 	<ul style="list-style-type: none"> U.S: FAA FAST program providing \$244.5 million (2024) for SAF blending, transport, and storage
Transferable sustainability certificates (SAFc)	<ul style="list-style-type: none"> Book-and-claim attributes used to broaden participation and add a secondary revenue stream. 	<ul style="list-style-type: none"> US: New Jersey Solar Renewable Energy Certificates registration program.

Pillar



Market Creation & Demand Certainty



Supply Enablement & Investment Support



Sustainability & Traceability Assurance



System Design & Policy Resilience



Observed practices



Description



Case in point

Feedstock guardrails & traceability	<ul style="list-style-type: none"> Eligibility lists and chain-of-custody frameworks steering toward advanced/waste-based inputs. 	<ul style="list-style-type: none"> ICAO: CORSIA sustainability certification recognized through ISCC and RSB schemes.
Robust MRV, registries & book-and-claim rules	<ul style="list-style-type: none"> Standardized CI methods, batch docs, and registry retirement to avoid double counting and align claims. 	<ul style="list-style-type: none"> SABA: SAF certificate registry system with issuance and retirement for corporate claims.
Cross-sector, integrated policy approach	<ul style="list-style-type: none"> Mandates paired with tradable credits and infrastructure support to build durable markets. 	<ul style="list-style-type: none"> Brazil: RenovaBio framework combining mandates, decarbonization credits, and infrastructure support
Cost-containment & consumer protection	<ul style="list-style-type: none"> Buy-outs, phased coverage, and banking/borrowing used to temper cost spikes and sustain support. 	<ul style="list-style-type: none"> UK: Renewable Transport Fuel Obligation with capped compliance cost mechanism
Policy clarity & durability	<ul style="list-style-type: none"> Multi-year roadmaps, consistent CI/LCA/MRV rules, and scheduled reviews used to reduce policy risk. 	<ul style="list-style-type: none"> Brazil: RenovaBio multi-year carbon-intensity targets and verification framework.
Interoperable governance & sequencing	<ul style="list-style-type: none"> Linked registries, single-use retirement, and defined audit/LOA steps minimizing claim conflicts. 	<ul style="list-style-type: none"> EU: Union Database linking national registries with mass-balance accounting rules.

Pillar



Market Creation & Demand Certainty



Supply Enablement & Investment Support



Sustainability & Traceability Assurance



System Design & Policy Resilience

Exhibit 4.5. 9: Overview of policies practiced boosting SAF adoption

Key Takeaways:

When rules are stable, clear, and aligned, confidence builds, capital follows, and partnerships deepen across the value chain. That momentum unlocks new plants, steadier offtake, smarter infrastructure, and credible sustainability claims, shifting SAF from promising pilots to everyday practice. As more countries converge on predictable frameworks, production and demand can rise together, reinforcing one another and nurturing a complete SAF ecosystem.

- Policy is the primary lever to scale SAF by creating predictable demand and lowering investment risk and valuing verified carbon benefits
- Rapid policy changes and rules that are not aligned across regions create planning risk and complicate eligibility credit stacking and sustainability claims
- Coordinating demand measures like blending targets and price certainty with aligned supply incentives such as production tax credits or grants can scale entire ecosystem

Chapter 4 | Section 6: The Role and Purpose of Certification in SAF

Certification reinforces the policy framework and enables adoption across the entire SAF value chain. With robust certification, producers, traders, airports, airlines, financiers, and regulators can rely on common rules and comparable data. This assurance allows verified emission reductions to be recognized within programs such as CORSIA, the EU Emissions Trading System, and the US Low Carbon Fuel Standard.

Technical Certification: Ensuring Safety and Performance Integrity

Technical certification ensures that SAF performs to the required safety and quality standards. It verifies that the fuel can be used safely in existing aircraft engines and fuel systems, making it a true drop-in fuel. This process is governed by ASTM International, the global authority for aviation fuel specifications.

At its core lies ASTM D7566, which defines

standards for synthetic blending components known as Synthetic Paraffinic Kerosene (SPK). Once a new SAF pathway meets D7566 requirements, its blends automatically comply with ASTM D1655.

Each annex within ASTM D7566 specifies the feedstock, conversion process, and blending limits for an approved pathway. Current examples include HEFA-SPK, FT-SPK, and AtJ-SPK, typically allowing up to 50% blending with conventional jet fuel.

The approval process as detailed in Exhibit 4.6.1, follows a rigorous, multi-stage evaluation. Developers begin with laboratory and property testing (Tier 1 and Tier 2), then progress to component, rig, and engine testing (Tier 3 and Tier 4) conducted by OEMs and the US Federal Aviation Administration. Only after successful review by the ASTM Aviation Fuels Subcommittee (D02.J) is a new pathway added as an annex to ASTM D7566.

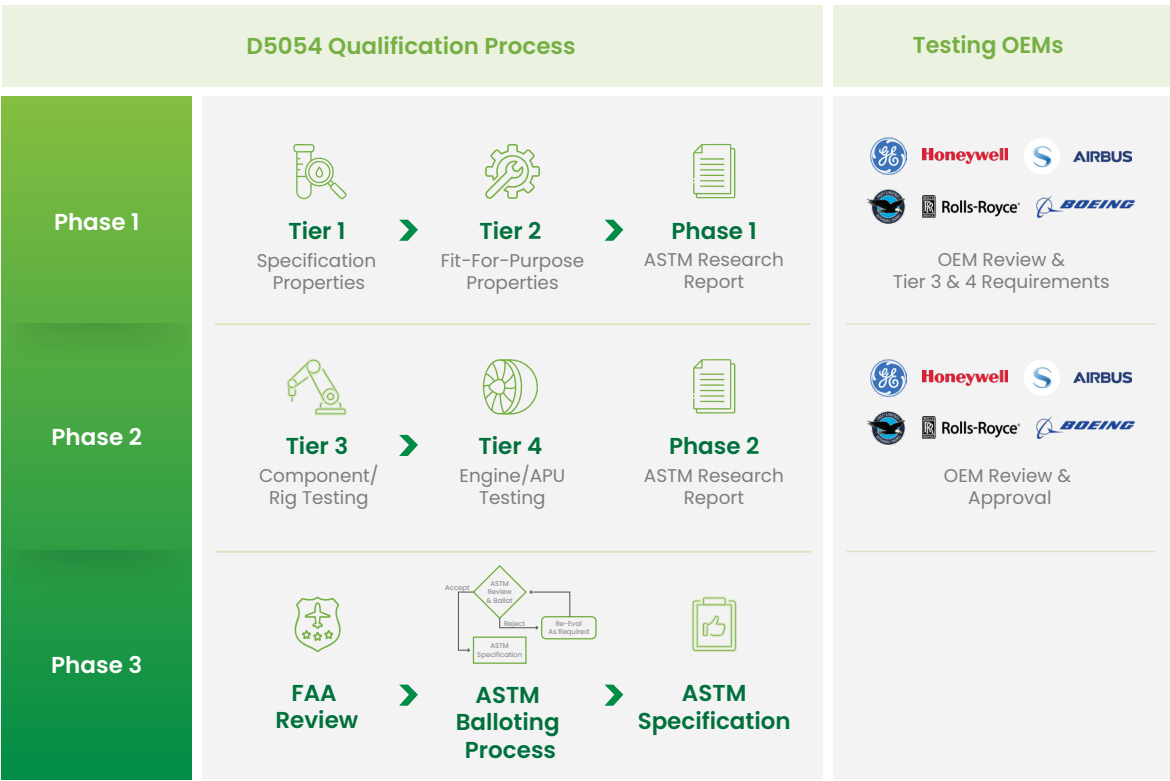


Exhibit 4.6.1 : Technical qualification process

Technical certification thus serves as the first gateway in the SAF value chain, guaranteeing safety and system compatibility. Once approved, the fuel can pursue sustainability certification to verify its environmental performance.

Sustainability Certification

Sustainability certification translates environmental and compliance requirements into verifiable proof so that each tonne of fuel can be credited toward an airline’s climate obligations. Certified operators issue a Proof of Sustainability (PoS) containing standardized data on feedstock origin, Chain-of-Custody, and life-cycle emissions, which airlines use to substantiate reductions under programs like ICAO’s CORSIA and EU’s ETS while avoiding double counting.

The certification ecosystem includes regulators and independent Certifying Bodies(CBs). Global regulators such as ICAO through CORSIA and the European Commission under RED II/III set the sustainability rules and oversight framework. Certification schemes like ISCC and RSB convert these rules into verifiable standards applied across the fuel chain. Their authorized certification bodies undertake audits, while accreditation agencies ensure the auditors themselves meet ISO standards of competence and impartiality. Across the supply chain, each party that owns or alters material such as feedstock producers, processors, traders, etc. must be certified, ensuring end-to-end traceability.

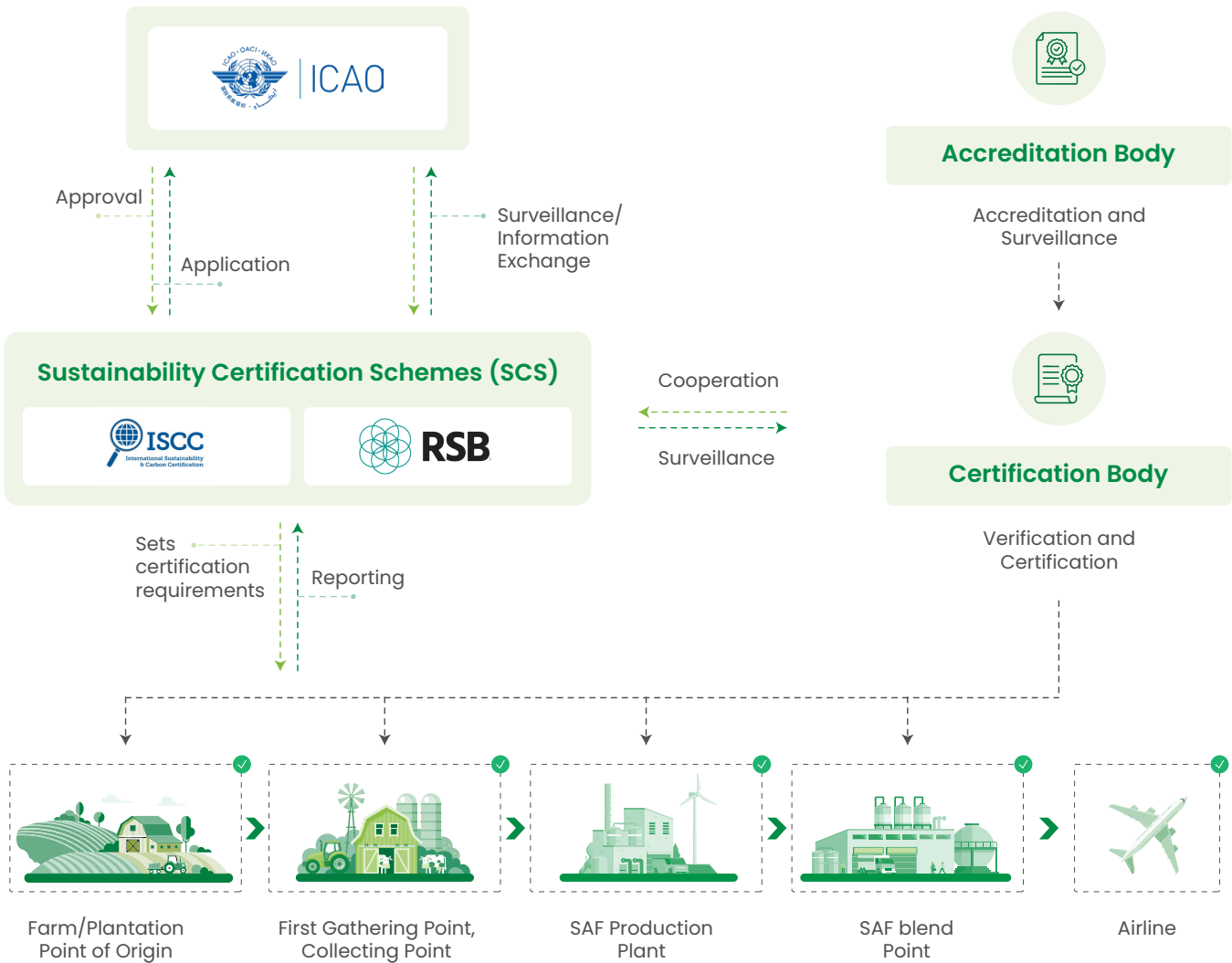


Exhibit 4.6.2 Overview of SAF sustainability ecosystem

Book and Claim Adoption

Book-and-claim systems are emerging as a parallel model for tracking SAF sustainability attributes. In voluntary markets, they are already widely used. Airlines and corporate buyers can purchase SAF certificates through audited registries and claim the corresponding emission reductions against Scope 3 or other non-regulatory targets. The decoupling of physical fuel movement from environmental attributes allows SAF benefits to be allocated flexibly, supporting participation from regions that lack direct access to supply infrastructure. In compliance markets, the approach remains less settled. Most jurisdictions still require a physical link between production and use, to qualify under regulatory mandates. Within the EU's ReFuelEU Aviation framework, policymakers have signalled openness to virtual or book-and-claim models in the future, but formal recognition has yet to be established. As regulatory and voluntary systems evolve in parallel, alignment on how virtual claims interface with physical supply will be central to ensuring both integrity and accessibility in global SAF deployment.

Path Forward to Scale Sustainability Certification

Scaling sustainability certification will be central to mainstreaming SAF. The system that once served early projects must now adapt to a global market spanning multiple jurisdictions, feedstock types, and delivery models. Achieving this shift requires tackling structural and operational gaps that limit efficiency and trust today. The following section explores four areas which can build a certification framework fit for large-scale SAF deployment.

1) Governance & Recognition

Fragmented and Overlapping Frameworks

A key step toward scalable certification lies in aligning international and regional sustainability regimes. CORSIA, EU RED III, and national frameworks continue to apply differing feedstock lists, lifecycle assessment methodologies, and documentation requirements. The result is duplication in audits and reporting to maintain cross-jurisdictional eligibility for the same fuel batch.

Moving forward, a dual conformance model could allow a single Proof of Sustainability (PoS) to meet both CORSIA and EU RED requirements, a step that could significantly reduce cost and administrative burden for players in the SAF value chain. While ICAO and the European Commission are examining the concept, it remains unimplemented.

Inconsistent Acceptance of Chain-of-Custody Models frameworks

Chain-of-custody (CoC) models also need harmonization. While the mass-balance approach remains dominant for its operational flexibility, digital book-and-claim systems are emerging to enable trade of SAF environmental attributes decoupled from physical fuel movement. Broader regulatory acceptance of book-and-claim with interoperable registries will be essential to unlock SAF access in markets without direct supply. Establishing shared CoC definitions, registries, and cross-recognition protocols can simplify transactions and provide buyers with confidence that sustainability attributes remain credible across borders.

2) Operations, Paperwork & Claims Frameworks

Fragile Documentation Chain

Certification today still depends on a complex documentation flow of records that confirm emission reductions. The PoS serves as the key instrument, but once surrendered upstream, for instance, to meet blending mandates, it cannot be reissued downstream without risking double counting. Emerging tools such as standardized Proof of Compliance (PoC) and digital registries being developed by ISCC, RSB, and the EU's Union Database aim to close this gap. Scaling these solutions globally would allow for real-time tracking, faster validation, and lower risk of lost or invalidated claims.

Strengthening Double-counting Safeguards

As SAF markets expand across compliance and voluntary channels, the risk of duplicate claims remains material with registry systems operating in relative silos, and PoS retirement processes varying by scheme. The EU's Union Database is expanding to include SAF transactions, but interoperability with ICAO and voluntary platforms is still evolving. There is a need for data exchange to become seamless across registries, with additional assurance checks required from suppliers and airlines to confirm that emission reductions are counted once.

3) Capacity & Access

Workforce and Capability Gaps

Expanding certification coverage will require a concerted effort to build human and institutional capacity beyond traditional hubs. Today, the concentration of qualified auditors and LCA experts in Europe and North America constrains emerging producers in Asia, Africa, and Latin America. Targeted training programs, joint auditor exchanges, and standardized guidance for new market entrants can help ensure consistency in

verification quality while reducing dependency on international audits.

Access to Certifying Bodies

Scheme-approved CBs remain unevenly distributed, leading to long lead times and higher costs outside mature markets. The below exhibit maps the available CBs across the world, showcasing clear regional concentrations. Increasing CB presence through regional accreditation partnerships, and digital verification technologies can accelerate certification cycles and lower barriers for smaller producers.

4) Data, IT & Monitoring

Infrastructure and Digitalization Needs

Sustainability certification depends on reliable, high-quality data across the value chain. Yet many operators still depend on systems with limited capabilities to record feedstock provenance, emissions factors, and blending information leaving room for errors and delays. Under CORSIA, additional data fields such as batch identifiers, blend ratios, and blender details must be tracked, while the European Union is integrating similar SAF functionality into its Union Database. Integrating ERP and manufacturing execution systems with scheme databases and registries can provide a solution, automating data capture and reduce compliance risk. Industry-wide interoperability remains a frontier that will define efficiency and confidence in SAF certification.

Enabling Continuous Monitoring and Timely Reporting

Certification extends beyond issuance. Each transaction must be monitored, verified, and reported through successive stages of the fuel chain. Airlines make PoS submissions with annual CORISA emissions reports, while suppliers issue PoS at contracted delivery points. In practice, the lag between physical supply and verified records can delay claim

Certification bodies primarily based out of EU with limited presence in Africa and Asia



Sources: Natural Earth Country boundaries without large lakes

Exhibit 4.6.1: Distribution of SAF certification bodies around the world

recognition. Emerging digital systems are beginning to close this gap, linking registries, operators, and auditors in near real time. As these tools mature, certification is expected to become more continuous and data-driven, reinforcing confidence in emission accounting as SAF volumes expand.

As SAF transitions from niche projects to global commodity markets, sustainability certification must scale and evolve in parallel to simplified, harmonized, and digitally enabled systems. Establishing mutual recognition between major frameworks, modernizing data systems, and expanding global audit capacity will not only reduce friction but also build the transparency and trust that investors, regulators, and airlines increasingly demand. A robust certification ecosystem can act more than as a gatekeeper for sustainability, it can be the infrastructure that enables large-scale SAF deployment.

Key Takeaways

- Harmonized sustainability frameworks and consistent chain of custody can streamline certification across regions and reduce double counting risk
- Interoperable registries for mass balance and book and claim with integrated data systems are required to enable real time tracking and faster audits
- Auditor and certifier capacity is concentrated in a few regions and a broader global base is required for efficient and lower cost certification
- Stakeholders across the value chain require capability building and digital infrastructure to collect maintain and report high quality data at scale

Chapter 5 | Recommendations

Realizing the SAF opportunity will require decisive and coordinated interventions across the entire value chain. Scaling SAF demands commitments across the ecosystem, including technology, investment, policy, certification, and awareness. The SAF ecosystem stands at a critical inflection point with strong intent from producers, consumers and policymakers taking shape. Converting this momentum into sustained market transformation will depend on targeted structural actions that unlock scale, reduce costs, and build long-term investor confidence.

Building on the challenges identified and levers introduced earlier, the path to accelerating SAF now comes into view with six strategic pillars of intervention identified for various stakeholders (Exhibit 5.1). These span coherent policy alignment, demand mobilization, production scaling, technology innovation, layered financing frameworks, certification and book-and-claim systems. Together, they form an integrated approach to accelerate SAF deployment globally.



Exhibit 5.1 Strategic pillar to boost SAF adoption

Coherent Policy Alignment

Stable, long-term policy is the most critical unlock for the entire SAF value chain. The high capital cost of biorefineries and the significant "green premium" over fossil jet fuel cannot be overcome by market forces alone. Governments and policymakers must provide a stable, long-term "rules of the sky" that de-risks private investment. Policymakers should strive for long-term consistency, clear implementation guidelines, strategic coverage, and global coordination.

This involves enacting clear 10-to-20-year roadmaps which provide guaranteed support for the whole ecosystem. The framework should also be clear, with transparent mechanisms for compliance, credit generation, and incentive claims. Coordinating demand-side measures like blending targets and price certainty mechanisms with carefully coordinated supply-side incentives, such as production tax credits or grants, can build the entire ecosystem. However, strong supply-side or demand-side mandates alone such as

revenue certainty mechanisms and compliance penalties can also provide a strong foundation to the ecosystem. Further, as SAF is a globally traded commodity, pursuing alignment on sustainability criteria and lifecycle analysis (LCA) methodologies is essential to reduce market friction and ensure a level playing field for all producers. When policy is predictable and coherent, it can anchor capital, provide signal for long-term commitment, and build the foundation on which industrial ecosystems grow.

Mobilize Demand

Building stable and predictable demand with price support mechanisms is central to unlocking investment and driving scale in SAF. Airlines, cargo carriers, and corporate buyers can act collectively to aggregate demand and sign multi-year offtake agreements that provide producers with commercial certainty and lenders with confidence to finance new capacity. Public procurement can also provide stable SAF demand to producers. Embedding reliable supply terms and transparent pricing within these agreements can reduce budgeting risk and enable faster decision making. Long term policy clarity from governments remains a critical factor in allowing market participants to plan ahead and align procurement with national blending trajectories. Targeted price support mechanisms are needed to bridge the early cost gap between SAF and incumbent, and maintain momentum as production scales. Instruments such as contracts for difference or production tax credits can stabilize pricing and protect early adopters from volatility.

As these elements align, interest consolidates into firm commitments, participation broadens across markets, and a durable demand base begins to take shape. Predictable demand attracts new investment, supports expansion of production capacity, and over time drives cost reductions through learning and scale. Stable and visible demand is therefore the foundation on which the SAF market can mature into a self-sustaining system.

Scale Production

ASTM has approved multiple technology pathways for SAF production, enabling the use of a wide range of sustainable second-generation (2G) feedstocks and allowing the industry to scale well beyond the limited availability of waste oils used in HEFA today.

The next phase of growth depends on expanding from pilot facilities to an integrated network of regional clusters that link feedstock, conversion, and distribution. Building robust feedstock collection systems with standardized aggregation, quality assurance, and digital traceability will enhance transparency and reliability across the value chain, critical to meeting compliance requirements and strengthening confidence among offtakers and investors. Combining efforts to refine feedstock pre-treatment processes can support specific feedstocks like agricultural residues and organic waste. Further, diversifying beyond lipid-based inputs into lignocellulosic biomass, forestry residues, and municipal solid waste can broaden the feedstock base, increase scalability, improve sustainability and reduce vulnerability to supply constraints.

Production projects should be backed by a combination of revenue-stabilizing instruments such as long-term offtake agreements to secure demand, and price-support mechanisms (e.g., indexed formulas with floors or contracts for difference) to mitigate market volatility and improve bankability. Performance wraps and insurance instruments can provide additional mitigation mechanisms for new facilities and attract private capital during early operation. As these production facilities develop, building regional supply infrastructure such as storage, blending, and transport links, is required to connect production hubs to major airports and strengthen logistical resilience.

As new plants come online, sharing operational experience and performance data widely can shorten learning curves and enhance process efficiency across the industry. Building such interconnected systems and knowledge networks can transform SAF from a niche commodity into a mature industrial ecosystem.

Accelerate Technology Innovation

Technology advancement is central to driving cost competitiveness and sustaining long term growth of SAF. Accelerating next generation pathways while improving the efficiency of proven ones is a key priority. Reducing the CAPEX and OPEX in existing pathways like HEFA can deliver rapid gains in cost and output. Targeted research support for new conversion routes such as Alcohol-to-Jet and Fischer-Tropsch can help in enabling early commercialization. Setting up early lighthouse projects can act as a critical validator for performance, creating confidence for further scale-up to full commercial facilities and for investors and offtakers.

Innovation should also be guided by regional resource strengths so that technology development aligns with locally available feedstocks and infrastructure. Building innovation clusters with shared data can enable faster learning, avoid duplication, and spread operational insights across pathways and geographies.

Deeper collaboration between industry and academia can extend the impact of innovation clusters further by connecting applied research with industrial deployment and creating the skilled workforce needed to sustain technological progress. A coordinated approach that links grants, demonstration facilities, data-sharing and partnerships can shorten development cycles and accelerate cost reduction, providing a strong foundation for scaling SAF technologies.

Layered Financing Frameworks

To effectively scale SAF production and deployment, policymakers, investors, and industry stakeholders should prioritize the development of adaptive financing structures that align with the evolving maturity of technologies and the expanding scale of projects.

Early stages of technology development typically require high-risk-tolerant capital to build foundational confidence and attract subsequent private investment. Specifically, support to pilot and demonstration projects through targeted research grants, concessional loans, and strategic equity investments can work well. To further bolster investor assurance during initial operations, insurance products and performance guarantees can provide pathway to a credible track record.

As SAF pathways progress toward commercial readiness, blended finance models can serve as an intermediary to transition from innovation to industrial application, and help attract private capital. Instruments such as credit guarantees, revenue support mechanisms, and viability-gap funding, combined with long-term offtake agreements, can be employed to generate reliable cash flows and facilitate access to senior debt. Patient capital from sovereign wealth funds, strategic investors, and impact-oriented entities can anchor these arrangements, drawing in conventional lenders and reducing overall financing barriers.

Once technologies reach maturity and revenue streams stabilize, traditional project finance frameworks can assume a leading role. This includes leveraging green bonds, infrastructure equity funds, and private credit facilities to enhance market liquidity and broaden investor participation.

To sustain long-term growth, building specialized capacity in financial institutions for assessing biofuels projects, including standardized appraisal methodologies can promote consistency and scalability. Ultimately, a multi-layered financing architecture tailored to the technology lifecycle is recommended to minimize the cost of capital, expedite project rollout, and establish SAF as a robust, investable sector within the global energy landscape.

Scale Book and Claim with Standardize Certification

Production capacity will often emerge in feedstock-rich regions, while early demand will be concentrated in policy-driven markets with blending mandates and support schemes – many of which face structural feedstock constraints. These mechanisms enable SAF produced where it is most efficient to be credited where it is most needed. Instead of transporting fuel across long distances, Book-and-Claim allows local SAF uplift while transferring the verified emission reduction to distant buyers through sustainability certificates. This mechanism enables airlines to credibly account for Scope 1 emission reductions from SAF use, while allowing corporate customers to claim corresponding Scope 3 reductions from business travel within auditable, certification-based frameworks.

Establishing a centralized digital registry is essential to record certificate issuance, transfer, and retirement with full traceability. A strong set up of shared sustainability standards, an expanded network of accredited verifiers, and interoperable data infrastructure can ensure transparency and prevent double counting. It is important to build technical capacity across the value chain to strengthen implementation and trust. As market confidence grows, linking these registries to emerging carbon trading systems can deepen liquidity and lower transaction costs.

Coordinated industry communication and generative awareness can drive broader acceptance, normalising the use of SAF certificates as a credible instrument. A globally aligned, transparent, and data-driven certification ecosystem thus becomes the soft infrastructure that provides a foundation for integrity, liquidity, and long-term market confidence in SAF.

Strengthen Global Cooperation

SAF is a global industry that demands coordinated action across borders and stakeholders. The International Civil Aviation Organization (ICAO) continues to play a leading role in shaping this effort through standard setting, consensus building, and long-term policy guidance. Complementing this, platforms such as the GBA can strengthen coordination between governments, industry, and international organisations, aligning ambition with investment and implementation.

Strong partnerships across the SAF value chain will be essential to unlock scale. Collaboration between feedstock suppliers, technology developers, producers, financiers, and offtakers can accelerate innovation, reduce project risk, and expand market access. At the same time, joint research programmes, transparent data sharing, and cross-sector demonstration projects can shorten learning cycles and create replicable models for deployment. On similar lines, financial and industrial alliances can help align offtake, logistics, and certification, ensuring that supply reliability matches emerging demand.

With governments, collaboration should focus on developing best-in-class policies and moving toward harmonised sustainability standards, certification systems, and market mechanisms. As these partnerships deepen, coordination can become the catalyst that turns isolated progress into a globally connected SAF industry capable of driving aviation's net-zero transition.

Coherent Policy Alignment

Coordinate demand- and supply-side programs



Enact stable, long-term policy frameworks



Pursue global policy alignment



Leverage green public procurement



Adopt and harmonize global sustainability standards



Prioritize SAF within broader biofuels policy



Demand Mobilization

Aggregate airline demand pools



Provide credible supply assurance mechanisms



Ensure transparent, predictable price visibility



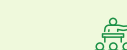
Establish durable policy certainty



Offer targeted price support instruments



Advocate SAF benefits to buyers



Scaling production

Improve feedstock collection systems



Diversify the feedstock base



Secure performance wraps for production facilities



Implement robust revenue-certainty mechanisms



Develop regional fuel supply infrastructure



Share operational best practices widely



Technology Innovation

Provide targeted research grants



Lower Capex and Opex for proven pathways



Build early lighthouse demonstration projects



Form innovation clusters with shared data



Deepen industry-academia collaboration



Prioritize by regional resource strengths



Layered Financing Frameworks

Secure insurance wraps



Mobilize blended and concessional finance



Offer viability-gap funding



Attract long-horizon patient investment capital



Form equity partnerships and strategic investments



Build institutional biofuels- specific financing capacity



Certification and Book & Claim

Create a centralized certificate registry



Develop global carbon trading markets



Drive acceptance by generating awareness



Expand network of accreditation agencies



Build capacity for stakeholder across the value chain



Deploy interoperable data infrastructure



Governments/ Policymakers



Industry stakeholders



IOs, Industry bodies , Academic



Financial institutes

Exhibit 5.2: Focused action required across key areas to unleash the potential of SAF

SAF stands at the centre of aviation's decarbonisation pathway, offering an immediate and scalable solution while longer-term technologies mature. The transition now depends on keeping momentum coordinated to translate early ambition into sustained industrial scale.

The Global Biofuels Alliance can play a pivotal role in this journey by fostering collaboration across governments, industry, and financiers, promoting shared learning. With aligned intent and collective execution, SAF can be the lever to unlock global aviation's net-zero future.

Chapter 5 | Next steps

Accelerating SAF deployment will require coordinated progress across multiple fronts. The pathway to scale depends on many moving parts working in concert rather than isolation. The SAF ecosystem spans a wide value chain from feedstock providers and technology developers to producers, fuel suppliers, airlines, financiers, and regulators.

The Global Biofuels Alliance, together with its partner institutions, is well positioned to facilitate this multistakeholder effort and support coordinated action across the SAF value chain by connecting policy, industry, finance and stakeholders across borders.

The following outlines the next steps for each stakeholder group to help bring SAF to full commercial scale.

Feedstock Providers and Aggregators

- Expand sustainable lipid-based waste feedstock supply through optimized supply chains.
- Develop local aggregation hubs and digital traceability systems to ensure quality and compliance with sustainability criteria.
- Promote and accelerate cultivation of novel vegetable oils (NVOs) on degraded or rotational land through farmer outreach and pilot programs.

Technology Developers and Equipment Providers

- Localize technology designs to regional feedstock strengths and infrastructure readiness.
- Provide performance guarantees and operational wraps to enhance investor confidence.
- Standardize modular and pre-certified plant designs to enable rapid replication (FOAK-to-NOAK) and lower CapEx per tonne of SAF output.

Producers (including Refiners)

- Secure sustainable feedstock supply and maintain feedstock sustainability certification.
- Share operational data and performance benchmarks to accelerate industry-wide learning and cost reduction.
- Pursue brownfield refinery conversions and modular new builds linked to long-term offtake contracts.

Fuel Suppliers and Distributors

- Participate in SAF certificate registries and ensure transparent issuance and retirement of sustainability claims.
- Enable regional blending hubs or modular mobile units near airports to improve supply flexibility.
- Develop shared-use infrastructure models (PPP blending hubs, shared tank farms, or regional logistics corridors) to improve capital efficiency and reliability of SAF delivery.

Airlines and Corporate Offtakers

- Enter long-term offtake agreements to provide bankable revenue visibility for producers.
- Aggregate demand through alliances and collective purchasing programs to secure stable supply and better pricing.
- Support passenger and corporate engagement programs to increase awareness and voluntary SAF adoption.

Financiers and Investors

- Develop blended-finance structures to de-risk early projects.
- Introduce first-loss guarantees, performance insurance, and credit enhancement tools for FOAK facilities.

- Standardize appraisal frameworks and risk metrics for SAF investments
- Channel patient capital from sovereign, green, and impact funds into early commercial projects.
- Establish dedicated SAF financing facilities or guarantee programs to pool capital and finance portfolios of projects under standardized risk-sharing frameworks.

Policymakers and Regulators

- Enact long-term policies to build SAF demand and provide long-term visibility in pricing with clear compliance and enforcement mechanisms.
- Establish national SAF financing platforms or guarantee schemes to mobilize private capital.
- Promote cross-border policy interoperability and certification recognition to enable regional trade and market integration.

Certification Bodies and Registries

- Expand accredited auditor networks in emerging regions to reduce bottlenecks and verification costs.

- Digitize Proof - of - Sustainability documentation and integrate registries through interoperable platforms.
- Advance interoperability between mass-balance and book-and-claim systems to facilitate cross-border trade.

International Organizations

- Develop harmonized templates for offtake contracts, financing term sheets, LCA methodologies, and certification rules to reduce transaction friction.
- Create shared industry databases on feedstock availability, technology performance, and project costs to accelerate learning curves.
- Establish multi-stakeholder “SAF accelerators” or regional hubs connecting projects, investors, and regulators to coordinate investment and permitting



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