MARKETING COMMUNICATION

INVESTMENT BANKING

IRELAND'S OPPORTUNITY: THE ENGINE MRO "SUPER CYCLE"

Goodbody

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Airlines

25 Sep 2025

Ireland's opportunity: The engine MRO "super cycle"

Questions remain about SAF's scalability & technological developments…

The commercial aviation industry has committed to achieving net-zero carbon emissions by 2050, thus aligning itself with the Paris Agreement's climate goals. This ambitious target is expected to be met through a combination of sustainable aviation fuel (SAF), next-generation engine technologies, operational efficiencies, and market-based measures such as carbon offsets and carbon capture. SAF is expected to do most of the heavy lifting, with IATA originally expecting SAF to contribute up to 65% of the carbon emissions reduction. However, SAF scalability remains a major challenge. While new technologies like hydrogen powered aircraft, electric aircraft and blended wing body aircraft may offer long-term promise, their commercial viability is still decades away. In the short to medium term, the emerging supply of SAF, operational improvements, improvements in engine efficiency and carbon offsets will be critical to reducing carbon emissions.

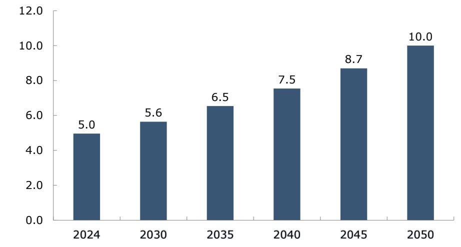
…suggesting the net-zero by 2050 target is too big a stretch

Despite the strong commitments and some progress to date, in the last few months several stakeholders in the commercial aviation sector have expressed growing doubts about the sector's ability to achieve the net-zero by 2050 target. Based on our analysis we believe that the commercial aviation sector is unlikely to meet its net-zero target by 2050 without a major breakthrough in carbon capture technology or a very significant increase in carbon offsets which raises questions about the sector's decarbonisation strategy. Goodbody's emissions model forecasts that, even with aggressive SAF adoption, next generation engine efficiency and gains from operational improvements, emissions (pre-carbon capture and carbon offsets) will decline to 67% of 2024 levels by 2050. To close the remaining gap market-based measures would need to deliver reductions on par with those of SAF. This is an outcome considered unlikely under the current trajectories. However, in the context of a global fleet that will have more than doubled by 2050 the emissions reduction is still very substantial. On that basis our analysis raises a key question: does narrowly missing net-zero in 2050 matter if the overall climate impact is transformative?

However, there is a significant opportunity for Ireland Inc.

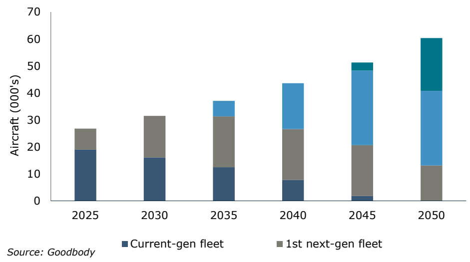
With the global commercial fleet expected to double by 2050, the engine maintenance, repair, and overhaul (MRO) market is entering a structural "super cycle." Ireland, already a global leader in aircraft leasing, is well-positioned to expand into high-value engine MRO. By leveraging its existing aviation ecosystem, investing in infrastructure and skills, investing in education and attracting OEM partnerships, Ireland could establish itself as the EU's engine MRO hub. Capturing even a small share of this growing market could generate billions in revenue and thousands of high-skilled jobs, anchoring a new pillar of the Irish aviation economy.

IATA expects passenger numbers to double by 2050…



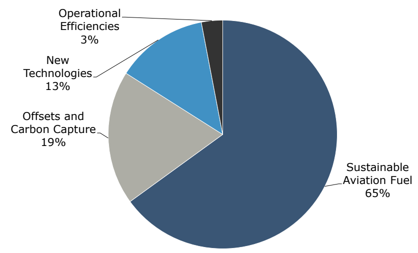
Source: IATA, Goodbody

…while the global fleet increases to c.60k aircraft…



Source: Goodbody

…with SAF expected to offset the bulk of carbon emissions



Source: IATA, Goodbody

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Table of Contents

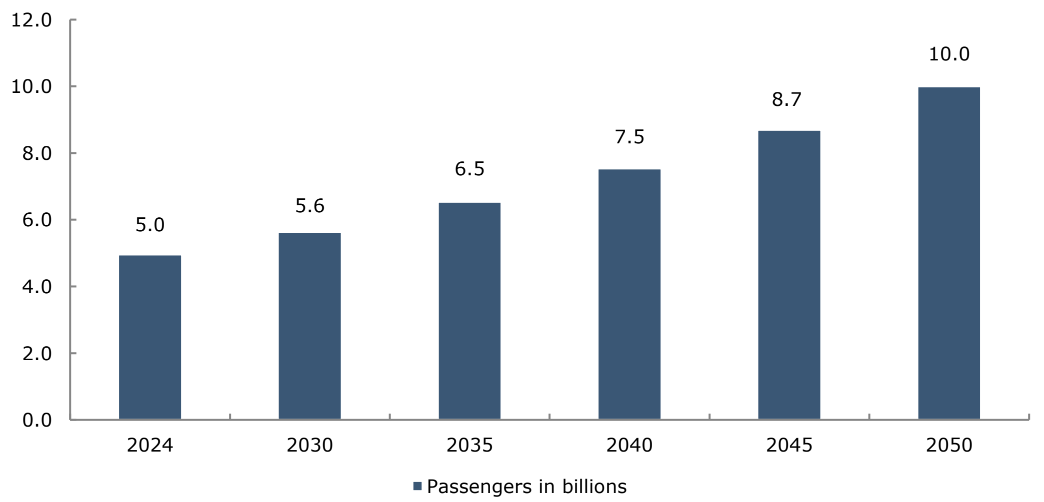
Commercial Aviation – A challenging journey to net-zero by 2050

It is generally accepted that the commercial aviation industry accounts for c.2.5% of global carbon emissions although the overall contribution to global warming is said to be closer to c.4% due to the impact of contrails, water vapor and other non-carbon emissions. While c.2.5% of global carbon emissions may not sound like a very significant share this needs to be considered in the context of the current propensity to fly, how that will change as incomes rise over the medium term and how other industries are responding to the need to cut emissions. Indeed, while commercial aviation has become significantly more energy efficient since 1990 the sector's carbon emissions have doubled. Carbon emissions from the commercial aviation sector are estimated to have increased from 0.5bn tonnes in 1990 to c.1bn tonnes in 2024, while ASKs have increased by roughly threefold to c.10bn ASKs in 2024.

At the IATA AGM in 2021, its members committed to achieving net-zero carbon emissions for their operations by 2050 (IATA represents c.300 members which account for c.80% of global air traffic). This was followed by the Air Transport Action Group (ATAG) adopting a long-term climate goal of net-zero carbon emissions by 2050. The net-zero by 2050 target aligned the aviation industry with the climate goals of the Paris Agreement which was signed at the end of 2015 with the aim of limiting global warming by pursuing efforts to limit the temperature increase to 1.5C above pre-industrial levels.

It was well known at the time that carbon mitigation in the commercial aviation sector would be an enormous technical challenge requiring very significant investment from all of the stakeholders. Indeed, IATA has estimated that passenger numbers could increase from the current c.5bn passengers to c.10bn passengers annually by 2050 and the expected carbon emissions on a "business as usual" trajectory over the period from 2021 to 2050 was c.21.2 gigatons.

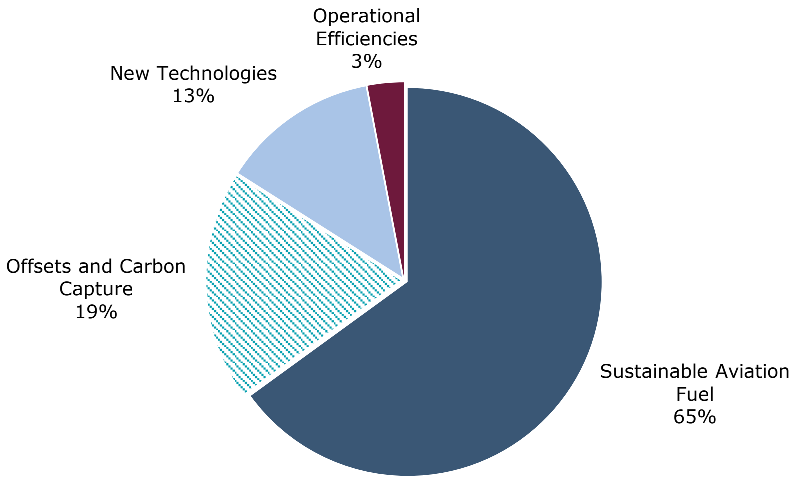
IATA is forecasting a doubling of passenger numbers by 2050



Source: Statista, IATA, Goodbody

The net-zero objective was to be met through a combination of eliminating emissions at source and the use of offsetting and carbon capture technologies. At the time of the net-zero by 2050 commitment IATA expected the key elements of this commitment to be sustainable aviation fuel, offsets and carbon capture, new technologies and operational efficiencies.

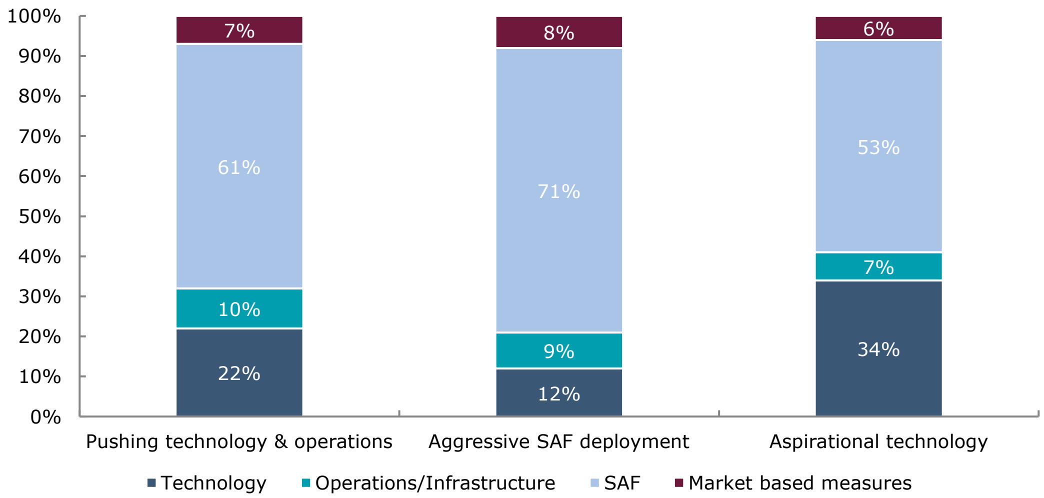
IATA expects SAF to do most of the heavy lifting...



Source: IATA, Goodbody

In its Waypoint 2050 report in September 2021, ATAG outlined several different scenarios including a continuation of current trends, pushing technologies and operations, aggressive SAF deployment and aspirational and aggressive technology deployment. In each of the scenarios SAF plays a pivotal role in carbon emissions reduction although technology also has an important part to play especially in the aspirational and aggressive technology deployment scenario.

...as does ATAG although it also sees a bigger role for technology



Source: ATAG Waypoint 2050, Goodbody

The clear message from both IATA and ATAG is that the approach to decarbonising the commercial aviation sector will have to be multi-faceted, and it requires significant action and investment now. On that very point, we note that in July 2024 Air New Zealand removed its Science Based Targets initiative (SBTi) approved 2030 emissions target and withdrew from the SBTi. With the carrier stating that**:**

"Many of the levers needed to meet this target are not progressing at the pace required and are outside our control. These include the availability of new aircraft, the affordability and availability of sustainable aviation fuel (SAF), and global and domestic regulatory and policy support."

Air New Zealand has since introduced revised and less ambitious 2030 emissions targets with a target for 10% SAF in 2030 and a net "well-to-wake" GHG emissions reduction of 20–25% versus 2019 by 2030.

Commenting on climate change targets in May 2025, Airlines for Europe (A4E) stated:

"Our members remained committed to the sector reaching Net Zero by 2050, with 'abundant and affordable' SAF critical in order to reach the goal. However, we are deeply concerned that the ReFuelEU legislation is failing to create the affordable SAF market it promised. The European Commission and member states must now take responsibility as fuel suppliers are not delivering."

A4E added that without urgent action credibility will be severely undermined and a reassessment of the SAF mandates will be needed. While Airlines for America (A4A) commented that:

"many regulations are unnecessary and costly, negatively impacting the industry's ability to create jobs and facilitate economic growth…The government needs to adopt regulations that are based on science and facts, can be justified on a cost-benefit basis and eliminate inefficient rules…A4A works to shape and advance productive and practical federal, state, local and international environmental measures, including policies to address climate change, noise impact and more."

Conclusion

In the short-term increased deployment of the latest, most efficient aircraft engines, carbon offsets (including regulatory frameworks such as CORSIA and ETS) and SAF are the most viable tools for emissions reduction in the aviation sector. Over the medium-term, the next generation of engines technology, operational efficiencies, carbon capture and advanced SAF will further reduce emissions before the industry looks to transition to zero-emissions aircraft in the longer-term. However, while SAF will most likely be the biggest contributor to reducing carbon emissions, there are still significant question marks over the scalability of SAF production. At the same time while we have seen some benefits from increased operational efficiencies, progress has been very slow, the use of carbon offsets remains a somewhat questionable practice and carbon capture technology has yet to be fully developed. As a result, we believe that the importance of next generation and new technologies on the journey to net-zero by 2050 cannot be downplayed. However, Airbus has recently "delayed" its planned introduction of a hydrogen powered aircraft by between 5–10 years and Boeing has "paused" full scale construction of its X-66A Thin Wing aircraft. Furthermore, the latest developments in the field of electric powered aircraft suggests that it is likely to continue to struggle to go beyond regional aircraft in the near term while concepts such as the blended wing body are still just concepts. This highlights the increasing importance of the development of the next generation of jet engines in the journey to net-zero by 2050. However, with the engine OEMs targeting c.+20% improvement engine efficiency over the medium term the net-zero by 2050 target looks to be out of reach of the aviation industry. In conclusion, while there is no doubt that there is a willingness amongst the various stakeholders to strive towards net-zero by 2050, based on the slow pace of progress to date and the technological barriers that the industry needs to overcome we believe that the commercial aviation sector, like other sectors, will fall somewhat short of its net-zero by 2050 target.

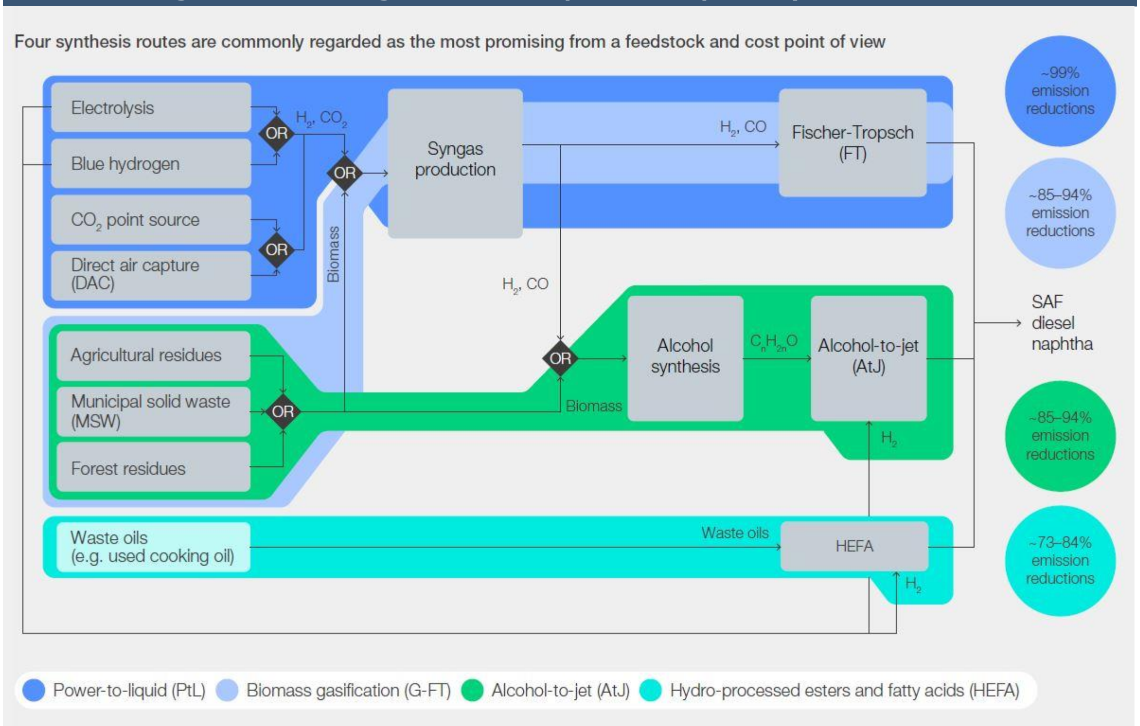
Sustainable Aviation Fuel – The key question remains scalability

In almost all of the net-zero scenarios that have been identified by the commercial aviation industry, SAF is the largest contributor to reducing carbon emissions. Unlike battery powered or hydrogen powered propulsion, SAF can be used as a drop-in replacement for conventional jet fuel in existing aircraft and infrastructure without significant modification. However, SAF is not a single product, it is a diverse category of fuels produced through various technologies and feedstocks, each with distinct advantages and limitations. Depending on the production pathway, lifecycle CO2 emissions can be reduced by up to 99% when compared to conventional jet fuel, although typical reductions range from 60% to 85%. One of the main differences between SAF and conventional jet fuel is the absence of aromatic compounds, which can affect sealing and aircraft engine lubrication. At present, this can be solved by blending SAF with conventional jet fuel to achieve a composition that meets the required specifications. In 2023, the American Society for Testing and Materials (ASTM) approved several production pathways for SAF, each with defined maximum blend ratios. Currently, the highest approved SAF blend for commercial use is 50%, ensuring safe operation with existing aircraft and engine systems. Over the medium-term, after extensive testing and validation, engines will be modified to allow for 100% SAF, and we note that several 100% SAF test flights have already been conducted.

SAF can be classified in multiple ways including the production pathway, feedstock origin, conversion technology and commercial readiness. We have chosen to categorize SAF according to its production pathway. Each method presents its own advantages and challenges in terms of scalability, sustainability and potential emission reductions. The three main types of SAF we identified are

- **Hydroprocessed Esters and Fatty Acids (HEFA)**
- **Advanced Biofuels**
- **Power-to-Liquid (PtL) and eFuels**

SAF can be organized according to its various production pathways



Source: Kearney and Airports of Tomorrow, Goodbody

Hydroprocessed Esters and Fatty Acids (HEFA): HEFA fuels are currently the most commercially established form of SAF. They are produced from waste oils and fats, such as used cooking oil or animal fats, and processed through hydrotreatment to produce clean jet compatible fuel.

- The advantages of HEFA include its technological maturity and reliability. HEFA is already certified for use in commercial aviation and can be blended up to 50% with conventional jet fuel without requiring any changes to aircraft engines or airport infrastructure. Depending on the feedstock, lifecycle emission reductions can reach up to c.80%, making it a strong candidate for near term decarbonisation.

- HEFA's limitation mainly lies in feedstock availability. Waste oils are finite and unevenly distributed across geographies, which restricts scalability. There are also concerns about the potential impact on land use when virgin oils are employed at this could compromise the overall sustainability profile.

Advanced Biofuels: Advanced biofuel is SAF produced from non-food biomass and waste-based feedstock, using more complex conversion technologies. Two prominent SAF pathways based on advanced biofuels are Fischer-Tropsch Synthetic Paraffinic Kerosene and Alcohol-to-Jet.

Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK): FT-SPK is a synthetic fuel produced via Fischer-Tropsch synthesis, which converts syngas (a mix of hydrogen and carbon monoxide) into liquid hydrocarbons. Syngas is typically generated by gasifying solid feedstocks, such as biomass or municipal waste. Biomass-to-Liquid (BtL) is one of the most prominent production pathways to produce FT-SPK, using agricultural residues, forestry waste, or other organic materials as the feedstock.

- SAF produced through FT-SPK offers emissions reductions of up to 95%. This also provides a valuable solution to waste management, turning discarded materials into high value energy.

- The challenges relate to the low energy density of biomass requiring large volumes to produce meaningful quantities of fuel. The logistics of waste collection, sorting, and processing are complex and costly. The infrastructure required for gasification is capital intensive and not yet widespread and finally, without access to a significant supply of green electricity the emissions savings are quite a bit lower.

Alcohol-to-Jet (AtJ): AtJ SAF is produced by fermenting sugars such as corn, sugarcane and cellulosic biomass, into alcohols (typically ethanol or butanol) which are then converted into jet fuel.

- This pathway offers flexibility in feedstock sourcing and emissions reduction typically between 60% to 80%. It also leverages already existing agricultural supply chains and fermentation technologies.

- The biggest criticism of AtJ relates to its potential competition with food production. Using crops for fuel raises ethical and economic questions, especially in regions facing food insecurity. Additionally, the cultivation of feedstocks can be resource intensive, requiring significant water and land raising concerns about the overall sustainability of the process.

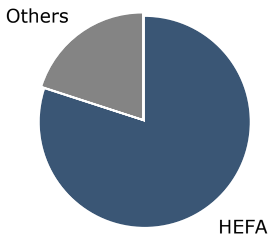
Power-to-Liquid (PtL) and eFuels: PtL and eFuels are synthesised from renewable electricity, water electrolysis (to generate hydrogen) and captured carbon dioxide. The result is a synthetic fuel that can be nearly carbon neutral when powered entirely by clean energy sources.

- The strength of this technology lies in its deep decarbonisation potential. If powered entirely by renewable energy, these fuels can reduce emissions by up to 99%. They offer a circular solution by recycling CO_2 emissions back into usable fuel.

- PtL is still in its infancy. The process is extremely energy intensive and relies on significant amounts of green electricity, which is not yet available at scale. Production costs remain very high and commercial deployment is still limited.

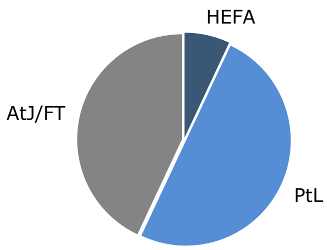
In 2024, the majority of SAF was produced via the HEFA pathway. IATA estimates the HEFA method to account for c. 80% of SAF production in 2024. This underscores the dominance of this production pathway in the current market. Looking ahead, EASA projections point to PtL fuels accounting for up to 50% of projected global SAF production capacity by 2050 while HEFA is expected to decline to c.7%, with AtJ and FT technologies making up the remaining 43%.

IATA estimates that c.80% of SAF production in 2024 was via HEFA pathway…



Source: IATA, Goodbody

…while EASA expects HEFA's share to fall to 7% by 2050



Source: EASA, Goodbody

The government role in SAF adoption

Decarbonisation strategies differ across regions, with governments using varying strategies from regulation, incentives, and industrial policy to scale SAF and support net-zero goals. The EU and the UK are combining regulatory mandates with financial support while the pre-Trump US was following an incentive-based strategy to achieve production targets. Regardless of the different strategies, these geographies share the common goal of decarbonising aviation.

European Union

The EU's SAF strategy for the aviation sector is based on the "ReFuelEU Aviation Regulation". Its primary objective is to increase the adoption of SAF throughout EU airports thereby reducing the sector's carbon footprint in line with EU climate targets. This regulation establishes legal requirements for the gradual ramp up of SAF usage in aviation fuel for all flights departing from EU airports regardless of destination. From 2025, aviation fuel must contain a minimum of 2% SAF. This will increase progressively every 5 years reaching 6% in 2030, 20% in 2035 and 70% by 2050. There is also a target for synthetic fuels (efuels) which starts at 1.2% in 2030, reaching 35% by the middle of the century.

To support the transition to net zero and the adoption of SAF, the EU has introduced several additional regulations. The phasing out of the EU Emissions Trading System (EU ETS) aims to reduce the free carbon allowances for airlines and to encourage SAF uptake. The Net Zero Industry Act (NZIA) includes SAF as a strategic technology, aiming to boost domestic production, investment and supply chain resilience. Additional measures include a "book and claim" system, which allows airlines to purchase SAF certificates even if they cannot physically acquire SAF at a particular airport, helping to create a more flexible SAF market. At the same time the prohibition of "tankering", introduced as part of the ReFuelEU, aimed at preventing airlines from carrying extra fuel to avoid refuelling at a destination airport which might have costlier SAF blends. The measures introduced by the EU include:

- **20m ETS allowances worth c.€2bn to offset SAF costs -** The EU ETS has been amended to help airlines offset the higher cost of SAF. According to the International Council on Clean Transportation (ICCT), 20m ETS allowances are being set aside between 2024 and 2030 for airlines to offset the additional costs of SAF. The ICCT estimates this funding at c.€2.0bn, covering somewhere between 50% to 100% of the price gap between SAF and jet fuel, depending on the SAF type.

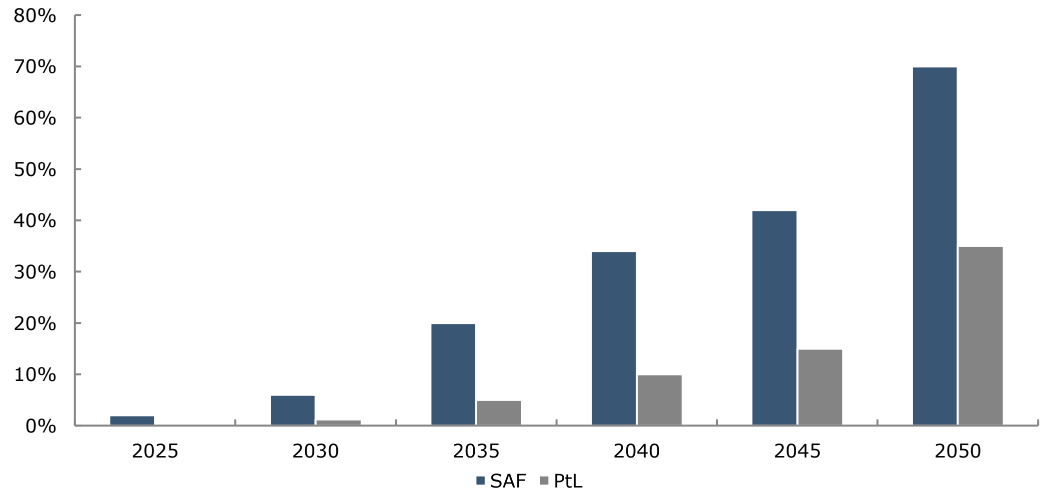
- **Green finance access via inclusion in the EU Taxonomy -** The EU Taxonomy Regulation provides a common framework for classifying sustainable economic activities, including the production and use of SAF. This inclusion helps SAF projects and companies demonstrate their environmental sustainability, which is a requirement for attracting green finance.

- **Innovation funding through "Horizon Europe" and the "Innovation Fund" -** Both Horizon Europe and the Innovation Fund are sources of public funding in the EU aiming to accelerate innovation in clean and low carbon solutions, including SAF. The Innovation Fund is backed by ETS revenues and is offering c.€40bn (between 2020 and 2030) to support the development of low carbon technologies. Horizon Europe is a research and innovation fund, including aviation related projects, with a €93.5bn budget running until 2027.

- **Technical support via the EU SAF Clearing House -** The EU SAF Clearing House is a technical support platform for SAF. It helps companies in regulatory, certification and technical matters regarding SAF, promoting knowledge sharing and facilitating the development of new technologies.

- **Favourable tax treatment under the revised Energy Taxation Directive (ETD) -** The revised ETD proposes favourable tax treatment for SAF. If adopted, the ETD would create a tax differential. Conventional jet fuel would have a minimum tax rate of approximately €0.38 per litre during a 10-year phase in period while SAF would be exempt from taxation during this period and benefit from lower minimum rates. This change aims to make SAF more attractive relative to conventional jet fuel. However, these tax reforms are still under discussion and have not yet come into force.

European Union SAF and PtL mandates



Source: Goodbody

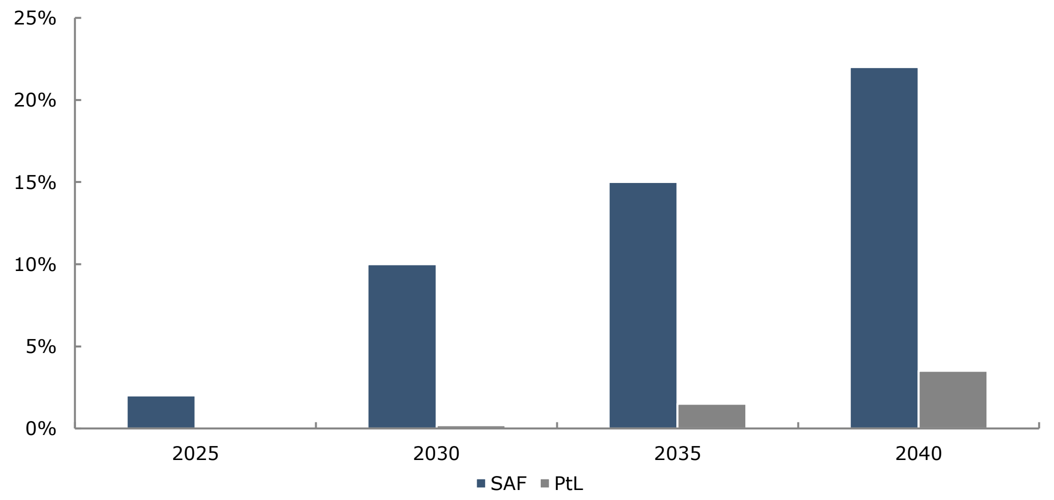
United Kingdom

The UK SAF Mandate is broadly similar to the EU mandate, requiring fuel suppliers to blend SAF starting at 2% in 2025 before increasing to 10% by 2030 and 22% by 2040. It also includes a target for PtL fuels although it is less ambitious than the EU as it is only aiming for 3.5% by 2040. To incentivise supply, the UK employs:

- **Tradeable certificates -** As suppliers blend SAF with jet fuel they are awarded certificates. These can be sold or used in the next year's quota (up to 25%). This aims at creating a market for SAF certificates incentivising its adoption.
- **Buy-out prices for non-compliance -** If a supplier does not meet the SAF blending requirements and does not own the certificates it will be required to pay a penalty per litre (£4.70/L for SAF and £5.00/L for PtL).
- **HEFA cap to promote higher integrity alternatives -** Due to the reliance of HEFA on biomass, due to limited feedstock availability, the UK has introduced a separate obligation to incentivise the development of more advanced fuel alternatives. HEFA can meet 100% of SAF obligations in 2025 and 2026, decreasing to 71% in 2030 and 35% in 2040.
- **Revenue Certainty Mechanism -** Although not implemented yet, the UK intends to guarantee strike prices for SAF to de-risk investment in SAF production.

Beyond this, the UK government has also created an Advanced Fuel Fund (AFF) and a SAF Clearing House as part of its "Jet Zero Strategy". The AFF fund provides grants to help develop and scale SAF production projects in the UK. It had allocated £135m up to March 2025, in supporting advanced fuel projects and aims to award a further £63m more by March 2026. The SAF Clearing House focuses on providing support, testing and qualification of new fuels.

United Kingdom SAF and PtL mandates



Source: Goodbody

United States

The US approach towards SAF is defined by the "SAF Grand Challenge", a government initiative launched in 2021 led by the Department of Energy (DOE), Department of Agriculture (USDA), the Department of Transportation (DOT) and the Federal Aviation Administration (FAA). SAF is seen as the most viable short-term solution for decarbonising aviation, which accounts for c.3% of total US greenhouse gas emissions. The Grand Challenge sets targets to produce 3bn gallons of SAF annually by 2030 and to meet 100% of domestic aviation fuel demand by 2050 through expanded SAF supply and end use, cost reduction, and enhanced sustainability. The US incentives to increase SAF production and adoption include:

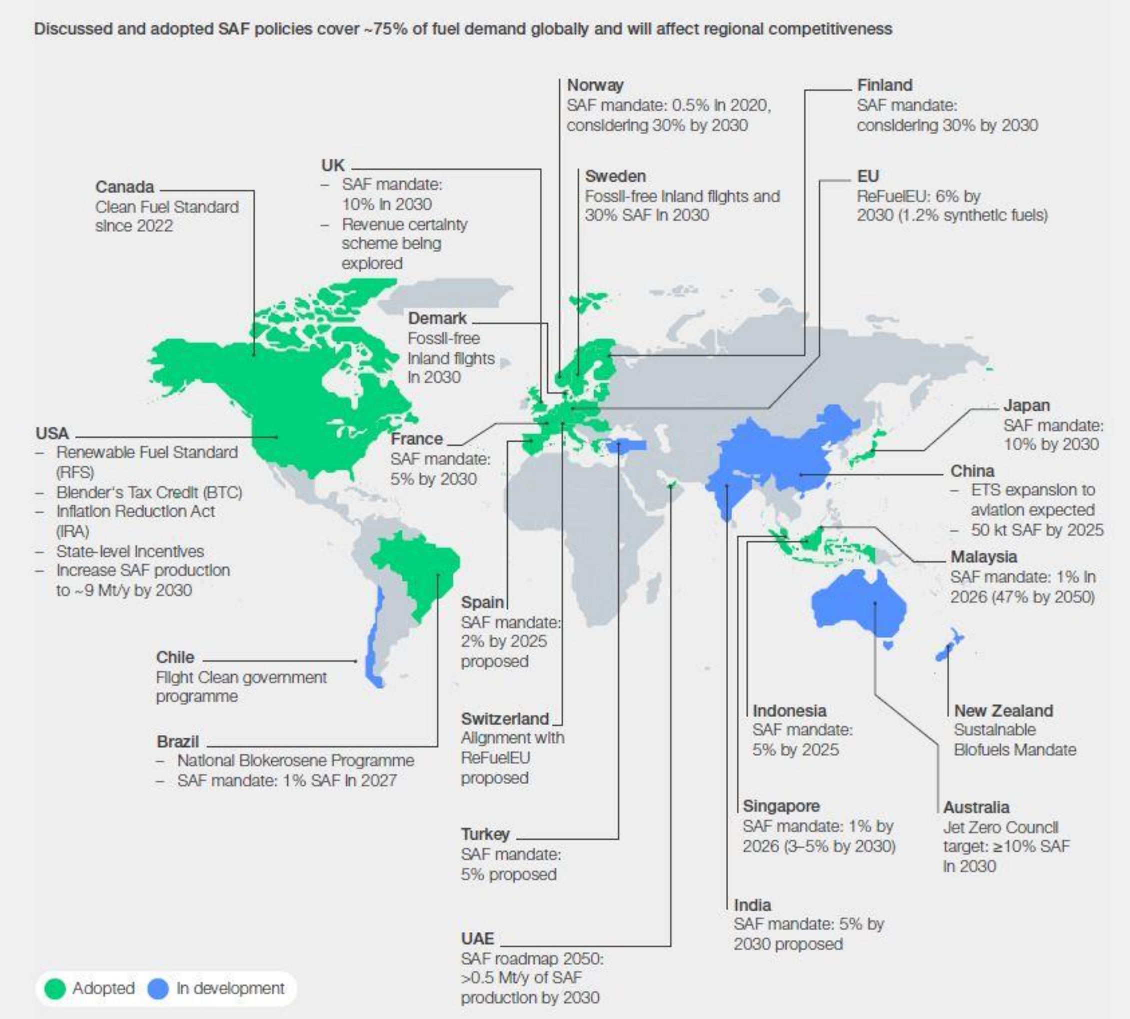
- **Tax credits under the Inflation Reduction Act (IRA) -** Tax credits currently range from $1 per gallon up to $1.75 per gallon according to the amount of greenhouse gas reduction. However, the "One Big Beautiful Bill" Act replaces this with a flat $1 per gallon rate starting in 2026 and it will limit feedstock eligibility to materials sourced from the US, Canada and Mexico, excluding most feedstock imports.

- **The FAA's FAST program -** The FAST program had awarded $244.5m grants to 22 SAF related projects by August 2024 and $46.5m to 14 projects relating to low emission aviation technologies. Moreover, the DOE has awarded $151m to 28 SAF related projects between 2021 and 2024. This funding was matched by c.$156m in private sector investment.

- **State level incentives -** The US also provides various state level incentives. For example, Illinois offers $1.50 per gallon SAF credits through 2032 while Washington provides up to $2.00 per gallon based on emissions reductions.

While the EU and UK have focused on regulatory mandates, blending obligations, and structured financial support, the US approach has prioritised scale and investment, relying heavily on tax credits and federal funding. In effect the European approach is the "stick" approach while the US approach is the "carrot" approach. However, the US is now tightening its framework. The "One Big Beautiful Bill" Act marks a shift by standardising tax credits and restricting feedstock sources. Combined with ongoing reviews of state level incentives, this introduces more uncertainty into the US policy landscape. Still, despite differing strategies, the various regions across the globe share a common goal: accelerating the decarbonisation of aviation.

SAF mandates across regions



Source: Goodbody, ICAO, ACI, IEA, Eurocontrol, Biomass magazine, S&P Global

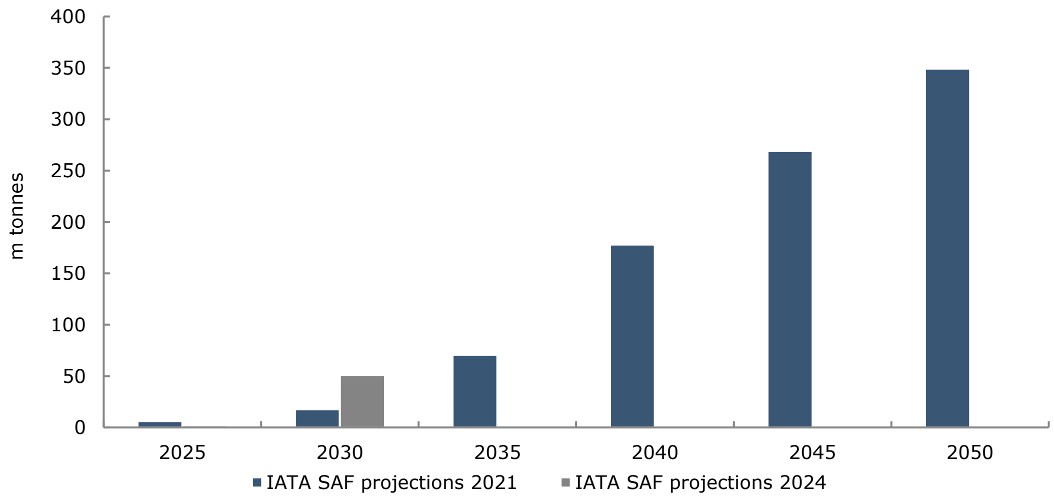
SAF markets

As governments, industry bodies, and airlines have committed to the net-zero by 2050 target, SAF has taken centre stage with significant expectations from stakeholders regarding the scaling of production and bridging of the green fuel gap. However, despite the announcements of high-profile projects, the actual progress in SAF deployment, cost competitiveness, and the geographical spread has remained constrained by a range of challenges. The future development of the SAF industry remains uncertain, with a wide range of technologies, feedstocks, and production pathways under development and numerous projects underway making forecasts of capacity highly variable and dependent on successful scale up. As a result the levels on investment into SAF projects has been somewhat disappointing to date.

According to IATA, global SAF production was c.1m tonnes (1.3bn litres) in 2024. This represented a doubling on the previous year's output, but it still fell short of the 1.5m tonnes expected as delays in scaling up key production facilities in the US pushed production into 2025. While SAF represented 11% of global renewable fuel, the amount of SAF produced in 2024 accounted for just 0.3% of total jet fuel used worldwide, highlighting the slow pace of progress in decarbonising aviation.

Looking to the future, one of the biggest issues is that there is significant variation in forecasts for SAF production over the medium-term. In 2021, IATA projected that SAF production would reach 6.1m tonnes (7.9bn litres) by 2025. However, in 2024, this forecast was revised down to 2.1m tonnes (2.7bn litres) due to delays in facility developments and policy uncertainty. This would account for 0.7% of total aviation fuel production and 13% of global renewable fuel capacity. Despite the slowdown in short term expectations, IATA increased its medium-term outlook. Based on 140 announced renewable fuel projects, SAF production is expected to reach 51m tonnes in 2030, a considerable increase from earlier projections of c.23m tonnes.

IATA forecast point to a steepening in the production curve in the medium to short term



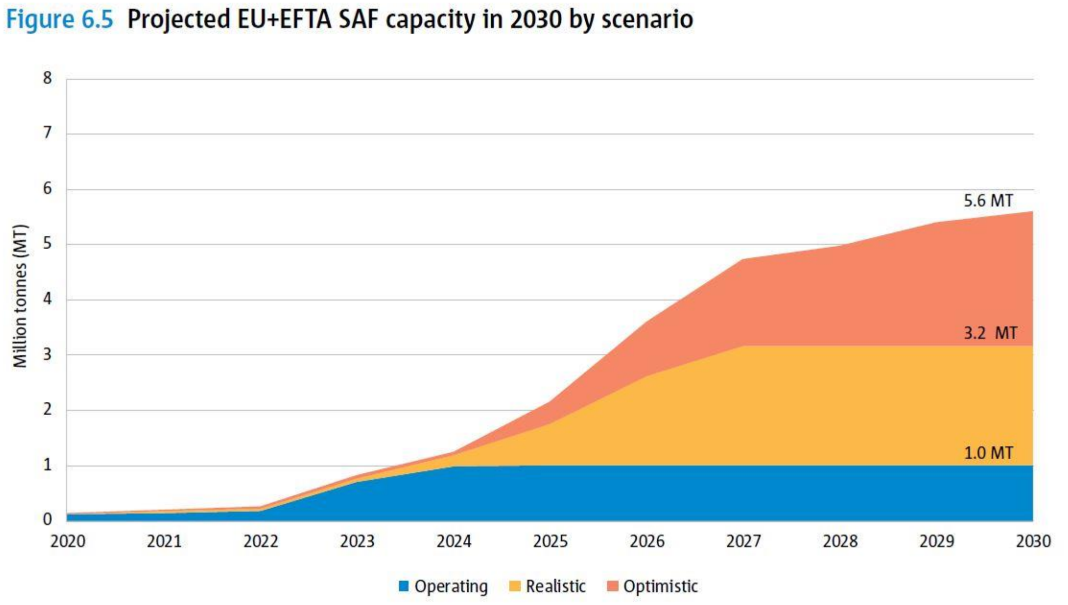
Source: IATA, Goodbody

Other institutions have more conservative estimates. The Centre of Competence for Climate, Environment and Noise Protection in Aviation forecasts global SAF production at 35m tonnes by 2030, with European production expected to reach approximately 8m tonnes per year. Separately, EASA has estimated that, based on facilities currently under construction being completed as planned, SAF production capacity in Europe could reach 3.2m tonnes by 2030 This estimate excludes PtL, as no commercial scale PtL plants have yet been planned.

In June 2024 SkyNRG projected that European SAF production could reach 3.8m tonnes by 2030, including 0.3m tonnes of PtL, while the International Energy Agency (IEA) forecasts a similar level by 2038. Both SkyNRG and the IEA have acknowledged the need for a significant acceleration in PtL plant development to meet the first sub-mandate of 0.7% PtL by 2030. Elsewhere, the ReFuelEU Aviation Member State Network and SkyNRG have developed an "optimistic scenario" assuming all planned projects, including PtL facilities, are operational by 2030. Under this scenario, European SAF production capacity could reach 5.6m tonnes—a substantial step toward scaling SAF, although still an optimistic projection.

The range and evolution of SAF projections highlight the disparity between near term challenges, in execution and scalability in SAF development, and the growing momentum of investment and policy support expected over the coming decade.

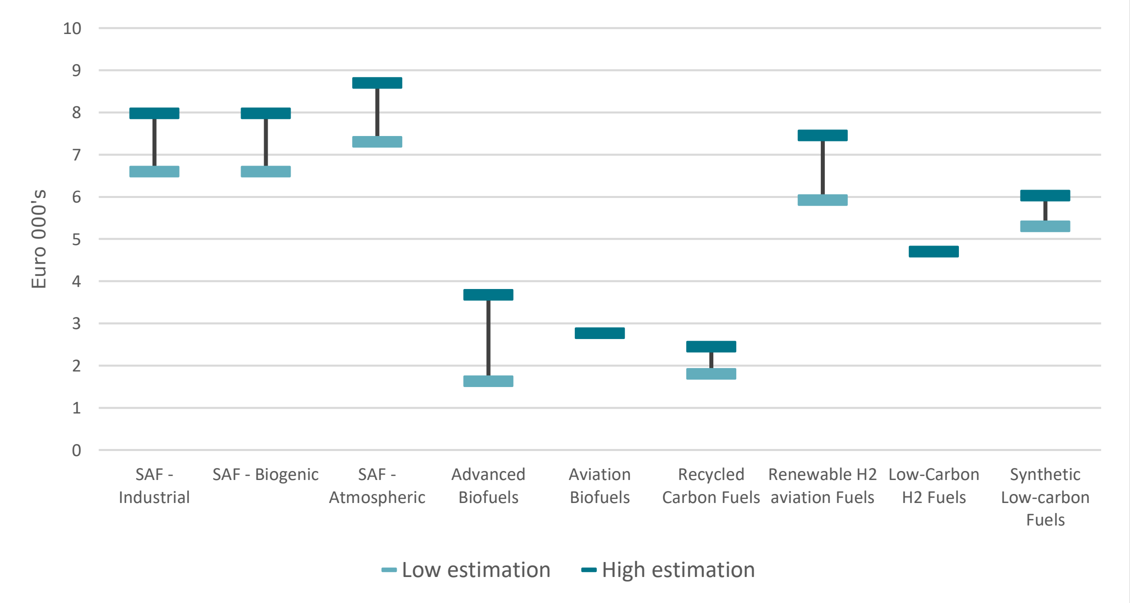
EASA projections for EU + EFTA SAF capacity in 2030



Source: EASA, Goodbody

Finally, until SAF production scales significantly the biggest barrier to SAF adoption will be price. In 2023, conventional jet fuel averaged €816 per tonne, while bio SAF cost more than three times at €2,768. Other SAF types, such as advanced biofuels and PtL, are still emerging and not widely available. Their prices reflect high feedstock, technology, and energy costs, ranging from €1,600 to €8,700 per tonne. EASA expects these costs to decline as production technologies mature and energy markets evolve, particularly for PtL. According to a Cena Hessen report published earlier this year bio SAF cost €2,085 per tonne (down from the €2,768 reported by EASA in 2023) while eSAF is now at €7,685 per tonne. However, as KPMG has commented “While it remains cheaper for airlines to offset carbon emissions through trading schemes than through the use of SAF in place of Jet A-1, we do not expect SAF supply to meaningfully exceed government mandated levels.”

Estimated price of the different types of SAF in 2023



Source: EASA, Goodbody

Conclusion

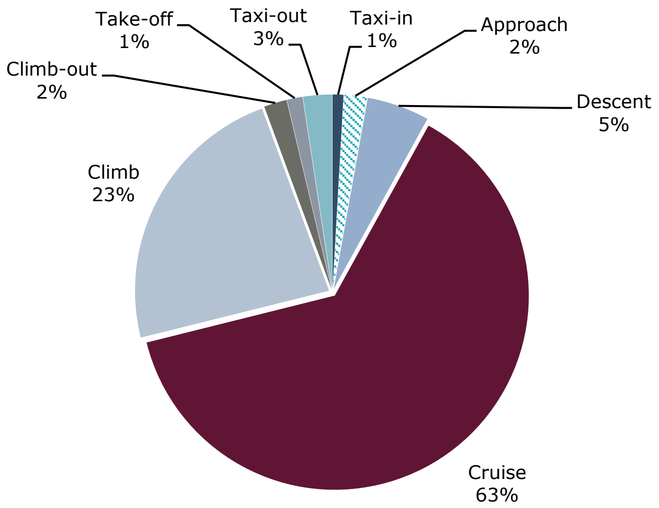
SAF is central to aviation's decarbonisation strategy, offering immediate compatibility with existing infrastructure. However, SAF faces significant scalability challenges due to limited feedstock, high production costs, and technological issues. HEFA currently dominates SAF production, but its long-term viability is constrained by resource availability. Advanced biofuels and PtL technologies offer deeper emissions reductions but require substantial investment and infrastructure. Government policies across the EU, UK, and US are attempting to drive SAF adoption through a mix of mandates, incentives, and funding. However, approaches vary, with Europe leaning on regulation and the US favouring financial incentives. Forecasts for SAF production remain highly variable, reflecting uncertainty in project execution and policy stability. Price remains the most significant barrier, with SAF costing significantly more than conventional jet fuel. Long-term success depends on scaling production, reducing costs, and accelerating technological innovation. Ultimately, SAF's future hinges on coordinated global efforts to align policy, investment, and infrastructure development.

Operational efficiencies – Reasonably big wins are possible, but it is a slow march forward

In 2021, when its members committed to achieving net-zero carbon emissions for their operations by 2050, IATA only expected operational efficiencies to make a small contribution to the decarbonisation of commercial aviation. However, while there may be some differences in definitions, we note that the 2004 Single European Sky (SES) initiative aimed to reduce carbon emissions per flight by 9.3% through 2050 while the Next Generation Air Transportation System (NextGen) program in the US aims to reduce emissions related to inefficiencies in air traffic management which may be as high as 12% according to JetBlue.

The SES builds on five pillars: economic regulation, airspace organisation/network management, technological innovation, safety and human dimension. The SESAR (Single European Sky ATM Research and Development) project is the technological innovation pillar of the SES aiming to modernise air traffic management through defining, developing and deploying innovative technological systems and operational procedures. In 2020, the European Commission launched SES2+ which aimed to reform SES to more effectively reach its objectives. SESAR aims to address the full scope of aviation's environmental impact including carbon emissions, non-carbon emissions and noise pollution at every phase of flight. According to EASA the total gate to gate carbon emissions within the EUROCONTROL area were 180.2m tonnes in 2023 (+14% yoy). As expected, the cruise phase and the climb phase have the highest share of emissions at 63% and 23% respectively.

EUROCONTROL - Carbon emissions by flight phase in 2023



Source: EASA, EUROCONTROL, Goodbody

The introduction of free route airspace (FRA) is a SESAR initiative which allows the aviation sector to freely plan a route between any defined entry and exit point, subject to airspace availability. SESAR estimates that fixed flying routes cause aircraft to fly an average of 20km further than the most direct route between two points. Fixed flying routes also limited the opportunity to take advantage of favourable winds and more efficient routes. The implementation of FRA over the last few years has improved flight efficiency. It is expected that FRA implementation with cross-border dimension and connectivity will be completed by the end of 2025. Cross border FRA areas have been implemented between several states with the BOREALIS FRA (Denmark, Estonia, Ireland, Iceland, Finland, Latvia, Norway, Sweden and United Kingdom) being seen as a pioneer. SESAR estimate that FRA will save c.6m tonnes of fuel and c.20m tonnes of carbon emissions over the coming decade. Outside the implementation of FRA, SESAR would still also like to address:

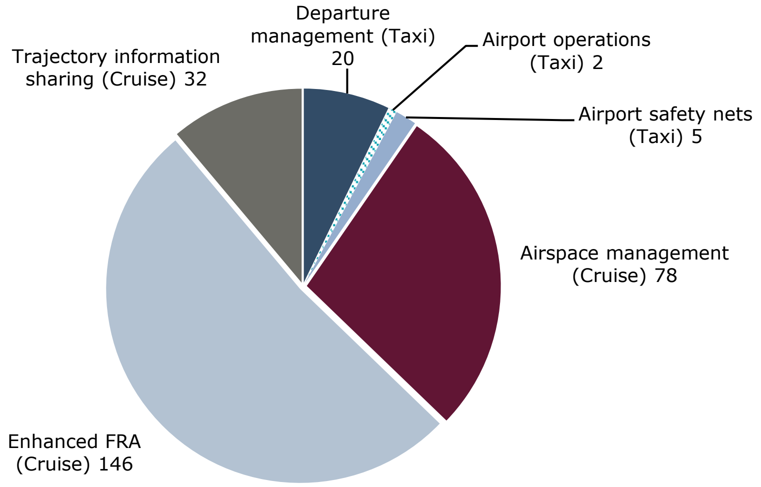
- **Taxi phase –** A key objective is to reduce engine-on time. Increasing the predictability of the take-off clearance time to reduce waiting time at the runway hold point. Single engine taxi and engine-off taxi, where aircraft are towed by a sustainable taxi vehicle, can also reduce overall engine emissions. It is projected that an engine off taxi could reduce emissions by c.50%.

- **Climb & Descent phase –** Leveraging the optimum profile for each flight through an Extended Projected Profile (EPP), which allows aircraft to start their descent 35-70 nautical miles before what would be their optimum Top-of-Descent point. The EPP provides visibility of the optimum top-of-climb and top-of-descent points on the ground, making it possible for air traffic controllers to facilitate a better trajectory. SESAR is also advocating for a transition to a more dynamic deployment of RNP (Required Navigation Performance) route structures as it believes that using dynamic routes increases capacity during peak periods, optimises fuel consumption during off-peak hours, and decreases the noise footprint, particularly during night time operations.

- **Cruise phase –** Increasing vertical flight efficiency is a priority as it will provide sufficient airspace for aircraft to fly at their optimum altitude. The increase in emissions varies by aircraft type and flight conditions but some SESAR studies suggest that flying at lower altitudes can increase fuel consumption by approximately 6-12% compared to optimal cruising altitudes. SESAR believes that an increase in vertical capacity can be achieved through digital and automated support for all air traffic management processes.

The current SESAR Common Project (CP1) aims to reduce inefficiencies and to generate fuel and carbon savings in different phases of flight, especially cruise. CP1 is due to be completed by 31 December 2027 with the expected performance benefits from CP1 representing c.20% of the European air traffic management Master Plan performance ambitions for 2035. 65% of CP1 carbon savings are expected to be found in the cruise phase, 25% in the descent phase and 10% in the taxi-out phase. According to EASA, by the end of 2023, CP1 had delivered €4.6bn worth of cumulative benefits and this is set to reach €19.4bn by 2030, once the CP1 is fully deployed.

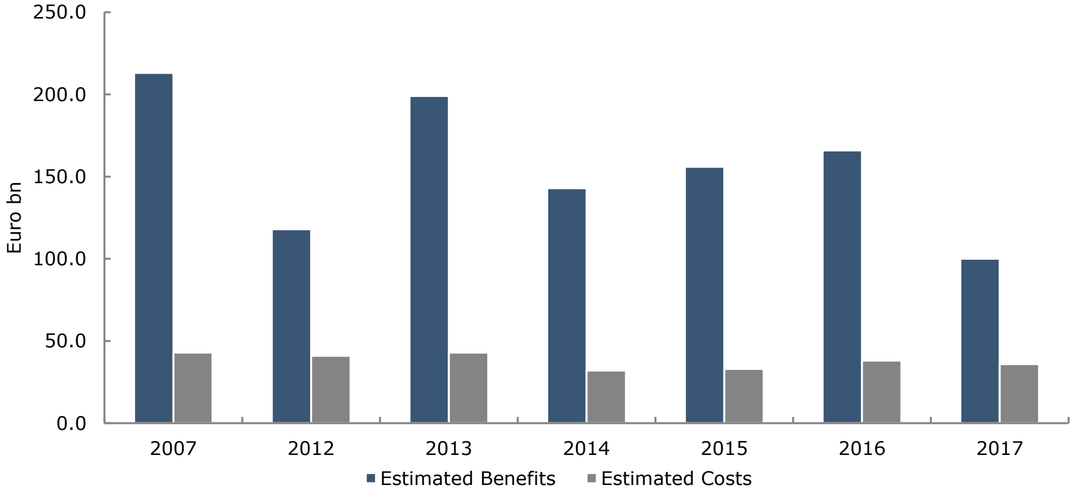
Full deployment of SESAR CP1 could save 283kg of carbon per flight



Source: Goodbody

In the US the FAA is working to a similar agenda to SES with its NextGen program as it looks to revamp ATC infrastructure for communications, navigation, surveillance, automation and information management. The aim is to modernise ATC infrastructure, enable trajectory-based operations, increase safety & efficiency, support emerging navigation technologies, improve environmental performance and enhance airport infrastructure. The FAA had targeted to have all of the major systems deployed in some shape or form by 2025 with full deployment in the 2030's. However, the program has faced significant delays.

Implementation delays and diminished programs have reduced the expected benefit from NextGen from $213bn to $100bn



Source: FAA, Goodbody

In 2007 the initial business case for NextGen suggested that it would generate $213bn in benefits although by 2017 the FAA put this figure as low as $100bn. Between 2010 and 2024 the FAA believe that NextGen delivered $12.4bn in benefits with the fuel savings related to NextGen amounting to $2.2bn and it highlights that the fuel savings also mean lower carbon emissions.

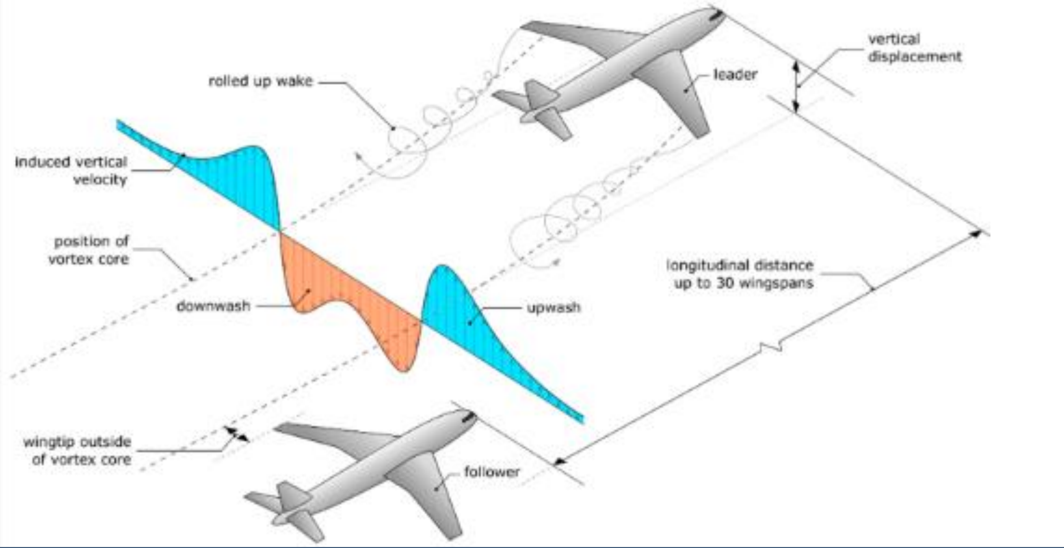
Another interesting area of potential emission reduction is that of formation flying otherwise known as wake energy retrieval (WER) or cooperative trajectories. This is where an aircraft following another aircraft could benefit from reduced air resistance and free lift enabling them to reduce engine thrust and fuel consumption. In 2019 Airbus presented an idea called "fello'fly" with two aircraft flying a few miles apart allowing the following aircraft to feed off the leading aircraft's downwash. Airbus claimed that this could save up to 5% of fuel burn on long-haul flights. The OEM undertook a test flight from Toulouse to Montreal which confirmed the potential fuel saving of 5% or more. In 2023 Airbus followed up with an EU funded project as part of SESAR 3 called GEESE. It was aimed at investigating how to enable WER from an air traffic management perspective.

Separate work by HAL Open Science* on optimised flight formations suggested that the fuel savings could be as high as 10%. However, the work also concluded that there are some downsides including aircraft operating at sub-optimal conditions, detours to a rendezvous point can add extra flying time and the ability to maintain station must be considered. Over time improved automation, station keeping, the ability to pass information between aircraft and enhanced tools for situational awareness.

The dawn of AI most likely means that we are getting closer to realising the environmental benefits of wake energy retrieval in commercial aviation. However, significant issues over separation safety, the sharing of benefits and related scheduling mean that this development remains some way off from adoption by the commercial aviation industry.

* Donald Erbschloe, Adam Antczak, Dennis Carter, Gary Dale, Carsten Doll, et al.. Operationalizing Flight Formations for Aerodynamic Benefits. AIAA Scitech 2020 Forum, Jan 2020, Orlando, United States. ff10.2514/6.2020-1004ff. ffhal-03224973

Wake energy retrieval could reduce fuel burn by up to 10%



Source: Marks et al**, Goodbody

Conclusion

The case for emissions reduction through increased operational efficiencies is well established, with potential savings of up to 10%. However, the pace of implementation remains a significant challenge. The Single European Sky (SES) initiative, first launched in 2004, exemplifies this slow progress—many of its components are still pending deployment. While the emergence of AI technologies offers a promising avenue to accelerate change, realising this potential will require commitment across all stakeholders—airlines, regulators, air navigation service providers, and manufacturers. Such alignment may prove difficult. On that basis, we believe that while operational efficiencies will contribute meaningfully to decarbonisation, they are unlikely to deliver the full extent of emissions reductions originally hoped for.

** Climate Impact Mitigation Potential of Formation Flight by Tobias Marks, Katrin Dahlmann, Volker Grewe, Volker Gollnick, Florian Linke, Sigrun Matthes, Eike Stumpf, Majed Swaid, Simon Unterstrasser, Hiroshi Yamashita and Clemens Zumegen.

Carbon capture and carbon offsets

When the commercial aviation sector set out on its journey to net-zero in 2050 ATAG estimated that market-based measures such as carbon capture and carbon offsetting would account for mid-to-high single digits of the overall emissions reduction. This seemed like quite a low estimate, and we note that IATA believed that market-based measures would account for up to c.19% of the emissions reduction. Given the investment and time required to scale up both SAF production and new technologies, carbon capture and carbon offsets were always likely to be particularly relevant for the aviation sector in the short to medium-term. While carbon capture and carbon offsets are often discussed in tandem, they are very different:

Carbon capture: Carbon capture technologies are designed to extract carbon either from concentrated emission sources, such as factories, or directly from ambient air. The main objective of this technology is to prevent carbon from entering the atmosphere, by storing it underground or utilising it in the manufacturing of fuel. In aviation, direct onboard carbon capture is not yet technically feasible, so ground-based solutions, such as direct air capture (DAC) can be used to either offset emissions with the carbon being permanently stored or used to produce SAF.

Carbon offsets: Carbon offsets work as a compensatory mechanism, allowing companies to purchase credits equivalent to emission reductions or removals elsewhere, such as through reforestation, renewable energy projects, or engineered removals like DAC. Airlines use these credits to address emissions that are challenging to offset directly.

Carbon Capture Technologies

Carbon capture comprises several distinct technology classes, each with unique features and varying degrees of maturity.

- **Direct Air Capture (DAC) -** Captures carbon from ambient air using chemical and physical processes (solid adsorbents or liquid solvents). The carbon can either be stored or used to produce SAF. Airlines cannot use this technology onboard so they purchase DAC removal credits for offsets. DAC is in an early commercial phase and it is scaling up.

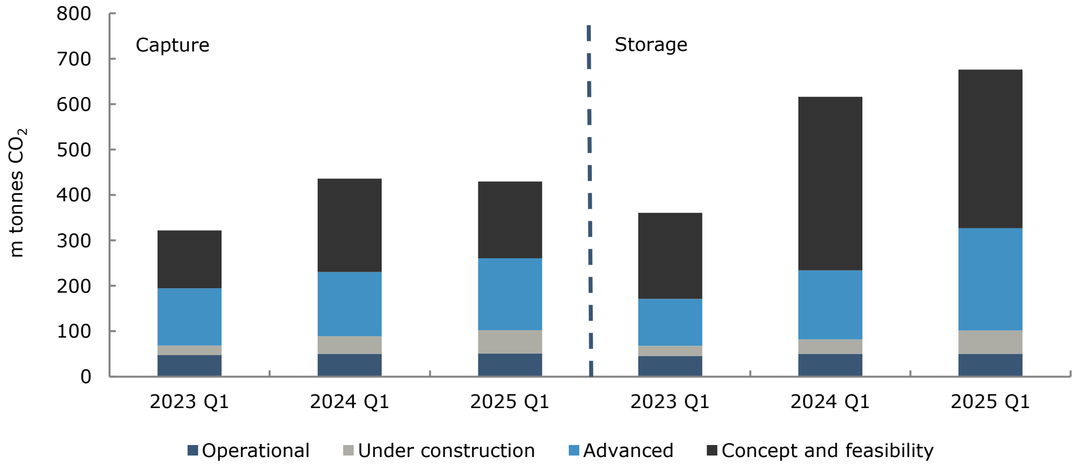
- **Bioenergy with Carbon Capture and Storage (BECCS) -** Biomass is burnt for energy and the carbon is captured and stored underground. This can be potentially carbon negative as biomass also absorbs carbon during growth. This method can supply low carbon or even net negative carbon for SAF production.

- **Point-Source Carbon Capture -** Point-source carbon capture is a process where carbon is captured directly from industrial emitters, such as refineries and ethanol plants. This concentrated carbon is often more cost-effective to capture than carbon captured from ambient air. This carbon can also be used for SAF production.

- **Carbon Capture and Utilisation (CCU) -** Carbon capture and utilisation involve capturing carbon and combining it with green hydrogen (produced from renewable electricity) to make synthetic hydrocarbons via processes such as Fischer-Tropsch. This produces PtL SAF which can be used as a drop-in replacement for conventional jet fuel.

Carbon capture, utilisation, and storage (CCUS) is gaining traction as a key component for long term decarbonisation, particularly in sectors like aviation where direct emission reductions remain challenging. As shown in the chart, global capacity of operational projects for carbon capture and storage amounts to 50m tonnes in early 2025. IEA projections point towards carbon capture capacity to reach 430m tonnes annually by 2030 while storage capacity should amount to 670m tonnes per annum based on the current project pipeline.

Announced and operational CCUS capacity for 2030 according to IEA



Source: IEA, Goodbody

Carbon capture technologies face several challenges in their rollout. DAC, depending on the technology and the scale of the project, is expected to cost between $600 and $1,000 per metric tonne of carbon. According to Forbes, industry and government efforts aim to bring this below $100 as this is considered the inflection point for this technology. Beyond this, major investments in infrastructure, from pipelines to storage facilities, will also be required. Finally, carbon capture systems will require large amounts of renewable energy, especially for producing green hydrogen that is used to make synthetic fuels. Despite these challenges, carbon capture is likely to remain a critical piece of the journey to net-zero.

Carbon offsets

Carbon offsets are mechanisms that allow polluters to offset their emissions by funding projects that reduce or remove carbon elsewhere. Each offset credit issued typically corresponds to one metric ton of carbon equivalent reduced or captured. The effectiveness of these offsets is sometimes called into question due to issues such as poor verification and monitoring, double counting, additionality (proving that the carbon savings would not have occurred anyway) and permanence. There are several different offset pathways, each with its own advantages and challenges with the most popular being:

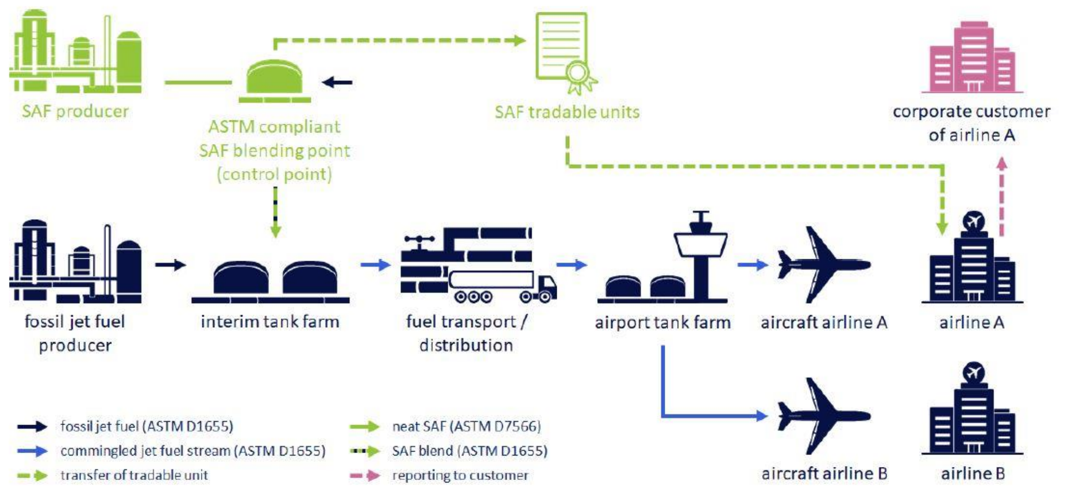
- **Nature-based solutions (Reforestation & REDD+)** - Nature-based solutions focus on protecting or restoring ecosystems such as forests, wetlands, and mangroves to absorb carbon. These are currently the major source of carbon credits but face challenges around permanence and additionality.

- **Avoided emissions -** Avoided emissions aim to reduce carbon emissions by lowering biomass use and improving combustion efficiency. While this will lead to reduced fuel usage and lower emissions, they also run the risk of being over credited due to flawed assumptions and monitoring challenges. We note that studies from UC Berkeley research suggest that many cookstove "saving credits are vastly overestimated, by a factor of 10".

- **Renewable energy credits** - Renewable energy credits can be generated by replacing fossil fuels with renewable energy sources. These are used to offset emissions, but concerns persist around "additionality".

- **SAF certificates and Book-and-Claim** - SAF certificates and Book-and-Claim systems allow airlines to decouple the emission reduction benefits of SAF from its physical delivery. Airlines and customers can claim the climate impact of SAF, even if the fuel is not physically supplied to their aircraft in a certain jurisdiction or geography. As SAF is still not widely available at all airports and its physical distribution can be costly and complex, book and claim simplify logistics and improves the overall system efficiency.

Boo-and-claim systems should improve SAF logistics



Source: aireg, Goodbody

In aviation the two largest offset schemes are the EU & UK ETS (Emissions Trading Scheme) and CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation). While there are some differences between the EU ETS and the UK ETS they are very similar as the UK scheme only came into effect post Brexit.

EU ETS

The EU ETS is a cap-and-trade system. The cap refers to the total amount of greenhouse gas emissions that can be released under the system with this limit being reduced annually according to the EU climate target. By putting a price on carbon and allowing trading the EU ETS intends to encourage cost effective emission reductions and drive investment in cleaner technologies. It is a cornerstone of the EU climate policy to achieve its goal of climate neutrality by 2050. This system was implemented in 2005 and, according to the European Commission it has helped decrease emissions in the covered sectors by 47% in 2023 vs 2005 levels. Under the EU ETS companies must monitor and report their emissions annually. If emissions exceed the allocated allowances the company must purchase additional permits on the carbon market or face financial penalties. If a company emits less than its allowances, it can sell the surplus credits creating a financial incentive to reduce emissions. While most allowances are auctioned some sectors receive free allocations to maintain competitiveness and prevent carbon leakage. In 2012 the system was expanded to include the aviation sector. Initially, it applied only to flights arriving to or departing from airports in the European Economic Area (EEA) with flights to and from non-EEA countries being excluded to support the development of CORSIA, the ICOA's global offsetting scheme. In June 2023, following the adoption of the Fit for 55 legislative package, the EU ETS Directive was amended to strengthen the aviation contribution to climate goals:

- **Broader scope** - ETS expanded to apply to more regional connections including the EEA, Switzerland and the UK, while CORSIA covers long haul international flights.

- **Free allocation phase-out** - airlines received 25% less free allowances in 2024, 50% fewer in 2025, and none from 2026, transitioning solely to the free market or auction.

- **Cap tightening** - A 4.3% annual reduction factor applied to aviation allowances from 2024 onwards.

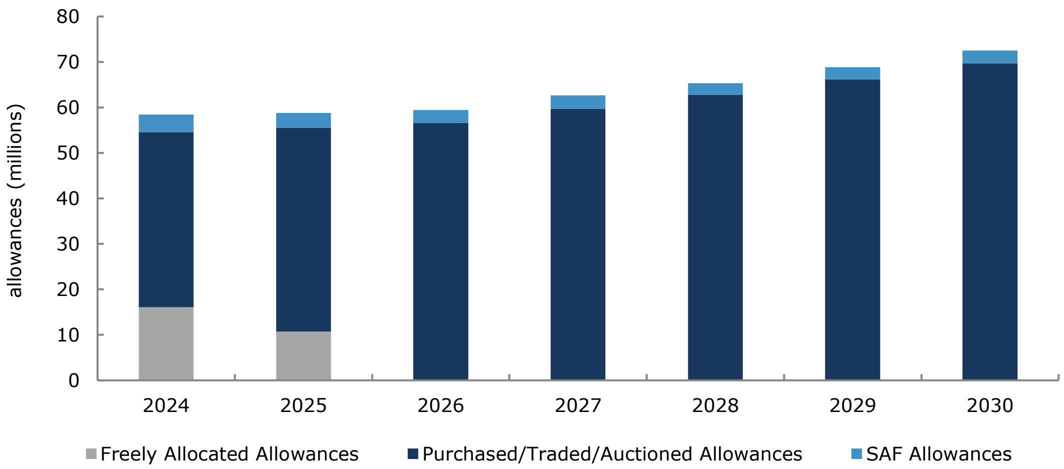
- **SAF incentives** - Up to 20m ETS allowances will be allocated between 2024 and 2030 to help bridge the cost gap between SAF and conventional jet fuel.

- **Non-carbon emissions monitoring** - A new system for tracking non-carbon emissions aviation effects (such as contrails) has been established.

- **CORSIA review** - The European Commission will assess CORSIA environmental performance after the 2025 ICAO Assembly (scheduled for the end of September) and report every 3 years.

While the EU ETS reforms aim to strengthen aviation's contribution to emissions reduction, IATA has raised several concerns about their broader implications. The extension of the EU ETS system to all flights to and from the EU after 2026 unless CORSIA is "positively evaluated" poses a risk of "potential competitive distortions to the market". Beyond this, IATA has commented that airlines are concerned about the impartiality and objectivity of the EU review process, given its long-standing preference for ETS. IATA has also raised concerns about the allocation of the SAF related ETS allowances between 2024 and 2030. While it welcomes this initiative, IATA states that the real impact is very limited with allowances only covering between 4% - 7% of estimated annual demand between 2024 and 2030. For context, airlines are expected to require around 50m allowances in 2025 alone, rising to nearly 60m in 2026.

SAF related ETS allowances are expected to have a very limited impact on airlines



Source: IATA, Goodbody

Furthermore, airlines face practical barriers in claiming SAF-related benefits under the ETS system. The current rules require SAF to be physically delivered to the departure airport, which is often logistically complex and costly especially at smaller airports with limited supply infrastructure. This requirement not only restricts flexibility but also discourages long-term SAF offtake agreements [WHY]. IATA advocates for the implementation of a robust book- and-claim system, which would allow airlines to purchase SAF and claim its environmental benefits without requiring physical delivery at the point of departure. Such a system would align ETS with the flexibility already granted to fuel suppliers under ReFuelEU and help unlock more efficient SAF supply chains across Europe.

CORSIA

CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) was developed by the International Civil Aviation Organisation (ICAO) to address carbon emissions from international flights. Unlike the EU ETS, which sets a cap on emissions, CORSIA aims to stabilise emissions at the 2019 level, requiring airlines to offset any growth in emissions beyond that point until 2023 and beyond 85% of this level from 2024 onwards. Offsets need to meet strict environmental integrity criteria, including permanence, additionality, and the avoidance of double counting. The ICAO has approved certain offset programs which airlines must use under CORSIA. The scheme is designed to complement other measures such as technological improvements, operational efficiencies, and the use of SAF.

Under CORSIA, airlines must monitor, report, and verify their annual carbon emissions. If emissions exceed the baseline, the airlines must purchase carbon offsets from approved programs to compensate for this. The scheme was agreed in 2016 by the ICAO member states and entered its pilot phase in 2021, followed by a first phase which started in 2024 running until 2026, and a second phase from 2027 to 2035.

- **Pilot Phase (2021 to 2023) -** The pilot phase was voluntary for ICOA member states with no offsetting requirements.

- **First Phase (2024 to 2026) -** The first phase is still voluntary with airlines offsetting emissions above 85% of 2019 levels. Offsetting continues to apply only to routes between participating states with airlines being now required to meet offsetting obligations by purchasing and cancelling emissions.

- **Second Phase (2027 to 2035) -** CORSIA participation becomes mandatory for all participating states with all international flights covered. As before emissions above 85% of the 2019 level have to be offset. Exemptions will be granted to the Least Developed Countries, Small Island Developing States, Landlocked Developing Countries, and states with minimal aviation activity.

CORSIA is the first global climate agreement for a single sector and represents a major step in international cooperation. However, its effectiveness depends on broad participation and robust implementation. The EU has stated it will review CORSIA environmental performance after the 2025 ICAO Assembly, raising concerns about alignment between regional and global approaches.
As carbon offset markets evolve, ensuring the environmental integrity of credits, through robust methodologies, verification, and governance, will be essential for aviation to meet its climate goals credibly and effectively. Standardised accounting and reporting frameworks are already being developed to ensure transparency and avoid double counting. Beyond this, the IEA emphasises the need for robust crediting frameworks to ensure environmental integrity, and drive investment.

Conclusion

Carbon capture and carbon offsets are essential short-to-medium-term tools for commercial aviation's path to net-zero. While carbon capture technologies like DAC and BECCS offer deep decarbonisation potential, they remain costly and energy intensive. Carbon offsets provide flexibility but face scrutiny over credibility, additionality, and permanence. Nature-based solutions dominate carbon offset markets but they suffer from verification and long-term reliability issues. The EU ETS and CORSIA represent two major offset frameworks, with differing scopes and mechanisms. EU ETS reforms aim to tighten aviation emissions but raise concerns over fairness and market distortion. CORSIA offers a global approach, yet its success depends on widespread adoption and rigorous implementation. Book-and-claim systems could improve SAF integration and carbon offset flexibility, but they require regulatory alignment. Robust governance, transparency, and standardisation are critical to ensure environmental integrity. Ultimately, carbon capture and offsets must complement SAF, innovation and operational efficiencies to deliver credible climate action in aviation.

New Technologies – Potential "moonshots" getting pushed further into the future

Following IATA members' commitment to achieving net-zero carbon emissions by 2050, extensive discussions emerged around the future of aircraft technology over the next 30 years. While initial attention centred on hydrogen-powered, electric and hybrid aircraft, the conversation also expanded to include innovations such as thin-wing designs and a potential shift away from the traditional tube-and-wing configuration, a design that has remained largely unchanged since the advent of modern aviation.

Hydrogen – now looking like the 2040's at the earliest

An alternative to conventional jet fuel and SAF is the use of liquid hydrogen as a fuel. Hydrogen powered aircraft are seen as a long-term solution to decarbonising the sector. The big advantage of hydrogen is that it is the most abundant element in the universe. In its liquid form hydrogen is said to contain c.2.5x more energy than conventional jet fuel. From an environmental point of view burning liquid hydrogen only produces water vapour as the fuel has no carbon content. Hydrogen will also produce up to 90% less nitrogen oxides than conventional jet fuel and it eliminates the formation of particulate matter. The most sustainable route for generating hydrogen is to split a water molecule into hydrogen and oxygen through electrolysis. This can be done with desalinised sea water or fresh water. If the electrical energy is renewable, then this hydrogen is called green hydrogen. In theory, hydrogen can be produced anywhere in the world if those two ingredients, water and electricity, are available. However, there are significant challenges associated with liquid hydrogen including the volumetric density which is about 4x that of conventional jet fuel. This is further complicated by the requirement to store liquid hydrogen at -253c.

Advantages

- Zero carbon emissions at point of use
- High energy density by weight
- Potential for renewable production
- Reduced noise pollution

Disadvantages

- Storage and volume challenges
- Infrastructure requirements and aircraft architecture
- Safety perception
- Time to maturity
- Lifecycle emissions without green hydrogen

The Airbus ZEROe project was launched in 2020, it was the highest profile hydrogen aircraft project. The aim was to explore the feasibility of two primary hydrogen propulsion technologies - hydrogen combustion and hydrogen fuel cells. The hope was to develop a turbofan aircraft with capacity for up to 200 passengers. In 2025 Airbus announced that the hydrogen fuel cell had been selected as the preferred propulsion method for its future hydrogen powered aircraft which was originally expected to enter into service in 2035. However, while Airbus has reaffirmed its long-term commitment to liquid hydrogen as a transformative fuel for aviation, it has also revised its timeline for delivering a hydrogen-powered aircraft. Originally targeting 2035, Airbus now anticipates a delay with some analysts suggesting that this may be up to ten years due to significant challenges in infrastructure, technology, and regulation. According to Guillaume Faury (Airbus CEO):

"While a commercially viable product is now expected to come later than 2035, we will use this additional time to further develop the performance of the fuel-cell propulsion and the liquid hydrogen system technologies."

Smaller OEM's such as ZeroAvia are also working on developing zero emission engines for commercial aviation. However, ZeroAvia has stated that it is targeting a 300-mile range in 10 to 20 seat hydrogen-electric aircraft by the end of 2026 and up to 700-mile range in 40 to 80 seat hydrogen-electric aircraft by 2028. While these milestones would represent meaningful progress for the aviation sector, their impact will remain relatively modest in the context of commercial aviation, particularly when compared to the scale and range requirements of mainstream carriers.

Notwithstanding the Airbus delay we would highlight that a shift to hydrogen powered aircraft sounds great on paper but there are a number of very significant challenges with the availability of green hydrogen being a major issue. Indeed we note that several German industrial companies have recently highlighted the high cost of green hydrogen and they are considering resorting to fossil fuels as an alternative or using grey hydrogen.

Electric aircraft – Energy density is the big issue

While a lot of the focus in the last few years has been on the development of electric vertical takeoff and landing aircraft (eVTOLs) there has been significant amounts of work done in the development of traditional fixed wing aircraft that are powered by electricity.

Hybrid electric aircraft combine combustion and electric engines with the combustion engine largely used during take-off. Small hybrid electric aircraft are expected by 2030 with regional aircraft in the 2030's and possibly larger ones in the 2040s. Companies such as Heart Aerospace, the Swedish hybrid-electric OEM, are leading the charge in this area with its ES-30 aircraft expected to carry 30 passengers with a range between 200km (all electric) and 800km (hybrid with 25 passengers). Type certification is hoped for in 2029. According to Heart Aerospace the expected reduction of total industry emissions from the electrification of regional aviation by 2050 would be -22%. The Heart X1, a full-scale demonstrator for the ES-30 is due to conduct a test flight in 2025.

Heart Aerospace's ES-30 could carry up to 30 passengers

Source: Heart Aerospace, Goodbody

The next step would be fully electric aircraft. However, the challenge here is to achieve a balance between energy density and weight with the current lithium-ion batteries offering ~250 – 300 Wh/kg versus conventional jet fuel which provided ~12,000 Wh/kg. To match the range of a conventional aircraft the batteries will need to be much lighter and more energy dense.

Advantages

- Zero carbon emissions at point of use
- Lower operating costs
- Improved efficiency
- Reduced noise pollution

Disadvantages

- Battery limitations and weight issues
- Infrastructure challenges
- Safety concerns
- Lifecycle emissions without green electricity

Thin-Wing technology – On hold for now

NASA and Boeing were working on a thin-wing aircraft called the X-66. This aircraft was expected to incorporate a more complex transonic truss braced wing concept with ultra-thin, high aspect ratio wings that were supported by diagonal struts. The aim was to reduce drag and improve fuel efficiency by up to 30% compared to the current single aisle aircraft.

Boeing and NASA's thin-wing project has been paused

Source: Boeing, Goodbody

However, in April 2025 Boeing and NASA announced a strategic pivot with the X-66 demonstrator now on hold and the focus had shifted to ground based testing of thin-wing technology. The ground based testing is aimed at demonstrating the potential for long, thin-wing technology while the more complex transonic truss braced wing concept would be paused for later consideration.

Blended wing body aircraft – A promising avenue for emissions reduction

Another promising area of development is blended wing body (BWB) aircraft. The aim is to redefine aircraft design, fuel efficiency and emissions in commercial and military aviation. At present the leader in the space looks to be JetZero. JetZero's aircraft design is expected to reduce drag and produce lift across the entire wingspan. According to JetZero its Z4 BWB design has the potential to improve fuel efficiency by up to 50% versus a current tube and wing aircraft. The Z4 is designed to carry 250 passengers, and it will use conventional jet fuel but it can also use SAF which will add to the emissions reduction. BWB is seen as a win for everyone as it increases fuel efficiency very significantly. Aside from the emissions reduction this will also reduce operating costs for the airlines while also offering the potential of a more comfortable cabin experience for passengers.

JetZero's pathfinder (a 12.5% scaled demonstrator) was cleared by the FAA for flight tests in 2024. A fully sized demonstrator aircraft is on track for its first flight in 2027. Alaska Airlines and United have both invested into JetZero with United agreeing a path to an order for 100 aircraft and an option for an addition 100 aircraft. Alaska's deal included options for future aircraft orders.

Speaking about the BWB aircraft Andrew Chang, head of United Airlines Ventures (UAV), commented that:

"If successful, JetZero has the potential to evolve our core mainline business by developing aircraft with a bigger, more comfortable cabin experience for our customers while increasing fuel efficiency across our network,"

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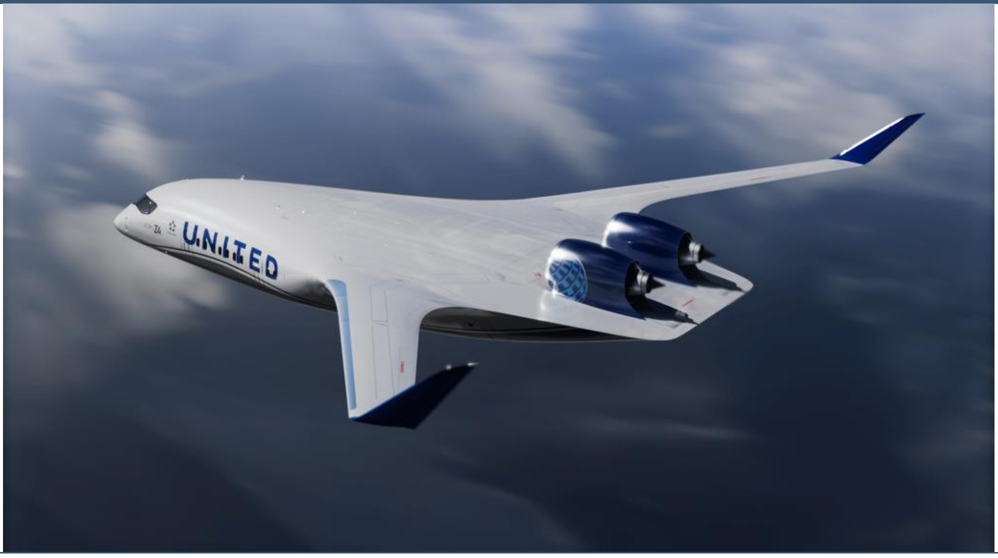


Source: JetZero, Goodbody

There are numerous promising technological developments in aviation, such as hydrogen-powered engines and BWB aircraft, and their potential to significantly reduce emissions is clear. However, progress to date has been very slow and there is still a very long way to go before any of the new technologies are certified. This suggests that these innovations are likely to play a more prominent role in the long-term. In the short to medium-term, the most impactful driver of emissions reduction is likely to be the continued refinement and re-development of existing engine technologies. Incremental improvements in fuel efficiency, materials, and aerodynamics can deliver meaningful gains across the current fleet, offering a more immediate path to lower emissions while next-generation solutions mature.

Jet Engines – Time to RISE above the norm

Between 1961 and 2014 the average fuel burn of a commercial jet aircraft declined by c.45%. According to Global Aerospace the majority of this reduction came from gains in engine efficiency. Industry executives have suggested that a general rule of thumb is that engine efficiency tends to improve by c.25% every 20 to 25 years. However, it's worth noting that newly introduced engines often experience initial reliability challenges which can significantly affect both time-on-wing and the realisation of expected efficiency gains in the early years – see below for some commentary on the issues with the Rolls Royce Trent engine, the CFM LEAP engine and the Pratt & Whitney GTF engine.

By far the most popular jet engine over the last few decades has been the CFM56. The CFM56 is a short-haul jet engine which powers a large proportion of the Airbus A320ceo and Boeing 737NG fleet. The engine first entered service in the early 1980's and according to CFM there are over 600 operators worldwide with over 34,000 engines delivered to date. The CFM56 is undoubtedly the workhorse engine of the short-haul fleet. As of 2025 CFM believe that there is still more than 23,000 CFM56 engines in service. The next most popular engine is the International Aero Engines (IAE) V2500 engine. The V2500 is another short-haul engine which is primarily used to power the Airbus A320ceo. IAE is a joint venture between Pratt & Whitney (P&W), Japanese Aero Engine Corp. and MTU Aero Engines. While it is harder to find statistics on the V2500 engine it is believed that over 7,800 engines had been produced by 2023 and according to P&W at that time the engine continued to power nearly 3,500 aircraft globally. Turning to long-haul engines the most popular engine is the GE Aerospace CF6 engine which first entered service in 1971. GE Aerospace has delivered more than 8,500 CF6 engines. The next most popular long-haul engine is the Rolls Royce Trent engine. According to simpleflying.com there were over 6,000 Rolls Royce Trent engines in service as of the middle of 2025. However, the Trent engine, particularly the Trent 1000, has not been without its issues:

> **Rolls Royce Trent** – The Rolls Royce Trent engine has had issues with the Intermediate Pressure Turbine blade, the High-Pressure Turbine blade, compressor rotor resonance and accelerated wear in "hot & harsh" environments. Rolls Royce has been working on improvements to increase the time on wing performance. However, several airlines have been publicly critical of Rolls Royce on this issue with Tim Clark, President of Emirates describing the Trent XWB engine as "not doing what we want". Indeed, both Air New Zealand and ANA have chosen to order GE engines after starting out as Rolls Royce customers.

Over the last 10 years we have seen the arrival of the next generation of short-haul engines, namely the CFM LEAP and the P&W GTF. Both are classified as compact core engines with a high bypass ratio which helps improve fuel efficiency. These newer engines offer between 15% - 20% better fuel efficiency* versus their predecessors so the emissions profile is also between 15% - 20% better. In keeping with most industries, both CFM and P&W have suffered post-Covid supply chain issues which have hampered their production ramp-up, however, there has also been specific issues with each engine:

> **CFM LEAP** - Since its introduction into service there has been several relatively minor issues with the LEAP engines including High-Pressure Turbine seal defects and a Load Reduction Device issue. However, the biggest issue with the LEAP has been some concerns about the engine's durability with some commentators pointing to reduced time on wing and increased maintenance in general for the LEAP versus the CFM56. Indeed, we have seen some speculation that the reduced time on wing and increased maintenance could go as far as negating the entire efficiency gain. As we approach the 10-year anniversary of the LEAP's entry into service we should start to get a better view on the durability of the LEAP versus the CFM56 because engines will be coming up to their first major overhaul.

P&W GTF - For its part the GTF engine has had very significant problems with have dramatically impacted time on wing. The initial issue for the GTF was accelerated wear and reduced time on wing in "hot & harsh" environments such as the Middle East, South Asia and parts of Africa. The problem was related to dust and sand ingestion which blocked cooling holes leading to degradation and premature component failure. In response P&W is introducing the GTF Advantage which it says features improved hot section durability. The Advantage is expected to double time on wing compared to the current GTF in "hot & harsh" conditions. The second, and very much larger, issue for the GTF engine relates to a defect in the powered metal used to manufacture High-Pressure Turbine disks which has led to micro cracks and premature wear. This raises the risk of an uncontained disk failure. The issue effects engines that were produced between late 2015 and late 2021 with up to 3,000 engines identified for inspection and potential removal. The GTF powered metal issue has resulted in a huge number of groundings globally (P&W expect this to peak at 650 aircraft grounded), it has put pressure on the P&W supply chain as demand for spare parts has increased dramatically and it has further exacerbated the already elongated MRO turnaround times. Furthermore, it has impacted P&W's ability to deliver new & uncontaminated engines as it has been dealing with the older, contaminated engines. While P&W's MRO capacity has been increasing, +35% in Q1 & +22% in Q2 after growing by +30% in 2024, and AOG's are slowly starting to fall, turnaround times remain elevated and there will still be AOG's in 2026. In July P&W commented that it "expects aircraft on ground levels for the PW1100 powered A320neo fleet to remain elevated through 2026".

Looking towards the next generation of long-haul engines, the GE Aerospace GE9X, which was designed for the 777X, the world's largest twin-engine passenger aircraft. The GE9X is said to be the largest and most powerful commercial aircraft engine ever built. GE are expecting it to be "the most fuel-efficient engine in its class". It is said to offer a 5% fuel consumption improvement versus any twin-engine available and a 10% fuel consumption improvement versus the current GE90 engine. After some setbacks the GE9X is expected to enter service in 2026. Rolls Royce's next generation long-haul engine is the UltraFan engine which is due to start testing between 2028 – 2030. The UltraFan engine has been designed with "new engine architecture, fan system technology, new materials and a power gearbox all create a very high bypass ratio engine. And that means greater efficiency and sustainability". This engine is expected to deliver up to 25% fuel and emissions savings versus the first-generation Trent engine although we note that it is only a 10% fuel and emissions savings versus the current Trent XWB. Rolls Royce claim that it will be 100% SAF ready from day one of service.

** CFM claim that the LEAP is 15% more efficient than the CFM56 while P&W claim that the GTF is 20% more efficient than the prior generation of engines.*

The CFM RISE Open Fan architecture may be the next step forward in engine efficiency

Source: CFM, Goodbody

Longer term the CFM RISE program (Revolutionary Innovation for Sustainable Engines) is an example of an open rotor engine project. RISE is aimed at building quieter and more efficient engines. According to CFM the hope is that RISE will pave the way for the next generation of aircraft. The program goals include "improving fuel efficiency by more than 20% compared to today's most efficient engines, as well as ensuring compatibility with Sustainable Aviation Fuels (SAF) to provide further emissions reductions". CFM believe that the new generation Open Fan architecture will be able to fly at the same speed as a current narrowbody aircraft with a lower "noise signature". Through the RISE program, CFM is said to be advancing engine technologies for 100% SAF compatibility. It is also integrating electrical motors to lower carbon emissions. In 2022 Airbus and CFM launched an A380 flight test demonstrator program for the advanced Open Fan to accelerate development of the technology. The test program is expected to achieve several objectives that could contribute to future engine and aircraft efficiency improvements. More than 350 tests have been completed and it is expected that a flight test campaign will be performed by the end of this decade.

Conclusion

Commercial aviation's path to net-zero by 2050 relies heavily on transformative technologies, but timelines are slipping. Hydrogen-powered aircraft offer zero-emission potential but face major hurdles in storage, infrastructure, and green hydrogen availability. Electric aircraft are promising for regional travel, yet battery energy density remains a critical limitation. While JetZero's BWB aircraft could revolutionise fuel efficiency and cabin design, with major airline backing already secured, the new aircraft designs such as thin-wing and BWB development is slow and complex. Incremental improvements in jet engine technology continue to deliver meaningful emissions reductions. However, reliability issues with current engines like LEAP and GTF highlight the challenges of innovation.
Open rotor concepts like CFM's RISE program may define the future, but they remain in early testing phases. In the near term, optimising existing technologies will be key while moonshot innovations mature.

Modelling the journey to net-zero: 2025–2050

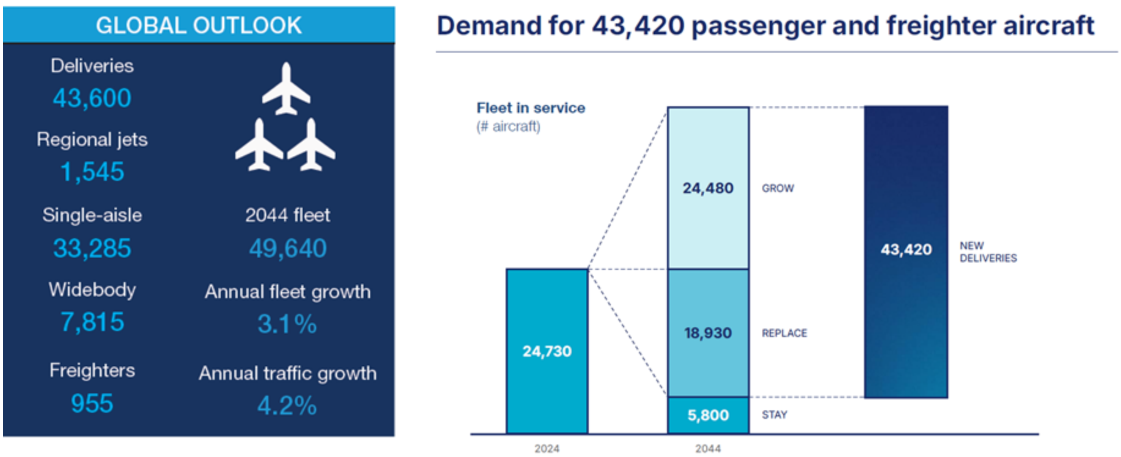
To assess the impact of the various factors on the journey towards net-zero in 2050 we model the emissions of the global commercial aviation fleet from 2025 to 2050. We estimate the annual change in emissions driven by a combination of the expected fleet growth and three core emissions-reduction strategies:

- SAF
- Engine efficiency
- Operational savings

This enables us to quantify the residual carbon emissions in 2050 that will need to be addressed through market-based measures (carbon offsets and carbon capture technologies). It's important to note that both IATA and ATAG estimate the contribution of these measures to be limited, with a maximum potential impact of around 20% under current projections.

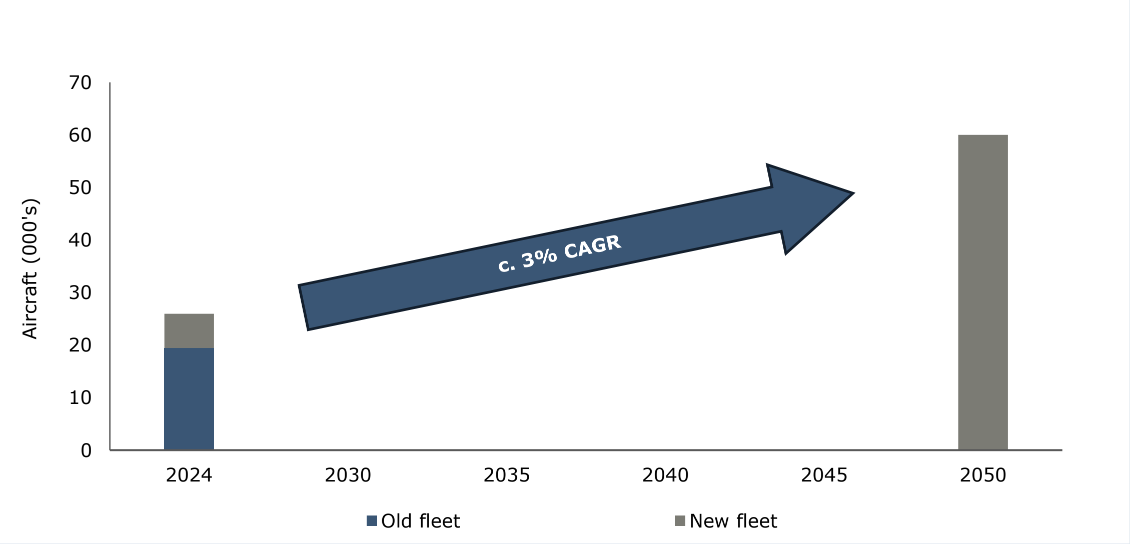
The expansion of the commercial fleet is based on an extension of the 20-year global fleet forecasts published by Airbus and Boeing in 2025. The increase in the commercial fleet is underpinned by an expectation of robust traffic growth. Airbus forecasts a +3.6% annual increase, supported by +2.5% global GDP growth and the addition of 1.5bn people to the global middle class. Boeing's outlook is slightly more optimistic, projecting +4.2% annual traffic growth, with the fastest expansion expected in South Asia, China, and Southeast Asia. What is clear is that both manufacturers anticipate strong growth in demand for air travel over the next two decades. Airbus forecasts that the global fleet will nearly double from 24,730 aircraft in 2024 to 49,210 by 2044, while Boeing estimates a similar increase from 27,150 to 49,640 aircraft over the same period. This translates to an average annual fleet growth rate of slightly above 3%.

Airbus and Boeing expect the global commercial aircraft fleet to reach 49k units in 2044



Source: Boeing (lhs), Airbus (rhs), Goodbody

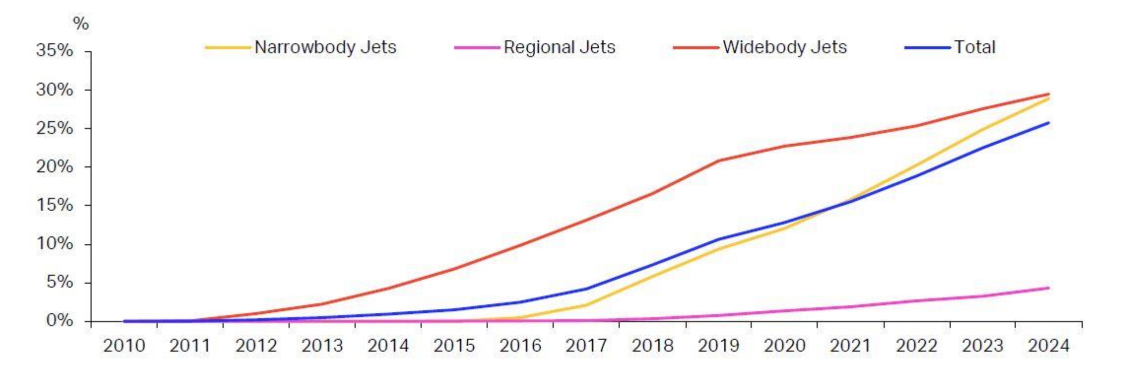
The global commercial aircraft fleet is expected to grow at a C.3% CAGR to 60k units in 2050



Source: Goodbody

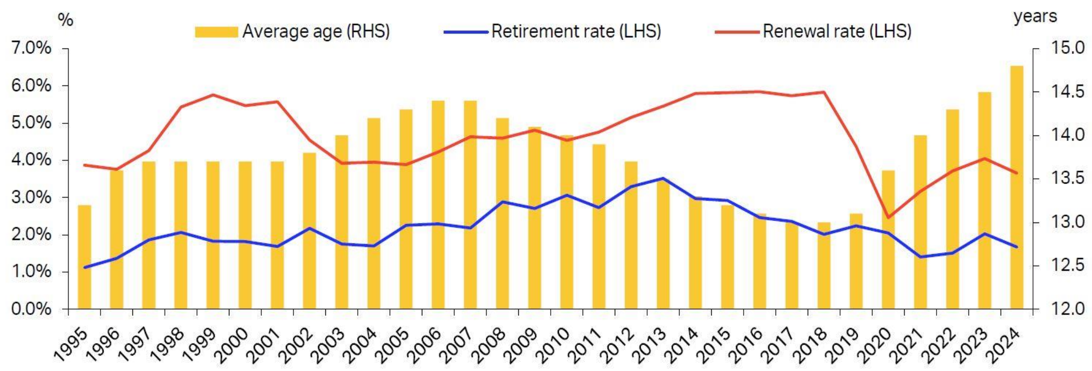
In their respective market outlooks, both Airbus and Boeing present a broadly aligned view on the scale and composition of future fleet requirements. Boeing expects the delivery of 43,600 new aircraft, including 33,285 narrowbodies and 7,815 widebodies, with these contributing to both the expansion of the fleet and the replacement of older, less efficient aircraft. Airbus forecasts 43,420 new deliveries, including 34,250 narrowbodies and 9,170 widebodies, also with a significant portion dedicated to fleet renewal. In our model we assume a next generation fleet of 25% of the current total commercial global fleet and a renewal rate of c. 4%, in line with IATA forecasts.

Share of NextGen aircraft in global commercial fleet, % of aircraft in service and in storage



Source: IATA, Goodbody

Average of global fleet, fleet retirement rate and renewal rate



Source: IATA, Goodbody

Despite minor differences in assumptions, both OEMs share a common view that there will be a very significant expansion of the commercial aviation fleet over the long term. These projections underscore the importance of continued investment in fleet modernisation and infrastructure to support both the growing demand for air travel and requirement for decarbonisation.

Modelling the emissions reduction journey

Assumptions	Baseline scenario
Total Fleet 2024	25940
SAF Blend rate 2025	2%
SAF Blend rate 2050	70%
Emission savings from SAF 2025	70%
Emission savings from SAF 2050	95%
1st generation engine efficiency 2025	18%
3rd generation engine efficiency 2050	41%
Global Fleet CAGR	3%
New Fleet delivery CAGR	4%
New Fleet 2024	6485
New fleet % 2024	25%
Operational efficiencies 2050	10%

Source: Goodbody

Decarbonisation Levers

- **SAF -** A core component of our model is the progressive adoption of SAF. Starting with a 2% blend rate in 2025, SAF usage is expected to increase steadily in line with international mandates and industry commitments, reaching 70% by 2050. Beyond volume growth, the carbon reduction potential of SAF will also improve over time. Initial reductions of up to 70% are assumed to increase to 95% as cleaner production pathways are developed and increasingly integrated into the fuel mix. Of our modelled emissions savings, SAF is expected to represent 57% of the emissions savings by 2050.

- **Engine efficiencies –** We also incorporate the progressive replacement of older aircraft with next generation models equipped with increasingly efficient engines as well as allowing for an ongoing improvement in engine efficiency over time. The ongoing improvements in engine efficiency are projected to represent 34% of our forecast emissions savings by 2050.

- **Operational efficiencies -** Operational improvements such as enhanced flight planning, optimised routing, and enhanced air traffic management are included as a third factor driving decarbonisation. Operational efficiencies are projected to contribute 9% of our total emissions reductions by 2050.

- **Carbon capture and carbon offsets –** Allowing for the impact of SAF, engine efficiencies and operational efficiencies through to 2050 still leaves carbon emissions from the commercial aviation sector at 67% of the 2024 level with carbon capture and carbon offsets expected to bridge the gap to net-zero.

Conclusion

Despite the global fleet more than doubling to nearly 60k aircraft by 2050, the combined impact of SAF adoption, next generation aircraft engine efficiency and operational improvements is expected to drive to a sharp reduction in carbon emissions over the period. Using 2024 as the base year, carbon emissions are projected to fall to 67% of 2024 levels by 2050. In the context of the significant fleet expansion this is a very good outcome. Without any intervention such growth would typically result in a dramatic increase in carbon emissions. Importantly, our model does not incorporate the impact on emissions of carbon offsets or carbon capture technologies both of which will further reduce emissions. However, the analysis suggests that without a major breakthrough in carbon capture technology or a significant increase in carbon offsetting, the industry is unlikely to achieve its net-zero by 2050 target. Based on the current trajectory market-based measures would need to deliver reductions on par with SAF to close the gap. We believe that this is unlikely although not impossible. Overall, the potential scale of emissions reduction is very impressive, and it raises the important question: does narrowly missing the net-zero target matter if the overall emissions reduction is transformative?

Commercial aviation emissions are projected to be 67% of 2024 levels in 2050

Year	Operational efficiencies	Engine Technology	SAF	Cumulative savings	Emissions (2024 = 100)
2025	0.4	0.9	1.4	2.7	99.0
2030	2.5	5.6	6.4	14.6	104.1
2035	4.8	12.3	15.4	32.5	103.9
2040	7.0	20.2	26.2	53.4	100.6
2045	9.1	29.0	41.0	79.0	91.9
2050	11.0	40.4	67.4	118.8	67.3

Source: Goodbody

Engine MRO - A "super cycle" that Ireland should look to play

With the global commercial fleet expected to more than double by 2050, the demand for engine maintenance, repair, and overhaul (MRO) services is entering a structural "super cycle." This presents a significant opportunity for Ireland to expand its aviation footprint beyond leasing and airframe maintenance into high-value engine MRO.

The number of aircraft engines will not increase at the same rate as the number of aircraft as some older four engine aircraft such as the 747 and the A380 will be replaced by more efficient twin-engine aircraft. However, the fleet is expected to increase by 130% over the 25-year period and we believe it is reasonable to assume that the number of engines in operation will double over the same period. At the same time the introduction of increasingly more efficient but also more complex engines is likely to impact turnaround times at engine MRO facilities. The newer engines incorporate advanced materials, tighter tolerances, and more integrated systems. These require specialised diagnostics, tools, and certifications, limiting the number of MROs that can service them.

According to the Global fleet and MRO market forecast 2025 – 2035 report by Oliver Wyman the general MRO market is already experiencing a super cycle driven by the shortage of new aircraft. MTU Aero Engines has said that it expects its MRO revenue to double to between €10bn - €11bn by 2030 before increasing to €15bn - €16bn by 2035. MRO spending is expected to be $119bn in 2025 before growing to $156bn by 2035. Ireland's position as the global leader in aircraft leasing offers a unique platform to integrate leasing and MRO services, creating a seamless value proposition for airlines. Capturing even 1–2% of this market could generate billions in revenue and thousands of high-skilled jobs for Ireland.

While the current uptick in demand has been driven by a combination of the greater maintenance needs of an aging fleet and the well documented engine issues, the ongoing trend for increased flying hours per aircraft is also a factor. This is occurring against a backdrop of already constrained MRO capacity, particularly for engines, with turnaround times having lengthened significantly since the pandemic. At present the P&W GTF engines that require repairs are currently taking c.300 days to return while standard turnaround times have more than doubled. On this very point Michael O'Leary of Ryanair recently commented that:

"the turnaround times have wildly escalated from typically around 65 days to something closer to 150 days"

In response GE, Rolls Royce and other MRO providers continue to invest in MRO capacity. GE Aerospace has said that it will invest over $1 billion to increase capacity, enhance training, and add advanced tooling in its MRO shops worldwide while Rolls Royce plans to significantly expand its global MRO capability including full engine overhaul capacity. Elsewhere Lufthansa Technik is planning to invest over €1bn over the next four years as part of its "Ambition 2030" growth strategy as it looks to increase revenues by €10bn with growth in engine MRO capacity a key target.

As we look forward to an elongated period for structural growth in the engine MRO sector it begs the question as to why Ireland would not target this market with a view to developing a cluster of engine MRO facilities. This is a highly skilled, highly paid segment of the MRO market. Ireland already has a well-established aviation ecosystem including several MRO facilities although these tend to be focused on airframe and component maintenance. This will require access to a pool of qualified mechanics, engineers and servicers. Irelandia's "Pathfinder for Irish Aviation" called for the strategic expansion of the MRO industry in Ireland by "building at least one world class aircraft engine overhaul facility on the island with a focus at either Shannon or Derry airports". It also suggested a 75% reduction in rates for air side MRO hangars and a 3x increase in the number of aviation apprentices through increased co-operation between the Department of Higher Education and the MRO industry. We would add that the

IDA should be actively looking to foster the evolution of an engine MRO ecosystem in Ireland through tax breaks and infrastructure supports.

A potential roadmap to develop an engine MRO industry in Ireland would involve:

Leverage Ireland's existing leasing dominance – Ireland manages over 50% of the world's leased aircraft, offering a strategic advantage. By integrating aircraft leasing and MRO services, Ireland can position itself as a seamless "one-stop shop" for global airlines.

Infrastructure development – Shannon & Derry airports both provide ideal starting points for engine MRO facilities. Both offer relatively uncongested airspace alongside strong connectivity via road and maritime transport networks. Ireland should look to co-locate engine MRO facilities, parts suppliers, logistics providers and training & education facilities.

Investment in workforce & skills – While initial talent may need to be sourced internationally Ireland should look to develop targeted apprenticeship and training programmes with engine specialisation through partnerships with universities and technical colleges.

Focus on one area of the market – At first Ireland should look to focus on one area of the engine MRO market such as high-demand narrowbody engine MRO.

OEM partnerships – The IDA could help to attract OEM partnerships while the Irish Strategic Investment Fund (ISIF) could co-invest in facilities. The Government could offer R&D tax credits for engine MRO innovation in areas such as engine diagnostics, predictive maintenance, and tooling.

Tax policy – The government could create tax incentives and grants for engine test cells and tools.

Sustainability – Ireland should look to position itself as a green MRO hub through the use of renewable energy, the digitisation of MRO and developing a more circular solution for used parts.

Promotion – Ireland could promote itself as the EU's engine MRO hub.

In the short term the target would be to have three to five engine MRO facilities operating in Ireland by 2030. This could create up to 2,500 high value jobs in engine MRO. This would be complemented by additional employment across ancillary services, including logistics, parts supply, training, and digital support. Ireland should not limit its ambition to three to five facilities. With structural growth expected over the next 25 years, the goal should be to establish Ireland as the EU's leading engine MRO hub. Securing one of Ryanair's planned facilities on the island would be a strategic catalyst for this vision.

Conclusion

The engine MRO market is in a long-term growth phase, driven by fleet expansion, aging aircraft, and complex next-generation engines. Ireland is well-positioned to capitalise on this trend, leveraging its aviation ecosystem and leasing dominance. Strategic investment in infrastructure, skills, and OEM partnerships could establish Ireland as a leading engine MRO hub in Europe. Policy support through tax incentives, sustainability initiatives, and targeted promotion will be critical to success. Capturing this opportunity could create thousands of high-value jobs and anchor a new pillar of Ireland's aviation economy.

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