GREENING OLD INDUSTRIES

Sustainable Aviation Fuel

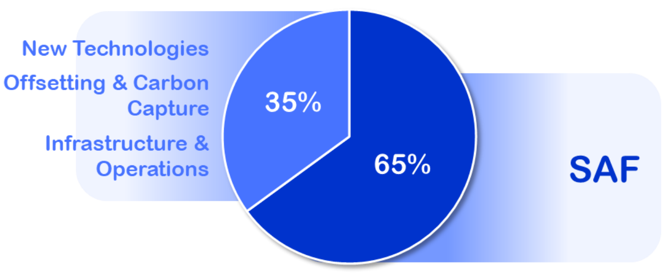
The aviation sector's long-standing reliance on fossil fuels to power their aircraft has long raised environmental concerns, and curbing its emissions to align with the global push for net-zero has become the major challenge of the industry. The need to scale-up and adopt sustainable alternatives is paramount yet difficult. Sustainable aviation fuels ("SAF") are viable solutions, derived from a number of renewable feedstocks or produced synthetically via technology that captures carbon directly from the air. When paired with policies to push efficiently the commercial production and deployment of SAF, these technologies will lead the industry's decarbonisation efforts.

INTRODUCTION

The aviation sector is crucial to maintaining our modern life, with an estimated 32 million domestic and international flights taken in 2022. Most current commercial and military aircraft use petroleum-derived hydrocarbon fuels, accounting for an estimated 2.5% of global carbon dioxide ("CO_2") emissions in 2022. There is, however, new and emerging technology for SAF which offers an opportunity to decarbonise the aviation sector. Virgin Atlantic's landmark flight in late November made headlines for using 100% SAF as a drop-in replacement for fossil derived jet fuels.

The International Air Transport Association ("IATA") estimate that SAF could contribute around 65% of the reduction in emissions needed by aviation to reach net zero in 2050, as shown in Figure 1. This shows the importance of the success of SAF, and many countries are now mandating or incentivising a transition to the use of sustainable fuels derived from low-carbon feedstocks and manufactured using low-carbon, renewable energy. Some are already in production, albeit on low volumes.

***Figure 1.** Contribution to Achieving Net-Zero By 2050 Within Aviation*



Source: International Air Transport Association

BACKGROUND

CURRENT TECHNOLOGY

Current petroleum-derived aviation fuels, comprised of the middle-distillates, "Kerosene" or "Diesel" and typically consisting of a distribution of branched, long chain, cyclic and aromatic hydrocarbon molecules with chain lengths varying from around 8-22 carbon atoms long. These fuels exist in a liquid state for a wide variety of temperatures and are an effective store of chemical energy.

SUSTAINABLE ALTERNATIVES

There are three main alternatives which could be used to decarbonise aviation: biofuels, synthetic fuels and alternative technologies (which do not involve the use of fossil fuels).

BIOFUELS

Biofuels are derived from renewable sources that are often waste residues, including otherwise waste oils – used cooking oils ("UCO") or non-edible plant oils – animal fats, algae and forestry residues. Biological sugars can undergo fermentation in anaerobic conditions to produce bio-alcohols, while biological fats and oils can be turned into biodiesel through the transesterification process, after reaction with methanol.

The two challenges of using high concentrations of biofuels are the presence of oxygen and nitrogen and the low level of aromatics that affect engine performance and life. These are being solved by extensive testing before they are used regularly in conventional jet engines. Bio-aromatics can be added to biofuels to improve their compatibility.

Conversely, renewable diesel, distinct from its biodiesel counterpart made through esterification, is derived from hydrotreating and hydrocracking organic biomasses. Renewable feedstocks, such as specifically cultivated non-food crops, are processed via hydrogenation to yield hydrogenated vegetable oils ("HVO") similarly to how petroleum-based diesel is created, only with more severe cracking of the longer chain carbon molecules. This makes renewable diesel chemically identical to petroleum diesel, meaning it is pure, unlike its biodiesel counterpart that is a blend.

SYNTHETIC FUELS

Synthetic fuels (also referred to as "efuels") closely mimic the composition of conventional fuels but are derived from renewable sources in a process known in industry as Power-to-Liquid, or "PtL". With eFuels, the production of SAF is no longer constrained by limited supplies of UCO and other residual fats as feedstock.

eFuels are made from syngas and then processed in the well-established Fischer-Tropsch synthesis to make longer carbon chain synthetic fuels. Syngas is a mixture of carbon monoxide and green hydrogen. The green hydrogen is derived from the electrolysis of water using green power, such as wind or hydroelectric power. The CO comes from carbon capture of CO_2 from industrial processes.

It is estimated that the use of synthetic or biofuels may result in over 70% reduction in lifecycle emissions compared with conventional jet fuel, when fully replacing kerosene, as the UK's Department of Transport outlined in their sustainable aviation fuels mandate.

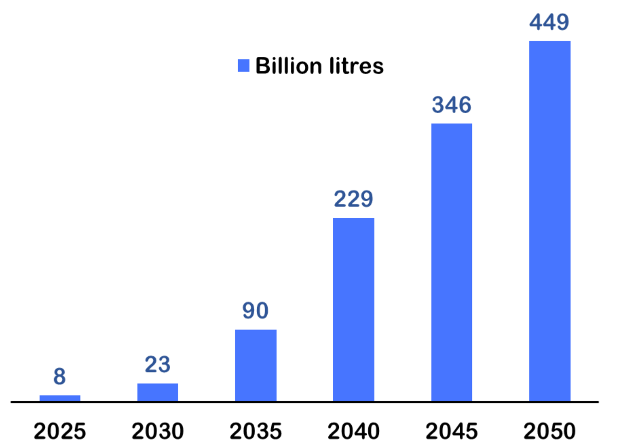
ALTERNATIVE TECHNOLOGIES

There are several alternative technologies which can be used to power aircraft, ranging from renewable hydrogen to battery technology or even solar. These technologies are currently less well developed and often heavy (batteries and cylinders). Consequently they are not yet suitable for the large-scale deployment in commercial air travel. Some estimates place hydrogen as a feasible aviation fuel for short-haul flight by around 2035 only.

MEETING SUPPLY TARGETS

In 2022 over 300 million litres of SAF was produced, a 200% increase on the previous year. Even with this increase, this reflected only about 01.% of total aviation fuel usage. Although the IATA forecasts production figures for 2023 to double to 600 million litres, going forward, the quantity of SAF produced globally will need to rapidly increase to meet the volume of SAF required to reach net-zero by 2050, as illustrated in Figure 2.

Figure 2. *Forecasted SAF Production for Net-Zero*



Source: International Air Transport Association

As shown in the figure, the annual production volume of SAF will need to increased to an estimated 449 billion litres per year by 2050. This reflects a 1500-fold increase from the annual quantity produced in 2022. A significant barrier to achieving this is the current production cost of sustainable fuel, which is around 2-3x times higher than conventional jet fuel. This is a significant cost for airlines, with fuel costs accounting for between 20 and 40 percent of their expenses.

ADVANTAGES AND DISADVANTAGES

A table of the common advantages and disadvantages of each of the sustainable alternatives is shown on the following page in Table 1.

ENGINE MANUFACTURERS - AIRPLANE MANUFACTURERS - AIRLINES

Importantly, SAF has the ability to be 'dropped in' to existing engines without the need for modification. Currently these have been verified for blended compositions up to 50%. The leading aviation sector engine manufacturers, CFM International, Rolls Royce, Pratt and Whitney and General Electric have all expressed their commitment to ensuring that pure SAF blends can be used in the near future.

The policies of the two major airplane manufacturers, Airbus and Boeing, with over 98% of global market share between them, are shown in Table 2 overleaf together with the stated policies of several airlines.

Some of the current key producers of sustainable fuels are shown in Table 3 overleaf, with each company's current or targeted annual production rate and their method of production shown.

CHALLENGES

There are four key challenges to face in the transition to widespread adoption of sustainable aviation fuels.

Cost Competitiveness: SAF is currently considerably more expensive than conventional fuel, leading to higher flight costs passed on to consumers. To drive adoption, subsidies to SAF producers can help lower the cost, making it more attractive to airlines and consumers alike.

Capital Investment for Production Capacity: Meeting net-zero targets requires a significant increase in SAF production capacity. However, high production costs and low adoption rates make it challenging for companies to secure funding for new production facilities. External investments can play a crucial role in accelerating production capacity growth and reducing SAF costs through increased supply. However, due to the uncertainties surrounding the extent and timescale of penalties to be imposed on greenhouse gas emissions, companies may be hesitant to invest. Ultimately, the costs of late adoption are unknown while early adoption is expensive.

Achieving Cost Parity: Widespread adoption of SAF hinges on achieving cost parity, or close to it, with conventional fuels. While increasing supply and subsidising SAF can help reduce costs, introducing carbon levies/taxes on conventional fuels can further incentivise adoption by making conventional options relatively less cost-effective. There is, however, a risk that these subsidies will be reduced as Governments react to the increasing backlash against the cost of green policies.

Feedstocks: A further challenge that SAF producers face is the acquisition of feedstocks. For SAF that are derived from biomass, plant oils or sugars it may be difficult to collect materials needed and the CO_2 reduction when compared to conventional fuels will be impaired by the fuel used during this collection process. Furthermore, there is competition for the aforementioned feedstocks to produce other renewable fuels for both road and maritime transportation sectors. Countries will need to prioritise carefully and allocate resources to ensure that the key sustainability targets are met.

By addressing these four key challenges, a smoother transition from conventional aviation fuels to more sustainable alternatives can be facilitated, contributing to the aviation industry's efforts to mitigate its environmental impact and achieve sustainability goals.

Table 1. Advantages and Disadvantages of the Different SAF and Alternative Technologies

Process	Method of Production	Advantages	Disadvantages
SAF:			
Biofuels	Alcohols "Alcohol-to-Jet"	Broad feedstock base Established process	Requires land that otherwise could be used for agriculture, although many specify only waste products may be used Chemical composition may pose difficulty for some engines
	Biodiesel	Established process (Transesterification) Low land use when utilising oilseed rape or palm oil, or otherwise waste oils or non-edible plant oils	Potentially requires land that otherwise could be used for agriculture Limited supply of inputs Time and resource intensive to collect feedstocks Chemical composition may pose difficulty for some engines
	Renewable diesel	Established process (Hydrotreating followed by hydrocracking)	Limited supply of inputs Time and resource intensive to collect feedstocks
Synthetic Fuels	CO_2 capture and green hydrogen followed by Fischer Tropsch "Power-to-Liquid"	Can be used with direct air capture (low land use and little feedstock competition) Can be used with industrial effluents (low energy intensity)	Electrolysis has very high CAPEX and OPEX and will rely on renewable electricity CO_2 capture has high CAPEX and medium OPEX Need to create infrastructure for CO_2 transport
Alternatives:			
Alternative Technologies	Solar	Potentially a net-zero carbon process	Despite the successful circumnavigation flight, unlikely to be used commercially until challenges of surface area for solar cells and flying at night are resolved
	Battery	Can be powered through renewable, carbon-neutral sources	Not fully developed for flight Not appropriate for long-haul flights due to the heavy weight of the batteries
	Hydrogen	Potentially a net-zero carbon process	Not fully developed for flight Not appropriate for long-haul flights due to the heavy weight of H_2 storage

Table 2. Key Aeroplane Producers and Key Airlines

Player	Ambitions
Airbus	Goal: to reach 10% pure SAF in the fuel mix of our own operations in 2023 Aims to make our entire product portfolio capable of flying with 100% SAF by 2030, acting as a catalyst to ready the ecosystem for a 10% global uptake by 2030
Boeing	Commitment for all the commercial airplanes Boeing delivers to fly on 100% SAF by 2030 Build and certify Boeing's first zero-emission, electric, autonomous aircraft via Wisk Support the commercial aviation sector's ambition to achieve net-zero carbon emissions for global civil aviation operations by 2050 Boeing has conducted the first ever commercial flight with 100% SAF on a 777 freighter
Key Airlines:	
Emirates	Flight EK 412 bound for Sydney successfully completed in October this year, using a 40:60 blend of SAF (supplied by Shell) and conventional jet fuel Operated the region's first 100% SAF-powered demonstration flight in January Emirates and Shell signed a Memorandum of Understanding ("MOU") to explore areas of collaboration around sustainable travel
DHL Express	Long-term 7 year strategic agreement signed with World Energy till 2030, for the purchase of ~ 668 million litres of SAF via sustainable aviation fuel certificates
Air France - KLM	Committed to buy 75,000 tonnes pa of SAF for a ten-year period from SkyNRG's refinery in Delfzjil, Netherlands
Lufthansa Group	Letter of Intent signed with HCS Group for the production of SAF at site HCS's site in Speyer, Germany. To start 2026 with a volume of 60,000 tons per year
Virgin Atlantic	Completed first long-haul flight on 100% SAF mainly derived from UCO and waste animal fats. No paying passengers on board—used to appeal for Government support

Table 3. Key Producers of SAF

Player	Production Volume/Target	Production Method
HCS Group	Aims to produce 60,000 tons per year to become the first large-scale producer of biogenic SAF in Germany, and compliant with Europe's Renewable Energy Directive RED II	"Alcohol-to-Jet": Biogenic residues from agriculture and forestry as feedstock
Neste	Neste is the world's leading producer of sustainable aviation fuel with a current production capability of over 1 million tons per annum. This will grow to 1.5 million tons per annum in the beginning of 2024. Investments should raise this to 2.7 million	Neste MY SAF is made from sustainably-sourced, 100% renewable raw materials
World Energy	Goal of supplying 1 billion gallons of sustainable aviation fuel annually by 2030 via scaled manufacturing investments totalling $4 billon	SAF is produced by World Energy at its refinery in Paramount, California, from a feedstock of agricultural waste fats and oils
Shell	Shell is building an 820,000-tonnes-a-year biofuels facility at the Shell Energy and Chemicals Park Rotterdam	SAF and renewable diesel made from waste; is expected to start production in 2025
Total Energies	Decarbonisation strategy - SAF: raising SAF production capacity to 210 kilotons per year at Grandpuits, in France	Made from waste and residue sourced notably from the circular economy such as animal fats or used cooking oils
SkyNRG	To produce 100,000 tonnes of SAF per year by 2027 at Delfzjil, Netherlands using Topsoe's HydroFlex technology. The first of a series of planned SkyNRG refineries	Uses feedstocks like biogenic oils and other regional waste and residue streams

N.B. The information above is from company statements and may not be directly comparable. Non-exhaustive list of companies

REACHING NET ZERO – POLICY AND LEGISLATION

Demand for sustainable fuels currently requires further support due to the additional cost when compared to their conventional equivalents. This demand can be created through legal mandates at an international or national level or through voluntary commitments. Some of these commitments are outlined in Table 4.

The EU and the UK have established firm legal mandates for the adoption of SAF. These mandates encompass specific volumetric targets, indicating that a certain percentage of aviation fuel used in flights must be SAF by designated dates. Within the EU, 20% of airline fuel must be sustainably derived by 2035. In the UK 10% of airline fuel must be sustainably derived by 2030.

In contrast, the United States, Middle East, and certain other nations have issued only non-binding guidelines or targets for SAF adoption, but these lack legal teeth.

This distinction highlights the more robust and structured approach taken by the EU and the UK in promoting the adoption of SAF in their aviation industries, with clear, enforceable targets for the gradual transition to more sustainable fuels and consideration to prevent the measures being bypassed.

Table 4. *Legislation and National Commitments for Some Countries/Regions*

Country/Region	Legislation/Targets
European Union	Aviation fuel suppliers to supply a minimum share of SAF at EU airports, starting at 2% of overall fuel supplied by 2025 and reaching 70% by 2050. The new EU jet fuel blend will need to also contain a minimum share of the most modern and environmentally-friendly synthetic fuels, which increases over time Aircraft operators departing from EU airports to refuel only with the fuel necessary for the flight, to avoid emissions related to extra weight or carbon leakage caused by 'tankering' practices (deliberately carrying excess fuel to avoid refuelling with SAF) Airports to ensure that their fuelling infrastructure is available and fit for SAF distribution
UK	Government decision: fuel suppliers that supply aviation fuel (avtur) in the UK will be required to blend an increasing proportion of SAF into their jet fuel supply Commitment to introduce a SAF mandate in 2025 requiring at least 10% of jet fuel to be made from sustainable feedstocks by 2030
USA	Launched The SAF Grand Challenge: a government-wide Memorandum of Understanding to attempt the scaling up of SAF production to at least 3 billion gallons pa by 2030, and by 2050 enough SAF to meet 100% of aviation fuel demand (c. 35 billion gallons pa) Increasing R&D activities to demonstrate new technologies to achieve at least a 30% improvement in aircraft fuel efficiency President Biden proposed a Sustainable Aviation Fuel tax credit as part of the Build Back Better Agenda
UAE	Target: 700 million litres/year SAF production by 2030
Sweden	Bound to reduce the climate impact of their sales of gasoline and/or diesel and/or aviation fuel by a certain percentage every calendar year, per unit of energy sold. This percentage increases every calendar year and is separate for gasoline, diesel and aviation fuel.
Canada	Goal: by 2030, SAF should be 10% of projected Canadian jet fuel use. Based on this goal and the total market for jet fuel in Canada, C-SAF has established a target of 1 billion litres of SAF production by 2030

CONCLUSION

Sustainable aviation fuels appear an attractive and technically feasible solution for decarbonising the aviation sector. However, achieving the required scale-up in production to lower costs and meet net-zero targets will need substantial investment and subsidies, as well as regulation to make conventional fuels more expensive. Going further, incentives and regulation paired with mandated use will be critical for growth. Despite their current higher costs relative to conventional fuels, sustainable fuels remain a leading decarbonisation option, and eFuels provide a way to scale-up SAF without feedstock limitations. Companies may display reluctance to make substantial investments in these fuels due to uncertainties regarding the scale and magnitude of potential penalties on greenhouse gas emissions. However, the resulting cost escalation for late adopters lacking the established infrastructure or economies of scale to produce sustainable alternatives cheaply, persist as motivation to discourage inaction.

ABOUT NATRIUM CAPITAL

Natrium Capital Limited is an independent Chemicals M&A boutique set up by Alasdair Nisbet in 2012. Natrium Capital provides high level strategic and M&A advice primarily focused on the chemical, personal care, adhesive, engineering materials, paints, inks and coatings, biotechnology and clean technology industries. Headquartered in London, Natrium Capital and team advise on complex global cross-border transactions and have advised on over $100bn transaction value in the sector.

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ADVISOR TO	ADVISOR TO	ADVISOR TO	ADVISOR TO	ADVISOR TO
nanocyl	WILBUR-ELLIS	DOMO	SOLVAY	ELEMENTIS
on the sale of the Carbon Nanotube business to	on the merger of Connell, its Asian Speciality Chemical Distribution business with	in the acquisition of Performance Polyamide Business in Europe from	in the sale of its Amphoteric Surfactant Business in N. America & Europe to	in the acquisition of
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