Evolution of alternative fuels for aviation

Harnessing new technologies for a more sustainable industry

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Introduction

While the aviation sector will have to overcome huge challenges to achieve its goal of net zero carbon emissions by 2050, the industry has made great strides in its decarbonization journey. The uptake of sustainable aviation fuel (SAF) is growing, with global SAF capacity expected to be nearly 6 billion gallons by 2030 from 1.3 billion gallons in 2023.[1] However, today it is severely constrained by the limited availability of alternative aviation fuels that are low in lifecycle carbon, cost-effective, safe, and high-performance.

Although the aviation sector only accounts for just over 2 percent of global energy-related greenhouse gas (GHG) emissions,[2] air transportation is growing fast as global populations become wealthier. It means under a business-as-usual scenario, air travel could consume up to 10 percent of the planet's remaining 1.5°C carbon budget by 2050.[3]

Air freight, while it only represents one percent of world trade by volume, also continues to increase with double digit growth expected in 2024.[4] Higher value and more perishable goods tend to use air over other heavy transportation such as shipping. Combined, they are putting the aviation industry under immense pressure to become more sustainable.

Practical decarbonization of the aviation industry is likely to require a combination of approaches over various timeframes up to 2050. The uptake of SAF shows that the sector is making progress. However, net zero will require much higher SAF use, as well as carbon offsets and pricing mechanisms, and the adoption of new technologies which can modify aircraft and engine design as well as making operating aircraft and ground operations more efficient.

This report is tailored for leaders and stakeholders in the aviation industry, seeking to offer actionable insights on alternative fuels and a detailed analysis of readiness and adoption potential in the aviation sector.

By using the insights and recommendations provided, aviation organizations can better navigate the complexities of this transition, mitigate associated risks, and capitalize on emerging market opportunities.

The uptake of sustainable aviation fuel (SAF) is growing, with global SAF capacity expected to be nearly 6 billion gallons by 2030 from 1.3 billion gallons in 2023.

1 SkyNRG, "SkyNRG Releases Sustainable Aviation Fuel Market Outlook 2024", June 2024.
2 International Energy Agency (IEA) website, "Transport, Aviation", Accessed May 2024.
3 Mission Possible Partnership, "Making Net-Zero Aviation Possible, An industry-backed, 1.5°C-aligned transition strategy", July 2022.
4 Xeneta, "Mid-term analysis puts global air cargo on pathway to double-digit growth in 2024", 5 June 2024.

About the lead authors

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Chris is a Partner leading the KPMG Global Strategy Group in Ireland. He has over 18 years of professional experience spanning organic strategy, new market entry and M&A commercial due diligence. Leading a wider team across several sectors, Chris's personal focus sectors are the aviation and data center value chains. He has worked with airlines, ground handlers, airports, air navigation service providers, SAF producers, lessors and the aerospace supply chain. He has led global mandates on the viability of SAF ramp up to the ability of alternative propulsion technologies to disrupt regional aviation. He previously spent three years in the UK and seven years in China with the KPMG Global Strategy Group.

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Monika is an Associate Director in the ESG Strategy practice at KPMG in the UK, with a demonstrable track record in quantifying climate risk and implementing decarbonization strategies. Monika's expertise lies in the areas of strengthening climate resilience and creating value through innovative sustainable finance and carbon offset strategies. One of her notable works includes her contribution to the Aviation 2030 article series, which focused on solutions like alternative fuels to address climate change issues. Monika has worked extensively with both technology providers and financiers to mobilize finance into new technologies and solutions. In a previous role at Plastic Energy, Monika supported the commercialization of recycled fuels technology where she defined their strategic growth plan and opportunities in the recycled fuels market, including decarbonization targets and implementation.

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Glossary

Alternative fuels: Fuels other than traditional petroleum-based fuels (such as gasoline and diesel) that are used to power transportation vehicles. Examples include biofuels, hydrogen, natural gas, and e-fuels (synthetic fuels).

Biofuels: Fuels derived from biomass, such as plant materials or animal waste. Common types include ethanol, biodiesel, and renewable diesel.

Blending: The process of mixing biofuels with conventional fuels to create a fuel that can be used in existing engines.

Carbon capture and storage (CCS): Technology used to capture and store carbon dioxide emissions from industrial processes, preventing CO_2 from entering the atmosphere.

Carbon dioxide (CO_2): A colorless, odorless gas produced by burning carbon and organic compounds and by respiration, commonly associated with greenhouse gas emissions.

Decarbonization: The process of reducing carbon dioxide emissions using low-carbon power sources, increased energy efficiency, and changing industrial processes.

E-fuels: Synthetic fuels produced from renewable electricity. Examples include e-methanol and e-diesel.

Electrolysis: A process that uses electricity to split water into hydrogen and oxygen, commonly used in the production of green hydrogen.

Environmental, social, and governance (ESG): A set of criteria used to evaluate a company's operations and performance on sustainability and ethical impacts.

European Union Emissions Trading Scheme (ETS): A market-based approach used by the EU to control and reduce industrial greenhouse gas emissions through the trading of emission allowances.

Feedstock: Raw materials used to produce biofuels and other alternative fuels.

Green hydrogen: Hydrogen produced using renewable energy sources, such as wind or solar power, through the process of electrolysis.

Greenhouse gas (GHG): Gases that trap heat in the atmosphere, contributing to the greenhouse effect and global warming, including CO_2, methane, and nitrous oxide.

International Energy Agency (IEA): An autonomous organization that works to ensure reliable, affordable, and clean energy for its member countries and other nations.

Lifecycle analysis (LCA): An analysis method used to assess the environmental impacts associated with all stages of a product's life.

01

Sky high potential

Case in point

Aviation sector decarbonization commitments

One of the key immediate enablers for aviation to stabilize emissions in the short-to-medium term should be the strengthening of sector commitments to meet net zero goals. This involves taking a more unified approach to reducing and offsetting aviation emissions on a global scale. To date, major commitments include:

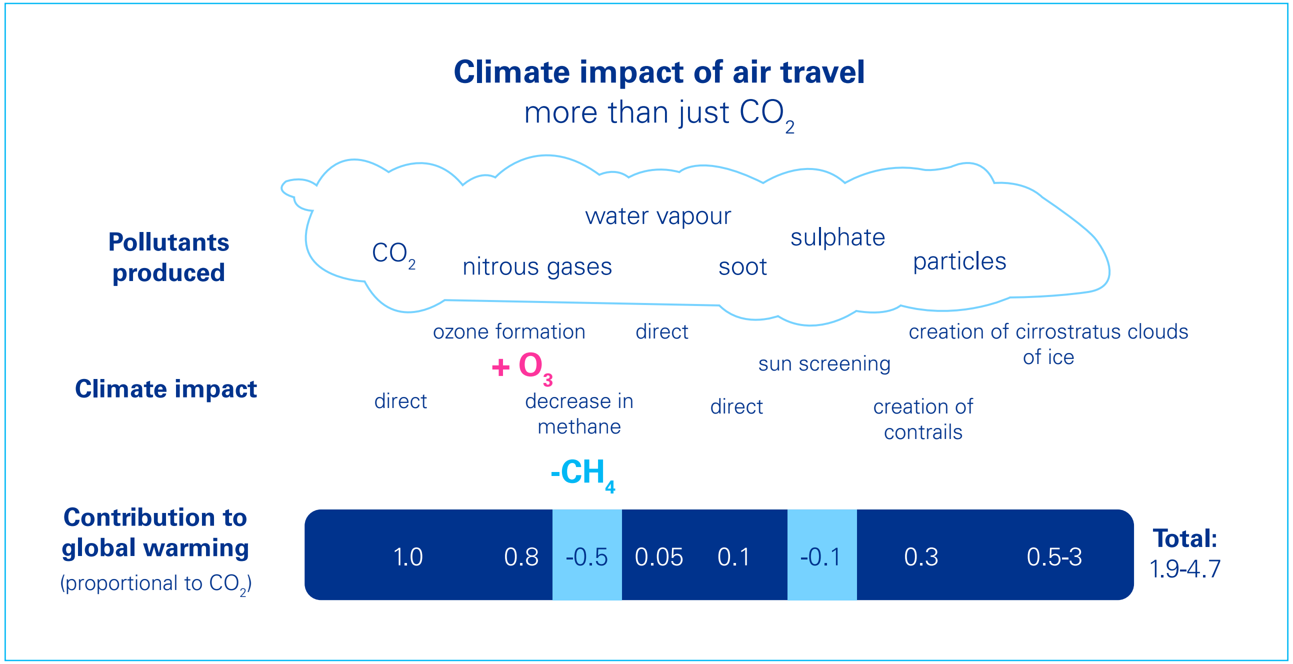
- **Fly Net Zero:**[5] At the 77th International Air Transport Association (IATA) Annual General Meeting in Boston, USA, on 4 October 2021, a resolution was passed by IATA member airlines committing them to achieving net-zero carbon emissions from their operations by 2050. This pledge brings air transport in line with supporting efforts of the Paris Agreement's temperature goal. It estimates that to achieve net zero by 2050, the industry will need to be using 65 percent SAF; will have to adopt 13 percent of new technology, electric and hydrogen; will have to make 3 percent efficiencies in its infrastructure and operations; and will have to use 19 percent of carbon offsets and carbon capture technologies.
- **CORSIA:**[6] Initiated by the International Civil Aviation Organization, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is a global mandate designed to offset international flight emissions. CORSIA sets baseline levels for emissions exceeding 85 percent of 2020 levels. While still in the voluntary phase, all regions have breached the baseline as of the start of 2024. The mandatory phase of CORSIA will begin in 2027, with individual airlines becoming accountable for their emissions by 2030.
- The **Clean Skies for Tomorrow Coalition** is a mechanism initiated by the World Economic Forum and brings together aviation industry and state leaders to work on a path to net-zero emissions by 2050. It aims to accelerate the supply and use of SAF technologies to reach 10 percent of global jet aviation fuel supply by 2030.[7]
- "**Making Net-Zero Aviation Possible**" is an industry-backed, 1.5°C aligned transition strategy which outlines how the aviation sector can reach net-zero emissions in aviation by 2050. It is endorsed by major global aviation leaders including Airbus, American Airlines, Air France-KLM, bp, easyJet, and Shell. Signatories include more than one third of the global airline industry, about 95 percent of the global commercial aircraft manufacturing industry, and 1,950 airports in 185 countries.[8]
- Many airlines have individually committed to reaching net-zero emissions by 2050, including major carriers like Delta, United Airlines, British Airways, and Qantas. These commitments often include investing in sustainable aviation fuels, new technologies, and operational efficiencies.
- Aircraft manufacturers are also committing to more fuel efficient and zero emission aircraft. Airbus aims to develop the world's first zero-emission commercial aircraft by 2035, focusing on hydrogen propulsion technology,[9] while Boeing has committed to delivering commercial aircraft capable of flying on 100 percent sustainable aviation fuels by 2030.[10]
- In Europe, the Airports Council International has engaged the whole European airport industry to eliminate its carbon footprint at the latest by 2050. Based on the 2019 air traffic volumes and the estimated carbon intensity of the industry (1.31 kg CO_2/pax, derived from data provided under Airport Carbon Accreditation), it means that an annual footprint of 3.14 million tons of CO_2 could be eliminated. Numerous smaller airports have already achieved net zero status, while many larger airports worldwide have made net zero commitments. Amsterdam's Schiphol airport in the Netherlands, the world's 13th busiest airport with over 53 million annual passengers, is on track to achieve its net zero by 2030 goal.

5 International Air Transport Association (IATA) website, "Our Commitment to Fly Net Zero by 2050", Accessed June 2024.
6 ICAO website, "Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)", Accessed May 2024.
7 World Economic Forum, "Clean Skies for Tomorrow", September 2021.
8 Energy Transitions Commission, "Making Net-Zero Aviation Possible", July 2022.
9 FlightGlobal website, "Airbus 'will be ready' to develop hydrogen-powered aircraft by 2035 goal: CEO", September 2023.
10 Boeing website, "Boeing Commits to Deliver Commercial Airplanes Ready to Fly on 100 percent Sustainable Fuels", Accessed June 2024.

Under the International Air Transport Association's (IATA) "Fly Net Zero" resolution and as agreed upon at the 41st Assembly of the International Civil Aviation Organization (ICAO) in October 2022,[11] the aviation sector has committed to industry decarbonization by 2050.

In addition to reducing carbon emissions, the industry also has other pollutants to consider. Nitrous gases, sulfate and soot all contribute to global warming. Water vapor, soot and supersaturated regions of the atmosphere also combine to create contrails which have an impact on the climate (chart 1).

Chart 1: Climate impact of air travel



Source: atmosfair

Alternative fuels for aviation

The hard work of delivering its net zero commitments starts now for aviation, but the sector has a major hurdle to overcome. As of today, it has limited alternative fuels options certified for use by commercial aircraft. Added to this, only a few of these sustainable fuel production pathways are likely to ever be fully commercial.

Sustainable aviation fuel (SAF) made from bio products (bio-SAF) is the only realistic short term sustainable fuel for aviation. Its widespread adoption means, in addition to overcoming its economic challenges, it must also deal with issues around availability and scalability, as well as supply chain bottlenecks and questions over the sustainability of feedstocks.

Power to liquids (PtL) e-fuels (synthetic SAF), obtained from low-carbon hydrogen and carbon dioxide, represent a more scalable product for use, longer term. However, e-fuel is significantly more expensive than other SAF pathways, and its potential is unlikely to be achieved without major investment in renewable power generation, electrolysis and carbon capture technology development and deployment.

The use of hydrogen as an aircraft fuel and batteries are also under consideration but are far from commercial in scale. Hydrogen can power modified gas-turbine engines or be converted into electrical power, using renewable energy, via fuel cells, enabling a clean and highly efficient, hybrid-electric propulsion systems.

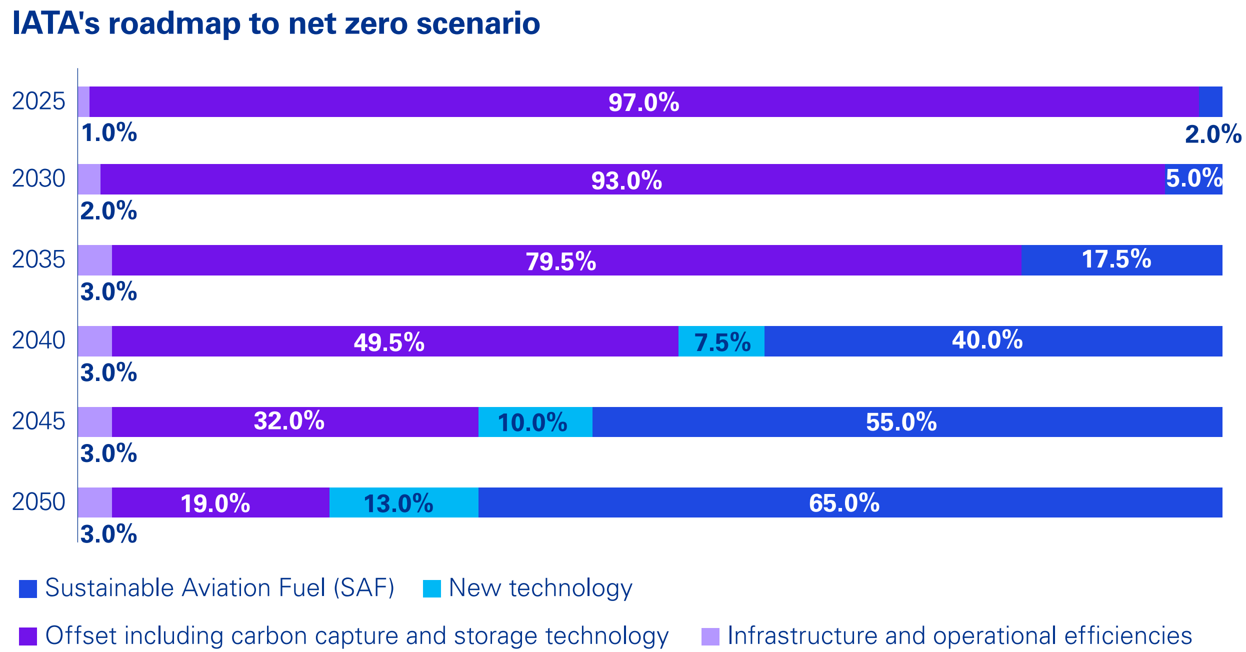
Both hydrogen and batteries have safety and capacity challenges for larger aircraft. Hydrogen also produces much greater amounts of water vapor than jet fuel, which has implications for developing more contrails, with associated atmospheric warming effects.

Even with increasing adoption of SAF and the potential future use of alternative fuels like hydrogen, there is a growing consensus that on its current pathway, the aviation sector is unlikely to achieve its 2050 net zero target.

KPMG projects that only 50 percent of energy demand in aviation will be met by SAF by 2050.[12] The difference will need to be met through carbon offsets, which could represent as much as 30-40 percent of the total net zero goal in the aviation sector (chart 2).

[11] ICAO, "Emissions Reduction Resolution of the 41st Assembly of the International Civil Aviation Organization", October 2022.
[12] KPMG analysis, "Aviation 2030" article series, 2022-23.

Chart 2: Aviation's Net Zero 2050 target is likely to be met through offsets



Source: IATA, "Net zero 2050: offsetting and carbon capture", 2024.

According to KPMG, 30-40 percent of net zero journey is likely to be met by purchasing offsets

KPMG anticipates several challenges with IATA's roadmap to 2050:

- Amount of CO2 abatement is almost three times higher (KPMG assumes it to be 1,785 million metric tons in 2045)
- There could be limited supply of SAF due to constraints related to supply of feedstock as well as lack of financial support
- New propulsion technologies, although launched by 2035, may take additional 20 years to be present across the global fleet
- Sufficient attention is not given to the emissions that result due to contrails

Source: KPMG analysis, "Aviation 2030" article series, 2022-23.

> "As we recently saw with Universal Hydrogen's funding challenge, even the relatively more modest ambition of scaling hydrogen retrofits for turboprops could prove difficult. But when it comes to hydrogen for higher altitude, long-haul aircraft, Airbus are still testing whether the depositing of water vapor (without soot) by hydrogen combustion creates contrails with a greater climate change effect than a conventional flight."

Chris Brown
Partner
KPMG in Ireland

As highlighted in this report the aviation sector should undertake a more proactive approach to solve its alternative fuels supply and adoption challenges. This involves finding more economic ways to transition to net zero cost effectively and, in addition to greater adoption of SAF, could include enhancements in airframe designs and engine technologies, operational optimizations and energy demand management solutions.

There are possible benefits to be gained if the sector follows a new roadmap to net zero which would allow it to:

- Undertake energy transition more 'at their own speed' rather than face disruptions due to regulatory deadlines or sudden market changes.
- Carefully select and test a fuel mix appropriate to their organization own unique technologies, resources, financial goals, and strategic business goals.
- Enjoy first-mover advantages in new and developing markets involving sustainable goods and services.
- Take advantage of government subsidies and tax benefits for alternative fuels sooner and reap the rewards of incentives before they disappear.
- Establish themselves publicly as leaders, not laggards, in environmental responsibility.

02

Alternative fuels readiness

Case in point

Taking off with alternative fuels

Over 450,000 flights have now taken off using a mix of SAF and traditional aviation fuels, and over 50 airlines around the world now have at least some experience with SAF.[13]

While commercial airlines are still not authorized to use 100 percent SAF fuel, in November 2023, the UK's Civil Aviation Authority granted Virgin Atlantic a special "permit to fly" the world-first transatlantic flight, Flight100, using 100 percent SAF. The flight showed a 95 tonnes CO_2e reduction and around a 40 percent reduction in particulate matter emissions compared to a standard Virgin Atlantic flight from London Heathrow to New York JFK.

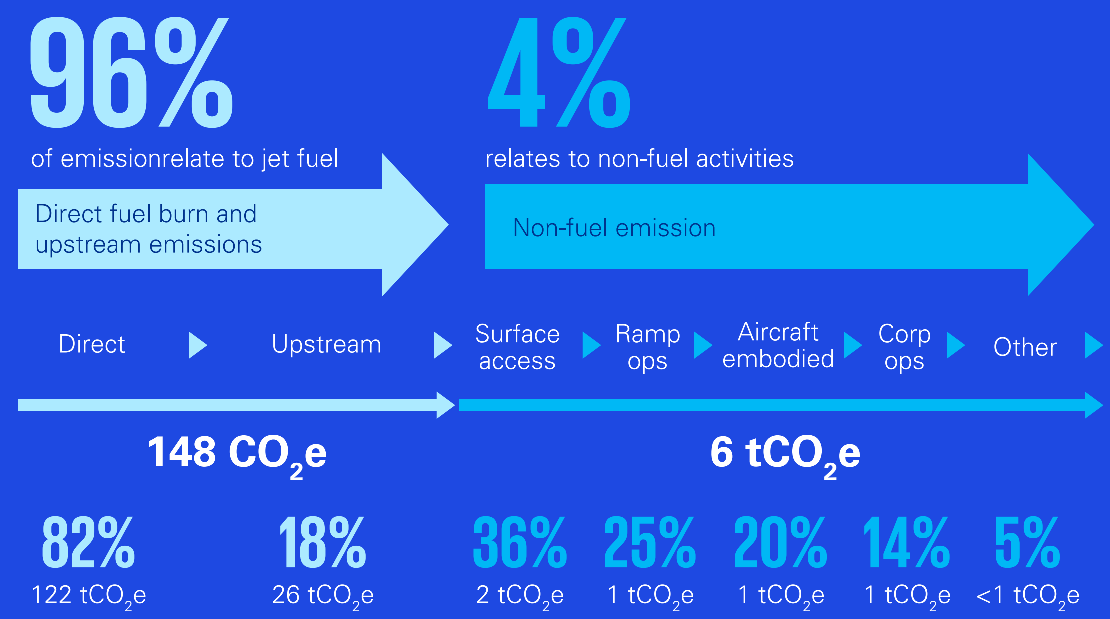
Several previous flights have used 100 percent SAF but none over this distance (including World Energy Gulfstream's G600 flight in 2023 which traveled from Savannah Georgia to Farnborough Airport in the UK using on 100 percent SAF). The success of the Virgin flight highlights 100 percent SAF's long haul potential.

Virgin's flight was the result of impressive collaboration between numerous organizations and deployed nine ground and flight operation efficiency initiatives. It has provided a replicable framework that could be adopted across the aviation sector. Shai Weiss, Virgin Atlantic CEO stated that test flights like Flight100 are important as "they are demonstrating that the SAF uptake challenge isn't operational, if we can make it, we can fly it."[14]

In 2009, a Qatar Airways Airbus A340-600 made history when it undertook the world's first revenue passenger service with e-fuel made from natural gas, blended with conventional aviation fuel.[15]

In January 2021, KLM flew a plane from Amsterdam to Madrid in what the company called the world's first flight powered by e-fuel made from renewable sources. E-fuel made up around 5 percent of the fuel; the rest was conventional jet fuel, but the company said it was a step towards more widespread adoption.[16]

Chart 3: Emissions profile of an end-to-end LHR-JFK flight



Source: Virgin Atlantic

CO_2e stands for carbon dioxide equivalent and is a metric used to compare the emissions of various greenhouse gases based on their global warming potential.

[13] i6 Group, "Which Airlines Are Embracing SAF", 2024.

[14] Imperial College, "World's first transatlantic flight on 100 percent sustainable aviation fuel takes off", 28 November 2023.

[15] Shell, "World First Synthetic Kerosene Takes to the Air", Accessed June 2024.

[16] Reuters, "Dutch airline KLM says operated first flight with synthetic kerosene", 8 February 2021.

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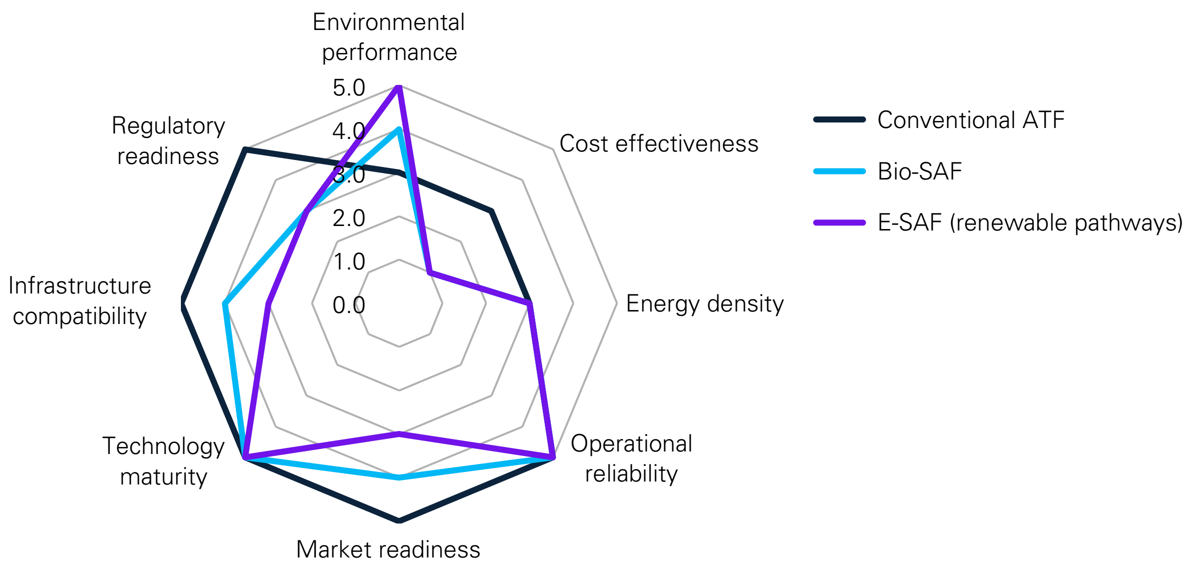
Chart 4: Alternative fuels readiness factors



Source: KPMG analysis, "Fueling the energy transition," 2024.

Each fuel is scored on promise in reducing carbon emissions and readiness for wider adoption (low: 1.0, low to medium: 2.0, medium: 3.0, medium to high: 4.0, high: 5.0)

Replacing jet fuel for commercial aircraft is proving to be a hard problem to solve. Conventional jet fuel is not only highly refined for performance but also contains specific additives, including anti-icing agents and corrosion inhibitors to enhance performance under extreme temperatures and altitudes. These additives improve lubricity, prevent corrosion and icing as well as ensuring thermal stability.

Such safety and performance considerations mean that, today, commercial airlines are only certified to fly with a maximum of 50 percent SAF to conventional jet fuel blends unless specifically exempted.[17]

> **"SAF is a viable near-term solution for aviation decarbonization, compatible with current planes and capable of reducing emissions when blended with regular jet fuel. However, competition for biofuel supply and sustainability issues with certain biomass and crop feedstocks, as well as used cooking oil or municipal waste, pose challenges. E-SAF, a synthetic fuel made from low or zero carbon hydrogen, presents a scalable alternative, but significant investment in electrolysis and carbon capture technologies is needed to make it cost-effective."**

Monika Dangova
Associate Director
ESG Strategy
KPMG in the UK

[17] USA Department of Energy, "Alternative Fuels Data Center", Accessed June 2024.

It means, global aviation fuel demand is still primarily made up of conventional jet fuel (jet fuel demand is forecast to be around 100 billion gallons or between 6-7 billion gallons per day in 2024) with SAF still only making up about 0.5 percent of that global demand.[18]

At current adoption rates, the industry is unlikely to get near to even 50 percent SAF consumption, with the IEA forecasting that SAF will make up less than 2 percent of global aviation fuel demand even towards the end of this decade.[19]

SAF take up rates remain low despite the fact that it can be easily blended with conventional jet fuel due to its identical chemical composition. It means, that despite its higher cost, greater SAF usage could reduce aviation GHG emissions with little upfront capital outlays, engine or infrastructure modifications.

Bio-SAF

As a drop in fuel to blend with conventional jet fuel, bio-SAF (made from biomass or waste materials) has significant carbon mitigation potential. It reduces aviation carbon emissions (depending on production methods and feedstock used) by up to 80 percent, and, when blended with conventional jet fuel, it reduces particulate emissions by up to 65 percent and sulfur oxides by around 40 percent.[20] It also has the potential to mitigate the warming effects of contrails as it contains less soot and particulate emissions.

Despite being more expensive than conventional jet fuel, SAF is expected to become cost-competitive as production scales up and technology advances. Growing biofuel demand across other transport modes, such as trucking, and feedstock limitations are driving the development of more numerous SAF fuel production pathways. While its regulatory readiness is moderate to high, challenges remain in approving 100 percent SAF fueled flights for general commercial operation.

E-Fuel

E-fuel or synthetic SAF also offers good decarbonization solutions. Produced using electricity, combining hydrogen, water and carbon dioxide (so-called "power to liquids" technologies) e-fuels are high energy-density fuels. It has virtually zero emissions and alleviates contrail formation and markedly improves local air quality around airports.

However, its high costs remains a challenge. Estimates suggest e-SAF can be three to four times pricier than traditional jet fuel, although expected improvements in technology and renewable energy affordability may enhance cost competitiveness.[21] It could also require large investments in electrolysis and carbon capture technology.

Efficiency-wise, e-fuel offers highly efficient propulsion methods, although energy losses in the conversion process affect overall efficiency. It also has similar energy density and efficiency as conventional fuels, depending on production methods.

Technically, e-fuels for aircraft are more mature fuels technically. Their high quality mean they require no major aircraft modifications and can use existing infrastructure. Regulatory frameworks will, however, need to be adapted to accommodate their wider adoption by aviation, to make sure they pass all safety and infrastructure compatibility tests.

[18] IEA, "Energy System, Transport, Aviation", 2024.
[19] IEA, "Oil — Analysis and forecast to 2028", 2023.
[20] IATA, "Net zero 2050: sustainable aviation fuels", May 2024.
[21] IATA, "Sustainable aviation output increases, but volumes still low", September 2023.

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03

Barriers to SAF adoption

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Despite its relative ease of use, ongoing challenges in the SAF supply chain continue to limit its widespread adoption by the sector. The aviation industry faces huge challenges to unlock SAF's potential and increase its supply, some of which some of which are highlighted below:

Production costs and supply chain

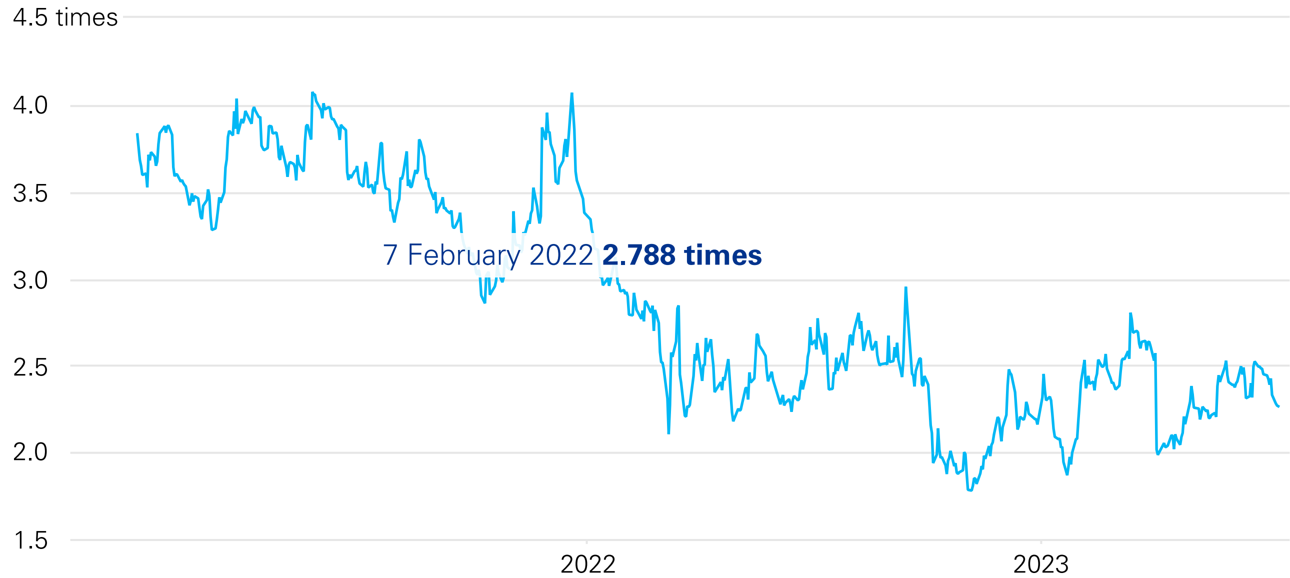
One of the main barriers to SAF adoption is the that its average price is more than double that of conventional jet fuel, a premium which is expected to continue for the rest of the decade.[22]

IATA data[23] shows that SAF use added US$756 million to a record high fuel bill for airlines in 2023, meaning for many, it is still too expensive for everyday use.

The high cost of SAF is largely associated with the production process which is more complex and less established than conventional fossil fuel refining. SAF production facilities are new and few, necessitating significant investment to build and expand. The main production pathways are immature and expensive technologies and, as yet, have lower economies of scale. As the supply chain is less mature and widespread compared to conventional jet fuel, SAF also has higher logistics and distribution costs.

Bio-SAF also relies on raw materials including agricultural residues, waste oils, or specially grown crops, are costlier to source and process than crude oil, with limited availability and competition from other transportation sectors such as road transportation (bio-diesel for trucking) driving up prices (chart 5).

Chart 5: Price premium of SAF over conventional jet fuel



Wholesale prices for large volume shipments

Source: Wall Street Journal/S&P Platts

SAF production locations

While low carbon fuels production is growing, with a number of renewable diesel and biomethane facilities already established across Europe, the USA, Asia and South America, much of the biofuels produced serve the road transport market rather than the aviation sector.

There are only three major dedicated commercial producers of SAF globally today, in contrast to numerous biofuel refineries which produce SAF in batches along with other alternative fuels such as bio-diesel.

- California started commercial SAF production at plants in Paramount, California in 2016. The US$2 billion project, operated by Air Products at World Energy's Sustainable Aviation Fuel (SAF) production and distribution hub has an annual SAF production capacity of 340 billion gallons and is being expanded to supply numerous airports in California.[24]

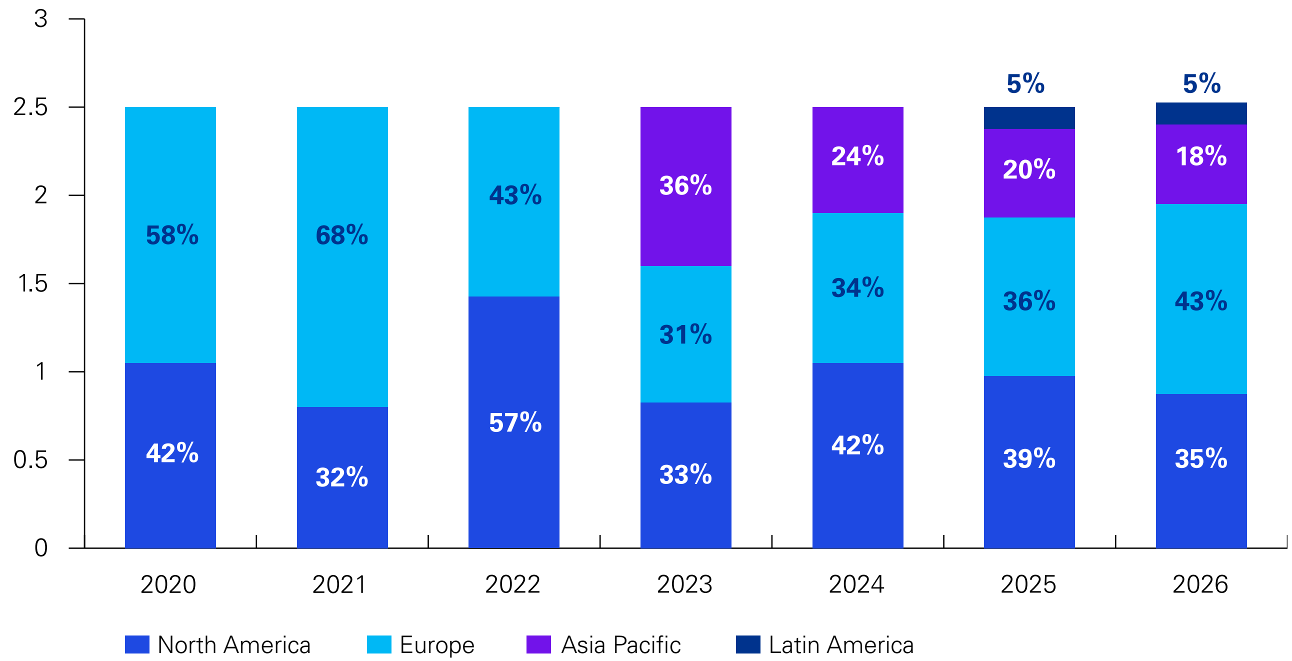
22 IEA, "World Energy Outlook 2023", 2023.
23 IATA, "SAF Volumes Growing but Still Missing Opportunities", 6 December 2023.
24 Air Products, "Air Products Teaming Up with World Energy to Build $2 Billion Conversion of Sustainable Aviation Fuel (SAF) Production Facility in Southern California", 22 April 2022.

- Neste MY SAF is already available at key global airports, including San Francisco International Airport (SFO), Los Angeles International Airport (LAX), Frankfurt Airport (FRA), Amsterdam Airport Schiphol (AMS), Changi Airport (SIN), and Narita International Airport (NRT), and is scaling their production capability up to 1.5 million tons per annum in early 2024.[25]
- Montana Renewables LLC began production in partnership with Shell at an existing petroleum production plant in 2023, supplying fuel to several partner airlines.[26]

While many SAF supply hubs are developing (chart 6) many more will be needed if more supply availability boosts demand. SkyNRG, a major airline fuel supplier, estimates that 400 new SAF refineries alone are needed in the USA and Europe to meet any real growth in demand.[27] Also, some SAF producers are warning of growing disparities between supply and demand, potentially leading to excess short term SAF production capacity if demand does not pick up.

Chart 6: Cumulative SAF production capacity by region

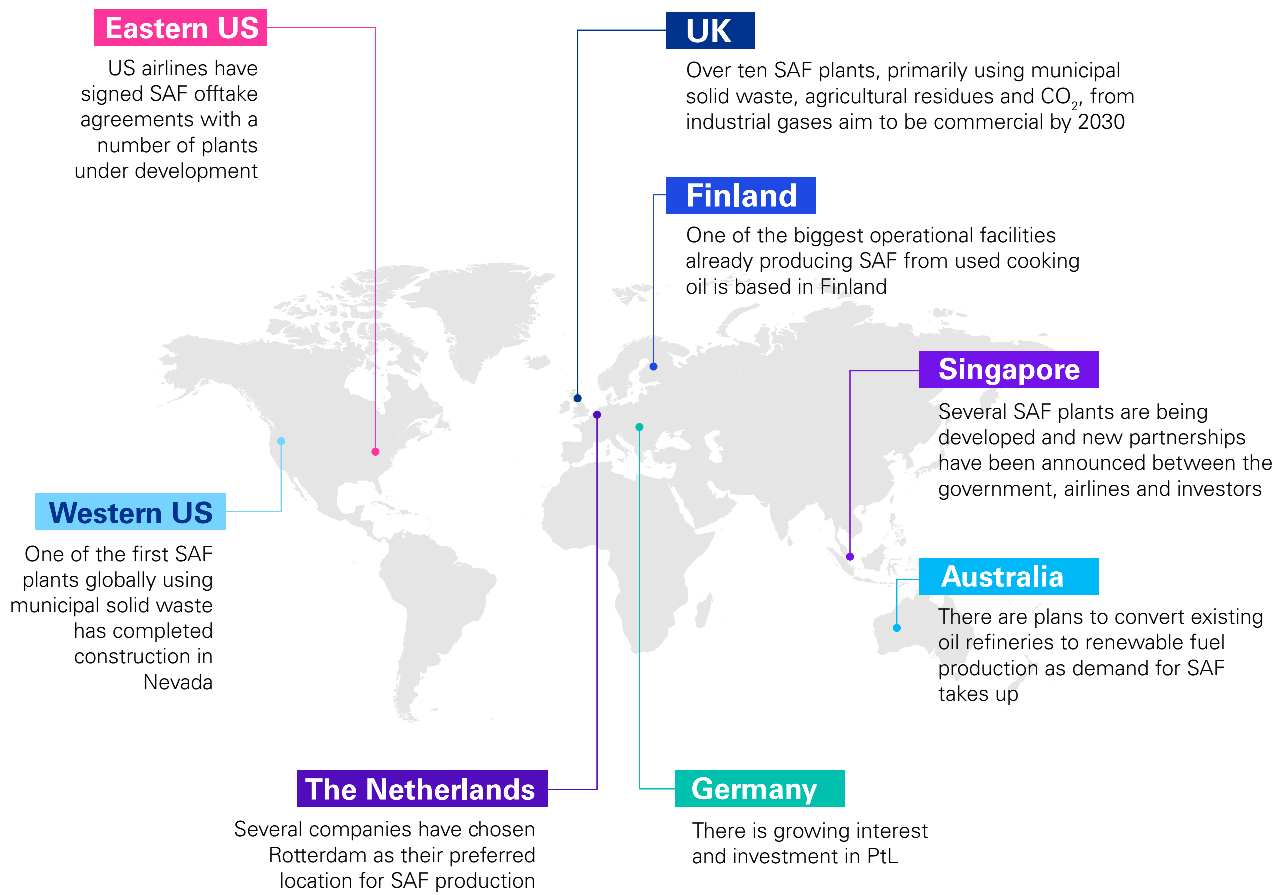
(Billion gallons per year)



Source: BloombergNEF, ICAO SAF facilities.

25 USA Department of Energy, "Alternative Fuels Data Center", Accessed June 2024.
26 USA Department of Energy, "Alternative Fuels Data Center", Accessed June 2024.
27 Neste, "Neste MY SAF — an easy leap towards sustainable aviation", Accessed June 2024.

Chart 7: SAF hubs developing worldwide



Source: KPMG analysis, "Aviation 2030" article series, 2022-23.

Aviation fuel regulations

Ensuring the next aviation cycle is more sustainable is increasingly important, not only to reach net zero and reduce emissions but also for a continued license to operate.

New regulations on carbon emissions for aviation involve a combination of mandatory measures, market-based mechanisms, and incentives to reduce the carbon footprint of the aviation industry.

These measures promote the use of SAF, enhance emissions tracking and reporting, and promote innovation in new sustainable aviation technologies to mitigate the environmental impact of aviation and support the transition to a more sustainable sector.

Stricter regulations targeting aviation fuels are now being introduced around the world. Regulatory developments are driving SAF demand, with mandates and aspirational targets adding up to a total demand of 16.1 Mt (5.3 Bgal) across multiple countries.[28]

The EU's "Fit for 55" package plans to reduce emissions by at least 55 percent by 2030. For the aviation sector, it has proposed a revision of the EU Emission Trading Scheme (ETS) to reduce the emissions cap by 4.2 percent annually as opposed to current 2.2 percent. The EU's ETS mandates would apply to intra-EEA flights and flights to UK and Switzerland and new fuel and electric infrastructure will also be required at major airports.[29]

[28] SkyNRG, "SkyNRG Releases Sustainable Aviation Fuel Market Outlook 2024", June 2024.

[29] European Council, "Fit for 55", April 2024.

Unter the EU RefuelEU aviation initiative, it has mandated that from 2025, all aviation fuel suppliers at EU airports supply jet fuel which contains a minimum percentages of SAF. From 2030, a minimum share of e-fuels will also be required. Both these proportions will gradually increase until 2050. Fuel suppliers will have to incorporate 2 percent SAF in 2025, 6 percent in 2030 and 70 percent in 2050. From 2030, 1.2 percent of fuels must also be e-fuels, rising to 35 percent in 2050[30] (chart 8).

Chart 8: EU sustainable aviation regulatory programs

	ReFuel EU aviation	Renewable Energy Directive (RED II)	Energy taxation directive	EU emissions trading scheme (EU ETS)
Description	A volume based demand side mandate on aviation fuel suppliers is proposed with percentage volumes mandated ramping up at 5 year intervals. Suppliers are responsible for compliance.	RED II sets renewable energy share targets. Member states typically ensure compliance by implementing tradeable certificate systems based on these target volumes. Selling excess certificates to obligated parties that are not meeting their volume obligations allows renewable fuel producers to realise a subsidy.	A point of sale tax on aviation fuel. Aviation fuel has historically been tax free in EU countries. The EU is proposing a per unit energy tax on aviation fuel, with a linear implementation period. Sustainable aviation fuels will be exempt from this tax.	A cap and trade carbon emission allowances system acts as a functional carbon price. The number of allowances is based on a target carbon emissions curve with a linear reductions factor.
Type Status	**Proposed Regulation** New as part of Fitfor 55, under consideration	**Existing Directive** Fit for 55 amendment under consideration	**Existing Directive** Fit for 55 revision under consideration	**Existing Directive** Fit for 55 revision under consideration
Value Indicative value	**Not applicable**	**1.55 EUR per litre** (2022 subsidy for HEFA from waste oils in the Netherlands)	**0.26 EUR per litre** (penalty, 2030 projection)	**0.22 EUR per litre** (penalty, 2030 projection)
Application How does the value or penalty vary	**Applies to sustainable aviation fuel** All sustainable aviation fuels that satisfy the sustainability criteria of RED II fulfil mandate.	**Applies to sustainable aviation fuel** Aviation is not obligated but sustainable aviation fuels can collect subsidies.	**Applies to fossil jet fuel** Sustainable aviation fuel, hydrogen and electricity are tax exempt until 2033.	**Applies to fossil jet fuel** All sustainable aviation fuels are treated as having zero lifecycle emissions by the ETS.
History Key dates and events	Proposal introduced 2021 Adoption expected 2023	Existing dir. adopted in 2009, revised 2018 Revision proposed 2021 Adoption expected 2025	Existing directive adopted in 2003 Revision proposed 2021 Adoption expected 2023	Existing directive adopted in 2005 Revision proposed 2021 Adoption expected 2024
Type Type of legislation	**Demand side mandate** Blending mandate	**Renewable energy share targets** Often supply subsidy but type of legislation dependent on member state implementation	**Excise tax** Point of sale tax	**Emissions penalty** Carbon price/cap

Source: KPMG analysis, "Aviation 2030" article series, 2022-23.

[30] European Union, "ReFuelEU Aviation Sustainable Aviation Fuels", Accessed June 2024.

Other countries are also bringing in new regulations which mandate greater usage of SAF. The federal government in the USA has a goal of replacing all conventional jet fuel with SAF by 2050 (projected at 35 billion gallons per year). It has launched a "SAF Grand Challenge"[31] which aims to produce 3 billion gallons of SAF per year by 2030. It also has proposals for a SAF tax credit that aims to cut cost and rapidly scale domestic production of SAF. Meanwhile, the US Environmental Protection Agency has set biofuel blending mandates for 2022 at 20.63 billion gallons.

The UK's Jet Zero strategy aims to achieve net-zero aviation emissions by 2050, with interim targets such as achieving net-zero domestic aviation emissions by 2040. The strategy includes a mandate for certain percentage of jet fuel to come from low-carbon sources (2 percent by the end of 2025 and 10 percent by 2030) as well as incentives and funding for SAF development and production[32] (chart 9).

Chart 9: Example SAF regulations excluding the EU

Country	Blending level	Target type	Status
Norway	0.05% (2020), 30% (2030)	Mandate (2021)-target (2030)	Implemented mandate only
Sweden	0.8% (2021), 27% (2030)	Mandate (2021)-target (2030)	Implemented mandate only
USA	FAA-1 billion US gallon SAF/year (2018) US RFS: 36 billion gallons of renewable fuels (2022)	Policies	—
UK	10% (2030), Up-to 75% (2050)	Mandate	In consultation
France	1% (2022)-Mandate, 2% (2025), 5% (2030), 50% (2050)	Mandate and Aspirational goal	On-going discussion for 2022
Spain	2% (2025)	Mandate	On-going discussion

Source: KPMG analysis, "Aviation 2030" article series, 2022-23.

[31] US Department of Energy, "SAF Grand Challenge", Accessed June 2024.

[32] UK Department for Transport, "Jet Zero strategy: delivering net zero aviation by 2050", Accessed June 2024.

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04

Strategic recommendations

- To achieve net zero, aviation organizations should carefully consider how to develop and deploy their preferred SAF adoption strategies.
- Most organizations recognize that greater use of SAF in their day-to-day operations can help support GHG emissions reductions and there is also the reward of better social, and governance (ESG) credentials.
- We believe there are several important steps that airlines and aviation companies can take which should mean they can effectively make the transformation their industry now needs to undertake:

01 Understand the SAF technology ecosystem

Understanding the numerous and new technology pathways for aviation fuels is important with organizations needing to align with and support production pathways which offer the best potential for cost reductions and scaling.

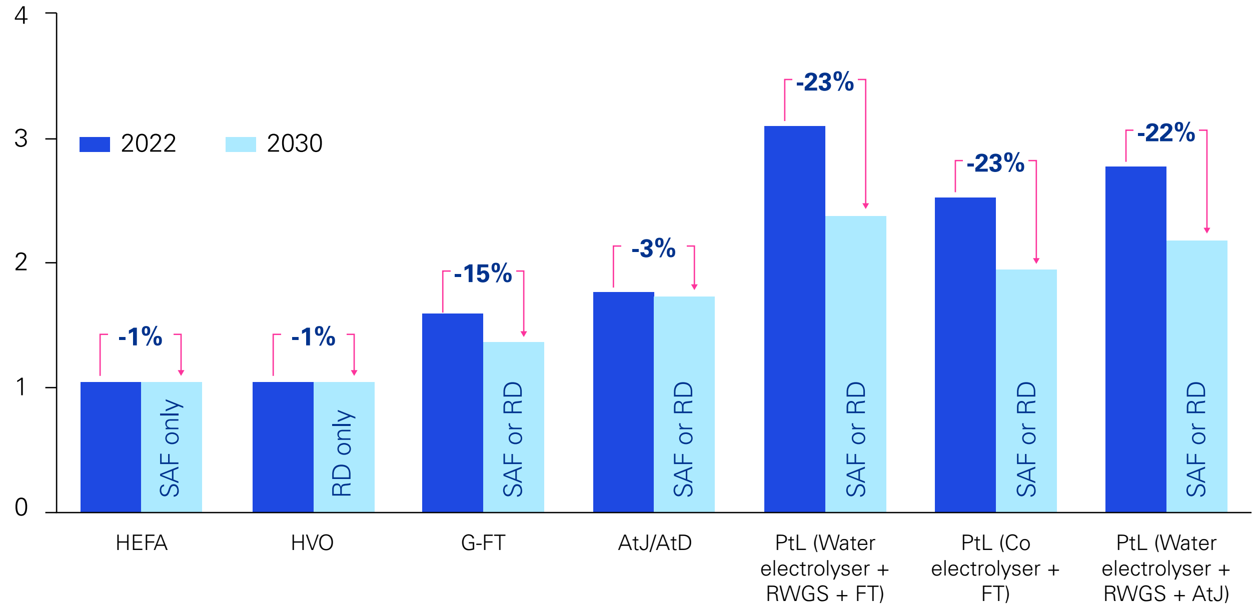
Organizations now need to invest in research and infrastructure that support the scalable production and use of SAF. This should help to enhance their SAF supply chain capabilities and ensuring wider availability of SAF at major airports.

KPMG analysis shows that by 2030, the hydro processed esters and fatty acids and hydrotreated vegetable oil (HEFA/HVO) production process is likely to remain the cheapest fuels technology pathway for aviation, followed by the gasification/Fischer-Tropsch process (G-FT) and the alcohol-to-jet process (AtJ).

Alternative fuels using the power to liquids (PTL) processes (including revere water gas shift reaction/ Fischer Tropsch process are not forecast to be cost competitive with any pathways in 2030 as the technology is as yet, too immature and expensive to use at scale (chart 10).

Chart 10: Renewable fuel production costs, 2030 versus 2022

EUR per litre



Notes: Assuming equal cost allocation to all products by volume. At a reference oil price of US$49.8/barrel, a diesel crack of US$13/barrel and a jet crack spread of US$18/barrel the production cost of fossil jet is 32 EUR/liter and the production cost of fossil jet is 34 EUR/litre. 5 percent variation in commoditized feedstocks assumed for error bars, expected feedstock cost variation used for forecastable feedstocks.

Source: KPMG analysis; bottom-up cost model (by technology), "Aviation 2030" article series, 2022-23.

Many commercial SAF producers are using or moving into the HVO/HEFA SAF production process. This is largely because the technology is relatively mature and scaling fast commercially and has the advantage of using a wide variety of feedstocks.

Also, as renewable diesel and sustainable aviation fuel are chemically similar, producers like this process because they easily blend both renewable diesel (for road transportation) and sustainable aviation fuel (for aviation) offering them more flexibility.

There is however limited potential for SAF produced via used cooking oil/fat feedstock. Its prices are relatively inelastic as it is volume/feedstock constrained and the process technology is mature and set.

There is much more potential for price reduction for e-fuels which are feedstock independent (CO_2 plus H_2 from renewables) These fuels are also linked to the cheaper cost of renewables, electrolysis costs and benefits from new technology efficiencies. With the cost of green hydrogen expected to decline, some estimates have the cost of e-fuel at 70 percent cheaper than conventional jet fuel by 2050.[33]

The Alcohol-to-Jet (ATJ) production is SAF production process is also growing fast, particularly in the USA (a major producer of ethanol from corn) offering opportunities for price reductions as supplies and competition increases. The SAF producer Gevo uses this process and, in 2022 the **one**world airlines alliance, signed a five-year deal with Gevo for 200 million gallons of SAF supplies from 2027.[34]

KPMG analysis also show that if there were enough supply of SAF available, incentivizing airlines to purchase it would still be required, as SAF prices remain prohibitive.

02 Develop more progressive financial strategies

Net zero in the aviation sector cannot be achieved without additional costs to the aviation supply chain and higher ticket prices as the industry pays for its decarbonization. It will add substantial cost pressures to a business which is already low-margin.

Extra expenses could include carbon taxes, SAF price premiums, required offsets, as well as the cost of retrofits for new fuels and replacing older aircraft with lower fuel consumption models. Some estimates put average annual investment for global aviation to reach net zero at US$175 billion (between 2022-2050), most of which is related to new fuels production.[35]

Over the past few years there has been reduced banking sector investment in aviation due to the losses from Covid pandemic. IATA data shows that during this period, the global aviation sector lost US$175 billion (2020) and US$104 billion (2021) compared to average annual losses of US$5 billion which was the highest economic loss experienced by any industry in the pandemic.[36]

The gaps in investment are being filled by alternative financing sources such as green bonds and private equity, leading to a notable increase in aviation sector activity from private equity firms and hedge funds over the past two years.

New investment

Attracting new investment into the sector is now important to meet the rising cost of meeting net zero goals. Some of the key lenders in the aviation sector are working with the Center for Climate Aligned Finance (CAF) to develop a financial framework to support decarbonization in the aviation industry under so-called Pegasus Guidelines[37] which they hope will attract new investors.

The Pegasus Guidelines instruct lenders to the aviation sector how to access high quality data and measure their emissions intensity and climate alignment compared to a 1.5°C roadmap. It further includes a measurement and disclosure methodology enabling financial institutions to calculate and disclose the emissions intensity and/or climate alignment of their aviation lending portfolios annually.

More initiatives like these will be needed from investors, aircraft manufacturers and airlines to support the establishment of innovative ways of financing that reduce the technology risk of new fuels and drive cost reductions.

Coming up with more progressive financial solutions should allow them to pre-empt future environmental scrutiny on the wider aviation value chain and may help secure the long-term growth of global aviation fleet.

[33] ING Group, "Synthetic fuel could be the answer to aviation's net-zero goal", 23 February 2023.
[34] oneworld "oneworld members to purchase up to 200 million gallons of sustainable aviation fuel per year from Gevo", 21 March 2022.
[35] Mission Possible Partnership, "Making Net-Zero Aviation Possible, An industry-backed, 1.5°C-aligned transition strategy", July 2022.
[36] IATA, "Understanding the pandemic's impact on the aviation value chain", December 2022.
[37] Center for Climate Aligned Finance, "Focus Sectors — Aviation", Accessed June 2024.

Options might include:

- Creating financial incentives or disincentives based on airlines Scope 1 emissions.
- Investing in new age technologies such as SAF production and hydrogen and electric powered aircraft.
- Preparing terms and conditions to boost relative and absolute emission reductions in airlines. For debt financing where the borrower will receive a discount if they reduce the grams of CO_2 per revenue passenger kilometer over time.
- Entering into longer-term, fixed-price SAF supply contracts which provide more demand security for producers.
- New programs, such as the United Airlines Ventures US$200 million Sustainable Flight Fund,[38] a first-of-its kind effort to reduce emissions and drive-up production of sustainable aviation fuel (SAF) through investments in startups. Set up in 2021, it now has 22 corporate partners investing exclusively in companies developing new technologies to try and resolve the low carbon fuel supply issue for aviation.

The aviation sector might also look to adjacent heavy transport sectors like shipping where new mechanisms are being put forward to close the price gap between traditional fuels and alternative fuels and leveling the playing field for those companies adopting new fuels.

The World Shipping Council's proposed Green Balance Mechanism aims to bridge the cost gap between fossil fuels and green fuels by applying fees to ships using fossil fuels and reallocating these funds to those using alternative fuels. This annual fee and fund allocation, based on fuel availability and market prices, promotes a competitive shift to low-emission fuels at minimal cost. By balancing fuel costs, the mechanism seeks to accelerate the shipping industry's transition to meet IMO's net-zero emission goals.[39]

KPMG case study

Green finance institute (GFI) — sustainable aviation fuels in the UK

The UK government has a new mandate requiring 10 percent (around 1-1.2 million tons) of jet fuel supplied to UK departing flights to be from sustainable sources in 2030. The government is also addressing the challenge of substantial barriers for investors to help with the transition to a decarbonized aviation sector.

The Green Finance Institute (GFI) leads global experts in unlocking investment. Barriers within the UK to create impactful and real economy outcomes to benefit the environment, society, and business. To help the UK market in this transition, the GFI is looking into ways to stimulate investment into UK Sustainable Aviation Fuel (SAF) production by identifying the right mechanisms to incentivize and stabilize the demand and use of SAF within the aviation sector.

GFI sought support from KPMG in the UK to help key market and financier participants to understand key pain points and enablers to growing this nascent industry, including market analysis, SAF sector bankability challenges, mechanisms to facilitate SAF investment and how to encourage commercial investment in SAF.

KPMG in the UK assisted the GFI to prepare and execute the Investor Roundtable and drafted a final market analysis report following the Roundtable, which covers the current global SAF landscape and the challenges the UK faces to stimulate investment into this growing market.

[38] United, "United Airlines Ventures", Accessed June 2024.

[39] World Shipping Council, "Green Balance Mechanism", February 2024.

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03 Take advantage of policy and regulatory incentives

Organizations need to be ready to take advantage of government incentives, subsidies, and regulatory frameworks that support SAF development and deployment, ensuring compliance, while benefiting from available financial support. This might be a short window of opportunity as regulations evolve and SAF prices become more competitive.

IATA has asked that "governments prioritize policies to incentivize the scaling of SAF production and to diversify feedstocks with those available locally".[45] As an estimated 85 percent of SAF facilities coming online by 2030 will be using HEFA production technology that will rely on increasingly limited quantities of feedstocks, IATA is advocating incentives which promote new SAF production pathways currently in the development phase.[46]

IATA has also highlighted other SAF challenges which need incentives to resolve. It wants to identify more potential feedstocks to leverage all SAF technologies to provide greater supply diversification and give more regional supply options.[47] IATA is also advocating that SAF incentives run for a much longer term. In the USA, for example, the current two-year incentive for new SAF production is insufficient to convert refining to SAF and get a realistic return on that investment.

Governments and producers are also trying to boost demand and support SAF production and make it more cost competitive with jet fuel. Several large SAF suppliers have also set targets for SAF production at locations primarily in Europe (chart 11).

Case in point

Flying high with alternative fuels

The US Inflation Reduction Act of 2022 offers tax credits for SAF, potentially supporting production to grow to 3 billion gallons (0.2 million b/d) by 2030 and 35 billion gallons (2.3 million b/d) by 2050, which would be adequate to meet all US flight needs by 2050.[40]

Individual US states are also encouraging SAF production. California, Oregon, and Washington all have low-carbon fuel standard programs offering incentives and tax credits to fuel producers and aviation providers that may benefit from producing or consuming low-carbon fuel.

In California, for example, which has both renewable fuel standard programs and a LCFS, SAF prices are much lower. One airline CEO notes, "Once it (SAF) is blended within California we usually see [a premium] of US$1 to US$2 per gallon…once you get outside of California, we've seen anything from US$4 a gallon to … US$11."[41]. Meanwhile, Illinois is one of the first US states to enact a specific SAF tax incentive. From 2023 to 2033, Illinois law will provide a US$1.50/gallon state use tax credit for air carriers that buy or use SAF in the state.[42]

SAF supply is also receiving support from EU Innovation Fund grants. EU Policy (ReFuelEU) is a blending mandate levied on fuel suppliers for a minimum SAF blend (including a minimum share of e-fuel) at EU airports is expected to start in 2025. For this year, the minimum volume of SAF has been set at 2 percent, going up in five-year intervals to reach 70 percent in 2050.[43] Elsewhere, Japan plans to mandate SAF for 10 percent of aviation fuel use by 2030 and, from 2026, Singapore will require that all departing flights use 1 percent SAF, rising to 3–5 percent by 2030.[44]

There are plans for another 290 plus of new SAF production facilities and other lower carbon aviation fuels (LCAF) which could also mean that the biofuel facilities already established across the world, which have predominantly served the road transport fuel market, could now prioritize production of SAF.

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40 IEA, "World Energy Outlook 2023", 2023.
41 Ainonline.com, "Many Projects Give Promise of More SAF", 2 October 2023.
42 The Tax Adviser, "Sustainable aviation fuel incentives take off", 1 June 2023.
43 IEA, "World Energy Outlook 2023", 2023.
44 Reuters, "Singapore to impose green fuel levy on flights from 2026", 19 February 2024.
45 IATA "SAF Volumes Growing but Still Missing Opportunities", 6 December 2023.
46 SkyNRG, "SkyNRG Releases Sustainable Aviation Fuel Market Outlook 2024", June 2024.
47 Green Air News, "IATA expects SAF production to rise to 0.5 percent of airlines' fuel consumption in 2024, adding $2.4bn to costs", 8 December 2023.

Chart 11: Producer SAF production targets

Announced production targets from selected producers
(non-exhaustive, 2022-2032)

Producer name	Announced production start year	Expected capacity (tonnes p.a.)	Production pathway	Plant location
Philips 66	2022	36,000	HEFA co-processing	UK
TotalEnergies	2022	285,000	HEFA	France
Arcadia eFuel	2024	80,000	Power-to-Liquid	Denmark
Neste	2026	500,000	HEFA co-processing	Netherlands
Norsk e-Fuel	2026	19,000	Power-to-Liquid	Norway
DG Fuels	2026	336,000	Power-to-Liquid and biomass	USA

Source: KPMG analysis, "Aviation 2030" article series, 2022-23.

Airlines are also supporting increased SAF production through focused schemes. There are over 40 airlines which have committed to using 3.5 billion gallons of SAF by 2030[48] which is around 3.5 percent of total global jet fuel demand projected for 2024.[49]

In 2023, United Airlines announced that it will begin using a SAF blend on all departing flights from San Francisco International Airport and at London Heathrow Airport.[50] as part of its "Eco-Skies Alliance", which lets customers and companies contribute to the purchase of SAF. The scheme aims to raise United Airlines SAF consumption to around 10 million gallons in 2023 (10 times more than it was in 2019).[51]

[48] IATA, "SAF Volumes Growing but Still Missing Opportunities", 6 December 2023.
[49] OPIS, "Jet Fuel Demand Continues to Recover in 2024 as Sustainable Aviation Fuel Use Increases", 16 January 2024.
[50] United Airlines, "United to Triple SAF Use in 2023, Adds SAF on Flights at San Francisco Airport", 4 May 2023.
[51] United Airlines, "Eco Skies Alliance", Accessed June 2024.

Taxing jet fuel

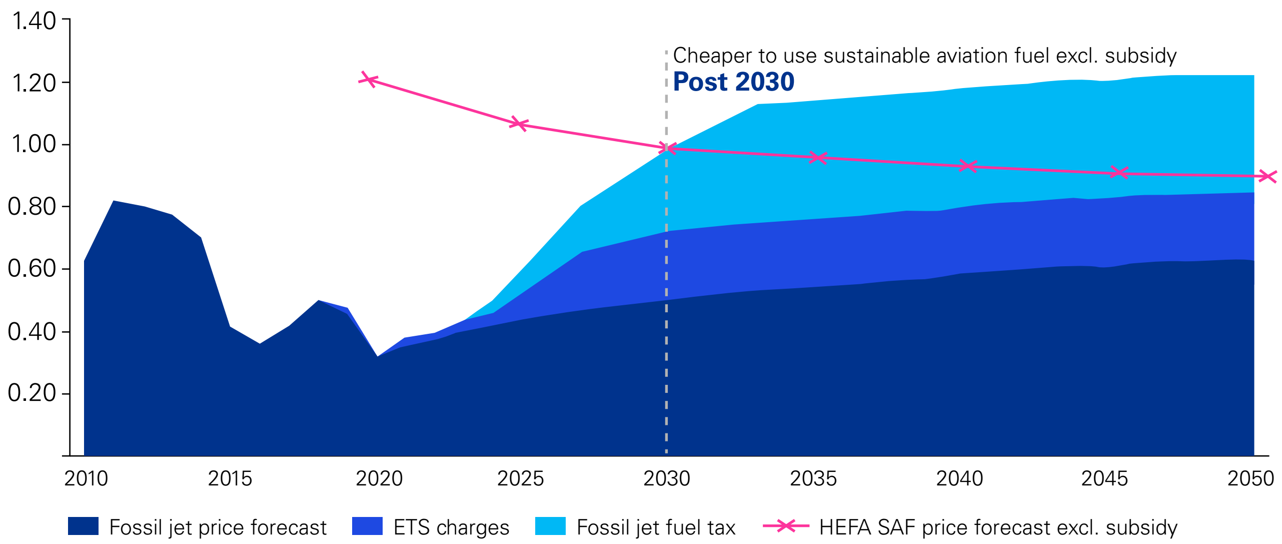
If the aviation industry is lobbying for similar or greater incentives for alternative fuels, to fossil fuels, it is also hoping that higher fossil fuel taxation will accelerate SAF price parity with jet fuel.

Jet fuel is almost exempt from taxation globally. In the EU, for example, under the EU's Fit for 55 initiative, SAF costs could be similar to jet fuel by 2030 (even before the production subsidies under Renewable Energy Directive II are considered) (chart 12).

Jet fuel taxation could also potentially generate significant revenue for investments in low-carbon transportation like high-speed rail infrastructure. The EU reportedly lost over €34 billion in revenue in 2022 due to aviation's low taxation levels which could finance about 1,400 km of new high-speed rail infrastructure.[52]

Chart 12: Fossil jet price, tax and ETS cost vs HEFA SAF price excluding subsidy, 2010–2050

EUR per litre



Notes: The graph on the left is illustrative only, to get the full picture the impact of production subsidies on sustainable aviation fuel price and the effect of new production pathways on production cost must be included.

Source: KPMG analysis, "Aviation 2030" article series, 2022-23.

[52] Transport and Environment, "Every hour European governments lose out on €4 million in aviation taxes", 12 July 2023.

04 Form strategic alliances and find ways to collaborate at scale

Case in point

Working together to land net zero

There are many collaborations underway in the aviation sector focusing on increasing the use of alternative fuels and scaling the new technologies needed to get to industry to net zero. They include:

- The World Economic Forums' Airports for Tomorrow[53] initiative focuses on addressing new infrastructure requirements for the energy transition. It brings together government leaders, climate experts and CEOs from the aviation, energy, construction, and finance sectors who agree on the urgent need to reach net zero. It is estimated that three quarters of the projected costs associated with SAF, hydrogen and battery electric for flights, are related to infrastructure rather than the renewal of the existing commercial aviation fleet. The initiative has explicit SAF blending mandates (e.g., 10 percent by 2030) committing dozens of operators to net zero targets.
- The EU's Clean Aviation Clean Aviation Joint Undertaking,[54] a public and private sector collaboration funding new research focused on developing those disruptive technologies and breakthrough innovations that can accelerate and achieve the best pathway for more sustainable future aviation.
- The Commercial Aviation Alternative Fuels Initiative (CAAFI) is a collaboration with San Francisco International Airport, several airlines, and SAF producers. It is facilitating substantial SAF procurement agreements between airlines and producers to guarantee SAF demand before modifications in fuel plants for SAF production, including with Shell Aviation and World Energy. They will supply SAF to Lufthansa Group on three routes operated by Deutsche Lufthansa and Swiss International Air Lines from San Francisco to Frankfurt, Munich and Zurich.[55]
- Heathrow, in the UK, is the worlds' 8th busiest airport, has a net zero goal of the mid 2030's and has launched the world's first airport SAF incentive program which aims to cover up to 50 percent of the extra fuel cost, making the fuel more affordable for airlines to use. For 2023, airlines committed to 1.5 percent SAF, this percentage will be scaled up for 2024 and beyond, with a target of 11 percent SAF usage by 2030.[56]

The pathways for the aviation sector to reach net zero are a mass of interconnected challenges and opportunities that look different to different parts of the industry. Organizations need to determine the most effective route for SAF into their business, whether it be through direct investment in SAF production or forming partnerships with fuel suppliers and distributors, or both.

While many airlines are already collaborating with key stakeholders, such as airports and regulatory bodies, to address common challenges associated with the procurement and supply of SAF, efforts now need to be accelerated so SAF supply can be scaled.

While there are some successful industry-led initiatives and private-public partnerships underway, more needs to be done through wider industry collaborations to resolve carbon emissions and alternative fuel development challenges. Airlines should actively participate in industry forums and working groups, sharing operational insights and best practices for new fuels development.

Thes might include supporting technology platforms that help with information exchange and focus on new fuels development and liaisons with investment communities, so they understand the need for new SAF funding.

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[53] World Economic Forum, "Airports of Tomorrow", Accessed June 2024.

[54] European Union, "EU's Clean Aviation Clean Aviation Joint Undertaking", Accessed June 2024.

[55] Shell, "Shell Aviation and World Energy collaborate to increase supply of sustainable aviation fuel", 7 January 2020.

[56] ACI Europe, "European airports commit to net zero carbon emissions under their control by 2050", Accessed June 2024.

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05 Increase consumer awareness

If the aviation is serious about cutting emissions, then airline passengers may need to bear some of the cost and responsibility for it too. Organizations now need to be able to communicate the environmental benefits of SAF adoption to passengers, investors, and regulatory bodies.

They are also recognizing that behavioral approaches and more education and engagement with their passengers is also necessary, to encourage more sustainable travel and achieve its decarbonization goals.

It means that airlines need to make the price of SAF supply more transparent to their customers as well as making it much easier for them to contribute to a SAF premium on the price of their ticket. Finally, discouraging passengers from flying when alternative travel might offer lower emissions, might have to be a counter intuitive strategy too.

Consumers might be more willing to pay for higher air fares which include a SAF contribution or contribute to offsetting the emissions of their flight, if they had a clearer understanding of the costs involved.

IATA estimates that the cost of SAF per seat to be about the cost of a drink or snack before getting on a domestic flight or a meal for a long-haul flight.[57] If air passengers understand that the cost of a SAF contribution was that small, it could encourage them to contribute to its wider use.

[57] Wall Street Journal, "Sustainable Aviation Fuel Leader Talks Green Premiums and Impact of Tax Incentives", 19 July 2023.

KPMG research[58] shows that most passengers may tolerate increases in fares to reduce a flight's carbon environmental footprint if it were a fair reflection of the extra cost. 80 percent of passengers said they would pay an additional US$2 per flight to support the use of SAF while about 50 percent of passengers would pay more than US$20 to offset their carbon footprint, without it impacting how frequently they choose to fly.[59] Low frequency travelers are also more tolerant of price increases, than those flying more frequently (chart 13).

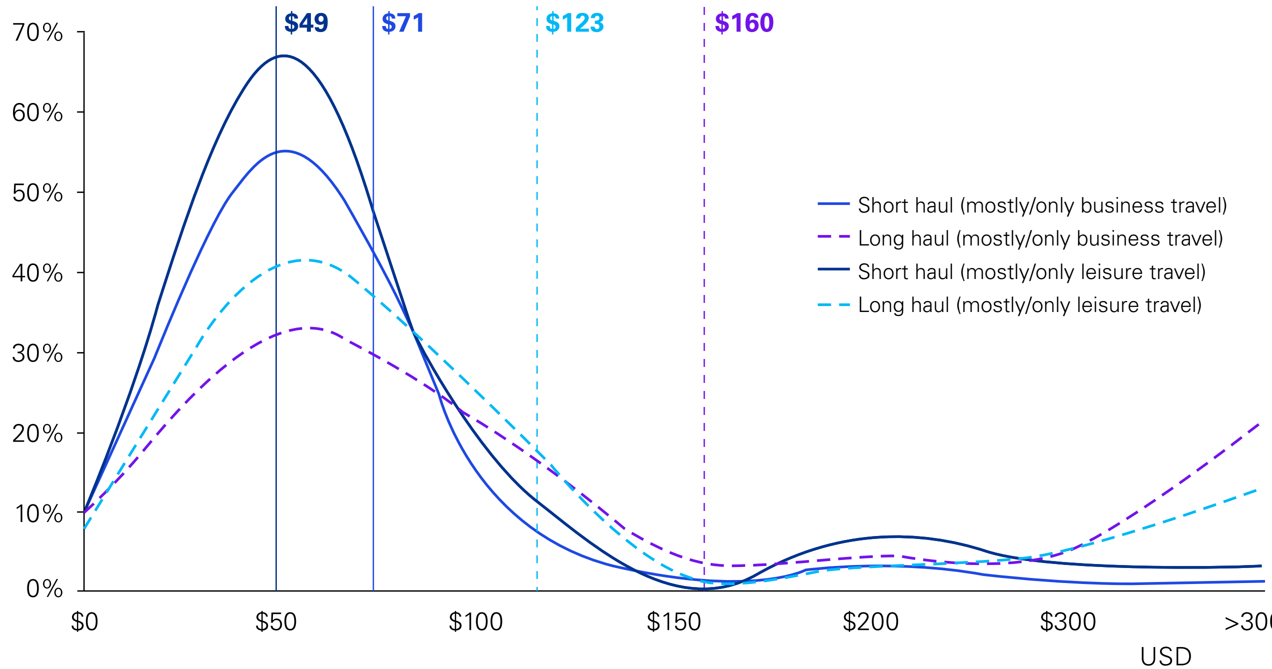
Airlines now need to consider how much ticket inflation consumers could tolerate before it affects the sector's growth, and the ability to continue to invest in emissions reduction technologies and new fuels adoption.

Some governments are now trying to change consumer behavior by prioritizing high-speed rail travel over flying to reduce carbon emissions. In May 2023, France banned by law, all short-haul flights where rail offered a faster alternatives.[60] Over the past two decades, China has developed the world's largest high speed rail network, which is reducing journey times and offering cheaper alternatives to driving and flying, with over 75 percent of larger Chinese cities now connected.[61]

Chart 13: Accepted airline passenger ticket price increases to cover decarbonization

Accepted price increases

What ticket price increase would you think is fair to cover aviation's decarbonisation, while not impacting your frequency of flying?



Source: KPMG analysis, "Aviation 2030" article series, 2022-23.

[58] KPMG in Ireland, "Who pays for aviation's decarbonization? Aviation 2030 series", 2030.
[59] TNMT.com "Sustainability drives real commercial impact in travel" 21 July 2021.
[60] Forbes, "France's Ban on Short-Haul Flights Where Rail Offers Fast Alternative Signed into Law Today", 23 May 2023.
[61] CNN, "Past, present, and future: The evolution of China's incredible high-speed rail network", 9 February 2022.

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Onwards and upwards

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With limited alternative fuel options and tightening carbon regulations, the aviation sector should now proactively manage its decarbonization journey to meet the commitments it has made.

Achieving net zero will require a more supportive regulatory environment, on top of those industry wide efforts to improve SAF adoption and reduce emissions already underway.

Not only will fuel producers need to supply high volumes of more cost-effective SAF but governments should be more actively engaged in eradicating inefficiencies in air traffic management and airspace infrastructure. Aircraft OEMs will also have to manufacture more efficient airframe and propulsion technologies. Finally, airport operators should accelerate the introduction of new fuels infrastructure to supply SAF at lower prices and on more flexible terms.

It is a complex picture and to achieve it will require building an effective roadmap. This will allow the industry to operate with the net zero goal always in sight, using collaboration and innovation to accelerate decarbonization. The roadmap can be enhanced with elements such as:

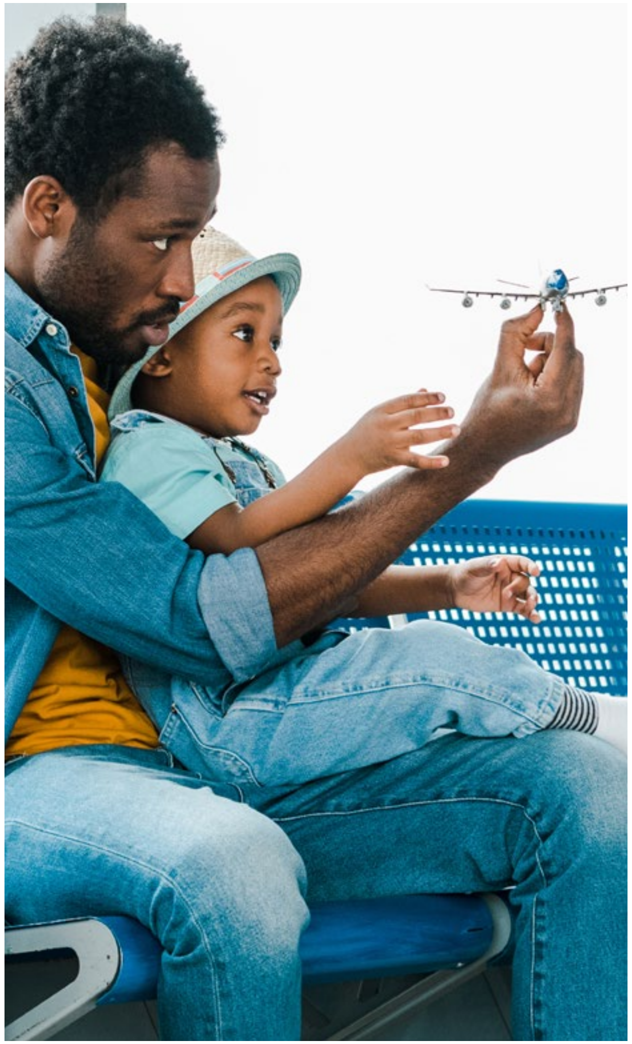
Outcome-based decision-making. If organizations are not going to be involved in SAF production, and become energy producers, they will need to focus on areas they can control to increase supplies and achieve their net zero targets.

Using more outcome-based decision making, which emphasizes achieving desired outcomes over following specific processes, will help them to better navigate uncertainties like fluctuating SAF supplies and costs, volatile commodity prices, changing regulations, and new technologies, with the net zero goal always top of mind.

It could mean prioritizing SAF procurement over jet fuel, fuel efficiency improvements over other operational procedures and moving faster on aircraft modifications and redesign. It could mean prioritizing new digital technologies which accelerate decarbonization including the use of artificial intelligence (AI).

AI is already being used by the aviation industry to reduce the contrails which account for roughly 35 percent of the sector's global warming impact, and over half of the impact of jet fuel emissions.[62] By harnessing data on weather patterns, flight paths and from satellites, AI programs are developing detailed contrail forecast maps, enabling pilots to avoid creating them.

In-depth assessment of procurement and supply chains. In aviation, procurement involves significant time and financial investment due to long lead times, costly assets, and extended product lifecycles while fleets cannot be easily replaced or expanded. In addition, airlines are dealing with global supply chain disruptions, rising costs and stricter safety regulations.



[62] IPPC, "AR6, WGIII, Chapter 10 Transportation" 2024.

The sector now needs to factor in procurement of greater supplies of SAF as well as identifying cost efficiencies and service enhancements throughout the alternative fuels value chain.

New procurement strategies and contracts with airports and fuel producers need to be explored. These might include the airport acting as a fuel demand aggregator as well as directly procuring SAF supplies.

IATA is starting to play its part and is endorsing a globally consistent 'book and claim' system for the SAF supply chain. Book & Claim models are now common practice across many sectors, where a sustainability claim made by a company is separated from the physical flow of goods.

For aviation, it means that SAF not physically transported and entered into the specific aircraft at a specific airport. The volume of SAF that is needed is entered into the production system and tracked and verified, after which corresponding carbon emissions factors are calculated and allocated to the person/organization to cover its premium.

By separating the physical logistics of SAF distribution from the environmental benefits associated with it, should alleviate some of the SAF supply chain challenges. By allowing SAF to be sourced for flights out of airports that do not have SAF supply available, can also reduce costs and develop a simpler and transparent SAF supply chain. SAF buyers can source SAF based on their total aviation footprint in one transaction, rather than dealing with each airline individually.[63]

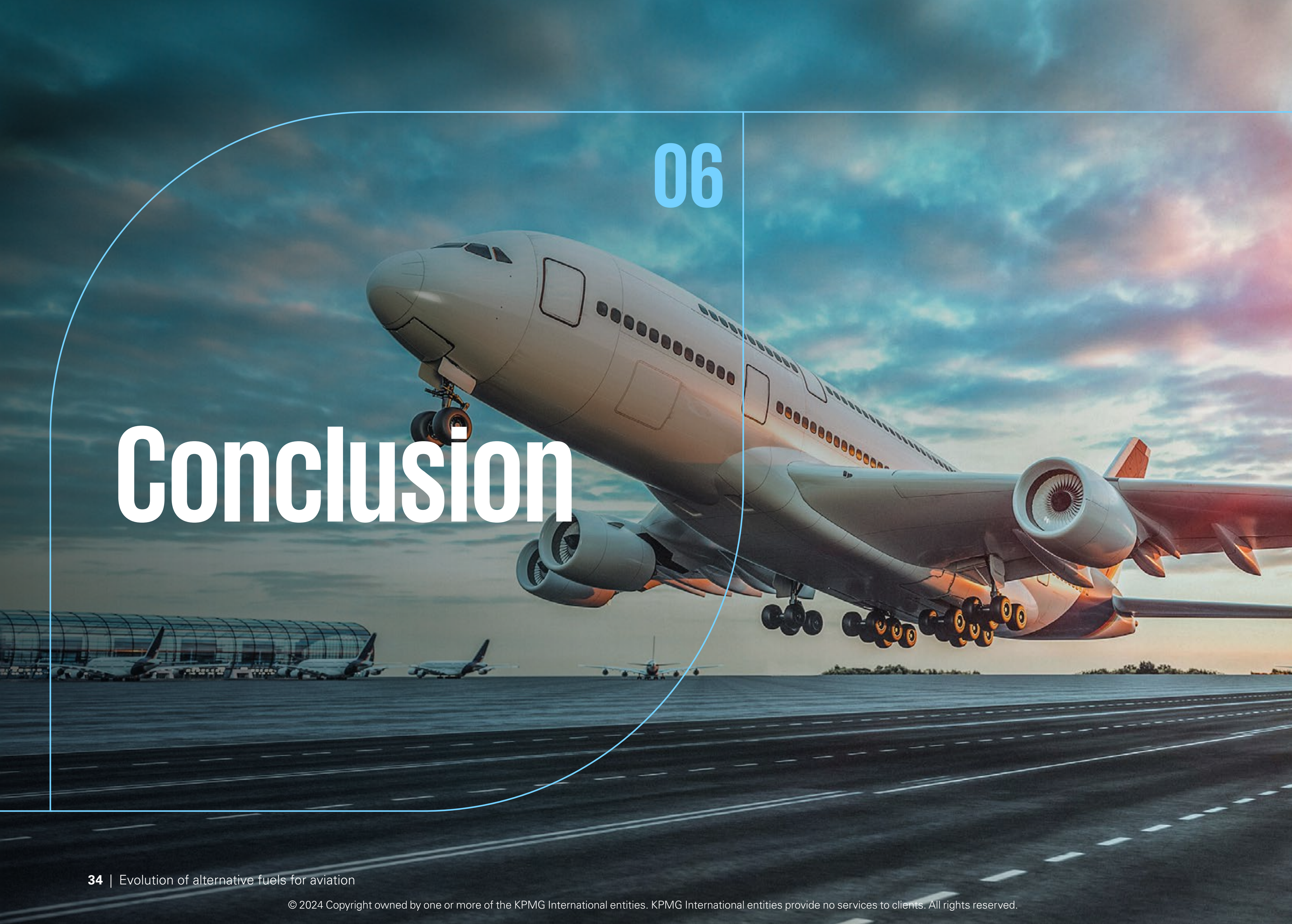
In addition to developing more book and claim systems, the aviation sector should also be developing new alliances with incentives to develop the SAF procurement and supply chain.

One example is the Sustainable Aviation Buyers Alliance (SABA)[64] which is accelerating the path to net-zero aviation. SABA is driving greater understanding of sustainability in the airline industry by bringing together the investment, technology and airline communities. It is encouraging more usage of SAF by asking its members to address emissions in their value chain as an aviation customer or air transport provider with investment in SAF certificates.

SABA's pilot procurement program in 2023 brought together major aviation customers to purchase nearly 850,000 gallons of high-integrity SAF. It has now been expanded to include multiple fuel providers and airlines, allowing customers to invest in a range of SAF fuels and support the entry of more new fuel technologies to market.

[63] IATA, "Unlocking geographical constrain on the global SAF market through a robust SAF accounting framework", September 2023.

[64] Sustainable Aviation Buyers Alliance (SABA) "Accelerating the transition to net zero aviation", Accessed June 2024.



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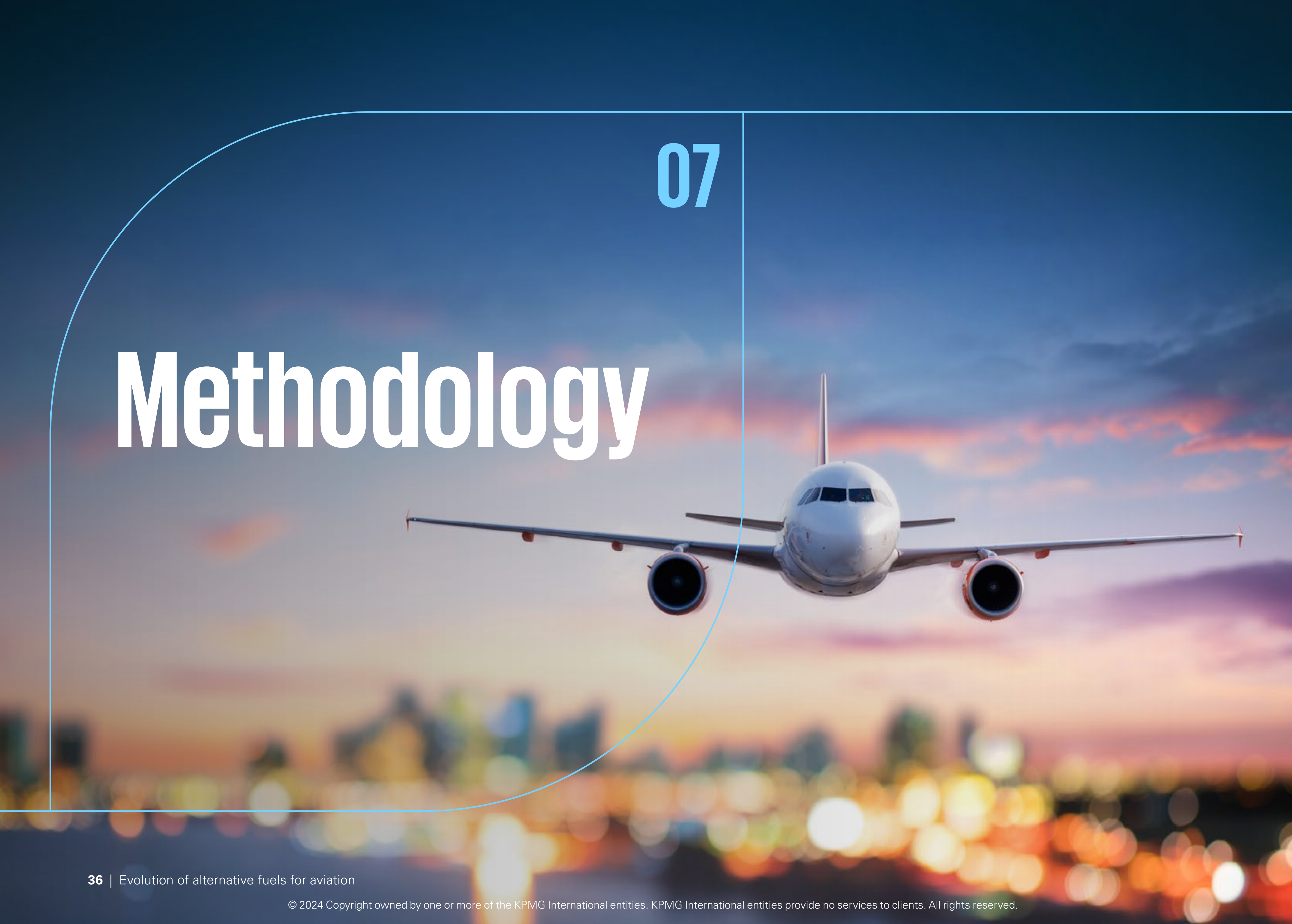
The next two decades could present a big opportunity for aviation to build a more sustainable future. By prioritizing and fast-tracking SAF adoption, the sector can reduce its environmental footprint, improve its operational efficiency, and position itself to take advantage of emerging value opportunities associated with the transition. ESG metrics improvements related to greater SAF use will also likely increase stakeholder trust and support.

Since aviation requires long investment horizons, given both R&D cycles and asset lifespan, the profitability of the next few decades is already being determined by decisions made today.

Meeting the challenge of achieving its net zero goal means the aviation industry has to overturn existing business models and develop new strategic roadmaps which include revamped procurement strategies and the development of new supply chains.

Educating and engaging with passengers is also important, as decarbonization may likely mean substantially higher airfares over the next few decades. Done well, these changes should enable the sector to have a much smoother energy transition and keep it flying high.



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Methodology

Two alternative fuels; bio-SAF and e-fuels (renewable pathways) have been benchmarked against mode-specific conventional fuels to assess the performance. The conventional fuel considered is Aviation Turbine Fuel (ATF) or jet fuel. The alternative fuels are benchmarked against the conventional fuels using the following readiness factors:

- Environmental performance: Lifecycle climate-related impacts of the fuel measured as a GHG emissions factor
- Cost effectiveness: Affordability compared to conventional fuels for specific modes and use cases
- Energy density: Productive energy content per volume of fuel
- Operational reliability: Reliability of propulsion technology utilizing the alternative fuel
- Market readiness: Commercial readiness of the fuel production technology pathways
- Technological maturity: Commercial readiness of the propulsion technology utilizing the fuel
- Infrastructure compatibility: Compatibility of conventional fuel infrastructure with alternative fuels and cost of developing new infrastructure for the fuels
- Regulatory readiness: Readiness of standards and regulations for the fuel at national, regional, multi-regional and international levels

To score these factors, a set of indicators is applied to each factor. The table below describes the indicators used for each of the readiness factors.

Readiness factor	Indicator
Environmental performance	Score based on reduction in well-to-wheel or well-to-wake (WTW) greenhouse gas (GHG) emissions per unit of productive output (net calorific value) versus conventional fuel
Cost effectiveness	Score based on reduction in production cost or price per energy unit versus conventional fuels
Energy density	Volumetric energy density of the fuel representing energy content per volume measured in MJ/L
Operational reliability	Qualitative score based on KPMG research and expert input
Market readiness	Qualitative score based on technology readiness level (TRL) from IEA Energy Technology Perspectives (ETP), KPMG research and expert input
Technological maturity	Qualitative score based on technology readiness level (TRL) from IEA Energy Technology Perspectives (ETP), KPMG research and expert input
Infrastructure compatibility	Qualitative score based on cost of developing infrastructure and adaptability of conventional fuel infrastructure for the alternative fuel being assessed
Regulatory readiness	Qualitative score based on maturity of regional, multi-regional and international standards and regulations for the fuel and the fuel infrastructure

The scoring for these indicators followed a mix of qualitative and quantitative approaches. Insights from the KPMG subject matter professionals are used to score the operational reliability, market readiness, technological maturity, infrastructure compatibility, and regulatory readiness of the alternative fuels. In-depth research (see sources below) using industry reports on alternative fuels by government bodies and energy institutes has been used to evaluate the environmental performance, cost effectiveness, and performance efficiency of alternative fuels. A scorecard is developed to represent the levels of maturity of these alternative fuels.

The scorecard follows a scale of 1-5 representing the following levels of maturity:

- Low: 1.0
- Low to Medium: 2.0
- Medium: 3.0
- Medium to High: 4.0
- High: 5.0

Conventional fuels have been scored 3.0 in the environmental performance, cost effectiveness, and performance efficiency indicators. This represents a medium level of maturity and a basis for the benchmark. For the other indicators, including operational reliability, market readiness, technological maturity, infrastructure compatibility and regulatory readiness, the conventional fuel is scored 5.0, given the high maturity levels in the market.

These scores are used to benchmark the alternative fuels against the conventional fuels. The scoring for these fuels is done across the three modes of transport — aviation, maritime, and road transit. After scoring each fuel at the sector level, the overall scores for these alternative fuels are calculated as an average of the factors for these fuels across applicable transport modes.

Alternative Fuels Readiness Index

Sustainable Aviation Fuel (SAF)	
Environmental Performance (5)	• SAF has the potential to significantly reduce carbon emissions compared to conventional jet fuel, with reductions in CO_2 emissions by up to 80 percent depending on feedstock and production processes. • Blended with conventional jet fuel, SAF can reduce particulate emissions by up to 65 percent and sulfur oxides by around 40 percent.[65] • The emissions footprint of SAF can be as low as 5.2 g CO_2e/MJ when municipal waste is used as feedstock.[66] • SAF can reduce the warming effects of contrails due to its cleaner burning features, potentially reducing overall contrail warming effects by 45 percent, as suggested by research from Virgin's Flight100, which used 100 percent SAF for a transatlantic flight in 2023.[67]
Cost Effectiveness (1)	• SAF is more expensive than conventional jet fuel, with an average price estimate around US$2,400/t in 2022, about two and a half times higher than conventional jet fuel.[68] • While SAF is more expensive than conventional jet fuel, its costs are expected to go down with technological advancements and scaled production. According to IATA, during 2022, the average SAF price estimate was around US$2,400/t, which is around two and a half times higher than the price of conventional jet fuel (US$1094/t) SAF is expected to become cost competitive with conventional fuel in late 2030s.[69]
Energy Density (3)	• SAF is almost chemically identical to traditional jet fuel, meaning it can be used in existing aircraft without modifications and is compatible with existing aircraft, engines, and infrastructure, offering similar performance and efficiency to conventional jet fuel.
Operational Reliability (5)	• SAF has been tested and proven to meet rigorous aviation fuel standards for performance and safety.
Market Readiness (4)	• SAF is designed to be a drop-in fuel, requiring little or no modifications to aircraft or fueling infrastructure. • Production of SAF is increasing, with many airlines and fuel companies investing in SAF projects.

[65] IATA, "Net zero 2050: sustainable aviation fuels", May 2024.
[66] International Council on Clean Transportation, "Assessing the sustainability implications of alternative aviation fuels", March 2021.
[67] Imperial College, "World's first transatlantic flight on 100 percent sustainable aviation fuel takes off", 28 November 2023.
[68] IATA, "Sustainable aviation output increases, but volumes still low", September 2023.
[69] IATA, "Sustainable aviation output increases, but volumes still low", September 2023.

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Technical Maturity (5)	• 9 biofuel production pathways are certified to produce SAF with the technology for producing SAF from various feedstocks is advancing, with ongoing research into more sustainable and efficient production methods.[70] • For advanced fuel conversion technologies, HEFA/HVO are the cheapest production pathways today.
Infrastructure Compatibility (4)	• As a drop-in fuel, SAF can use existing aviation fueling infrastructure without changes. • For 100 percent SAF use, new infrastructure would be needed to collect the feedstock, transport it to a bio-refinery, produce the fuel and then transport it to the airport.
Regulatory Readiness (3)	• SAF has a moderate to high regulatory readiness. Several biofuel production pathways have been approved for SAF, which can be directly blended into existing fuel infrastructure at airports. • Airlines may only use up to 50 percent SAF as fuel, and 100 percent SAF flights have not yet been approved for general commercial operation, apart from Virgin Atlantic's Flight100 test flight in 2023.[71]

[70] IATA, "Developing Sustainable Aviation Fuel (SAF)", Accessed June 2024.
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E-fuels	
Environmental Performance (5)	• E-fuels offer the aviation industry a pathway to decarbonize by using green hydrogen to produce e-fuels. • E-fuels can also reduce contrail formation and improve local air quality around airports due to lower particulate matter and sulfur emissions compared to jet fuel.
Cost Effectiveness (1)	• Some estimates see the levelized cost of energy e-fuel to be around 3-4 times the average price of jet fuel, even in 2030,[72] it is expected to become more cost competitive with traditional jet fuel as the market matures, technology improves, and renewable electricity becomes cheaper. • E-fuels costs will also be helped by the fact that jet fuel is likely to become more expensive, as fossil fuel taxes and regulations become stricter.
Energy Density (3)	• E-fuels offer the potential for highly efficient propulsion methods for aircraft, including powering modified gas-turbine engines or converting into electrical power via fuel cells. • While there are some energy losses in the conversion process from electricity to fuel which reduce overall efficiency, synfuels have similar energy density and efficiency as conventional fuels. Efficiency depends on the production method and product chemistry.
Operational Reliability (5)	• E-fuels can be produced with little to no modifications to existing engines, offering flexibility and compatibility with current infrastructure.
Market Readiness (3)	• E-fuels will require a more rapid expansion of power to liquids production to be readily available for aviation. This will involve both hydrogen electrolysis capacity and commensurate increases in direct air capture (DAC) to provide the volumes of CO_2 feedstock. However, the availability of carbon feedstock and advancements in production technology position e-fuel as a promising long-term option for SAF production. • If aviation relied on the production of e-fuels to decarbonize, it would require current global total electricity production (both renewable and non-renewable) to increase by up to 50 percent. While renewable energy availability might be limited in the short term (about 30 percent of global electricity is renewable) this is changing, and the IEA expects renewable energy sources account for over 42 percent of global electricity generation by 2028.[73]
Technical Maturity (5)	• E-fuels do not require any major modifications and can also be a drop in fuel.
Infrastructure Compatibility (3)	• E-fuels can leverage existing infrastructure, requiring minimal modifications for current engines and distribution systems.
Regulatory Readiness (3)	• Regulatory frameworks must evolve to accommodate the adoption of e-fuels in aviation, addressing concerns related to emissions, safety, and infrastructure compatibility.

[72] European Federation for Transport and Environment, "FAQ: the what and how of e-kerosene", November 2022.
[73] IEA, "Renewables 2023 — Electricity", 2023.

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How KPMG can help

Are you ready to soar to new heights in aviation? You should look no further than KPMG, among the industry leaders in providing tailored approaches for the aviation sector. Whether you're an airline, investor, aircraft manufacturer or airport operator, KPMG firms' experienced aviation sector specialists are ready to help you with your aviation transformation journey.

KPMG firms can offer consulting, deal advisory, tax and legal as well as risk management services across the aviation and other heavy transportation sectors in addition to the low carbon fuels supply chain.

KPMG professionals can help you align your decarbonization goals with your enterprise strategy, offering transformation support that is designed to enhance both the performance and value of your organization. Using propriety risk management software and analysis tools, we can also help you to navigate the multitude of regulations, technology pathways and portfolio growth strategies to enable your business to innovate and thrive.

KPMG professionals focus on positioning sustainable supply chains and procurement at the core of your operational strategies, enabling you to maintain your stakeholders trust as you work to meet your net zero goal.

KPMG firms offer a detailed suite of services tailored to support the transportation, infrastructure and energy sectors in achieving their decarbonization goals. Our approach leverages deep industry knowledge and innovative technological solutions tailored to the unique challenges of the energy transition.

Decarbonization pathways:

Strategic foresight and operational value in the decarbonization journey, from emissions measurement to implementation.

Energy transition advisory:

Development of strategies to replace traditional power sources with renewable energy, including regulatory strategy and hydrogen project advisory.

Low-carbon fuels consulting:

Broad support with tested tools and methodologies for navigating regulatory changes and capturing opportunities in the low-carbon fuels sector.

Sustainable supply chain and procurement:

Positioning sustainable supply chain and procurement at the core of operational strategy to help reduce environmental footprints.

Tax and legal services:

Navigating complex tax incentives, grants, and environmental taxes. Assessing carbon trading implications and managing compliance risks to enhance funding and cost management.

Workforce transition and strategy transformation:

Aligning decarbonization goals with enterprise strategy and providing broader transformation support.

Deal advisory:

Offering deal valuation, M&A support, and post-merger integration to help manage investments and achieve strategic objectives in the context of the energy transition.

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