WAYPOINT 2050

AN **AIR TRANSPORT ACTION GROUP** PROJECT

THIRD EDITION
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Balancing growth in connectivity with a comprehensive global air transport response to the climate emergency.

ATAG
AIR TRANSPORT ACTION GROUP

This report was developed by working groups coordinated by the Air Transport Action Group.

- **Primary analysis and coordination by** BlueSky DATA 2 DECISIONS
- **Detailed sustainable aviation fuel analysis by** ICF

The air transport industry is the global network of commercial aircraft operators, airports, air navigation service providers, manufacturers of aircraft and their components, maintenance providers and new energy companies. It is responsible for connecting the global economy, providing millions of jobs and making the modern, internationally-connected quality of life possible. The Air Transport Action Group (ATAG), based in Geneva, Switzerland, represents the full spectrum of this global business. ATAG brings the industry and related suppliers together to form a strategic perspective on commercial aviation's sustainable development and the role that air transport can play in supporting the sustainability of other sectors of the economy.

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FOREWORD: ASKING THE RIGHT QUESTION

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January 2026

I have often been asked lately "is net zero carbon by 2050 realistic for the aviation sector?". It's an understandable enquiry, but the question should really be "what must happen to *enable* net zero carbon by 2050 for aviation?"

We have always said that reaching aviation's climate goals would be incredibly challenging (indeed, achieving needed climate goals across the entire economy is enough of a challenge). It becomes even harder every year that substantial efforts are delayed. But that shouldn't hold us back from celebrating the progress we have achieved, and from recognising the importance of ambition in setting a destination.

Each year, before the COP climate talks, the United Nations Environment Programme publishes its *Emissions Gap Report* which assesses how the policies put in place by governments around the world are progressing towards the Paris Agreement aims: 'a temperature increase well below 2°C above pre-industrial levels and 'pursuing a limit of 1.5°C warming' by the end of the century. At the time of the Paris Agreement, the stated policies had the world on a likely temperature increase of 3.6°C by 2100.

A decade later, that number falls to 2.6°C if all nationally-determined contributions are implemented. It is still far short of what is needed. But it shows that progress can be made, despite all the odds. Our collective goal is to continue shrinking that temperature rise. Although aviation is just part of that equation, all sectors need to do their bit.

So the question should not be "is net zero for aviation possible?", but rather "***how*** do we best enable net zero carbon for air transport?" More specifically, what actions need to be taken in the next five years to minimise the use of out of sector measures in achieving net zero 2050. This is what we aim to outline in this update to the *Waypoint 2050* analysis.

The past decade has been spent setting the foundation for our decarbonisation journey: billions of dollars invested in new aircraft and relentless efficiency improvements, global policy measures through the International Civil Aviation Organization (ICAO); technical standards on new fuels; ongoing advocacy to the finance and energy sectors of the need to support the scale-up in sustainable aviation fuels; and a massive amount of advanced research and technology development.

The foundation is set. Now, acceleration is vital. At the heart of this edition of *Waypoint 2050* is a pivotal message: **net zero carbon for aviation can be achieved, but it will require significant support to be in place in the next five years to ensure we are on course for 2050.**

Waypoint 2050 is not a detailed prescription, but a global overview of where the aviation sector and its stakeholders should focus decarbonisation efforts to make the biggest impact. We encourage national aviation industries to develop detailed net zero action plans aligned to local context. And for each company in the industry to build decarbonisation into its long-term business planning.

This is the challenge – and responsibility – of a generation.

WHAT WILL ENABLE NET ZERO AVIATION BY 2050?

As this edition of *Waypoint 2050* illustrates, the paths to net zero carbon for aviation by 2050 are challenging, and still possible. But achieving this requires collaborative action across the aviation industry and a broad range of stakeholders including governments and policy makers, the energy industry and finance community.

Each year of delay makes it harder and more costly to achieve. Each missed opportunity for the right policy to be deployed pushes back progress. Many of the required foundations are in place. Now, urgent action is required to accelerate the scale-up and deployment of key measures to reduce carbon emissions.

There is a five-year window to accelerate work to:

» **Scale the production of sustainable aviation fuel (SAF) globally to match demand:**

- Strengthen government policies to implement industrial strategies which support the production and use of SAF at national levels, sub-national and regional levels, on both supply and demand sides.
- Accelerate commitments and use of SAF, including through engagement with individual passengers and corporate customers.
- Energy suppliers must invest in and build new and converted SAF capable facilities and logistics globally through global cooperation with solid and sustained commitment from the aviation sector.
- Ensure that SAF policies supporting coherent regulatory guidance are agile (any unintended consequences to the industry due to policy actions must be corrected to ensure a liquid, global, at-scale, and transparent functioning market for SAF).
- Encourage the use of innovative, globally-harmonised SAF accounting mechanisms (such as book and claim) to enable the efficient scale-up of SAF everywhere.

» **Reaffirm support for and continue to implement CORSIA:**

- The success of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is critical to short- and mid-term goals: expanded participation in CORSIA and supply of CORSIA-eligible emissions units with letters of authorisation (LoAs) is vital.

» **Deploy fuel-efficient aircraft faster into the fleet:**

- Ensure the timely delivery and in-service time of the latest generation of fuel-efficient aircraft by addressing remaining supply chain challenges.
- Improve durability of the latest technology engines and additional maintenance capacity to service growing maintenance needs.
- Accelerate research, development, certification, infrastructure readiness and deployment of next generation disruptive fuel-efficient airframe and propulsion (such as unconventional airframe configurations, efficient engine design, hybridisation, and electric and hydrogen propulsion) for longer-term opportunities.

» **Modernise air traffic management systems:**

- Upgrade or overhaul national and regional air traffic management systems to ensure safe and efficient operations and enable early climate action.
- Advance the opportunities for contrail mitigation as research and operational concepts develop.

» **Accelerate development and scaling of carbon removal:**

- Develop ways to recognise, account for and incentivise carbon removal solutions.
- Secure supply of sufficient volumes of affordable removals for the aviation sector.

This edition of *Waypoint 2050* details the actions the aviation industry is taking and calls for support from key stakeholders to decarbonise air transport across four measures, outlined on pages 8-9.

Two illustrative scenarios are presented on pages 26-27 to show the potential carbon emissions reductions towards the 2050 goal and form the basis for the calls to action.

EXECUTIVE SUMMARY

Waypoint 2050 **draws on the collective expertise of global civil aviation industry experts, to chart how the industry and its key stakeholders can fast-track joint efforts towards the world's climate goals. Collaboration isn't novel in aviation: it is central to how the system functions.**

In 2009, the air transport industry set one of the first global, sector-wide, climate plans for any industry. This *Waypoint 2050* Edition 3 is a review and continuation of the *Waypoint 2050* Editions 1 and 2 published in 2020 and 2021 respectively; it aims to ensure latest developments are taken into account.

Air transport continues to make progress towards net zero carbon goals

Whilst air transport surpassed pre-Covid-19 traffic levels in 2025, the after-shocks caused by the crisis continue to be felt in other areas across the sector. Supply chain disruptions continue to hamper the production of aircraft, engines and critical components, delaying delivery of more fuel-efficient aircraft and therefore fleet renewal and modernisation. Geopolitical shifts, conflicts and escalating tariffs may further intensify these pressures and drive up costs.

These realities pose an additional challenge for the industry's path to achieving net zero carbon emissions by 2050, diverting critical resources away from investments into aviation's four key measures: technology, operations and infrastructure, sustainable aviation fuel (SAF), and market-based measures.

Yet despite these pressures, in recent years the air transport industry has continued to make progress towards its collective goal.

Technology and operations:

Today, the CO_2 emissions per passenger-kilometre for a flight are comparable to those of a small car with average occupancy[1].

- *Technology:* advances in engine and airframe designs have reduced carbon intensity by over 80% since the introduction of jet engines in the 1950s. From 1990 to 2024, this has translated into an estimated ~29% fuel efficiency improvement per unit of revenue passenger kilometres (RPK) traffic.
- *Operations and infrastructure:* optimisation across fleet operations, flight procedures, infrastructure, and aircraft utilisation (such as higher load factors and optimised aircraft cabin usage) have delivered a 25% improvement in efficiency since 1990.

Combined, these two elements have delivered 54% improved efficiency per passenger kilometre since 1990. More information on progress is included in pages 15-20.

Sustainable aviation fuel:

- Global SAF production output has approximately doubled each year since 2018. This growth trend is expected to continue, with SAF production projected to nearly double again in 2025. Progress has also been made across the SAF supply chain. Since 2021, there has been a surge in announcements and actions related to SAF, driven by government initiatives, industry commitments, and technological advancements. Yet sustaining this pace of growth demands robust policy and investment backing.

Market-based measures:

- Since the last edition of *Waypoint 2050*, ICAO reaffirmed CORSIA as the only global market-based measure for international aviation, strengthening it in 2022, along with an agreement on a long-term aspirational goal (LTAG). Carbon removals have since materialised through demonstration projects with investments scaling this initial supply.

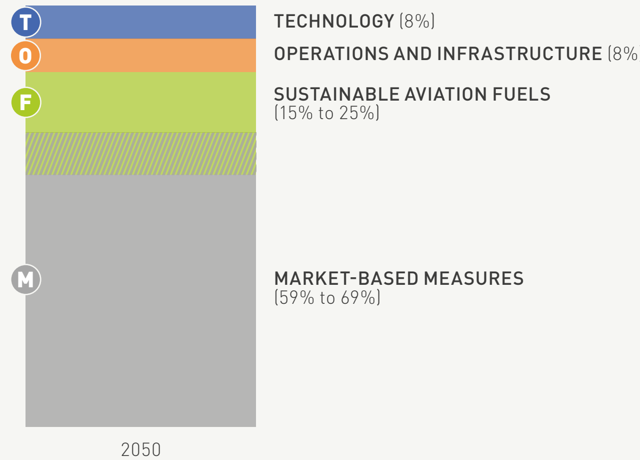
Net zero 2050 is challenging – but possible if action is taken now

Achieving net zero carbon air transport by 2050 is challenging but attainable, provided that key stakeholders across the industry, governments and policy makers, the energy sector and finance community provide the support needed to sustain the sector's decarbonisation trajectory.

This *Waypoint 2050* Edition 3 outlines where global decarbonisation efforts can have the most impact.

The analysis of the reference/baseline (Scenario 0) projects a continuation of current trends in aircraft technology, operational improvements and SAF deployment based on stated policies or goals, with the remaining emissions gap addressed through market-based measures (MBMs). It also assumes passenger traffic will grow at ~ 3.8% per year from 2023 to 2050 reflecting shifts in population growth, economic expansion and demographic trends; underscoring aviation growth continuing to foster worldwide economic and social connectivity.

Scenario 0: Reference/baseline trajectory shows the projected contributions of the four measures to 2050 decarbonisation are:



How can we achieve net zero carbon for air transport?

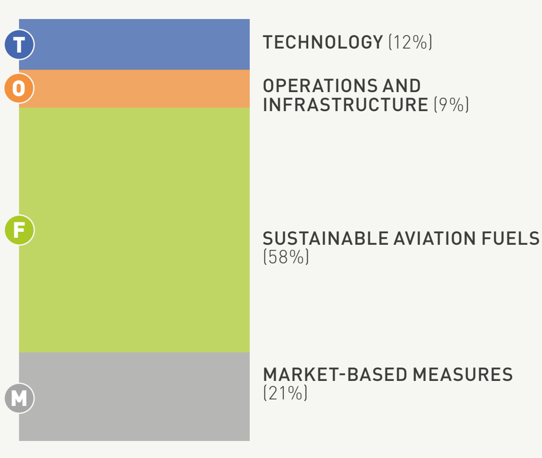
This edition of *Waypoint 2050* includes specific calls to action for key stakeholders (pages 8-9) based on analyses to accelerate the reference/baseline trajectory towards aviation's net zero 2050 goal.

To illustrate the potential emissions reduction from delivering these calls to action, two scenarios are presented in the report.

Exactly how air transport would achieve net zero carbon, would depend on the extent that the calls to actions were delivered; but, alongside efficiency, sustainable aviation fuel (SAF) would be central to both scenarios and a vital point of focus.

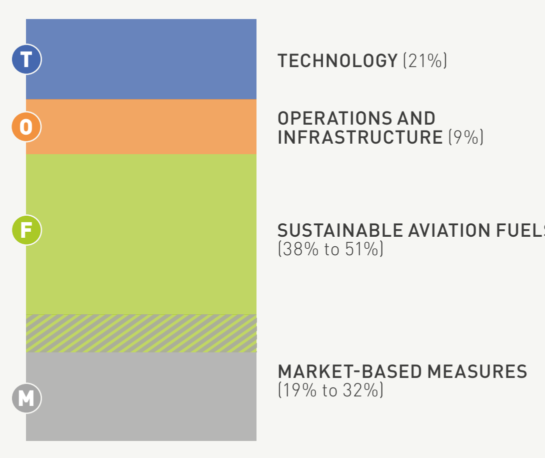
A range of actions are needed to reduce carbon emissions. In each section of the report, action points for different stakeholder groups are explored in detail.

Scenario 1: Sustainable aviation fuel (SAF) is the primary decarbonisation lever, with residual emissions to be addressed through carbon removals and market-based measures (MBMs). This scenario estimates the need for around 430-500 Mt of SAF and estimates the following contribution from each key measure:



Scenario 2: A technology-driven approach, featuring the very ambitious adoption of electric and hybrid-electric and eventually hydrogen aircraft, starting in the next decade, to deliver major emissions reductions. SAF and MBMs would close the remaining gap, but the exact split would be determined over time as solutions develop, with market-driven decisions being made.

Scenario 2 estimates the following contribution from each key measure:



CALLS TO ACTION: SUMMARY

A range of actions are needed to reduce carbon emissions. In each section of the report, action points for different stakeholder groups are explored in detail. Here is a summary of the broad areas of action for aviation decarbonisation.

The table below presents key actions to "**build on current efforts and drive near-/mid-term progress**", "**innovate and develop towards long-term progress**" and "**advocate and collaborate towards joint efforts and progress**".

	Aviation sector	Governments and policymakers	Research institutions	Energy industry	Finance community
T Pages 37-38	Address remaining challenges to ensure delivery of fuel-efficient aircraft Accelerate research and development of more efficient aircraft technologies Form partnerships with non-aviation technology providers and incubate start-ups in aviation and related areas	Adopt durable policies that incentivise and accelerate decarbonisation innovations Prepare agencies for certification processes	Continue research in collaboration with industry into critical topics Ensure research programmes for new technology reflect real-world requirement	Within strategic energy investment, recognise aviation requirements for renewable energy Collaborate with automotive, battery and hydrogen sectors to leverage technologies and build synergies	Fund new aircraft acquisition Explore sustainable finance opportunities
O Pages 43-44	Collaborate to progress efficiency improvements Encourage system efficiency initiatives Pursue community and aviation system engagement on new procedures and techniques for ATM Prepare for the future	Continue to engage in operational carbon emissions reduction initiatives Embed aviation's requirements into wider national energy strategies Support the modernisation and digitalisation of air traffic management (ATM)	Focus on operational improvements Accelerate innovation in operations, procedures and airport infrastructure Build global capacity by training the next generation of experts	Work in partnership with airports to ensure sufficient supply of cleaner energies	Fund infrastructure upgrades and developments

	Aviation sector	Governments and policymakers	Research institutions	Energy industry	Finance community
F Pages 56-57	Commit to SAF offtake Continue to support the qualification of SAF blending components Encourage investment in SAF	Develop policies that support SAF production and use Support the technical development of SAF Invest in SAF Demonstrate recognition of sustainable aviation fuel (SAF) as the primary driver of aviation decarbonisation to 2050	Implement SAF research programmes	Demonstrate substantial and long-term commitment to SAF production Commit to predictable supply of SAF at an affordable cost Guarantee access to airport fuelling infrastructure Other transport modes and energy sectors should prioritise best available energy options such as electrification	Focus on funding SAF opportunities worldwide Investigate innovative financing mechanisms Re-evaluate conventional project risk tolerance assumptions
M Pages 63-64	Continue to implement and strengthen ICAO's CORSIA Recognise the key role of market-based measures Recognise the key role of carbon removals to reach net zero and start to scale carbon removals	Reaffirm support of CORSIA and encourage States to volunteer for CORSIA Accelerate release of letters of authorisation for CORSIA eligible emissions units Support and promote the development of carbon capture and removal opportunities Ensure that environment taxes and levies support the aviation sector's decarbonisation	Accelerate the research into carbon dioxide removal Work on carbon storage and carbon recycling technologies	Support the financing, development and deployment of carbon capture and utilisation technologies	Fund projects to supply CORSIA emissions units and CDRs Facilitate the development and operation of carbon markets Integrate carbon removals in portfolios for aviation sector decarbonisation

The cost of inaction

It is estimated that the transition to net zero carbon by 2050 could cost up to $4.7 trillion. SAF will make up most of the incremental costs with estimates ranging from $1.2 trillion to 4.3 trillion from 2024 to 2050. But ultimately, the costs of inaction – higher capital financing costs, carbon costs associated with a patchwork of climate policy measures, higher insurance and adaptation costs of inaction related to climate change (including operational disruptions and infrastructure damage) – could far outweigh the required investments while constrained growth and waning demand from climate-conscious passengers and corporate customers, would erode its foundation. By contrast, committing to net zero would not only safeguard long-term competitiveness but also secure the trust of customers, investors, and society at large. The path may be challenging, but it is the only way forward for the future of aviation.

NOTE ON SHORT-TERM CHALLENGES

> **Since the last edition of *Waypoint 2050* was published in 2021, the aviation sector has continued to experience substantial challenges. The recovery from the impacts of Covid-19 affected the challenging airline demand-supply equilibrium. Supply chain bottlenecks have delayed aircraft deliveries. More recently, geopolitical challenges, from conflicts to rising tariffs have disrupted operations across the system.**

Continued recovery from Covid-19

The global Covid-19 crisis had an unprecedented impact on economies and societies worldwide, with aviation among the hardest-hit sectors. Its effect on air transport combined the severity of multiple past shocks (such as 9/11, SARS, the global financial crisis, and the Eyjafjallajökull volcanic eruption) into a single, unprecedented "black swan" event. In the early months of the pandemic, global passenger traffic plummeted by 60%, and industry revenues fell by 70%, dealing a devastating blow to the air transport system.

By 2023, the aviation industry had made significant strides in recovering from the pandemic, with many regions returning to 2019 capacity levels by year-end. However, the pace of recovery was uneven, with some areas recovering faster than others. In 2025, air transport has exceeded pre-Covid-19 traffic levels, but the shock caused by the crisis continues to be felt in other areas.

Supply chain challenge

As the aviation industry recovers from the Covid-19 pandemic, it continues to face significant supply chain challenges. Persistent shortages of critical aircraft parts and components, rising costs, labour shortages, debt burdens and manufacturing bottlenecks are hindering both new aircraft production and maintenance operations.

New aircraft and aircraft parts delivery shortages have become a capacity constraint to efficiently satisfy growing demand. IATA estimated that, as of June 2025, the backlog is at an historic high. If compared to a situation with a stable historical ratio of the backlog to the active fleet, the industry is short of an additional 540 aircraft[2].

Airlines and MROs (maintenance, repair, and overhaul providers) are particularly affected by limited availability of essential parts, while manufacturers struggle to scale production to meet strong demand. Aircraft are complex systems integrating thousands of large and small components, coming from a range of tier one suppliers which also rely on their own supply chains. Some more specialised components are made by small and medium-sized enterprises which focus on high-end aerospace manufacturing, sometimes for distinct parts (for example there are entire companies which only manufacture aircraft-grade springs, or 3D-printed brackets for aircraft seats). When Covid-19 hit and the global industry ground to a halt, some of these firms laid off staff or even ceased trading entirely. Replacing staff, or whole suppliers, takes time as aerospace manufacturing is demanding and requires high levels of quality.

The shortage of skilled labour (such as engineers, technicians) further compounds these challenges, slowing production ramp-up and extending maintenance turnaround times. Additionally, reliability and durability issues with some aircraft components, particularly in engines, have led to more frequent maintenance, adding further strain on the supply chain[3]. Issues being experienced with some latest-technology engines have resulted in grounded aircraft and financial and operational strain for airlines.

These disruptions are impacting both manufacturers and airlines, resulting in flight operation disruptions. Because of the slower than expected delivery of the latest generation of aircraft, airlines are flying older-generation aircraft for longer, causing a set-back in fleet-wide efficiency and potentially impacting climate action in the near-term.

At the same time, aging fleets and component reliability issues are driving up maintenance expenses, while parts shortages and longer maintenance cycles increase the risk of flight cancellations and service interruptions, affecting both customer satisfaction and airline revenues. In addition, there is a challenge to ensure MRO capacity is developed globally for the additional maintenance to service some of the high-technology engines more frequently – this will need to remain an area of key focus and action for years to come.

These factors contribute to increased operating expenses amidst strong demand for air travel. The supply chain issues are already starting to resolve themselves, but with a long tail of disruption which will cause efficiency to be impacted in the short-term.

Near-term action *to accelerate progress towards the 2050 goal:*

- *Address remaining supply chain challenges to ensure timely delivery of the latest generation of fuel-efficient aircraft.*
- *Continue to improve engine reliability of the latest technology engines and develop additional MRO capacity to service growing maintenance needs of the growing global fleet.*

Geopolitical challenges: conflict

Geopolitical conflicts and instability continue to disrupt global aviation, affecting air routes, airports, increasing insurance and security costs, and limiting the availability of essential materials and components. Conflicts in Ukraine and several areas of the Middle East have posed significant challenges to the sector, resulting in flight path disruptions, rising operational expenses, greater complexity in air traffic management, and impacts on both passenger and cargo traffic that risk reversing industry efforts to improve operational flight efficiency.

Airspace closures over Africa, Ukraine, Russia, and parts of the Middle East have forced airlines to reroute flights, leading to longer travel distances and extended flight times as well as closed airport infrastructure. For example, geopolitical tensions in the Middle East have added up to two hours to flights between London and Hong Kong. This rerouting increases fuel consumption, crew hours, and airspace overflight fees, all of which drive up operating costs and carbon emissions – particularly for long-haul flights.

Moreover, the narrowing of safe flight corridors has led to increased air traffic congestion and delays, especially in regions such as Central Asia. Airlines must also adapt to evolving security risks and sudden airspace restrictions, requiring constant adjustments to flight plans. This operational strain can reduce available capacity, contribute to flight delays or cancellations and impact industry revenues.

Large swathes of airspace affected by conflict

The past few years have brought frequent airspace closures due to conflicts, which are unprecedented in modern times. Over the last 24 months, the crucial airspace over Ukraine, Iran, Iraq, Jordan, Qatar, Syria, Lebanon, Israel, Pakistan and India has been completely closed or extremely limited. In addition, Russian Federation airspace has been closed to airlines from certain countries and European airspace closed to Russian carriers, together forging a complex and inefficient operating environment.

Image captured from Flightradar24 (www.flightradar24.com)

Geopolitical challenges: tariffs

Tariffs – taxes on imported goods – can have a significant impact on the aviation sector by raising production costs for aircraft manufacturers. These increased costs may be passed on to the industry and passengers, potentially resulting in higher ticket prices and ultimately reduced demand for air travel. Tariffs also discourage trade and economic activities, which directly impact air transport demand for both passenger and cargo.

Trade in SAF and feedstocks for SAF production are also affected by tariffs, which can raise the cost of SAF production and fuel prices. Particularly in the early stage of development of the SAF industry, tariffs can impede project development and production scale-up. In addition, supply chain disruptions caused by trade barriers are a major concern, particularly for OEMs that rely on complex, globally integrated supply chains. In some cases, these may lead to cancellations of orders and delay the entry of new fuel-efficient aircraft into the fleet[4]. Furthermore, trade barriers and disruptions could impede the rollout of new innovations and increase costs to operators, which limit resources that would otherwise be potentially available to support the decarbonisation transition.

The global aviation industry has consistently advocated for a tariff-free trading environment, as established under the 1979 Agreement on Trade in Civil Aircraft. This agreement, signed by 33 countries, eliminates duties on civil aircraft, engines, flight simulators, and related parts and components, supporting cost-effective, efficient global trade within the sector.

Near-term action:

» *Ensure a tariff-free trading environment, as established under the 1979 Agreement on Trade in Civil Aircraft.*

PROGRESS ON CLIMATE COMMITMENTS

In aviation, waypoints are significant points on a flightpath that pilots use in navigating their direction of travel. They are neither the start nor the end of a journey, but a guide to where the flight needs to go. As the flight progresses, conditions may evolve, requiring adjustments to trajectories.

This third edition of *Waypoint 2050* offers a timely checkpoint on recent progress since 2021, addressing three pivotal questions: How has the sector performed against our prior forecasts? Are we still on the trajectory towards the waypoint? And do we need to recalibrate our course?

Historical trends and progress

Fuel efficiency has been a core focus of the air transport industry since its inception, driving continuous advancements in technology and operations. The sector has achieved notable improvements in two key areas:

» Aircraft technology: Advances in engines and airframe design have reduced carbon intensity by over 80% since the introduction of jet engines in the 1950s. From 1990 to 2024, this has translated into an estimated -29% fuel efficiency improvement per unit of RPK traffic.

» Operational efficiency: optimisation across fleet operations, flight procedures, infrastructure, and aircraft utilisation (such as higher load factors and optimised aircraft cabin usage) have delivered a 25% improvement in efficiency since 1990.

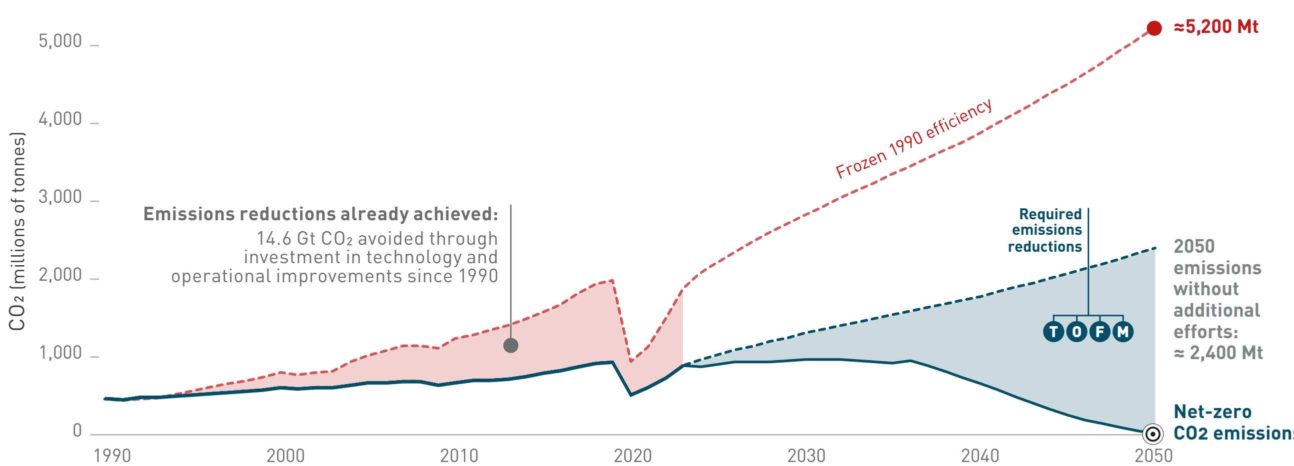
» Combined, these two elements have delivered 54% improved efficiency per passenger kilometre since 1990.

Today, the CO_2 emissions per passenger-kilometre from a flight are comparable to those of a small car with average occupancy[5]. Each new generation of aircraft brings further fuel efficiency gains; however, these incremental improvements are becoming increasingly difficult to achieve, as air travel is already highly efficient on a per-kilometre basis.

Looking ahead, ongoing fleet renewal remains a prime source of CO_2 reductions. Around 35% of the current global fleet comprises the latest generation aircraft, and future deliveries of aircraft will increase that proportion in the years to come. Modern aircraft already deliver substantial fuel and emissions savings compared to older models, providing immediate environmental benefits as previous generations are replaced.

Efficiency improvements have been impressive, more work is needed

Efficiency measures have already saved 14.6 Gt of CO_2 since 1990, but further work is needed to get the sector down to the industry goal in 2050 (the required emissions reductions are explored in this publication), towards net zero at a global level.



Recent progress

In 2021, during the Covid-19 pandemic, the air transport industry adopted the ambitious 2050 goal of net zero carbon emissions. Since then, the aviation sector has steadily recovered, restoring traffic levels and stabilising global operations. At the same time, the industry has made meaningful progress towards its climate goals, despite the ongoing challenges of post-pandemic recovery.

Recovery from the Covid-19 Pandemic

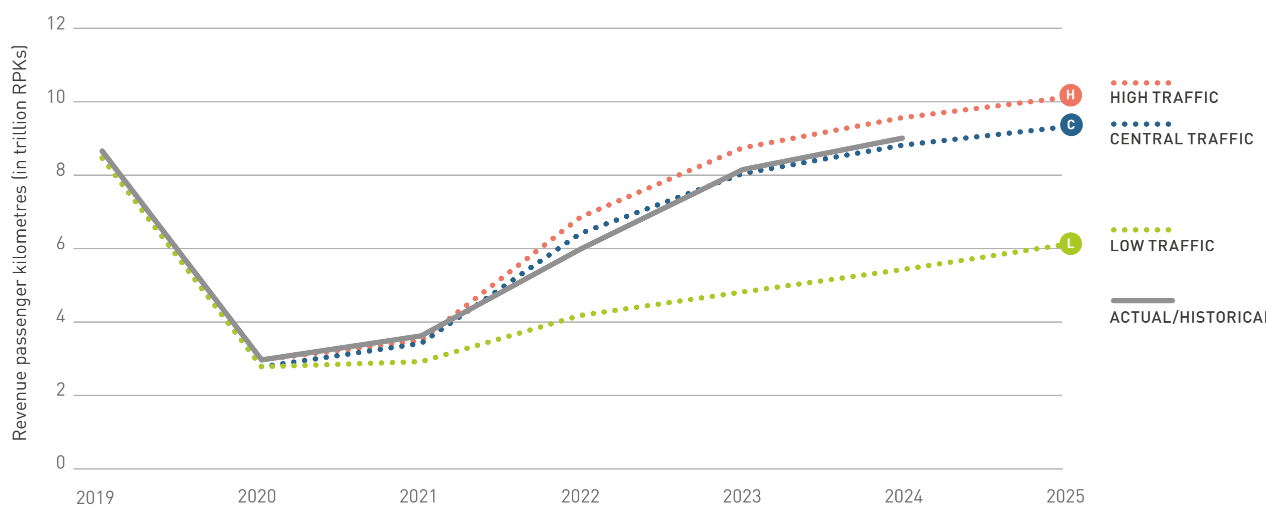
The *Waypoint 2050* Edition 2 was based on traffic forecasts published in July 2021. Since then, actual traffic data has become available, allowing a comparison with those earlier projections.

Overall, global passenger traffic has broadly aligned with the central (mid-range) forecast used for the analysis in *Waypoint 2050*. In 2022, the recovery was slightly slower than expected; however, this was followed by stronger-than-projected growth in 2023, bringing traffic levels to within approximately 1.5% of the original forecast.

Reported traffic for 2024 indicates that global passenger traffic could remain close to the original projections made in 2021, with deviation of around 2.4% in 2024 relative to the central forecast. Preliminary estimates for 2025 suggest that global passenger traffic could remain close to the projections made in 2021, with deviations of 1.7% in 2025 relative to the central forecast.

Global passenger traffic: actual vs. previously projected

Recovery from the Covid-19 pandemic continued since 2021. By 2023-2024, depending on region, traffic had recovered to 2019 levels. The *Waypoint 2050* central traffic scenario proved to be fairly accurate and representative.



Aircraft technology: progress and challenges

The Covid-19 pandemic had significant impacts on aircraft technology development and the entry into service of new aircraft models. Supply chain disruptions created severe challenges, contributing to production and delivery delays. Notable examples include delays in the Boeing 737 MAX-8 and -9 programmes, constraints on Airbus A350 production, and certification setbacks affecting several aircraft models, such as the Boeing 737 MAX-7 and -10, and the Boeing 777X. Similarly, first deliveries of the Airbus A350F have been postponed to 2027 due to supply chain issues.

Some future aircraft programmes anticipated in previous *Waypoint 2050* assessments were postponed or cancelled. For instance, a new midsize aircraft, initially projected for entry into service around 2027, is no longer expected in this timeframe. Adjustments to technology roadmaps reflecting these changes are discussed in the technology chapter on page 33.

Despite these delays, the industry has continued to advance research and development in key areas such as aerodynamics and structural improvements for next-generation tube-and-wing configurations. There is also sustained momentum in researching and developing unconventional designs, such as the blended wing body, and in improving engine propulsive efficiency within conventional ducted fan architectures.

Research into alternative propulsion concepts and energy systems, including open (un-ducted) fan engine designs, hybrid-electric systems, and hydrogen-powered aircraft, is ongoing. However, the anticipated contribution of hydrogen-powered aircraft in sector-wide emissions reductions now seems more modest than earlier forecasts, especially pre-2050: due to a combination of a slow ramp-up in the required hydrogen ecosystem coupled with initial products likely only addressing shorter range flights and thus a limited proportion of fuel consumption (see the technology chapter for further analysis).

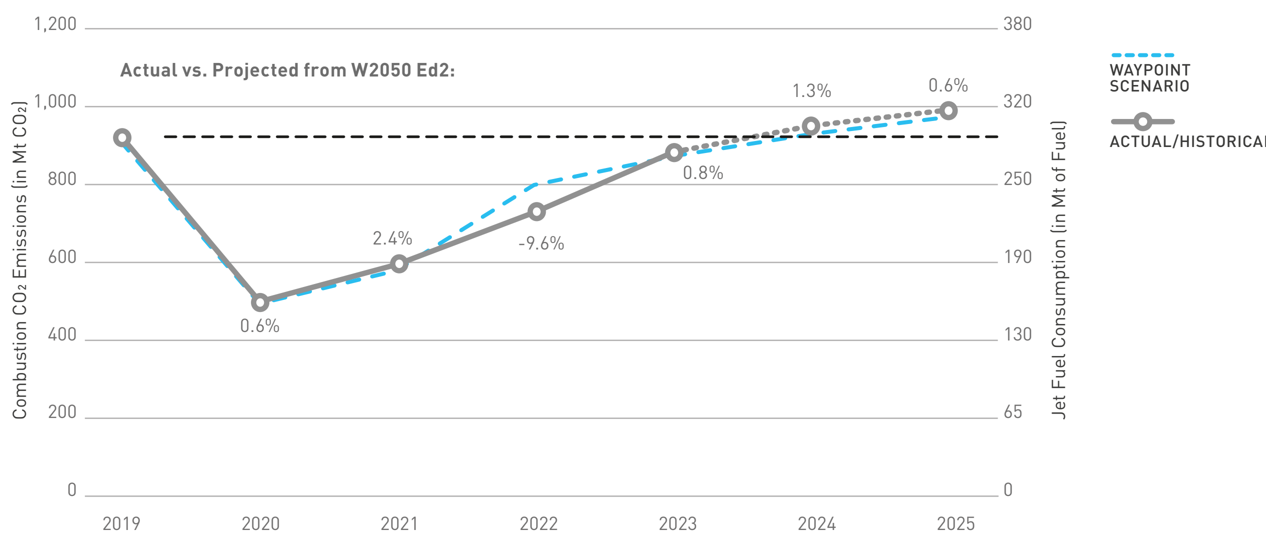
Fuel use and combustion CO_2 emissions

In addition to tracking actual global traffic against previous projections, recent data on fuel use and CO_2 emissions have also been compared with the *Waypoint 2050* scenarios. Overall, actual combustion emissions closely followed the projections outlined in the last *Waypoint 2050* report through 2023, with the exception of 2022, when lower-than-expected traffic during the post-pandemic recovery resulted in a temporary deviation.

By 2023, fuel use and CO_2 emissions aligned closely with prior projections, coming within 0.8% of the forecasted levels. While data for 2024 and 2025 are still estimated, current forecasts suggest emissions will remain within 1.3% and 0.6% of the *Waypoint 2050* scenarios.

Fuel use and combustion CO_2 emissions: actual vs. previously projected[6]

Actual recent combustion emissions came very close (0.8% in 2023) with previous projections used in *Waypoint 2050*, published in 2021.



Progress on sustainable aviation fuels (SAF)

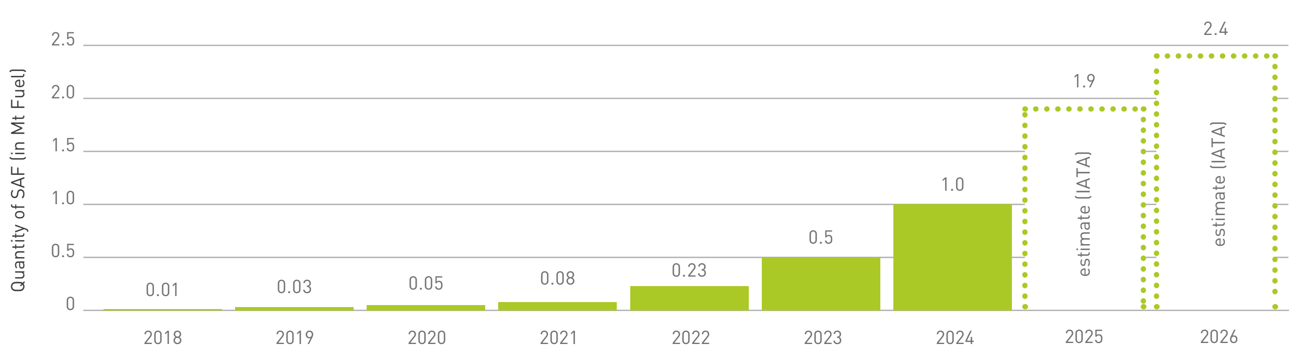
A transition from conventional jet fuel to SAF is widely recognised as a critical solution for reducing aviation's climate impact. Since 2021, SAF production capacity and SAF use by airlines have increased substantially.

Global SAF production output has approximately doubled each year since 2018, reaching an estimated 1 million tonnes (Mt) in 2024[7] – equivalent to about 0.3% of total aviation fuel consumption. This growth trend is expected to continue, with SAF production projected to nearly double again in 2025, reaching 2 Mt[8], or approximately 0.7% of total fuel use. Progress has also been made across the SAF supply chain. In 2024, 100 airports globally supplied SAF, including 47 airports receiving batch deliveries[9].

Since 2021, there's been a surge in announcements and actions related to SAF, driven by government initiatives, industry commitments, and technological advancements.

Recent historical evolution of the production of SAF

Recent data indicates a significant increase in SAF production, with volumes approximately doubling year over year through 2024. These levels are below what was anticipated in the previous edition of *Waypoint 2050*. A more aggressive acceleration is therefore needed now, and particularly in the 2030-2045 timeframe, in order to meet industry requirements.



SAF demand environment – airlines are taking a multi-faceted approach to voluntarily promote and adopt SAF to achieve ambitious decarbonisation goals, most notably the target of net zero carbon and / or GHG emissions by 2050. Over 50 airlines globally have voluntary commitments to incorporate SAF into their operations, with most aiming for 10% of their total jet fuel by 2030. These airlines represent 45% of global air traffic, by revenue tonne kilometres (RTKs), and therefore over 40% of global jet fuel use. A number of these airlines are already using SAF today, whilst many are using these voluntary commitments to drive ambition internally and with stakeholders.

SAF demand environment – air transport customers, corporations and other users of transport services have partnered with the aviation sector to purchase SAF emissions reductions to meet their own climate commitments. These transactions occur through airlines, fuel producers, or third-party demand aggregators using book and claim mechanisms. The partnership with corporations has been a key enabler of SAF in markets with voluntary SAF ambitions and incentives.

SAF demand environment – governments. In November 2023, governments adopted a collective vision to start the shift away from fossil fuels at the third ICAO Conference on Aviation and Alternative Fuels (CAAF/3): aviation fuel in 2030 should be 5% less carbon intensive than the fossil fuel which makes up nearly all of today's aviation energy. This is to be achieved through a transition to SAF and, as an interim tool, the use of lower carbon aviation fuels (LCAF). In order to meet the ICAO CAAF/3 vision, around 23-27 Mt of SAF would be needed in 2030 if it were applied to all global air traffic, or ~14 Mt if it were only applied to international traffic (ICAO's mandate).

Governments have developed national and/or regional SAF policies, including but not limited to:

- *Brazil:* National Sustainable Aviation Fuel Program (ProBioQAV) or "Fuel of the Future" programme, mandates airlines to reduce greenhouse gas emissions from domestic flights by using SAF, starting with a 1% reduction in 2027 and reaching 10% by 2037.
- *European Union:* The ReFuelEU Aviation initiative mandates a gradual increase in SAF blending by fuel suppliers, from 2% in 2025, 6% in 2030, 20% in 2035 reaching 70% by 2050.
- *India:* Indicative SAF blending of 5% in 2030 set for international flights.
- *Japan:* Collaboration between ministries aims for 10% SAF use by 2030, supported by tax credits and financial support for SAF production investments.
- *Singapore:* SAF use will be mandatory for departing flights starting in 2026.
- *South Korea*: 1% SAF blend mandate on international flights from 2027.
- *Switzerland:* Starting in 2026, the mandate will require a minimum of 2% SAF for flights departing from Swiss airports, increasing to 6% by 2030 (i.e., aligned with EU Regulation "ReFuelEU Aviation").
- *United Kingdom:* mandate in place of a 10% SAF use by 2030, up to 22% by 2040.
- *United States:* The SAF Grand Challenge, launched in 2021, set ambitious goals of increased domestic SAF production to 3 billion gallons per year by 2030, and 35 billion gallons by 2050[10].

SAF production ecosystem Between 2021 and mid-2025, global SAF production capacity and supply has significantly increased. In 2021, around five facilities could produce SAF, with an estimated production output of 0.08 Mt[11]. As of mid-2025, over 30 facilities have been commissioned, and production is now expected to be ~2 Mt in 2025[12]. Most of this capacity comes from refining fats, oils and greases (FOGs) or hydroprocessed esters and fatty acids (HEFA) pathway or in co-processing with fossil crude, accounting for over 99% of total production[13]. The production market has also expanded geographically. While SAF production was initially concentrated in the United States and the EU, approximately half of current SAF production capacity is in Asia. In addition to capacity already in production or close to completion, 145 facilities have been announced to come online by the end of the decade, with global production capacity expected to rise to over 18 Mt by 2030.

The last *Waypoint 2050* assessment exhibited high expectations for the role of SAF towards the decarbonisation of the global aviation sector. Despite substantial capacity scale-up and progress, actual production levels remain below all previous *Waypoint 2050* SAF scenarios.

***Near-term actions** to accelerate progress towards the 2050 goal:*

- *Develop new or strengthen existing global policies (revenue certainty mechanisms, direct research and development activities for local SAF production pathways and new energy industries) that drive voluntary SAF demand, incentivise the development and production and use of SAF and build a solid and stable market.*
- *Secure investments to accelerate the development SAF production capacity.*
- *Accelerate and remove barriers to the development of facilities to produce SAF.*
- *Broaden the access and use of SAF across operators and regions supported by appropriate and coordinated SAF accounting systems (book and claim systems).*
- *Prioritise aviation (and other hard-to-abate sectors) as a user of alternative fuel, especially through the prioritisation of critical feedstocks such as biomass or CO_2 for SAF production.*
- *Develop new partnerships across aviation and energy sectors and with governments to better enable SAF capacity development by the energy sector.*

SAF feedstock assessments

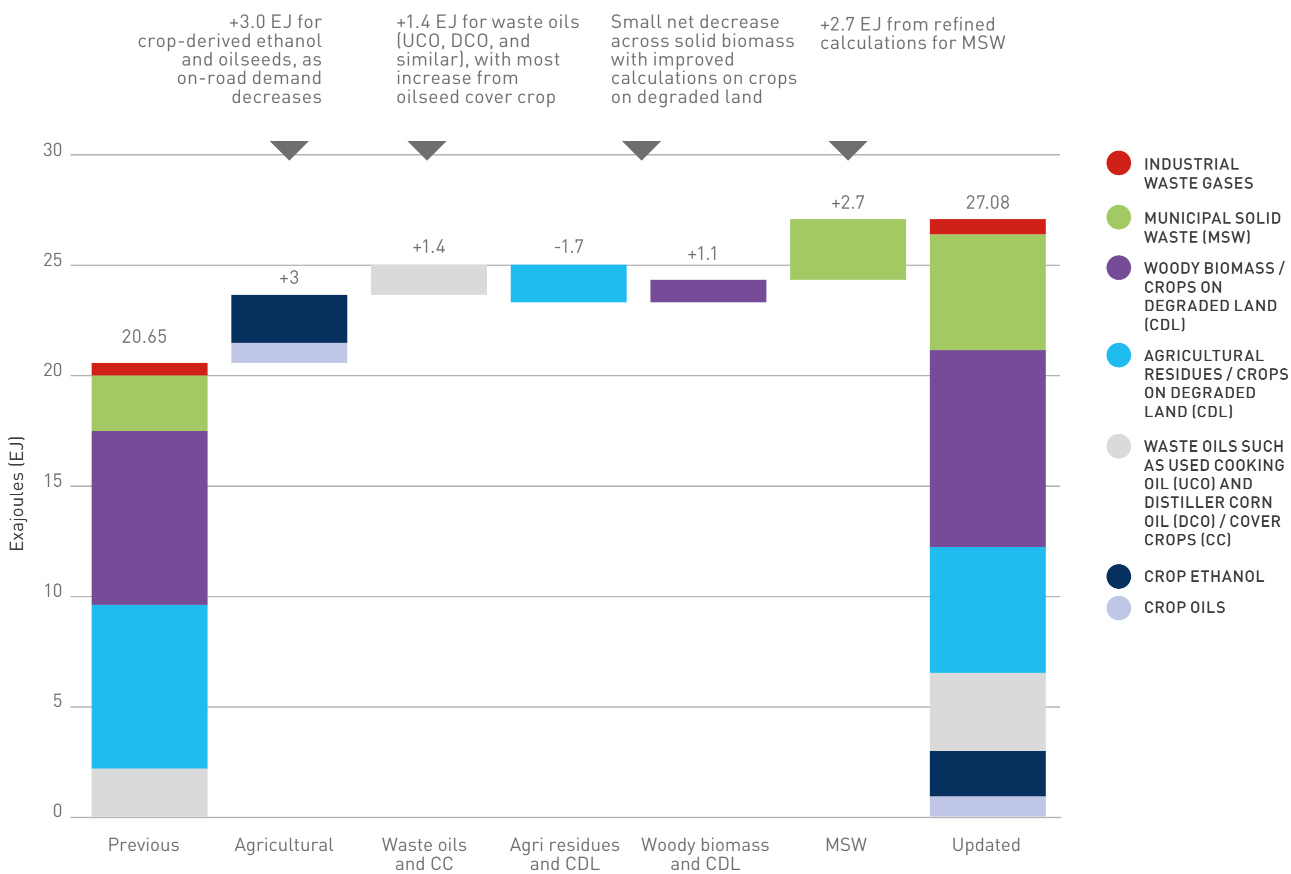
Continued research and practical knowledge development in the 2021-2025 period has allowed for increased detail and scope for the SAF feedstock analysis, including the addition of selected crop-derived oilseed (CDO) and ethanol feedstocks, additional analysis on the opportunity for cover crops (CC) and crops on degraded land (CDL), and refined calculations on other areas. In 2021, it was estimated that 20.65 exajoules (EJ)[14] of biogenic feedstocks were available for use in SAF refineries, and these updates have increased the estimated biogenic feedstock availability to 27.1 EJ by 2050 (+30%). This increase was driven by the addition of crop-derived oils and ethanol (+3 EJ), and an increased estimation for waste oils (UCO) and oilseed cover crops (+1.4 EJ). The estimate for municipal solid waste (MSW) also increased (+2.7 EJ), based on a detailed model of global MSW production, avoidance, recycling, incineration, and specifications suitable for SAF production. There was also a slight downward re-assessment of the potential for cellulosic crops on degraded land.

***Near-term actions** to accelerate progress towards the 2050 goal:*

» *Accelerate the certification of new feedstocks and pathways and avoid bottlenecks that could prevent the scale-up of SAF.*

New assessment on feedstock availability

Recent data indicate an increase in SAF feedstock availability in the 2050 timeframe due to factors including production efficiency gains, transition of feedstocks from on-road biofuels to SAF, and improved calculations[15]. This assessment does not include power-to-liquid SAF which, in theory, is not feedstock constrained.



Net CO_2 emissions

Through 2023, residual CO_2 emissions remained 4% below 2019 levels. Due to the lasting impacts of Covid-19, international aviation emissions also remained below the ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) baselines and therefore airlines did not require CORSIA-eligible emissions units for use during this period. As a result, net CO_2 emissions also stayed below 2019 levels.

However, trends for 2024 and 2025 show that both combustion and residual CO_2 emissions will continue to rise, surpassing 2019 levels. As emissions grow, market-based measures such as CORSIA will play an increasingly critical role in closing the gap towards the sector's goal of carbon-neutral growth.

NET ZERO CARBON SCENARIOS

> **Many hundreds of scenarios to decarbonise air transport are possible when forecasting such a complex global system. *Waypoint 2050* has chosen two illustrative options.**
>
> **This is to demonstrate that there is not just one pathway towards net zero carbon in 2050, but that all stakeholders will need to make choices as they accelerate progress.**

As the path to decarbonisation progresses, evolving conditions will require further adjustments in order to keep on track. This third edition of *Waypoint 2050* provides the opportunity to reassess recent progress and refine our paths towards the 2050 goal.

The sector's climate action framework is underpinned by advances in four areas: new technology, operational efficiency, new fuels, the development of more efficient infrastructure, bolstered by CORSIA, the world's first global carbon market mechanism for any global sector.

Scope: commercial aircraft operations above ~19 seats

Waypoint 2050 outlines the CO_2 emissions trajectory for commercial aviation over the next 25 years. The study focuses exclusively on aircraft operations and jet fuel use, excluding military aviation and most general aviation.

Emerging sectors such as unmanned aerial vehicles (drones), urban air mobility (air taxis), and supersonic aircraft were considered but excluded from the scope, as they are not expected to be significant contributors to aviation emissions by 2050, are likely to be niche markets or fall outside the scope for commercial air transport services. While efforts to reduce emissions from ground-based aviation sources (such as airport infrastructure, manufacturing sites or office facilities) are ongoing, these are outside the scope of *Waypoint 2050,* except where they directly affect aircraft fuel consumption.

Scope: decarbonisation

Waypoint 2050 deliberately tackles perhaps the most challenging part of air transport's climate action: the energy transition and decarbonisation of the sector. Not only does this require the industry and aviation institutions to work together, but for the energy sector to actively lead on transitioning its fuel energy supply to the aviation sector with significant input from energy, finance and government partners.

Another aspect of aviation's climate action are short lived climate pollutants ("non-CO_2" emissions), most visibly contrails – the white lines in the sky sometimes appearing after flights in certain atmospheric conditions. There are still many uncertainties about the scale of climate impact that contrails have. The latest scientific consensus is that contrails have, on balance, a warming impact, with an effect potentially in the same order of magnitude as aviation's CO_2 emissions, but the quantification of this impact currently has low confidence levels amongst the scientific community.

Significant research to improve scientific understanding as well as understanding of the potential mitigation options (operations, technologies, fuels) is currently ongoing. Operational elements could include horizontal or vertical trajectory adjustments to avoid areas of atmosphere likely to generate warming contrails, or the even the use of turboprop aircraft on appropriate routes, which tend to fly lower than contrail prone areas.

The aviation industry is committed to better understanding and mitigating its impact on the climate. It is actively contributing to scientific research, as well as undertaking operational trials, simulations and other studies aimed at developing the means to reliably reduce persistent warming contrails through a variety of mitigation options, further reducing the climate impacts of the sector.

» Further information on contrails and joint industry and research efforts to reduce this part of aviation's climate impact can be found at https://ataglink.org/48PGCzj

The current priority for industry and government climate action should continue to be CO_2 emissions reduction (where there is high scientific certainty) and the significant efforts underway to reach net zero carbon by 2050.

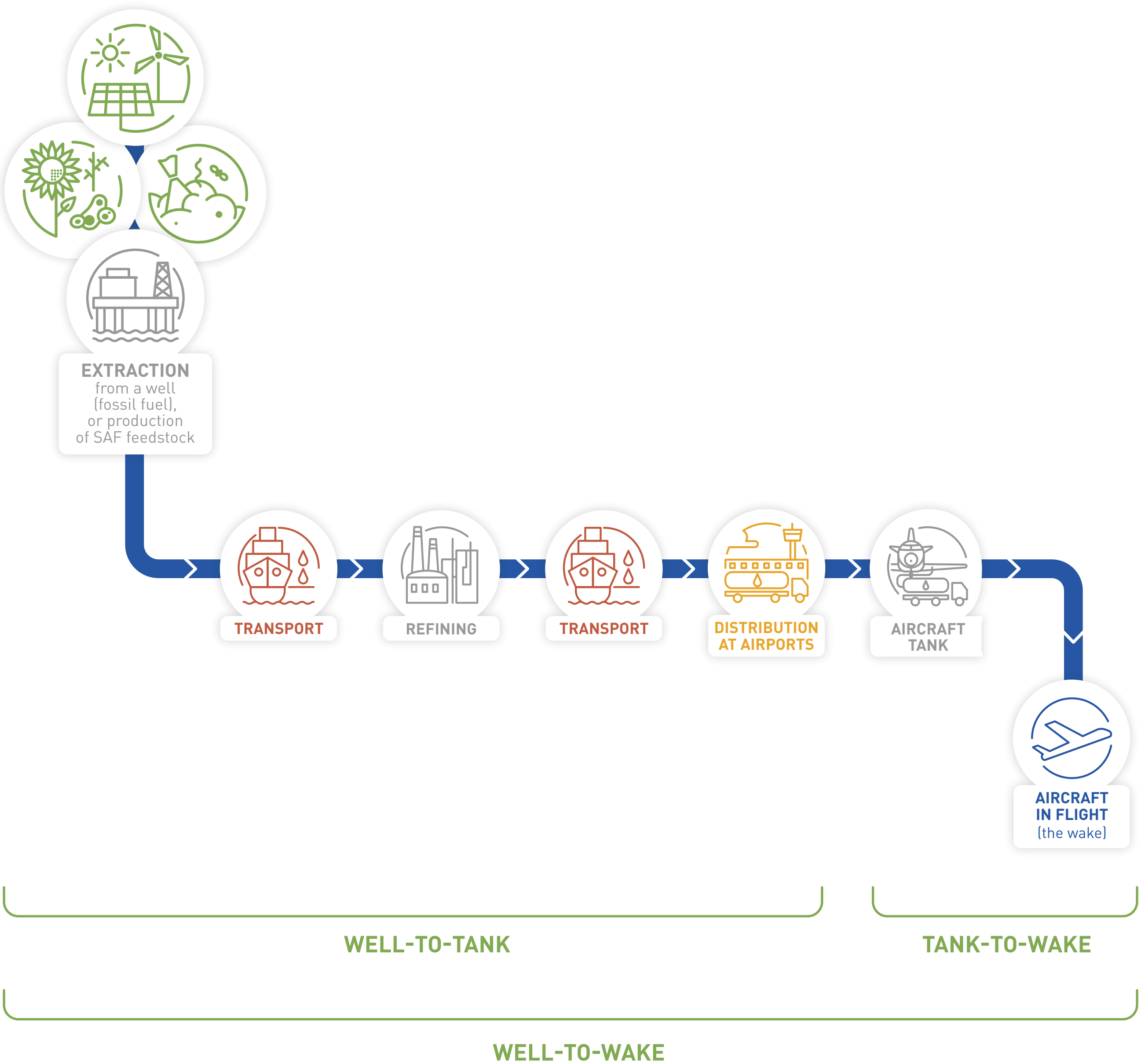
Scope: tank-to-wake

The emissions data presented in the charts below focus on tank-to-wake (TtW) emissions, also referred to as operators' Scope 1 emissions. Emissions reductions associated with SAF are accounted for through their lower life-cycle emissions relative to conventional jet fuel. The role of SAF in this analysis is based on the ICAO CORSIA methodology, which reflects the combustion-related emissions portion (3.16 gCO_2/gfuel) of life cycle values. It is important to note that within this methodology, a majority of the life cycle emissions reductions from SAF that occur in the well to tank (WtT) phase are accounted for as TtW reductions.

Well-to-wake (WtW) emissions accounting – which includes upstream production and transport emissions – is used in some industry greenhouse gas (GHG) reporting frameworks.

While WtW emissions and TtW emissions (with life cycle emissions reductions from SAF) used in this analysis differ in absolute quantities (e.g., in $MtCO_2$), relative improvements from aircraft technology, operations improvements and SAF towards net-zero emissions (in percent improvements) are identical.

The TtW scope used in this analysis is relevant and valid as the well-to-tank portion of fossil fuel delivery is in the control of the traditional fossil fuel suppliers and not the 'aviation' sector, which has limited ability to control the carbon emissions related to extraction and production. Furthermore, the application of market-based measures and carbon removals in aviation is expected to primarily be confined to addressing emissions within the TtW scope.



No silver bullet and no single path to reach the 2050 goal

This report presents two potential scenarios (Scenario 1 and Scenario 2) alongside a reference/baseline scenario (Scenario 0), which reflects conservative assumptions for aircraft technology, operational improvements and SAF deployment based on stated policies or goals, with the remaining emissions gap addressed through carbon removals by 2050. These scenarios are built on a series of sub-scenarios, detailed in the following chapters, covering a) traffic forecasts, b) technology, c) operations and infrastructure improvements, d) SAF, and e) market-based measures to address any remaining residual emissions. It is important to note that in all three scenarios, including the baseline, net zero carbon is (technically) achieved by 2050, but with varying degrees of reliance on market-based measures, including carbon removals. However, the ambition of the aviation sector is to maximise the use of SAF and the other in-sector decarbonisation options by 2050 with only remaining emissions addressed through out-of-sector market-based measures.

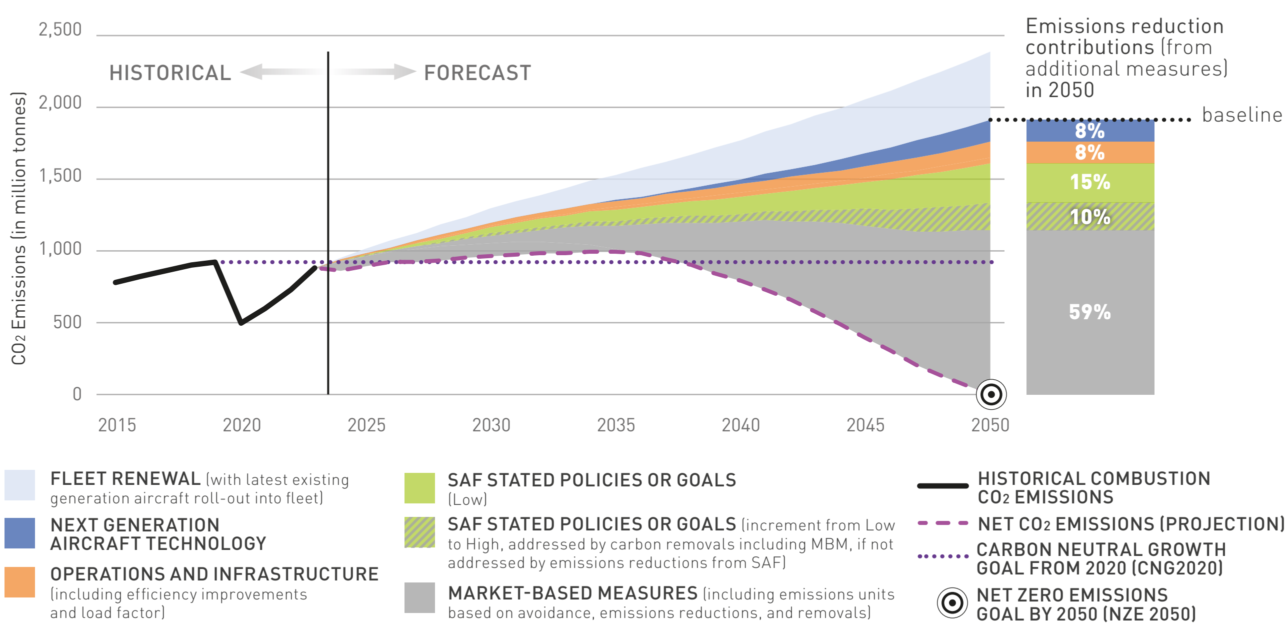
Summary of *Waypoint 2050* integrated scenarios

SCENARIO 0 Reference/baseline scenario		SCENARIO 1 Focus on SAF deployment scenario	SCENARIO 2 Technology-centric market scenario
C 3.8 %	**Traffic growth** Revenue passenger kilometre compound annual growth rate (2023-2050)	C 3.8 %	C 3.8 %
T2 Tube & Wing Configurations	**Technology developments** (beyond fleet renewal with the latest existing generation aircraft)	T3 Transition to New Configurations	T4 Towards hybridization and non-drop in energies
O2 Mid	**Operations and infrastructure improvements**	O3 High	O3 High
F1 ~ 150 Mt with ~ 56% to 94% ERF	**Sustainable aviation fuel** Quantity of SAF with emissions reduction factor (ERF) in 2050:	F2 ~ 430 Mt with ~ 84% ERF (Similar emissions reductions achieved with ~ 500 Mt with ~ 70% ERF)	F3 ~ 280 to 380 Mt with 81% to 84% ERF
M1 ~ 1150 to 1350 Mt CO_2	**Market-based measures** to address residual carbon emissions Residual CO_2 emissions gap in 2050:	M2 ~ 400 Mt CO2	M3 ~ 370 to 620 Mt CO_2

SCENARIO 0: REFERENCE/BASELINE SCENARIO

Traffic forecasts are in the 'central' range of around 3.8% per annum compound growth from 2023 to 2050. Addressing remaining supply chain challenges to ensure timely delivery of the latest generation of fuel-efficient aircraft is important to deliver system level improvements from fleet renewal (the light blue wedge in the chart below). Technology improvements are relatively conservative, relying on conventional tube and wing configurations for the next generation of aircraft joining current fleet replacement with today's most advanced aircraft in the mid-2030s. Despite mid-level traffic growth, investments in operations and infrastructure result in some net improvements and CO_2 reductions. SAF as developed according to stated policies or goals (existing blend mandates and announced policies alongside those expected before 2030) could result in ~150 Mt of SAF in 2050 representing 270 to 460 $MtCO_2$ of emissions reductions. Under this scenario, residual emissions would reach 1,150-1,350 $MtCO_2$ by 2050 requiring equivalent volumes of emissions units from market-based measures (MBMs) to reach net zero carbon emissions in 2050.

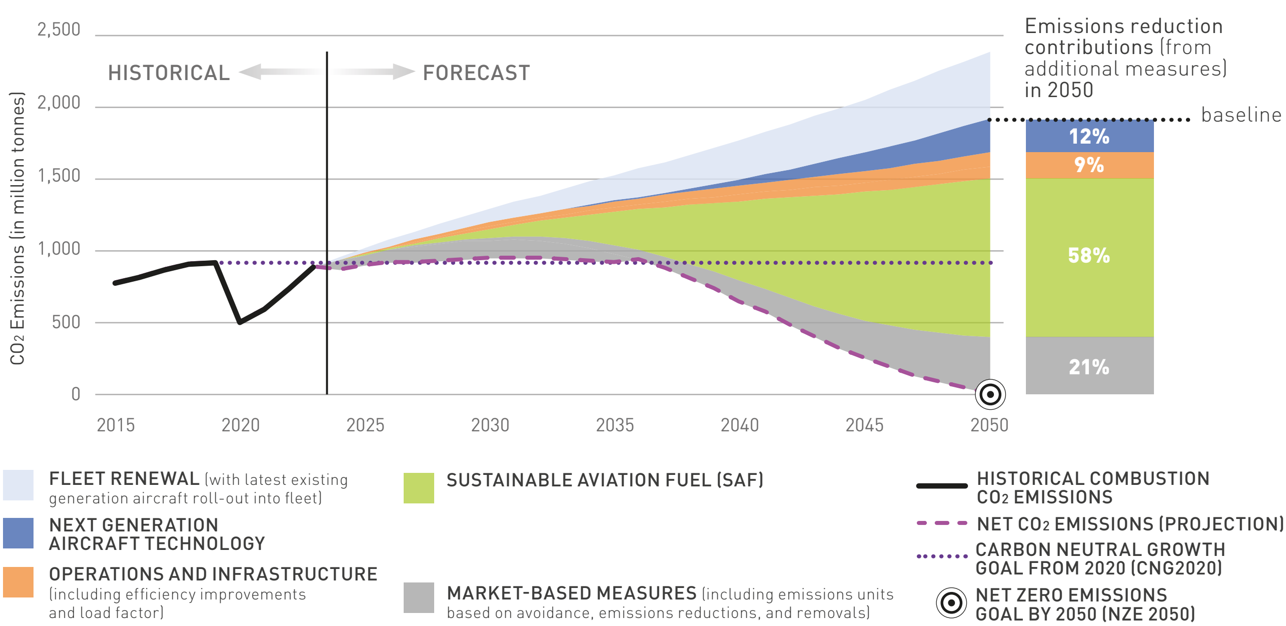
Traffic growth	C	Central scenario: 3.8% compound annual growth rate (CAGR) 2023-2050
Technology developments (beyond fleet renewal with the latest existing generation aircraft)	T2	Continuation of current development cycle and performance T2 improvement (conservative next generation of 'tube-and-wing'). Additional reductions (T2) ~ 160 $MtCO_2$.
Operations and infrastructure improvements	O2	Mid-range improvements
Sustainable aviation fuel	F1	F1 (low to high) depicts stated policies (as of 2025) reaching ~150 Mt (190 billion litres) of SAF by 2050 with ERF ranging across policies from 56% to 94%.
Market-based measures to address residual carbon emissions	M1	Contribution from market-based measures to meet the 2050 goal: ~ 1150 — 1350 Mt CO_2.



SCENARIO 1: FOCUS ON SAF DEPLOYMENT

Under this scenario, traffic forecasts follow a 'central' range of around 3.8% per annum compound growth from 2023 to 2050. Technology improvements are moderately ambitious including some limited deployment of new aircraft configurations such as blended wing body in the late 2030s, along with advances in both traditional engines and the introduction of open rotor technologies. There is no significant shift to electric or hybrid technologies, with the industry prioritising investment in sustainable fuels. Higher investments in operations and infrastructure result in additional improvements and CO_2 reductions. The gap between combustion CO_2 emissions (after technology and operations and infrastructure improvements) and the 2050 carbon goal is fulfilled for the most part with SAF. This requires significant amounts of SAF (~430 Mt). Reflecting anticipated emissions reduction factors (average emission reductions factor of 84% equivalent to carbon intensity of ~15 gCO_2/MJ), SAF may contribute to ~1,100 MtCO_2. Similar emission reductions from SAF can be achieved with 500 Mt of fuel with an average 70% emission reduction factor. The residual CO_2 emissions (~400 MtCO_2) would need to be addressed by market-based measures (mainly carbon dioxide removal (CDR)).

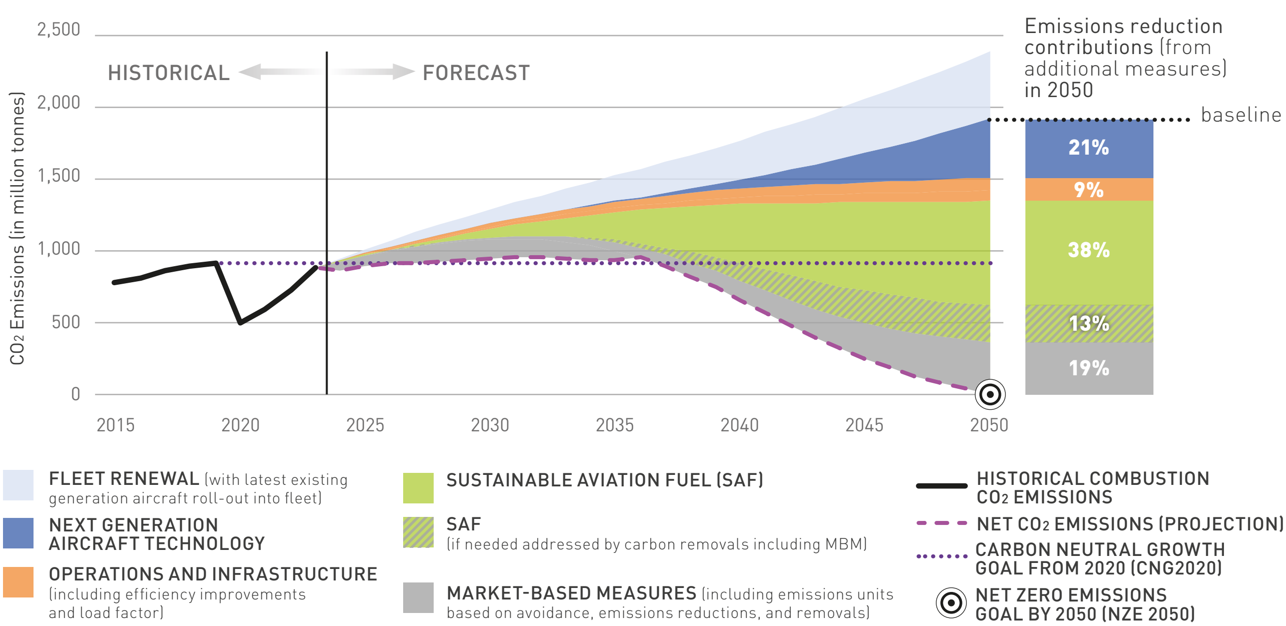
Traffic growth	C	Central scenario: 3.8% compound annual growth rate (CAGR) 2023-2050
Technology developments (beyond fleet renewal with the latest existing generation aircraft)	T3	Technology improvements are moderately ambitious with advances in both traditional and open rotor engines. Limited use of new aircraft configurations such as blended wing body. Additional reductions (T3) ~ 230 MtCO_2.
Operations and infrastructure improvements	O3	High-range improvements
Sustainable aviation fuel	F2	Around 1100 Mt CO_2 reduction to replace 90% of conventional jet fuel: 430 Mt (540 billion litres) of SAF with an average 84 % emissions reduction factor by 2050. Similar emission reductions from SAF can be achieved with 500 Mt Fuel with an average 70% emission reduction factor.
Market-based measures to address residual carbon emissions	M2	Contribution from market-based measures to meet the 2050 goal: ~ 400 Mt CO_2.



SCENARIO 2: TECHNOLOGY-CENTRIC MARKET SCENARIO

Under this scenario, traffic forecasts follow a 'central' range of around 3.8% per annum compound growth from 2023 to 2050. Technology improvements are ambitious with electric and/or hydrogen-powered aircraft entering service before 2045 and serving the below 100-seat market. From around 2035, hybrid-electric powered aircraft start to enter the narrowbody market segment followed by a new generation of widebody aircraft also with hybrid-electric power architecture[16] around 2040[17]. Despite a mid-level of traffic growth, higher investments in operations and infrastructure result in net improvements and CO_2 reductions. The gap between combustion CO_2 emissions and the 2050 carbon goal would be SAF and carbon removals. However, it is difficult to project 25 years out the exact split between the role of SAF and market-based measures such as carbon removals. This will largely be based on market cost dynamics guided by policy support which will expand the suite of options available to the sector on our decarbonisation journey. This scenario captures this uncertainty through an indicative wedge of emissions reductions that may be addressed by SAF or by MBMs, most likely carbon removals in the latter years. This wedge represents ~290 $MtCO_2$. It should be noted that even in the case where SAF is used to address this wedge of emissions, there would still be residual CO_2 emissions which would need to be addressed by MBMs. Under this scenario, total demand for MBM units would range from ~370 to 620 $MtCO_2$.

Traffic growth	C	Central scenario: 3.8% compound annual growth rate (CAGR) 2023-2050
Technology developments (beyond fleet renewal with the latest existing generation aircraft)	T_4	Hybridization for narrow-body and wide-body aircraft and electric and hybrid electric aircraft in the short-range and <100 seat category with entry into service from 2035/2040. Additional reductions (T4) ~ 400 $MtCO_2$.
Operations and infrastructure improvements	O_3	High-range improvements
Sustainable aviation fuel	F_3	Around 720-980 Mt CO_2 reduction to replace up to 66-90% of conventional jet fuel: 280-380 Mt (350-475 billion litres) of SAF with an average 81-84 % ERF by 2050.
Market-based measures to address residual carbon emissions	M_3	Contribution from market-based measures to meet the 2050 goal: ~ 370 — 620 Mt CO_2.



INPUT: TRAFFIC FORECASTS

> **Air transport has seen remarkable traffic growth over its 111 years of commercial service, fuelled by (and fuelling) a rise in global living standards. Covid-19's impacts lingered over the past 5 years, yet post-recovery, the global aviation sector is expected to continue to grow, delivering positive socio-economic benefits worldwide, albeit with regional variations in predicted growth rates shaping the global average.**

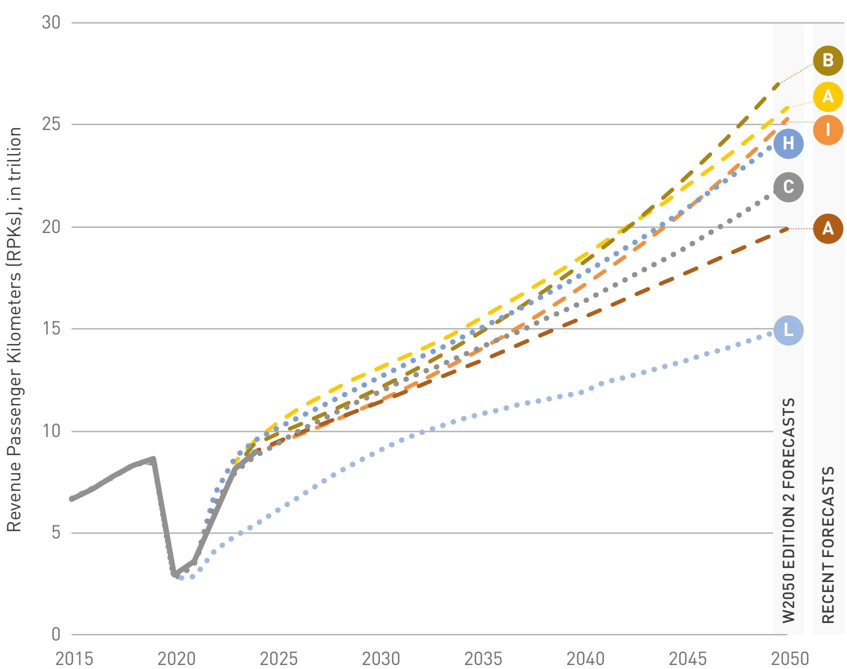
Traffic forecasts in *Waypoint 2050*

The updated assessments presented in this report are based on a central scenario – consistent with previous analyses based on IATA forecasts. This scenario projects an average annual traffic growth rate of approximately 3.8%, reaching 22 trillion revenue passenger kilometres (RPKs) by 2050, about 2.7 times higher than the 2023 level of 8.1 trillion RPKs. This is within the range of recent forecasts by other organisations such as Airbus[18], Boeing[19], ICAO[20] and ACI[21].

The forecasts reflect continued shifts in population, economic development, and demographic trends. For example, aging populations in countries such as China, Germany, Italy, Russia, and Japan, are expected to reduce the pool of potential air travellers. In contrast, countries such as Mexico, Canada, India, Indonesia, the United States, and Brazil are projected to experience growth in their "flying-age" populations, supporting increased demand for air travel.

Review of the recent traffic forecasts

Based on a review of recent forecasts, and for the purpose the updated *Waypoint 2050* assessments, passenger traffic is expected to grow at ~3.8% from 2023 to 2050.



COMPOUND ANNUAL GROWTH RATES (2023-2050)*	W2050 EDITION 2	RECENT FORECASTS	W2050 EDITION 3
B BOEING		4.2% (2025-2044)	
A AIRBUS	≈ 4.5% (GMF 2021)	3.8% (2025-2044)	
I ICAO		4.0% (2024-2050)	
H W2050 HIGH	3.9% (IATA July 2021)		
C W2050 CENTRAL	3.8% (IATA July 2021)		3.8%
A ACI		3.3%	
L W2050 LOW	4.3% (IATA July 2021)		

Note: Passenger forecast indexed to RPK in 2024

** Unless otherwise specified ().*

Whilst the pre-Covid decade saw above-average traffic growth, these rates are expected to moderate in the coming decades – even without considering the effects of the Covid-19 pandemic – an outlook incorporated into this central scenario.

Over the next 20 years, Africa, Asia-Pacific and the Middle East are anticipated to be key drivers of air traffic growth, while several regions, particularly Spain, Italy, Germany, Russia and former Soviet Eastern European states, may face headwinds due to demographic constraints. Additional demand growth may also arise from market liberalisation and price stimulation.

Could decarbonisation costs dampen demand growth?

Decarbonising the global aviation sector is expected to increase the cost of air travel, which may in turn lead to some reduction in realised demand. As outlined in the chapter on "costs of transition (page 65)," efforts to cut aviation emissions will increase costs across several areas, including aircraft technology, operational improvements, SAF, infrastructure adaptation to support new aircraft types and energy systems, and market-based measures, not to mention the changing dynamics of the costs of continued use of fossil fuels. Among these, the increase in jet fuel costs resulting from the transition to SAF is anticipated to be the most significant cost driver, given its critical role in decarbonisation and its substantially higher production cost compared to conventional jet fuel. Some of these additional costs will be offset by improvements in fuel efficiency, but it is expected that the cost of flying will, in general, increase over the coming decades.

This cost differential could be passed on to passengers through higher ticket prices. As a result, higher airfares – through price-demand elasticities – are expected to dampen the projected growth in air travel. For example, the *Destination 2050* roadmap[22] estimates that the impact of SAF-related costs could reduce passenger demand and emissions for European aviation by about 3% in 2030 and potentially up to 16% by 2050. Similarly, the UK Sustainable Aviation roadmap estimates a 14% demand reduction in 2050 from the combined costs of decarbonisation being passed on to consumers[23].

Assessing demand impacts at a global level is a significant challenge and is beyond the scope of this analysis. Price sensitivity (demand elasticity) varies sharply by region, with a corresponding impact on growth patterns. Other related costs such as jet fuel distribution at remote airports far from refineries, or government taxes and charges which could be reduced to spur connectivity growth also have an impact. In addition, the substantial air fare decreases in the past few decades in Europe and North America, and more recently Asia, have been driven by increased competition and efficiency improvements from which other regions could also benefit. Meanwhile, rising prosperity in emerging economies may reshape demand elasticities in those markets in 20 years compared with today.

These dynamic and competing factors mean that the effects on growth may vary significantly from year-to-year, across regions, countries, city-pairs and even passenger segments. Business travellers, for instance, are typically less sensitive to price increases and may not significantly reduce their travel.

Trying to provide an accurate assessment of demand impacts across multiple market types, in multiple currencies and very different dynamics was not a task undertaken for the *Waypoint 2050* global analysis. Scenarios in this analysis, therefore, do not include feedback effects on global aviation traffic from potential costs of decarbonisation.

MEASURE 1: TECHNOLOGY

Aviation has a strong history of solving challenges through technological innovation. From the first forays into powered flight, to the jet engine, use of composites and 3D printing, constant improvements are part of the sector's DNA. Responding to the climate change challenge is no different.

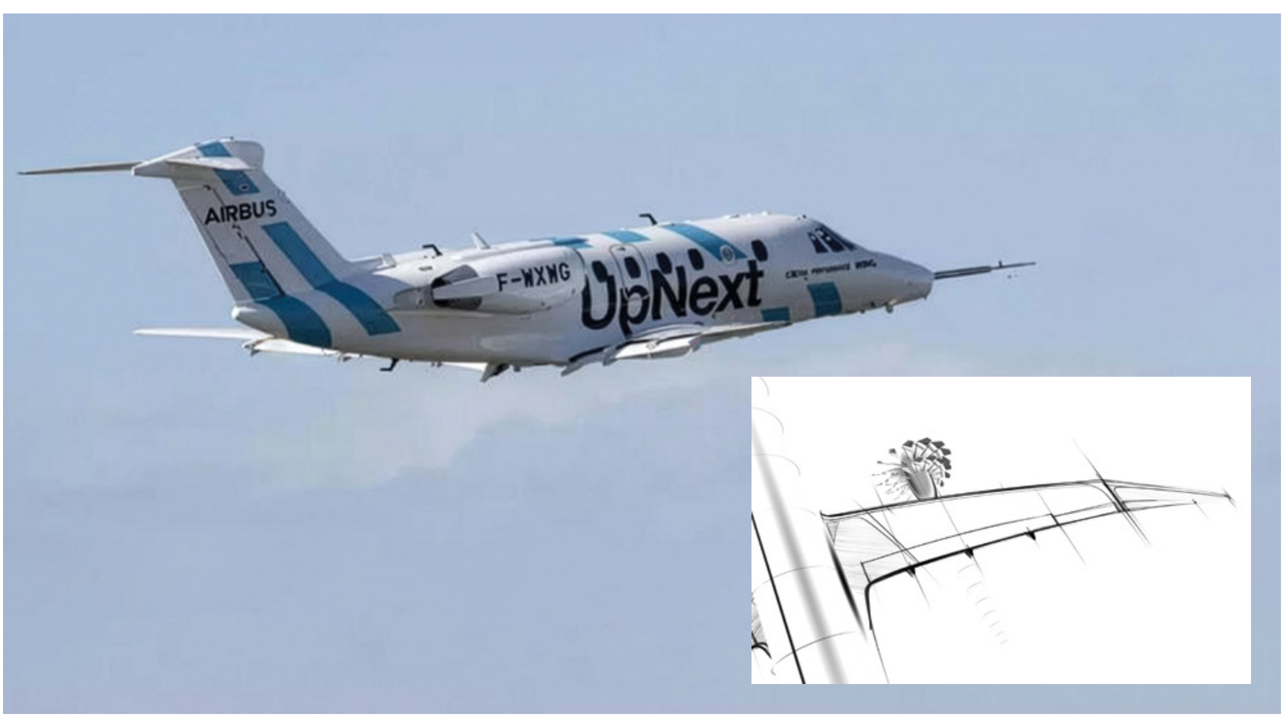
The past five years have exhibited both challenges and encouraging developments in aircraft and engine technologies. Several key technologies and aircraft programmes are progressing towards entry into service in the mid-2030s and beyond.

Foundational technologies: aerodynamics and structure improvements

Ongoing research and development in aerodynamics, structures, and other areas continue to advance next-generation tube-and-wing aircraft configurations. For example, under its Wing of Tomorrow programme, Airbus delivered its second wing demonstrator in 2023, supporting the maturation of advanced wing technologies and manufacturing processes. This initiative focuses on developing longer, leaner, and lighter wings to enhance fuel efficiency and reduce CO_2 emissions.

In parallel, Airbus' innovation subsidiary UpNext[24] is pursuing the eXtra Performance Wing project, which reimagines aircraft wing design to improve aerodynamic performance and address environmental challenges. Drawing on biomimicry – engineering inspired by nature – the project aims to create wings capable of morphing during flight to optimise aerodynamic efficiency. If successfully integrated into future aircraft, this technology could lead to significant reductions in fuel consumption.

Through collaboration with NASA on the X-66 programme, Boeing has refocused resources on the value of thin wings and associated technology that may be applicable to multiple aircraft configurations, influencing future generations of airplane design. Boeing aims to establish a sustainable and enduring capability to develop a pipeline of new wing technologies that will enhance the performance and efficiency of future airplanes.



Incremental improvements towards more disruptive technologies:

The ATR EVO is designed as a hybrid electric aircraft with an expected entry into service of 2035. Its ambition is to combine an ultra-efficient thermal engine with a battery-powered electrical motor, to optimise the engine core size through the use of electrical power, therefore maximising the overall efficiency of the propulsive system.

Designed to significantly reduce CO_2 emissions and direct maintenance costs (-20% compared to in-service aircraft powered by PW127M engines) while enhancing aircraft performance, the ATR EVO will remain a two-engine turboprop, with 100% SAF capability.

Beyond 2035, ATR intends to evolve the EVO further, ready to incorporate disruptive technologies as they mature.

Unconventional airframe configurations and technologies

Despite certification delays for some aircraft in development and delivery lags for in-production aircraft, the past five years have have fuelled research and development into unconventional designs, like blended wing body (BWB) configurations.

JetZero

The JetZero (Z4)[25] is a revolutionary all-wing design targeting the centre of the market (-250 seats, 5,000 nautical miles range) that aims to be around 50% more fuel-efficient compared to the 767-300. Unlike traditional tube-and-wing aircraft, this design merges the wings and fuselage into a single, wide airframe. This design reduces aerodynamic drag. The JetZero aircraft is designed for zero-emission potential by being compatible with hydrogen propulsion or advanced hybrid-electric systems in the future. JetZero is aiming for potential entry into service in the early 2030s.

Bombardier EcoJet (research platform)

The Bombardier EcoJet is an innovative blended-wing-body research aircraft aimed at drastically reducing CO_2 emissions in the business jet sector. Bombardier's EcoJet is not a commercial jet but a cutting-edge research platform pushing the boundaries on sustainable aviation design. With significant reductions in drag, and fuel use, and flexibility for future propulsion systems, it is a major step toward more efficient business aircraft and may shape the next generation of private aviation.

As with any innovation in aviation, new aircraft technologies must progress through multiple stages of technology readiness

before they can enter service and achieve widespread adoption across the fleet. Blended wing body aircraft are currently in technology readiness level (TRL) 6 phase. Based on historical developments of aviation technologies and precedents, TRLs 6 to 9[26] usually takes around six to eight years.

The continued momentum on research and development for unconventional configuration such as blended wing body aircraft is reflected in the *Waypoint 2050* Technology scenario T3 (toward unconventional configuration).

***Near-term actions** to accelerate progress towards the 2050 goal:*

- *Accelerate the development of the next generation of safe and fuel-efficient aircraft.*
- *Develop flexible airframe architecture that can adapt to novel energy/propulsion innovations as their TRL increases (such as hydrogen).*
- *Support and foster competition within the aerospace sector to accelerate innovation and entry to market.*

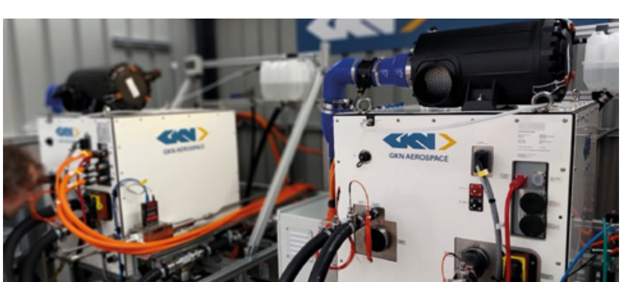
Structure and manufacturing improvements

The transition to composite materials for key aircraft structural elements, alongside the developments of unconventional configurations, demands advancements in manufacturing processes. Several improvements in composite manufacturing for aerospace focus on enhancing efficiency, accuracy and sustainability through advanced techniques such as automated fibre placement and automated tape laying, 3D printing, and digital twin technology, alongside innovations in materials including nanocomposites and self-healing materials. These advancements aim to reduce weight and improve fuel efficiency, while enabling more complex and reliable aircraft structures.

For example, the Hi-Rate Composite Aircraft Manufacturing project[27] is advancing key composite airframe technologies to meet single-aisle needs for aircraft weight, cost, and manufacturing quality, paving the way for swift fleet integration in the 2030s. Currently, this project explores multiple wing and fuselage applications in partnership with the established US Advanced Composites Consortium.

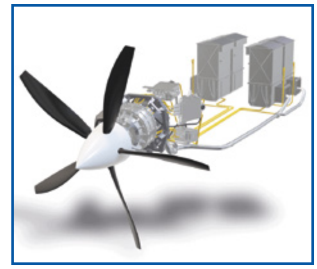
Propulsion and energy technologies

There is ongoing research and development into propulsive efficiency improvements for "conventional" ducted fan architecture as well as into unconventional configurations and energy systems (such as un-ducted fans, hybridisation and hydrogen propulsion).



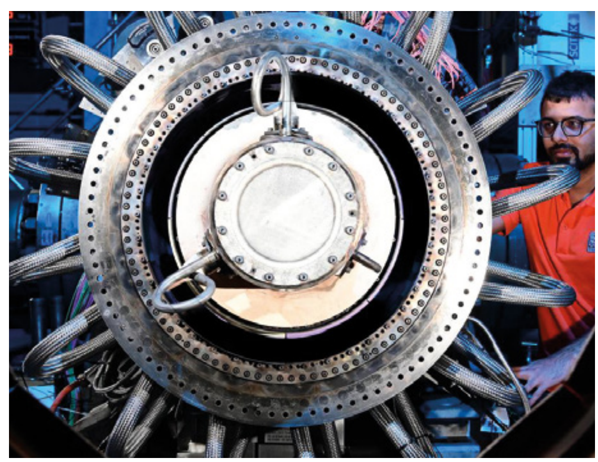
GKN Aerospace H2FlyGHT

CFM RISE
technology demonstrator



Zeroavia ZA600

Rolls Royce UltraFan



Rolls-Royce Pearl 700 (hydrogen combustion)

P&W Hydrogen Advanced Design Engine Study (HyADES)

** Not exhaustive (for illustrations purposes only)*

Substantial research and development into novel energy sources and engine architecture

Over the past few decades, engine technologies have largely focused on incremental improvements in specific fuel consumption via higher bypass ratios, use of lighter composite materials and more efficient combustor designs. More recently, building on foundational research, development has intensified on novel engine architectures like open rotors. A further step change into potential new energy sources (electricity or hydrogen) is driving ongoing research and development unlocking opportunities for aircraft-level emissions cuts but also introducing uncertainties in integrated aircraft systems and their potential entry into service.

These developments, including significant research into various levels of hybridisation, sustain the viability of W2050 Technology scenarios T3 (advanced architecture aircraft and propulsion "new configurations") and T4 (towards non-drop in energies: electrification, hybrids and zero-emission propulsion aircraft technologies).

The contribution of hydrogen powered aircraft by 2050

Progress on the development of hydrogen powered aircraft for small aircraft and regional markets is ongoing. However, recent shifts in the development of hydrogen-powered mid-size aircraft make the *Waypoint 2050* technology scenario T5 unlikely for mid-2030s entry (as was previously defined in Editions 1 and 2). Key enablers, such as scalable green hydrogen supply and aircraft technology maturity are advancing more slowly than forecast, prompting other analysis such as *Destination 2050*[28] to reduce projected 2050 contribution of hydrogen-combustion aircraft from 21% (2021 version) to 3% (2024 version).

It should be noted that despite delays in the development of hydrogen powered aircraft, demand for hydrogen for aviation, as an input to SAF production, is still necessary – this is explored in the chapter on "Measure 3: sustainable aviation fuels" on page 45.

***Near-term actions** to accelerate progress towards the 2050 goal:*

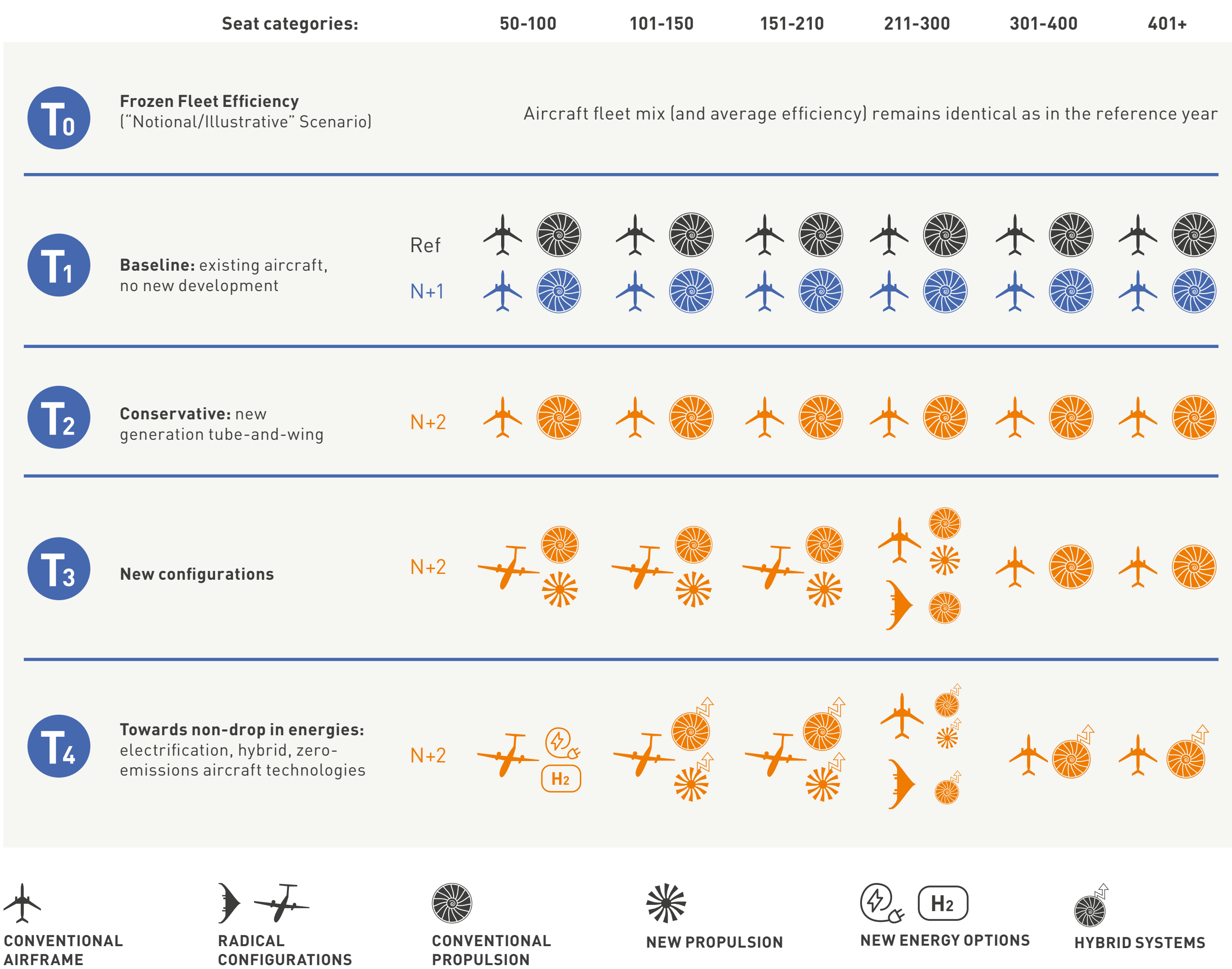
- *Accelerate the development of the next generation of airframes and fuel-efficient engines.*
- *Continue research and development into new low carbon energy/propulsion innovations (for example, hybridisation, hydrogen).*
- *Support building the value chain, infrastructure and certification and operational readiness needed for the commercialisation of new propulsion technologies.*

Updated W2050 technology scenarios

The baseline technology scenario is defined as the T1 scenario (based on existing aircraft and without new development and generation of aircraft). To acknowledge the contribution of fleet renewal the updated W2050 scenarios include an additional frozen fuel efficiency scenario captured in this edition[29]. The "Frozen Fleet Efficiency Scenario", labelled T0, captures a scenario where traffic would grow while keeping the same fleet-wide efficiency (technology and operational) as in 2023. It should be noted that this scenario is purely for modelling purposes as, in the real world, the efficiency of the fleet cannot be frozen. Even in the absence of any additional measures to reduce emissions, the entry into service of aircraft currently in-production would improve the fleet-wide efficiency.

Updated *Waypoint 2050* aircraft technology scenarios

Aircraft technology scenarios were updated to reflect recent developments in engines and airframe configurations, as well as expected entry into service.



In the T1 scenario, as older aircraft are retired, they are only replaced with aircraft that are currently in production, or are about to enter service (for example, new generation families: Airbus A220, A320 neo, A330 neo, A350, ATR 72-600, Boeing 737MAX, 777X, 787, Embraer E2), using conventional jet fuel or SAF. This scenario is not a realistic view of the future but sets a baseline for fleet evolution for other scenarios and highlights the ongoing efforts underway within industry to replace older aircraft with new ones.

The T2 scenario captures the future entry of a new generation of tube-and-wing aircraft. A new generation of aircraft follows the current models (above), but still with an evolution of the standard 'tube and wing' configuration with a turbofan engine propulsion system, using conventional jet fuel or SAF.

Scenario T3 includes the potential disruptive configurations of aircraft incorporating new structural elements such as the strut-braced wing or blended wing body; and open rotor engine concepts, using conventional jet fuel or SAF. In this edition of *Waypoint 2050*, this scenario reflects the observation of no confirmed announcement of new 'middle of the market' aircraft in the 2020s. However, as indicated in the section above, the announced JetZero all-wing body is reflected in this scenario with an initial entry into service in the early 2030s with 50% less fuel use compared to the previous generation (noted as "N" which relates in this size category to the B767-300).

The T4 scenario depicts a transition "towards non-drop in energies: electrification, hybrid, zero-emissions aircraft technologies". Most of the fleet-wide improvements result from the hybridisation and efficiency improvements from potential narrow- and wide-body aircraft. This scenario also reflects the possibility that the 50-100 seat segment could be supported by aircraft powered by hydrogen or electricity.

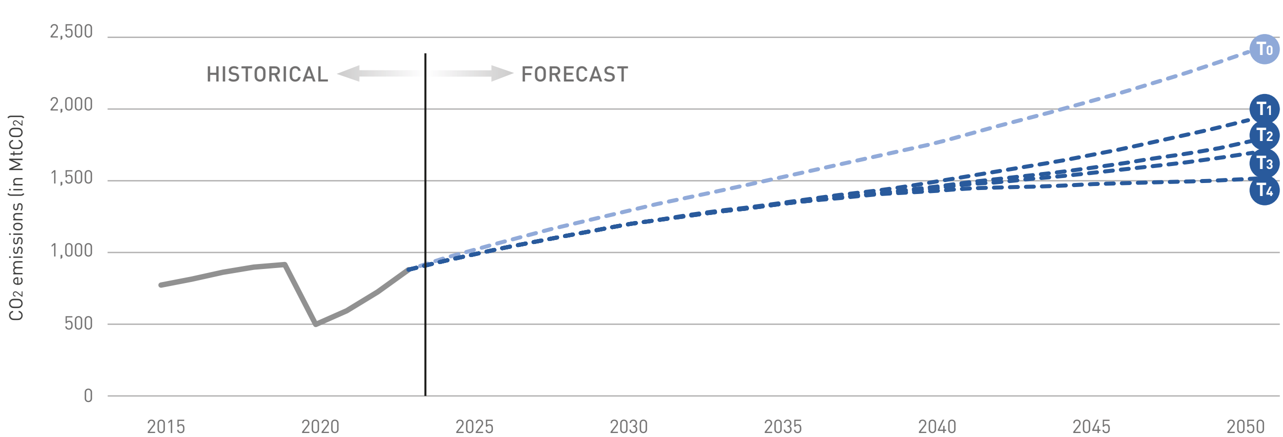
Overview of commercial aviation decarbonisation options

A simplified view of which energy options, across the range of technology scenarios, might be able to contribute to the reduction in CO_2 emissions from air transport in which approximate time period — for example, electric commuter-scale aircraft may be available in the latter half of the 2025-2030 timeframe[30].

		2020 › ~2025	~2025 › ~2030	~2030 › ~2035	~2035 › ~2040	~2040 › ~2045	~2045 › ~2050
Commuter » 9-50 seats » < 60 minute flights » < 1% of industry CO_2	~27% of CO_2 emissions	SAF	SAF, Electric, Hybrid/ Electric, and/or Hydrogen fuel cell	SAF, Electric, Hybrid/ Electric, and/or Hydrogen fuel cell	SAF, Electric, Hybrid/ Electric, and/or Hydrogen fuel cell	SAF, Electric, Hybrid/ Electric, and/or Hydrogen fuel cell	SAF, Electric, Hybrid/ Electric, and/or Hydrogen fuel cell
Regional » 50-100 seats » 30-90 minute flights » ~3% of industry CO_2	~27% of CO_2 emissions	SAF	SAF	SAF potentially some Hydrogen fuel cell	SAF, Hybrid/ Electric, and/or Hydrogen fuel cell	SAF, Hybrid/ Electric, and/or Hydrogen fuel cell	SAF, Electric, Hybrid/ Electric, and/or Hydrogen fuel cell
Short haul » 100-150 seats » 45-120 minute flights » ~24% of industry CO_2	~27% of CO_2 emissions	SAF	SAF	SAF	SAF, Hybrid/ Electric, potentially some Hydrogen combustion	SAF, Hybrid/ Electric, potentially some Hydrogen combustion	SAF, Hybrid/ Electric, potentially some Hydrogen combustion
Medium haul » 100-250 seats » 60-150 minute flights » ~43% of industry CO_2	~73% of CO_2	SAF	SAF	SAF	SAF	SAF, Hybrid/ Electric, potentially some Hydrogen combustion	SAF, Hybrid/ Electric, potentially some Hydrogen combustion
Long haul » 250+ seats » 150 minute + flights » ~30% of industry CO_2	~73% of CO_2	SAF	SAF	SAF	SAF	SAF	SAF

How different technology scenarios can impact growth in CO_2 emissions

The T0 scenario depicts the notional illustrative frozen fleet efficiency trajectory. Each of the T1-T4 scenarios is mapped using the central traffic growth forecast. The T1 scenario shows where CO_2 emissions would be with no further improvements in aircraft efficiency and no new technology beyond ongoing planned fleet renewal. This chart does not include reductions in emissions from the other pillars of action: operations, infrastructure, sustainable fuels or market-based measures.



TECHNOLOGY IN THE POST-2050 WORLD

This report acknowledges the limited potential pre-2050 of hydrogen aircraft to reduce aviation emissions. Given the focus of the *Waypoint 2050* assessments on charting potential paths between now and 2050, the T5 technology scenario, previously considered in *Waypoint 2050 Editions 1 and 2*, is not modelled in the integrated net zero carbon scenarios. However, continued research and development in hydrogen and new hydrocarbon fuels will be essential for unlocking their post-2050 potential.

There is a potential for increased use of hybrid-electric propulsion, drawing on direct electricity or engine-generated power. This could become a technical possibility around 2030 for regional and short-haul fleet, 2035 for medium-haul and 2045 for long-haul. This hybridisation promises fuel efficiency gains surpassing conventional engine technology advancements.

The technology roll-out depends on research advances, energy supply chains and economic viability to integrate these new designs and energy sources into the fleet. As new technologies evolve, assumptions may shift: batteries with higher energy density could extend electric ranges and enable larger aircraft to go electric; while strong governmental support might accelerate the hydrogen economy rollout.

CALL TO ACTION: TECHNOLOGY

The development of aircraft and engine technology solutions is largely within the expertise of the sector, although significant primary research can be catalysed through academic and institutional research programmes around the world before making their way into commercial applications. Support for the roll-out of new technology solutions is an additional accelerator.

The table below presents key actions to **"build on current efforts and drive near-/mid-term progress"**, **"innovate and develop towards long-term progress"** and **"advocate and collaborate towards joint efforts and progress"** on aircraft technology.

Aviation sector

Address remaining challenges to ensure delivery of fuel-efficient aircraft	» Address remaining supply chain challenges to ensure timely delivery of the latest generation of fuel-efficient aircraft.
Accelerate research and development of more efficient aircraft technologies	» Accelerate research and development of more efficient aircraft technologies including unconventional airframe and propulsion configurations, hybridisation, electric and hydrogen power, whilst preparing the necessary new energy requirements, infrastructure and operations for electric and hydrogen aircraft.
Form partnerships with non-aviation technology providers and incubate start-ups in aviation and related areas	» Form partnerships with non-aviation technology providers in areas such as battery development, materials research and biomimicry. » Provide incubator opportunities for new efficiency technology start-ups.

Governments and policymakers

Adopt durable policies that incentivise and accelerate decarbonisation innovations	» Adopt durable policies that incentivise and accelerate decarbonisation innovations for aviation. » Continue to fund research programmes where they exist, develop additional projects where they do not, including technologies for conventional and unconventional airframes, propulsion systems, and energy carriers. » Promote the development of new aircraft with radically better fuel efficiency. » Develop wider national energy and industrial strategies in addition to deploying sustainable aviation fuel (SAF) and including the hydrogen and low-carbon electricity requirements of aviation in national energy strategies. Ensure aviation requirements are identified in national green hydrogen and low carbon electricity infrastructure strategies.
Prepare agencies for certification processes	» Prepare agencies for certification processes for next generation aircraft and aviation fuels, including with unconventional airframe, propulsion, materials and energy sources.

Research institutions

Continue research in collaboration with industry into critical topics	» Continue research in collaboration with industry into critical topics such as (amongst others) materials, electric systems, cryogenic science and non-CO_2 effects of aviation.
Ensure research programmes for new technology reflect real-world requirement	» Ensure research programmes for new technology reflect real-world requirements through industry collaboration.

Energy industry (fuel producers)

Within strategic energy investment, recognise aviation requirements for renewable energy	» Define and implement industrial strategies for the development of SAF, LCAF and other alternative energies. » Plan strategic energy investment needs, including potential for aviation requirements for renewable energy and SAF, low-carbon electricity and low-carbon hydrogen.

Finance community

Fund new aircraft acquisition	» Fund new aircraft acquisition and roll-out.
Explore sustainable finance opportunities	» Explore sustainable finance opportunities that unlock capital at scale for fleets, new energy facilities and enabling infrastructure.

Other stakeholders

Collaborate with automotive, battery and hydrogen sectors to leverage technologies and build synergies	» Collaborate with automotive, battery and hydrogen sectors to leverage technologies and build synergies towards aviation technology pathways.

MEASURE 2: OPERATIONS AND INFRASTRUCTURE

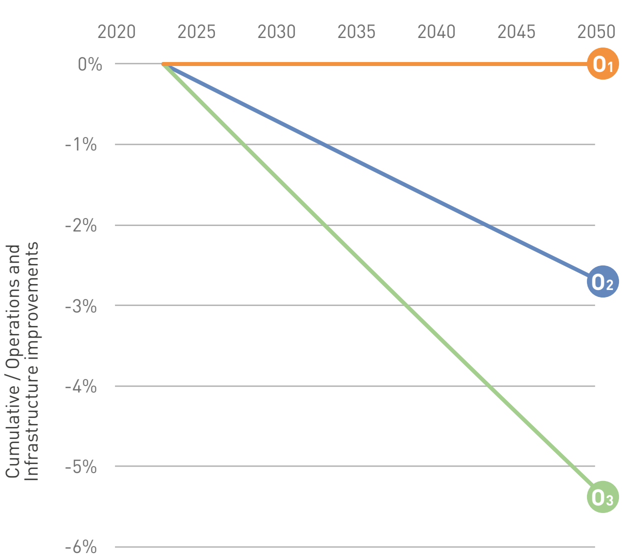
> **How aircraft are flown through the skies can significantly impact the efficiency of each individual flight and the collective performance of the aviation sector. On the ground, the amount of fuel consumed by aircraft is not insignificant and also provides opportunities for efficiency. Improvements in air and ground operations and infrastructure have the potential to contribute nearly 10% towards net zero carbon by 2050 and ensure no degradation in efficiency as traffic and congestion grows. Improvements in the near-term would also compound through 2050, increasing the positive effects.**

Operations and infrastructure scenarios

Operations and infrastructure efficiency improvements have the potential to contribute to reducing CO_2 emissions and help meet the 2050 carbon goal. While the overall emissions reductions from operations and infrastructure efficiency improvements will – by themselves – not be sufficient to meet the goal, these measures can often be implemented more rapidly than aircraft-level technologies (which are constrained by the rate of entry of aircraft into the fleet) and therefore the impacts from operations and infrastructure efficiency improvements can be significant contributors, particularly in the near term. This includes enhancements to horizontal and vertical flight profiles through operational initiatives such as reduced separation standards, free route airspace, and air traffic flow management, as well as ground operational improvements like airport collaborative decision making (A-CDM).

Operational efficiency scenarios for *Waypoint 2050*

Three scenarios were developed to illustrate potential pathways for operational and infrastructure efficiencies on a per-annum basis.



SCENARIO	DESCRIPTION	AVG. ANNUAL IMPROVEMENT
O1 LOW IMPROVEMENT	Investments in operational and infrastructure efficiencies are counterbalanced by congestion increases. Despite what looks like no improvement, if investment in operational efficiency did not take place, increasing traffic would lead to a worsening situation.	0.00%
O2 MID IMPROVEMENT	Substantial investments in operational and infrastructure efficiencies.	0.10%
O3 HIGH IMPROVEMENT	Additional substantial investments in operational and infrastructure efficiencies.	0.20%

To gauge the potential contribution for carbon emissions reductions from operations and infrastructure efficiency improvements, this edition of *Waypoint 2050* draws on key sources to shape two illustrative scenarios: ICAO Committee on Aviation Environmental Protection (CAEP) reports, the IATA Technology Roadmap, the CANSO Efficiency 2050 Goal, the ACI Long Term Carbon Goal Study for Airports Report (2021), and the UK Sustainable Aviation roadmap (2016). These baselines largely align with prior projections from recent studies largely remaining within the trajectory of previous scenarios[31].

Implementation of these operational and infrastructure efficiency improvements adheres to the ICAO Aviation System Block Upgrades guidance including data exchange, network management, and more efficient flight paths using tools such as continuous descents and climbs, and performance-based navigation.

With no fundamental changes in operational efficiency improvements since Edition 2, these scenarios remain valid, re-baselined to 2023 levels. Post-Covid-19 recovery has also validated load factor scenarios for 2050, which are now at historical highs.

Planning should also anticipate new entrant airspace users including advanced air mobility (such as eVTOL passenger and package delivery services) and commercial space launches, ensuring interoperable procedures, data protocols and airspace designs, from the start.

Additional opportunities: cabin configuration and seat densification

Additional analysis by ATAG members shows that similar orders of magnitude of benefit could be realised at a global level through increased utilisation of the installed cabin capacity via further increases in passenger load factor (the proportion of seats actually filled in a flight) and cabin densification (enabling more people to be seated on an aircraft). However, achieving these additional benefits are conditioned by individual airline business models and the constraints and expectations of the markets in which they operate[32].

The W2050 experts considered the inclusion of the potential role of future cabin densification. Recent trends towards larger first and business class cabins are countering opportunities for denser economy cabin layouts yielding minimal shifts in overall seating density. These assumptions were not included in this version of the *Waypoint 2050*, making the load factor scenario conservative and remaining fit for purpose. This merits deeper analysis in a future edition.

Additional opportunities: ground activities

Airport operational improvements are advancing steadily, including limitations on auxiliary power unit use in favour of electric ground power and air conditioning units, plus electrification of ground system equipment. Fixed electrical ground power and pre-conditioned air powered by local electrical grids or solar power enable airlines to delay auxiliary power unit start-up until closer to departure time, minimising idle emissions.

Innovations like single-engine taxiing enable pilots to taxi on one engine, and then start the rest nearer the runway. Some options like electric or assisted taxiing takes it further: specialised electric vehicles fitted to landing gears tow the aircraft from the terminal gates without the need to run the engines, reducing CO_2 emissions by up to 76% per towing movement. Airports like New Delhi, Amsterdam, Brussels, Paris CDG and New York JFK have been trialling or implementing electric taxiing[33].

Airports are also experimenting with 'digital twin' platforms that provide a virtual, real-time, and interactive representation of the airport, including the airfield. This platform supports multiple objectives, including enhancing operational efficiency.

Meanwhile, Airport Collaborative Decision Making (A-CDM) facilitates information sharing between the aircraft, ground handler, and air traffic control provider. This provides more accurate turnaround information for airlines and allows for the effective use of slots, which can minimise delays and fuel use. Improvement opportunities include automating platforms for information exchange, more integration between airports and ANSP and increased knowledge of A-CDM.

***Near-term actions** to accelerate progress towards the 2050 goal:*

- *A renewed focus on A-CDM, especially on increased information and data sharing between aviation partners, could help boost the efficiency (and other) benefits of this system.*

Additional opportunities: hydrogen or electric infrastructure development

Operating hydrogen-powered aircraft requires robust infrastructure readiness. A 2025 "concept of operations"[34], outlines how hydrogen and battery-powered aircraft will integrate into airports, supporting aviation's net zero carbon by 2050 goal. It details potential changes in ground handling, refueling, charging, safety, and emergency response, while identifying key knowledge gaps and helping ICAO shape future regulations. The document was developed by the International Industry Working Group (IIWG), the Airport Compatibility of Alternative Aviation Fuels Task Force, jointly led by ACI, Airbus (as a member of ICCAIA), and IATA.

The TULIPS consortium[35], led by Schiphol Airport, includes demonstration projects on future aircraft energy supply advancing procedures as well as operational and logistical practices for electric and hydrogen-powered aviation. These projects include initiatives at Rotterdam the Hague Airport, and Oslo Airport. The consortium is also developing airport-facilitated hydrogen flight demonstrations, to gain insights into operational processes and safety considerations across the entire hydrogen supply chain at airports.

Edmonton International Airport Hydrogen Hub[36] also explores opportunities to deliver zero-emission flights and decarbonise ground operations. It partnered with ZeroAvia and its Hydrogen Airport Refuelling Ecosystem to explore the use of hydrogen for the decarbonisation of aircraft operations, as well as for the wider airport ecosystem.

Airbus founded the Hydrogen Hubs at Airports project[37] which involves over 215 airports and aims at advancing the development of a global hydrogen ecosystem.

***Near-term actions** to accelerate progress towards the 2050 goal:*

- *Support the implementation at large-scale of operational improvements, such as electric ground power unit (GPU), electric or assisted taxiing, and A-CDM.*
- *Support the engagement in hydrogen or electric initiatives to accelerate the development of the ecosystem.*
- *Accelerate the decarbonisation of airports systems and facilities alongside implementation of ground operation efficiency measures.*

Additional opportunities: Complete Air Traffic System (CATS)

In 2021 a diverse group of industry leaders convened to develop an aligned plan to meet the future needs of airspace users and leverage innovative technologies to modernise air traffic management. The group included representatives from ANSPs, airlines, airports, aircraft OEMs, technology providers, advanced air mobility, high altitude platform systems commercial space operators and academic/research bodies.

The Complete Air Traffic System (CATS) Global Council, released a Concept of Operations (CONOPS) for Future Skies[38] in 2025 that is designed to ensure that both conventional and emerging aviation operations can seamlessly coexist in a safe, efficient, and sustainable airspace. The CATS CONOPS outlines a transformative pathway involving 16 key transformations: from digital information sharing to dynamic configuration of airspace and adaptive risk-based separation. Designed to be implemented in three primary phases, the transformations deliver real benefits at each phase, aimed at optimising flight efficiency and accommodating diverse users in an integrated airspace. The implementation of trajectory-based operations is the core of Phase 1, a concept that will improve aircraft fuel use by optimising flight paths in real time, considering factors like weather and airspace constraints. Later phases will leverage technology to provide real-time total system performance assessment and management.

The CATS Global Council continues to advance its plans for harmonised transformation, working with ICAO and other stakeholders to put the necessary frameworks in place. The planned changes will be a critical contributor to aviation's environmental sustainability by ensuring efficiency in skies that are growing busier with both conventional and emerging aviation operations.

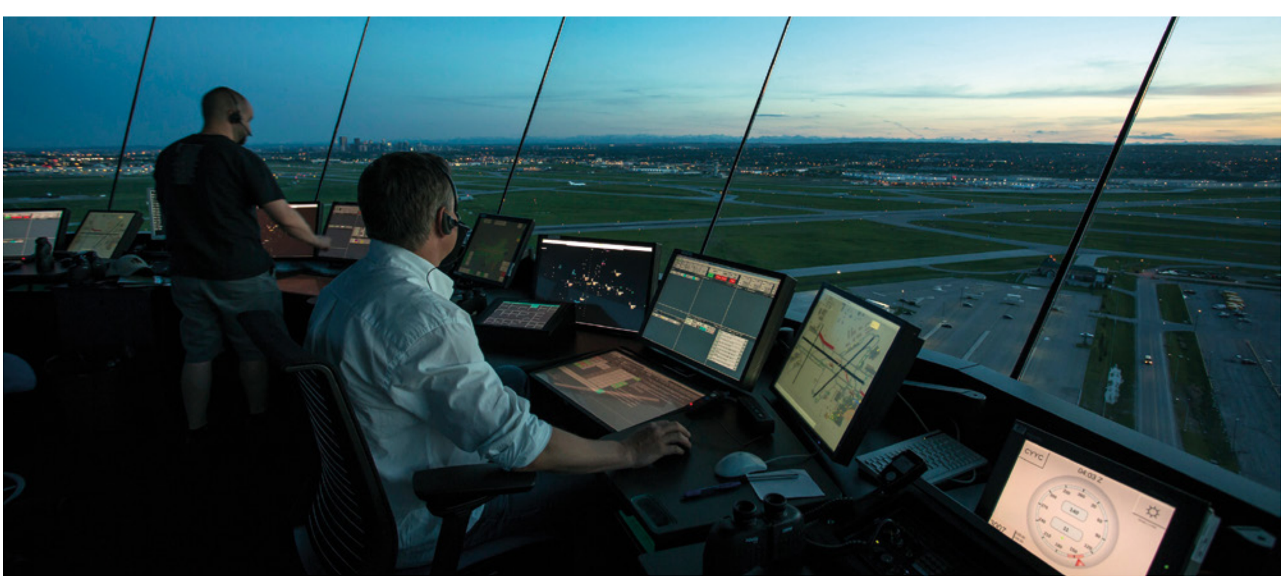
***Near-term actions** to accelerate progress towards the 2050 goal:*

- *Accelerate the upgrade of air traffic management (ATM) systems.*
- *Minimise airspace restrictions to enable more fuel-efficient flight paths.*
- *Accelerate the electrification of airports' systems to enhance operational and infrastructure efficiency.*

Additional opportunities: airspace efficiency

ANSPs are also increasingly using 'digital twin" AI platforms to unlock opportunities to improve demand capacity balancing and preserve flight efficiency given constraints. Digital twins are being used to quickly model the impact of different traffic management initiatives to optimise capacity and make informed decisions that help to optimise airspace utilisation.

Collaborative air traffic flow management is allowing ANSPs to efficiently allocate available airspace capacity and to coordinate with neighbouring ATS units to minimise regional impacts. This increasingly allows traffic flow to be preserved, and enables airlines to absorb delay when necessary on the ground rather than in the air, minimising emissions.



Studies have shown a high level of vertical flight efficiency in today's airspace, particularly in the climb and enroute phases of flight. Performance-based navigation (PBN) is enabling enhancements to horizontal flight efficiency and improving descent profiles in order to minimise fuel use. Improvements in aircraft equipage rates for advanced PBN are contributing to new opportunities for deployment.

Free Route Airspace continues to be deployed with associated improvements in airline's ability to plan for the most fuel-efficient routings and to optimise their route to make best use of weather conditions. Enhancements to cross border arrangements and airline flight planning tools are necessary to ensure that benefits are fully realised.

Inconsistencies in airspace separation standards between adjoining airspace continue to affect flight efficiency and to add complexity to airspace management. ICAO has initiated 'Project 30/10' to encourage implementation of longitudinal separations of 55.5 km (30 nautical miles) or less in oceanic and remote airspace, and 19 km (10 nautical miles) or less elsewhere. This would reduce bottlenecks caused by the need to adjust separations ahead of flight information region (FIR) boundaries.

Near-term actions to accelerate progress towards the 2050 goal:

- *Advance cross-border free route airspace and improve airline flight planning tools.*
- *Implement separation standard improvements in line with Project 30/10.*
- *Expand regional air traffic flow management.*

Additional opportunities: radical operational concepts

Further fuel use improvements and CO_2 emissions reductions may be possible by opening the aircraft design space and/or changing operating paradigms. Academic research into several concepts is ongoing. This includes, but is not limited to, designing a wider range of aircraft specifically for more fuel-optimum ranges (including cutting long-distance flights to ~1,500 nautical miles which would require multiple stops on intercontinental journeys) or lower design cruise speed[39], air-to-air refuelling, etc. While demonstrating potential improvements at the theoretical and aircraft design levels, these concepts could have substantial impacts on the operations of such next generation aircraft and the economics of the system, flexibility of the fleet, or passenger acceptance. These theoretical benefits need to be carefully assessed to ensure feasibility and whether they will ultimately result in actual system-level benefits.

NON-CO_2 EMISSIONS

Waypoint 2050 focuses on the decarbonisation of the aviation sector. Another aspect of aviation's climate action, is short lived climate pollutants ("non-CO_2" emissions), most visibly contrails: these are the white lines in the sky sometimes appearing after flights in certain atmospheric conditions. There are still many uncertainties about the scale of climate impact that contrails have. The latest scientific consensus is that contrails have, on balance, a warming impact, with an effect potentially in the same order of magnitude as aviation's CO_2 emissions, but the quantification of this impact currently has low confidence levels.

Significant research is underway to improve scientific understanding as well as understanding the potential benefits of some mitigation options (operations, technologies, fuels). The influence of the type of combustion chamber and the chemical composition of fuels are being evaluated. Operational elements could include horizontal or vertical trajectory adjustments to avoid areas of atmosphere likely to generate warming contrails, or the even the use of turboprop aircraft on appropriate routes, which tend to fly lower than contrail prone areas.

The aviation industry is committed to better understanding and mitigating its impact on the climate. It is actively contributing to scientific research, as well as undertaking operational trials, simulations and other studies aimed at developing the means to reliably reduce persistent warming contrails through a variety of mitigation options, further reducing the climate impacts of the sector.

- Further information on contrails and joint industry and research efforts to reduce this part of aviation's climate impact can be found at https://ataglink.org/48Dwzw8

CALL TO ACTION: OPERATIONS AND INFRASTRUCTURE

Operational and infrastructure efficiency is a vital component of reducing carbon emissions in the short term, whilst also for setting up a more efficient airspace in the future. More efficient airspace and ground operations are vital to help with costs and customer experience as growth adds more services and connectivity.

The table below presents key actions to **"build on current efforts and drive near-/mid-term progress"**, **"innovate and develop towards long-term progress"** and **"advocate and collaborate towards joint efforts and progress"** on operations and infrastructure.

Aviation sector

Collaborate to progress efficiency improvements	» Collaborate for progress towards full implementation of fixed electrical ground power, weight-based efficiency measures, airport collaborative decision making, aerodynamic efficiency opportunities and assisted taxiing opportunities. » Support for operational planning to assist airports and air navigation service providers from all parts of the air transport sector: airlines, ground service providers, and original equipment manufacturers (OEMs).
Encourage system efficiency initiatives	» Update/modernise demand/capacity balancing tools for future air traffic volumes with the use of optimised flight profiles supported by expanded data-sharing and collaborative platforms and global implementation of air traffic flow management. » Improve collaboration on severe weather management to reduce delay and other impacts.
Prepare for the future	» Investigate new approach technologies and procedures to reduce excess fuel use and emissions in the landing and take-off cycle at all applicable airports. » Investigate opportunities for increased use of intermodality, including for connecting air passenger traffic and passenger access to airports

Governments and policymakers

Continue to engage in operational carbon emissions reduction initiatives	» Establish supportive policies to foster the development and use of renewable and low carbon energy for air transport use, including production at airports where possible. » Support for next generation air traffic management initiatives.
Embed aviation's requirements into wider national energy strategies	» Engage with aviation stakeholders in initiatives to reduce CO_2 emissions from operations. » Make military airspace available for flexible use. » Encourage and fund, where viable, intermodal transport planning.
Support the modernisation and digitalisation of air traffic management (ATM)	» Support the modernisation and digitalisation of air traffic management (ATM) through both: funding of research programmes (such as the EU's Sesar Joint Undertaking, NASA and FAA research programmes and others); and with deployment funding and support » Implement the ICAO Aviation System Block Upgrades

»

Research institutions

Focus on operational improvements	» Focus on operational procedure improvements for the aviation system.
Accelerate innovation in operations, procedures and airport infrastructure	» Accelerate innovation in low-carbon operations, procedures and airport infrastructure through applied research and demonstration projects. » Translate research into practice by partnering with industry and governments to scale proven solutions.
Build global capacity by training the next generation of experts	» Build global capacity by training the next generation of experts.

Finance community

Fund infrastructure upgrades and developments	» Fund infrastructure upgrades and developments to meet system efficiency needs across both air and ground systems.

Energy Industry

Work in partnership with airports to ensure sufficient supply of cleaner energies	» Work in partnership with airports to ensure sufficient supply of SAF and other renewable low-carbon energy. » Develop power storage solutions that assist clean power resilience.

Other stakeholders

Pursue community and aviation system engagement on new procedures and techniques for ATM	» Pursue community and aviation system engagement on new procedures and techniques for air traffic management

MEASURE 3: SUSTAINABLE AVIATION FUELS

Sustainable aviation fuel (SAF) is critical for aviation decarbonisation. Made from a wide range of sustainable sources, SAF can significantly reduce greenhouse gas emissions compared to conventional jet fuel, with some pathways offering a substantial reduction.

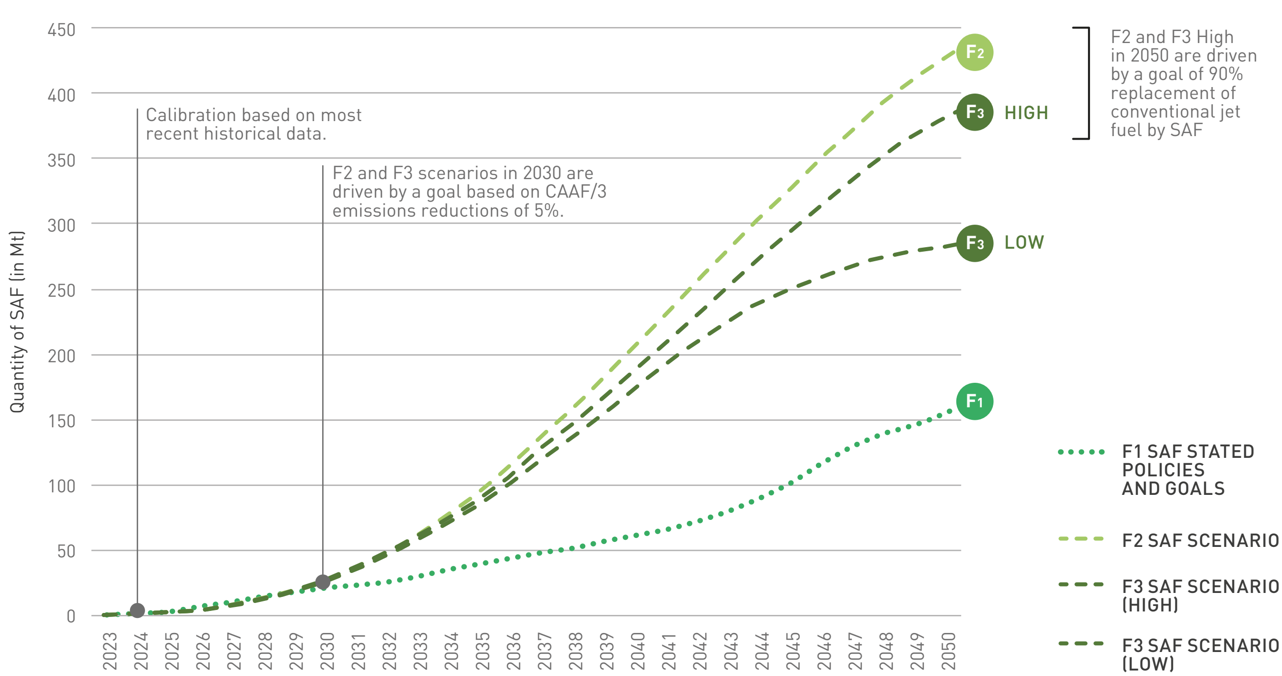
Updated SAF scenarios

Since the previous edition of *Waypoint 2050*, there has been slower-than-anticipated short-term progress in SAF deployment. Accordingly, this edition introduces revised SAF scenarios developed via two complementary approaches.

The first a forward-looking supply ramp-up trajectory to 2050. The second a 'backcasting' analysis from each consolidated net-zero scenario to quantify the SAF volumes required to 'close the gap' towards the net zero carbon vision.

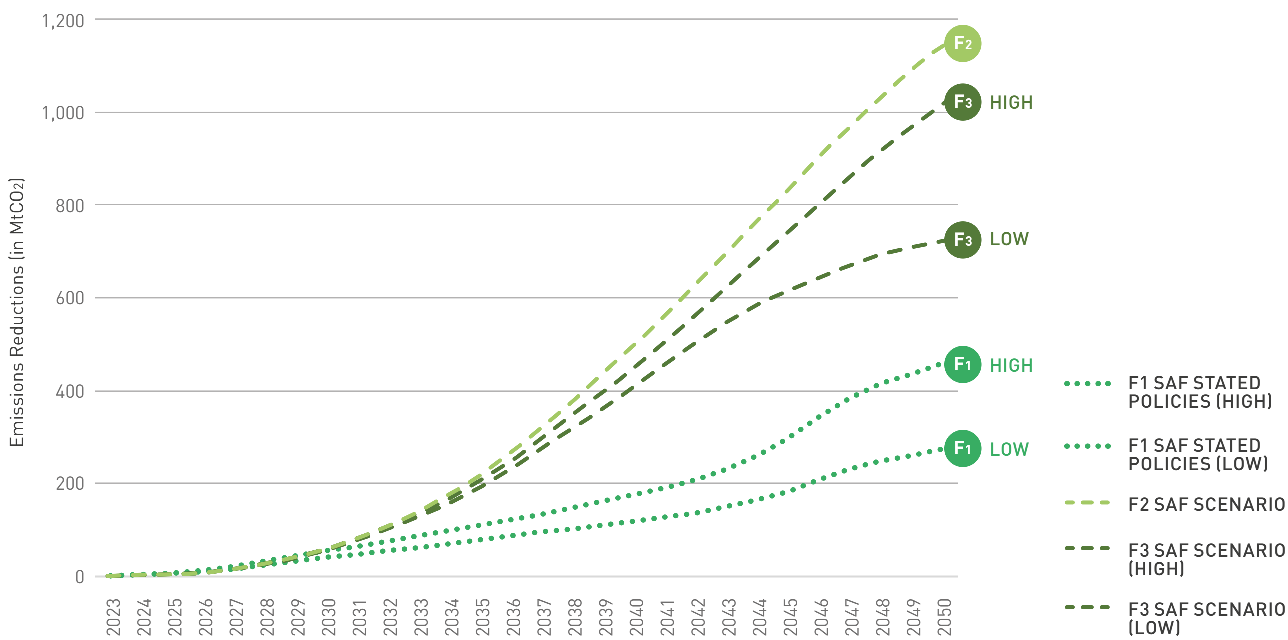
Waypoint 2050 summary of SAF scenarios: quantities of SAF

The F1 scenario — stated policies or goals — would result in ~150 Mt of SAF by 2050. To reach 90%[40] replacement of conventional jet fuel by SAF by 2050, as envisioned in the F2 scenario, would require ~430 Mt of SAF at an average 84% emissions reduction factor, or up to 500 Mt of SAF at an average 70% ERF. The F3 scenario reflects a balance between more expensive SAF and CDR opportunities resulting in a range of ~280 to 380 Mt of SAF by 2050. Scenarios F2 and F3 in particular showcase the need for a steep ramp-up of SAF supply in the 2030s — the policy and economic conditions for which need to have foundations in the 2025-2030 timeframe.



Waypoint 2050 summary of SAF scenarios: emissions reductions from SAF

The F1 scenario — stated policies or goals — could deliver ~260 to 440 $MtCO_2$ reduction through the use of SAF by 2050, depending on the average emissions reduction of that volume. The F2 scenario would generate the greatest emissions reductions through SAF deployment reaching ~1,100 $MtCO_2$ by 2050[41]. Finally, the F3 scenario, capturing the trade-offs between SAF and CDR could deliver emissions reductions from SAF ranging from ~720-980 $MtCO_2$ by 2050. Scenarios F2 and F3 in particular, showcase the need for a steep ramp-up of SAF supply in the 2030s — the policy and economic conditions for which need to have foundations in the 2025-2030 timeframe.



SCENARIO F1: STATED SAF POLICIES OR GOALS

SAF policies focus on accelerating the capacity development, production and use of SAF to reduce the carbon footprint of the aviation industry. Key enabling policies generally include government funding for research and development; revenue certainty mechanisms, grants and loan guarantees for new production facilities; tax credits for SAF purchase production and blending, and blend mandates for SAF supply. These policies should aim to incentivise SAF production, lower its cost, and increase its availability.

Country or regional level stated SAF policies or goals may be associated with quantified SAF volumes and/or emissions reductions. Combined quantities of SAF required by the 43 countries with stated SAF policies or goals could reach ~20 Mt by 2030. This could represent ~40 to ~56 $MtCO_2$ of emissions reductions by 2030 (~3.5% to 5.0% of global aviation emissions).

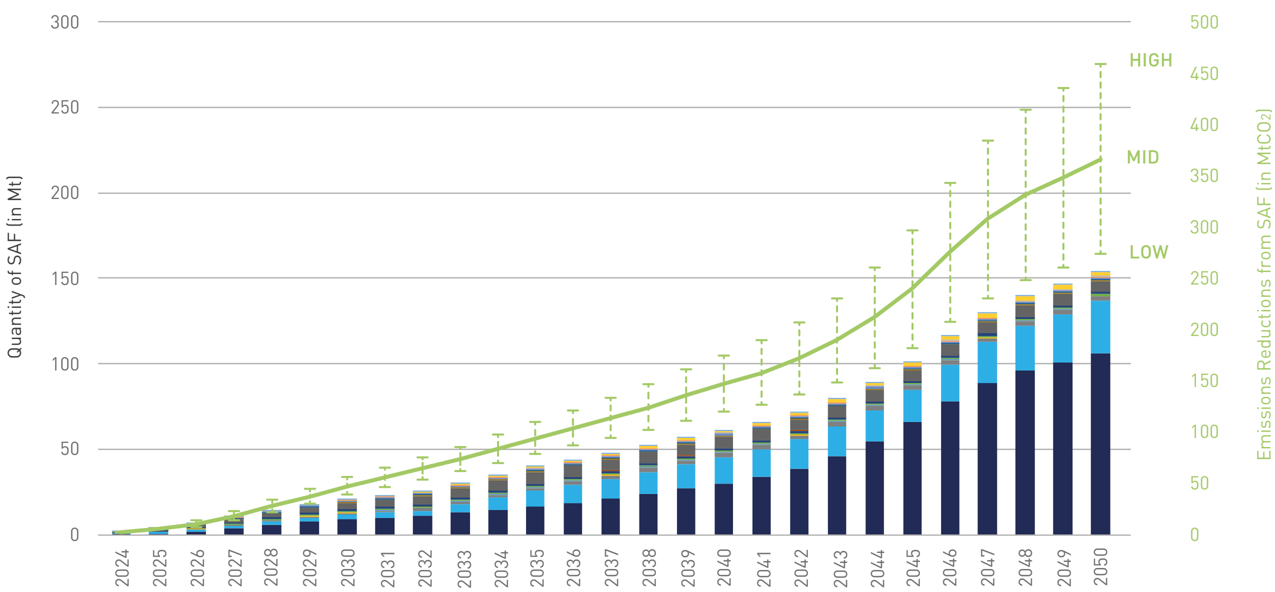
By 2050, stated SAF policies or goals from 29 countries could result in 150 Mt of SAF with average emissions reduction factors ranging from ~56% to ~94%[42]. This would represent between 270 and 460 $MtCO_2$ of emissions reduction.

It should be noted that these are stated policies or goals that have been announced or publicly indicated as of 2025. In November 2023, governments meeting at ICAO's Third Conference on Aviation and Alternative Fuels (CAAF/3) set a vision that aviation fuel in 2030 should be 5% less carbon-intensive than the fossil fuel which makes up nearly all of today's aviation energy. This has led to an array of new policy measures and national targets or goals which will likely further increase the 'stated policy' scenarios in the future.

It should also be noted that from a national energy strategy perspective, SAF lives at the intersection of several related energy sector interests. First, SAF (like conventional jet fuel) is co-produced with renewable diesel and other co-products that may also be of national strategic interest. For SAF scale-up to succeed, national policies must not disadvantage SAF to the benefit of other renewable fuels. Second, the long-term supply of SAF with very low carbon intensity will rely on the availability of low cost and abundant renewable energy, low carbon intensity hydrogen, and captured carbon dioxide supplies. The gap between the F1 scenario and the F2-F3 scenarios is where policy and production must be accelerated further in the hopes of closing the overall emissions gap.

Stated policies or goals for SAF

Several countries have now introduced policies targeting specific SAF volumes and/or emissions reductions through 2050[43]. Note the United States does not have a mandate, but the SAF Grand Challenge is included in here as a policy-driven approach[44]. According to stated policies, emissions reductions from SAF (depending on the emissions reduction factors of the SAF used) may reach from 40 to 56 $MtCO_2$ by 2030 and up to 270 to 460 $MtCO_2$ by 2050. In a conservative analysis, countries with 2030-only goals are assumed to continue at that same percentage through until 2050.



	2030	2050
United States	9 Mt SAF (3 billion gallons) | 14-29 $MtCO_2$	106 Mt SAF (35 billion gallons) 170-335 $MtCO_2$
European Union	3 Mt SAF | 5.7-7.1 $MtCO_2$	29 Mt SAF | 66-83 $MtCO_2$
United Kingdom	1.1 Mt SAF | 2.6 $MtCO_2$	*Same % as in 2040 i.e., 22% (2.5 Mt SAF | 6.3 $MtCO_2$)*
Norway	0.06 Mt SAF | 0.2 $MtCO_2$	*For scenario, assumed to be same as in 2030*
Brazil	0.3 Mt SAF | 0.7 $MtCO_2$	*For scenario, assumed to be same as in 2037 (0.36 Mt SAF | 3 $MtCO_2$)*
Singapore	0.68 Mt SAF | 1.7 $MtCO_2$	*For scenario, assumed to be same as in 2030*
Japan	0.68 Mt SAF | 3.5 $MtCO_2$	*For scenario, assumed to be same as in 2030*
Canada (BC only)	0.1 Mt SAF | 0.3 $MtCO_2$	*For scenario, assumed to be same as in 2030*
China	~ 3 Mt SAF | 7.6 $MtCO_2$	*For scenario, assumed to be same as in 2035*
Türkiye	0.5 Mt SAF | 1.3 $MtCO_2$	*For scenario, assumed to be same as in 2030*
UAE	0.5 Mt SAF | 1.3 $MtCO_2$	*For scenario, assumed to be same as in 2030*
Egypt	0.0 Mt SAF | 0.0 $MtCO_2$	*For scenario, assumed to be same as in 2030*
South Korea	0.076 Mt SAF | 1.9 $MtCO_2$	*For scenario, assumed to be same as in 2030*
India	0.4 Mt SAF | 1 $MtCO_2$	*For scenario, assumed to be same as in 2030*
Indonesia	0.05 Mt SAF | 0.1 $MtCO_2$	0.7 Mt SAF | 1.6 $MtCO_2$
Malaysia	0.04 Mt SAF | 0.1 $MtCO_2$	2.5 Mt SAF | 5.5 $MtCO_2$
Thailand	0.07 Mt SAF | 0.2 $MtCO_2$	*For scenario, assumed to be same as in 2030*

SCENARIO F2: AGGRESSIVE SUSTAINABLE FUEL DEPLOYMENT

For this update of the *Waypoint 2050* assessment, a hybrid of bottom-up and top-down approaches was used[45]. First, a bottom-up approach of supply-driven potential production of SAF was developed for seven categories of SAF. A top-down approach based on the backcasting assessment was also used. The gap between quantities of SAF from both approaches is expected to be addressed with the eighth category of SAF: power-to-liquid (PtL), which relies on renewable energy and waste, or captured carbon dioxide, as its primary inputs. All SAF pathways compete for resources (biomass, renewable energy, hydrogen, captured CO_2) with other uses and other sectors, all require substantial capital for capacity development.

Feedstock supply

A bottom-up assessment of seven categories of SAF (excluding power-to-liquid – PtL) estimates a total potential of ~27 EJ (or 1,777 Mt) by 2050 – a 30% increase over the previous edition of *Waypoint 2050*. This stems from more precise estimates for cover/degraded land crops and municipal solid waste, and the addition of crop-derived oilseeds and ethanol. This feedstock base could support approximately 306 Mt of SAF production annually by 2050.

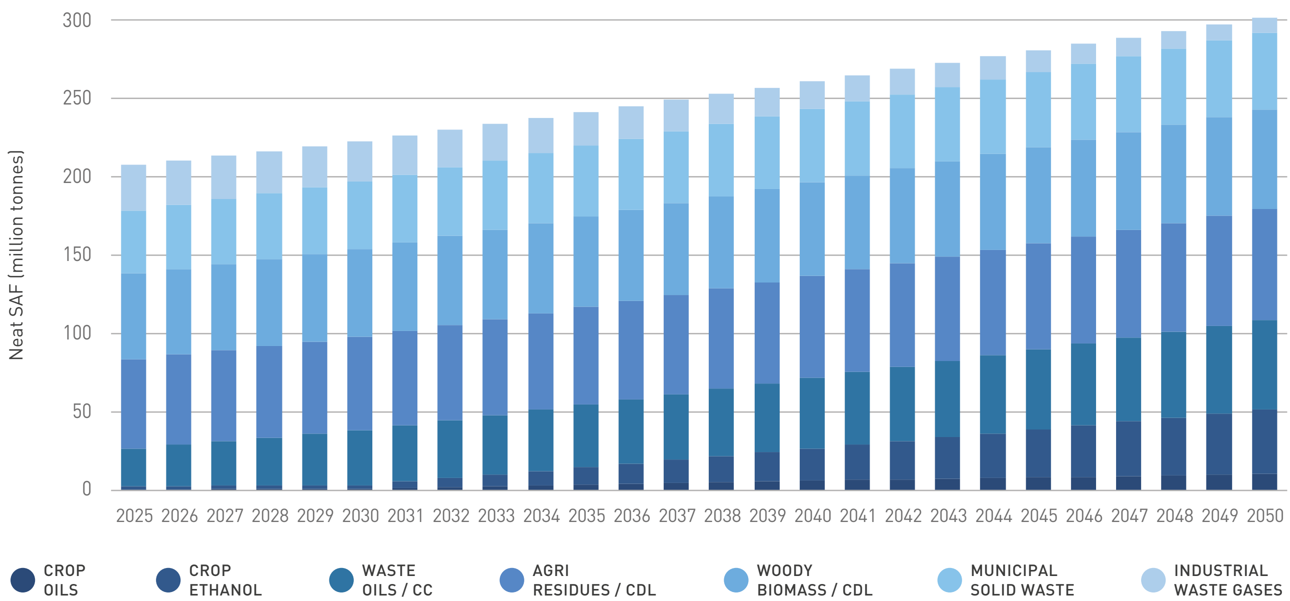
SAF categories considered in *Waypoint 2050*

A set of eight categories of SAF feedstock captures a wide range of feedstocks and supporting various pathways.

SAF Feedstock	Descriptions
Crop oils	Soybean oil, canola, rapeseed (excludes palm oil, as this does not meet the minimum CORSIA emissions reduction threshold).
Crop ethanol	Predominately from corn and sugarcane, with some very small volumes from wheat.
Waste oils, cover crops	UCO, waste animal fats, DCO, PFAD, camelina.
Agricultural residues, crops degraded land	Residues from global crops. Cellulosic crops on degraded land.
Woody biomass, crops degraded land	Sawdust, miscanthus, first thinnings, and other woody waste.
Municipal solid waste	Biogenic non-recycled fraction (greens, papers, card, other) and small % of fossil derived waste where it cannot easily be separated.
Industrial waste gases	From steel, Industry, and similar.
Power-to-liquids	SAF produced where green hydrogen is primary source of energy, with carbon sourced from biomass or direct air capture.

SAF production potential from biogenic feedstocks

Biogenic feedstock availability and production chemistry vary across pathways, reflecting evolving supply/demand dynamics with other sectors. This graph shows the total technically achievable SAF volume from these biogenic sources only. Power-to-liquid pathways are excluded because their potential is theoretically unlimited (constrained solely by renewable electricity and CO_2 capture capacity).



Utilisation of existing refining capacity – co-processing and refinery retrofitting

Co-processing refers to the simultaneous processing of renewable oil feedstocks, such as used cooking oil, alongside conventional fossil streams within existing refinery units, typically in hydroprocessing or fluid catalytic cracking units. Retrofitting, by contrast, refers to modifying existing fossil fuel refining assets, such as hydroprocessing units, to convert those same units to handle 100% renewable feedstocks. Both approaches leverage existing refinery assets, delivering significantly lower capital costs and faster deployment timelines when compared to greenfield standalone HEFA facilities.

Co-processing is already practiced in several refineries, particularly for renewable diesel production and in the EU, where it has been adopted as a lower-cost option to meet renewable fuel targets using available waste oils and fats. However, under current ASTM specifications, SAF produced via co-processing of fats, oils and greases (FOGs) is limited to a maximum blend of 5%, which constrains the volume that can be credited towards SAF targets. Recently, the UK Defense Standards body revised upwards the co-processing blend limit to 30%, a move which may be repeated in other jurisdictions. While this *Waypoint 2050* assessment does not explicitly distinguish retrofitting and co-processing from greenfield standalone HEFA pathways, the routes rely on the same lipid-based feedstocks. As a result, the availability of feedstock and the overall SAF production potential remain unaffected by the chosen production route.

However, the ability to retrofit existing assets or co-process renewable feedstocks could significantly reduce investment requirements and shorten deployment timelines, particularly in the early phases of SAF scale-up. Currently, the global potential for co-processing in 2030 is estimated at around 2[46] to 2.6 Mt[47] of SAF per year.

Feedstock criteria: conservative sustainability assessment

The feedstocks identified in this *Waypoint 2050* analysis were selected to ensure a representative selection, robust sustainability, and accessibility compared to competing uses. At a minimum, all feedstocks had to meet the CORSIA sustainability criteria such as avoiding food security risks and avoiding other negative impacts such as additional land use change.

Particular care has been taken to ensure crop-derived feedstock volumes are both technically achievable and deliver genuine emissions reductions. This analysis assumes no land use change, using only existing agricultural land for feedstock production. Co-products from the crops used to produce fuels (e.g., oils and corn starch) remain available for food and feed, ensuring no compromise to food security. Conservative yield increases have been included, recognising both the long record of improving yields, and limitations from the changing climate. Existing demand for on-road low-carbon fuels has been modelled and forecast. This 2025 analysis assumes that only the surplus generated by slight supply increases (from higher yields) and by reducing on-road demand (with growing electric vehicle uptake), can be used for SAF production. No food or feed primary crop availability has been assumed in Europe, due to the regulatory outlook. This results in very limited volumes available today, as most supply is already in use, with increasing availability through the analysis. By 2050, there is an estimated availability of 78 Mt of ethanol (primarily from corn and sugarcane), and 20.6 Mt of oil from oilseed crops such as soybeans and canola.

The availability of cover crops (sometimes referred to as intermediate crops) has been calculated based on the latest literature[48] and ICF analysis. This estimated the potential for cover crops as between 10%-20% by region, with many locations starting at the lower end of this range and increasing towards the upper limit over time. Of this potential, 20% was assumed to be suitable for cover crops appropriate for SAF production. Camelina was used as a benchmark to estimate the potential yield from this land, giving a total opportunity for 2.1 EJ by 2050. The opportunity for crops on degraded land was calculated through a similar methodology, using the Food and Agriculture Organization Statistics (FAOSTAT) data forecast for degraded land, and research showing that between 1.5% and 7.5% is suitable for cellulosic perennial crops such as miscanthus, assuming that 15% of this potential is accessible for SAF production.

Crops on degraded land can be processed through both alcohol-to-jet (AtJ) and gasification fischer-tropsch (FT). To capture this, the potential was split between the two pathways, with the AtJ share added to the agricultural residue potential and the FT share added to the forestry residue potential, both taken from the previous edition of *Waypoint 2050,* which draws on Energy Transitions Commission[49] estimates.

It is important to note that there are many variables that can have a significant impact on the final estimated values calculated for both cover crops and crops on degraded land. These include species choice, regional variability of yield and general adaptability to diverse climates. Similarly, SAF production from agroforestry residues is affected by factors such as feedstock availability and cost, the technology used, and the logistics of collection and processing.

The analysis deployed SAF capacity based on a merit ranking of the most affordable pathways, accounting for production costs and the value of the reduced emissions (with the assumed carbon value increasing from \$50/tCO_2e in 2020 to \$200/tCO_2e in 2050). This value is to represent a global average, and some regions already call for much higher abatement values, such as under the Low Carbon Fuel Standard (LCFS) in California, and the Carbon Intensity (CI) adjustment mechanism in the UK SAF mandate, or the implied abatement cost in ReFuelEU Aviation and UK SAF mandate fuel prices. This deployment distribution varies if the assumptions on technology availability, developments, and carbon value are changed.

Alternative assessments

Feedstock availability estimates vary widely, depending on the feedstocks included, methodological approaches, and key assumptions (conversion yields, collection rates, competing uses, and the share allocated to aviation). In this analysis, ICF took a conservative approach to quantifying the total availability, with other feedstocks (see below for those not included) and assessments offering additional sources of SAF potential. A newly published IATA assessment[50] shows a similar overall potential, although the analysis reflected different considerations on feedstock availability and overall approach. The IATA bottom-up analyses focused primarily on global feedstock availability and the production technology required to convert these feedstocks into SAF[51]. The IATA analyses show that a total of 400-500 Mt of bioSAF and PtL combined is possible, depending on the access to feedstocks and the speed of the technology scale-up.

Potential SAF production, 2050
ICF and IATA analysis

Crop-based and waste oils	63 - 72 Mt
Crop ethanol	36 - 45 Mt
Agroforestry residues	108 - 176 Mt
Municipal solid waste	29 - 49 Mt

Feedstock criteria: conservative share of feedstock availability

Many of the overarching assumptions from the first edition of *Waypoint 2050* have been retained to ensure this represents a pragmatic analysis, aligned to international sustainability standards, and recognises that aviation competes with other sectors for use of biogenic feedstocks, renewable energy, hydrogen and captured carbon resources.

The allocation of biogenic feedstocks to aviation in this assessment has been guided by broader analyses of competing biomass demands across sectors. Studies by the Energy Transitions Commission[52] (ETC) and the International Energy Agency[53] (IEA) highlight that total forecast demand for sustainable biomass, including its use in construction materials, textiles, plastics, energy, and fuel production, is expected to exceed sustainable global availability. Both organisations recognise aviation as a priority end-use sector due to the limited cost-effective alternatives to liquid fuels, particularly in the medium term before large-scale e-fuel production matures. The ETC and IEA allocate approximately 15-20% of total sustainable biogenic feedstocks to aviation in their global scenarios. In this analysis, a similar proportional allocation has been retained, ensuring that the aviation sector's feedstock potential is considered in the context of these competing demands and aligned with expert consensus on sectoral prioritisation.

Feedstock criteria: not included in assessment

This assessment focuses on feedstocks that are either currently used in SAF production or are expected to play a significant role under prevailing sustainability frameworks and policy mandates. However, several feedstocks have not been included due to regulatory constraints, limited data availability, or lower anticipated near-term uptake. Assuming these feedstocks could overcome sustainability questions, scale-up challenges and the regulatory and public acceptance environment, they could provide additional global SAF capacity in addition to what has been outlined in this conservative *Waypoint 2050* assessment.

» Palm oil, while currently used in the production of renewable fuels in some markets, has been excluded as it is not eligible in many low carbon fuel schemes. Palm oil's public perception, especially in Europe and North America, juxtaposed with the economic opportunities seen by many emerging markets for advancement in energy security makes for a challenging discussion. Significant economic development opportunities exist, but any use must be carefully managed to ensure the impacts on forest cover, biodiversity, local populations and other crops are taken into account.

» No primary food crop-based feedstocks have been included for use in the EU or UK. This includes crop-based ethanol, such as corn or wheat ethanol, and oilseeds such as soybeans and rapeseed. This is due to their exclusion from eligibility under both the UK SAF mandate and the ReFuelEU Aviation Regulation.

» Biogas, biomethane, and renewable natural gas have not been included or modelled as SAF production pathways in this edition (no operating facilities are currently using this approach). Several projects are in development using these pathways, but most of the feedstocks these processes would rely on (landfill municipal solid waste, agricultural residues, and forestry residues) are already included in the assessment under more conventional SAF pathways.

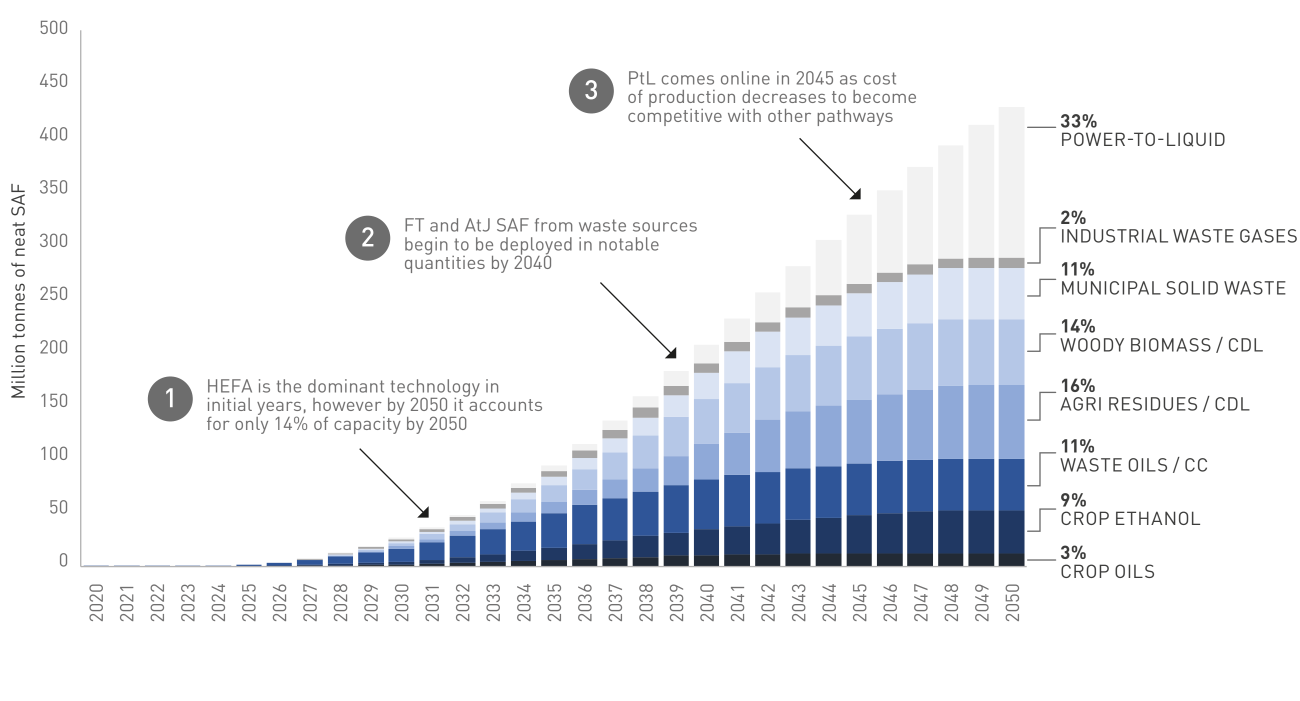
» Some other novel feedstocks such as manure, sewage sludge, or tyre pyrolysis oil have not been quantified in this assessment, but they have potential. These feedstocks lack consistent data across regions. Nevertheless, their inclusion could increase the total estimated feedstock potential, particularly in light of growing interest and the emergence of novel production pathways that are capable of converting these resources into SAF. The total global potential scale-up opportunity of using sewage as a feedstock has been estimated at ~32 Mt per year[54].

Each of the SAF categories includes one or more specific feedstock and pathways with associated life cycle values and carbon intensity (CI). For each category of SAF, CIs were collected and combined into an average value in 2025 and in 2050.

Projections of SAF volumes through 2050

Estimates of SAF production by feedstock category based on feedstock availability and production chemistry varies the feedstock distribution, reflecting the evolving supply/demand from other sectors.

SAF deployment profile – F2 scenario



SAF carbon intensity (CI) assumptions and scenarios

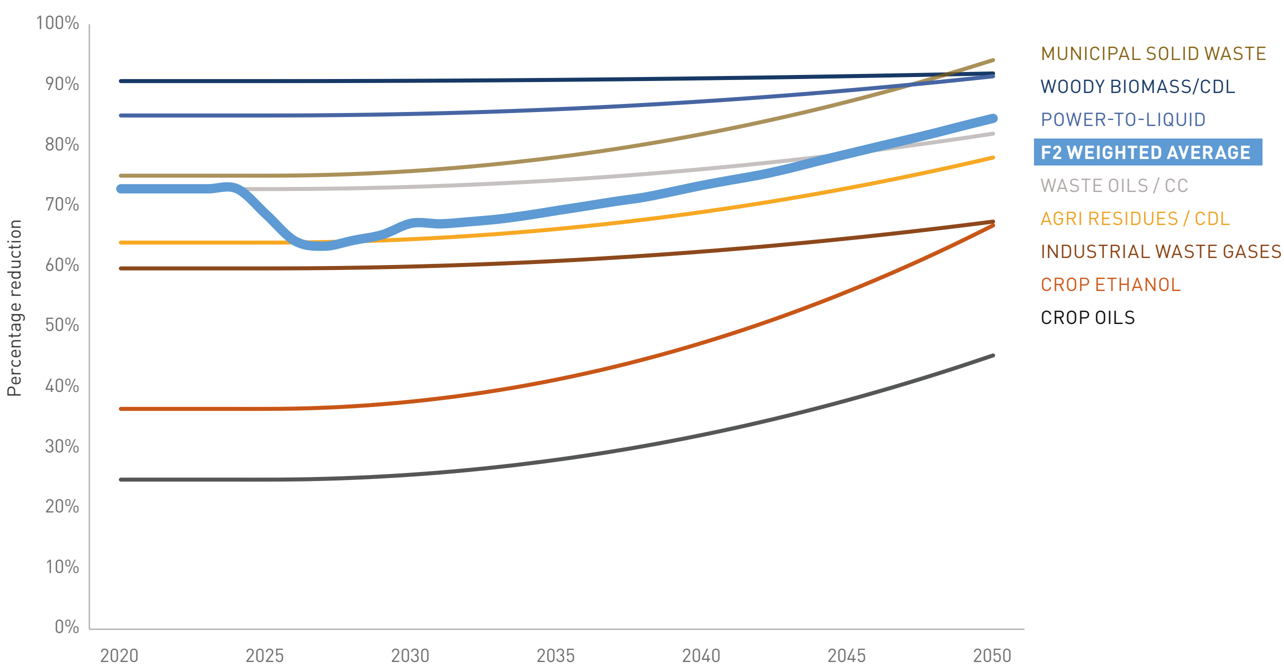
The carbon intensity (or CI) of SAF, in gCO_2e/MJ, refers to the quantity of greenhouse gas emissions released per unit of energy over the lifecycle of the fuel. The emissions reduction factor (ERF) normalises the SAF carbon intensity to conventional jet fuel, with a 0% ERF meaning that the carbon intensity of the SAF is equivalent to that of jet fuel and 100% meaning a carbon intensity of zero (0) gCO_2/MJ. Several of the carbon intensity values contained in the table below are based on publicly available information available from the CORSIA default values which tend to be conservative estimates[55]. In real-world use cases, the emissions reduction capability of a SAF will dictate its use, with a likely user and regulatory preference for SAF that delivers larger savings, particularly over 50%. In the event where actual CIs are lower than anticipated or contained in these scenarios, the difference and resulting additional residual carbon emissions would have to be addressed by MBMs.

SAF feedstock	Pathway	2025 CI emissions reduction factor	2050 CI emissions reduction factor	Reference/Source (2025)	Reference/Source (2050)
Crop oils	HEFA	67.0 gCO_2e/MJ (25%)	48.8 gCO_2e/MJ (45%)	Average of CORSIA default values for Canola and Soybean	ILUC values and cultivation improves by 25%, 50% reduction in fuel production emissions due to decarbonisation
Crop ethanol	AtJ	56.7 gCO_2e/MJ (36%)	29.6 gCO_2e/MJ (67%)	Average of CORSIA default values for sugarcane and corn grain with a reduction in the ILUC of corn	ILUC values and cultivation improves by 50%, 50% reduction in fuel production emissions due to decarbonisation
Waste oils, cover crops	HEFA	24.2 gCO_2e/MJ (73%)	16.1 gCO_2e/MJ (82%)	Average of CORSIA values for tallow, fats, UCO, PFAD and DCO	Includes cover crops. 50% reduction in fuel production emissions due to decarbonisation
Agricultural residues, crops degraded land	AtJ	32.2 gCO_2e/MJ (64%)	19.6 gCO_2e/MJ (78%)	Average of CORSIA default values for integrated and standalone	50% reduction in fuel production emissions due to decarbonisation
Woody biomass, crops degraded land	G-FT	8.3 gCO_2e/MJ (91%)	7.2 gCO_2e/MJ (92%)	CORSIA	50% reduction in fuel production emissions due to decarbonisation
Municipal solid waste	G-FT	22.3 gCO_2e/MJ (75%)	5.2 gCO_2e/MJ (94%)	CORSIA default value with 10% non-biogenic carbon content (NBC)	0% NBC to account for improvements in sorting
Industrial waste gases	AtJ	35.9 gCO_2e/MJ (60%)	29.0 gCO_2e/MJ (67%)	Average of CORSIA default values for integrated and standalone	50% reduction in fuel production emissions due to decarbonisation
Power-to-liquids	FT	13.4 gCO_2e/MJ (85%)	7.6 gCO_2e/MJ (91%)	Internal assumptions	Reduction in electricity requirements due to operational improvements and technology improvements

Evolution of SAF emissions reductions factors

The weighted average emissions reduction factor of deployed SAF evolves over time. It reflects both continuous improvements within individual pathways and shifts in the overall SAF supply mix, as the shares of different feedstocks and production pathways evolve. These dynamics are influenced by factors such as the decarbonisation of energy inputs, technological and supply-chain efficiencies, and the adoption of more sustainable farming practices. The average emissions reduction dips modestly in 2025-2030 as lower-cost crop-based SAF scales to meet rising demand, then rises again toward 2050 with the growing contribution of advanced waste-based and PtL SAF pathways.

SAF Emissions reduction compared to fossil fuel baseline (89gCO2e/MJ)



Lower-carbon aviation fuels

ICAO considers that lower-carbon aviation fuel (LCAF) can serve as a complementary measure alongside SAF in helping reduce aviation greenhouse gas lifecycle emissions. LCAF is fossil-based aviation fuel with reduced emissions from the upstream extraction, refining and production of the fuel (included in "well-to-tank" emissions). This may include capturing and sequestering CO_2 in the production of the LCAF. Given few details in the forecasts of LCAF supply (there are currently no certified LCAF products) coupled with its limited emission reductions factor (estimates put the upper potential ERF from LCAF at around 14% in the optimistic scenario[56]), LCAF has not been included in this assessment of SAF scenarios. However, all measures that meet sustainability criteria remain welcome and necessary to decarbonise aviation's fuel supply.

SCENARIO F3: TECHNOLOGY-CENTRIC MARKET SCENARIO (MARKET-DRIVEN USE OF SAF AND MBMS BY 2050)

Scenario 2 assumes an extremely ambitious SAF rollout, reaching ~90% replacement of conventional jet fuel by 2050. While technically feasible, this scale will be extremely challenging. Moreover, given the large abatement cost differences across SAF types (power-to-liquid SAF being far more capital intensive and, initially, much more expensive than other feedstock/pathways or conventional fuel) and the lower cost of alternatives such as carbon removals, market dynamics in a technology-neutral environment are expected to govern the relative contribution of each measure to 2050 emissions reductions.

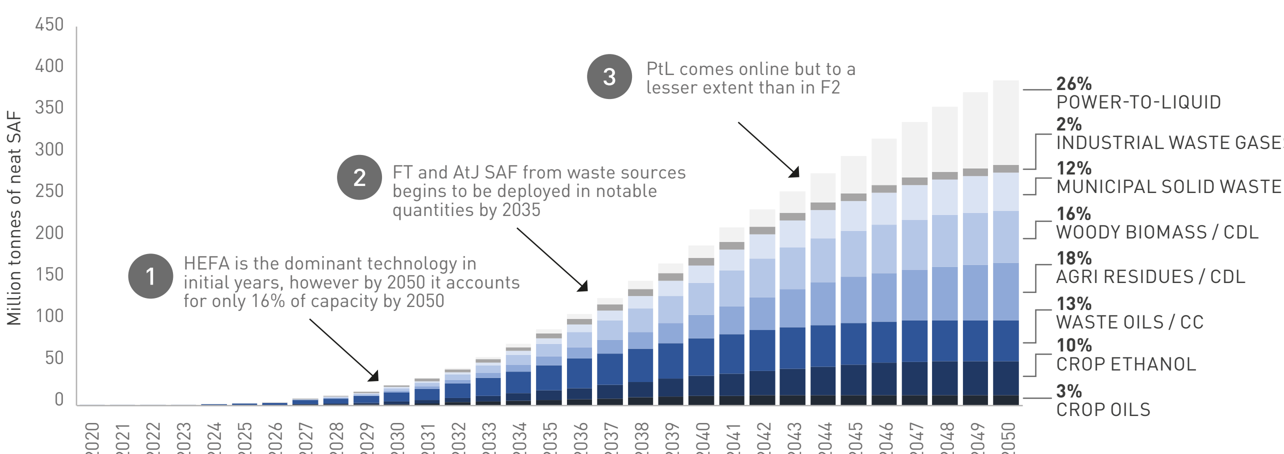
Near-term actions *to accelerate progress towards the 2050 goal:*

- » *Develop new or strengthen existing policies to incentivise the development and production of SAF.*
- » *Secure investments to accelerate the production of SAF.*
- » *Accelerate the development of facilities to produce SAF through revenue certainty mechanisms.*
- » *Create level playing field for the use of SAF across operators and regions.*

Potential trade space between SAF and carbon removal solutions through 2050

SAF produced from crop oils, crop ethanol, waste oils, cover crops, crops grown from degraded land agricultural residues, woody biomass, municipal solid waste, and industrial waste gases may contribute up to 280 Mt by 2050 (representing ~720 $MtCO_2$ of emissions reductions). In addition, SAF from PtL pathways could contribute a further 100 Mt, yielding approximately ~290 $MtCO_2$ of further emission reductions. At the same time, carbon removal opportunities should scale up to commercial size facilities to address residual emissions not addressed by SAF. The SAF requirement to meet this illustrative scenario is shown below.

SAF deployment profile – F3 scenario



SAF demand and distribution environment – airports

Although airports are rarely the direct producers or purchasers of fuel, they are essential enablers of SAF deployment. Their contributions range from coordinated purchasing and on-site blending, to supportive financial mechanisms and book and claim systems, R&D investment, feasibility studies, and even feedstock collection in some locations. Today, 172 airports worldwide already distribute SAF (regularly or in batches). Their role includes awareness-raising, advocacy, and direct engagement with fuel suppliers, airlines and governments. The level of airport involvement varies by business model and regulatory environment, yet successful SAF programmes universally depend on proactive cross-industry collaboration.

Impact of the global energy transition on conventional aviation fuel

The energy transition is reducing demand for fossil-based fuels like gasoline and diesel, especially with the rise of electric vehicles and liquified natural gas[57]. According to IEA analysis, global oil demand is expected to peak around 2030, resulting from a sharp decline in ground transport fuel demand[58]. However, aviation fuel demand is projected to grow through 2050, making it an outlier. This creates challenges such as potential supply chain disruptions and price volatility due to refinery closures, shifts in refining capacity, and shifts in required refined product mix.

Refineries, traditionally focused on diesel and gasoline, now face economic and technical hurdles as demand patterns change – some are shutting down or repurposing. There is a distinct shift of refining capacity from developed to emerging economies, which will lead to longer supply chains (and increased disruption risk) for jet fuel supplies. IATA has estimated that North America and Europe are expected to see a net reduction of 2.4 million barrels per day[59] (114 Mt per year) in refining capacity from 2020 to 2026.

Currently, jet fuel makes up around 6-7% of refining capacity. That can be optimised upward to a certain extent but becomes uneconomical the higher it is pushed. So, as refining capacity overall reduces, the supply of fossil jet fuel will either become constrained or economically challenging. Either way, the cost of fossil jet fuel is likely to rise in the years ahead.

Yet, this shift also offers opportunities: SAF could help fill the gap in conventional aviation fuel supply while enhancing energy security and price stability. Regulatory support is essential to help repurpose closed refineries for SAF production and ensure a reliable, SAF supply.

Secondary requirements

Explorations of the different pathways for aviation's energy future as part of *Waypoint 2050* work have identified that the sector will need access to low-carbon electricity and green hydrogen both to produce power-to-liquid SAF and potentially for primary use in aircraft propulsion.

Analysis for *Waypoint 2050* shows that this could consume between 1% and 9% of the *currently planned* low-carbon electricity production between 4% and 52% of the *currently planned* green hydrogen supply in 2050, depending on the scale-up of PtL in particular. However, this depends on the pursued *Waypoint 2050* scenario which represents the maximum cases as a comparison.

Any shift to these forms of energy for aviation will likely bring an increase in generation of both low-carbon electricity and green hydrogen to meet the needs of air transport, as the IEA and International Renewable Energy Agency (IRENA) analysis of production does not include hydrogen for direct use in aviation.

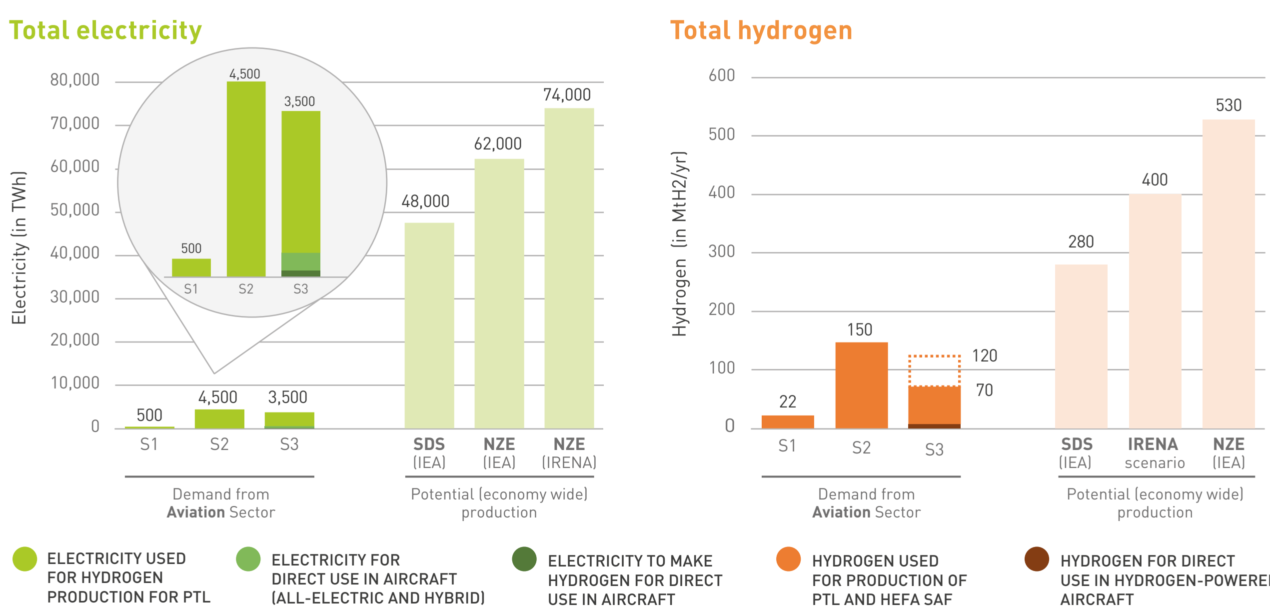
Combined air transport demand for electricity and hydrogen, 2050

Whether for use as direct energy for aircraft, or as part of the process to produce hydrogen or PtL SAF, this illustrates the total possible demand aviation may have for low-carbon electricity and green hydrogen in 2050 across each of the three *Waypoint 2050* scenarios. These represent upper-bound estimations for illustrative purposes: it is likely that requirements will be lower than this. The IEA and IRENA scenarios also don't account for the full use of hydrogen or electricity in aviation, so aviation will likely boost investments and supply in these energy sources above the current scenarios.

It is notable that the estimated quantity of hydrogen demand from aviation for its energy needs is a significant share of the forecast economy wide production of hydrogen. In order for PtL SAF to be economically viable for aviation, renewable energy and hydrogen need to be abundant and low cost. As such, aviation requirements for renewable energy and hydrogen need to be considered in wider national energy strategies, in addition to aviation's requirements for renewable liquid fuels.

Combined air transport demand for electricity and hydrogen, 2050

Whether for use as direct energy for aircraft, or as part of the process to produce hydrogen or PtL SAF, this illustrates the total possible demand aviation may have for low-carbon electricity and green hydrogen in 2050 across each of the three *Waypoint 2050* scenarios in context of potential economy wide production of green electricity and hydrogen[60]. By comparison, the IEA has estimated[61] the energy requirements for data centres, boosted by demand for artificial intelligence, might reach 945 TWh by 2030 in a base case, with the upper scenario requiring potentially over 1,700 TWh in 2030 — or 4.4% of global electricity demand. BloombergNEF has estimated that by 2050, data centre electricity demand could exceed 3,700 TWh[62].



CALL TO ACTION: SUSTAINABLE AVIATION FUEL AND OTHER NEW ENERGIES

Waypoint 2050 and numerous studies agree that sustainable aviation fuel offers the greatest potential to decarbonise the air transport sector. Transitioning away from fossil fuels through the use of SAF helps to avoid significant changes to fleet or fuelling infrastructure, but it is also an effort which will require significant coordination outside the direct air transport sector. Leadership is needed from energy providers, feedstock suppliers, finance and government. Success will not only decarbonise aviation but also boost green energy jobs and enhance energy security through diversified supply.

The table below presents key actions to **"build on current efforts and drive near-/mid-term progress"**, **"innovate and develop towards long-term progress"** and **"advocate and collaborate towards joint efforts and progress"** on sustainable aviation fuel and other new energies.

Aviation sector

Commit to SAF	» Aircraft operators should define and implement industrial and procurement strategies to use SAF in their operations. Aircraft operators that have taken lead positions to continue to scale up their commitments and use of SAF. Other aircraft operators, not yet using SAF, should investigate SAF opportunities — small or large — and start the process of using SAF. » Expand SAF offtake agreements at an early stage across many points in the value chain.
Continue to support the qualification of SAF blending components	» Continue to support the qualification of SAF blending components through the ASTM and other aviation fuel standards agencies.
Encourage investment in SAF	» Encourage the establishment of mechanisms such as contract for difference to de-risk investment and secure medium to long term offtake agreements. » Make the case to energy sector, governments and the finance community to lead and invest in SAF production scale-up across all regions. » Encourage air transport customers to participate in SAF offtake initiatives.

Governments and policymakers

Develop policies that support SAF production and use	» Develop wider clean energy transition strategy to, in addition to deploying sustainable aviation fuel (SAF), include hydrogen and low-carbon electricity requirements of aviation in national energy strategies. Ensure aviation requirements are identified in national green hydrogen and low carbon electricity infrastructure strategies. » Monitor the effectiveness of SAF policies in delivering what is intended to deliver and to proactively correct any unintended consequences that discourage SAF adoption. » Work with industry to develop comprehensive and robust SAF registry interoperability, facilitate transparent SAF book and claim transactions (including exploration of international book and claim mechanisms such as being developed by the Civil Aviation Decarbonization Organization63) to increase efficiency of complying with regulatory demand policies such as blend mandates. This will ensure a more efficient roll-out domestically, promote system efficiencies, reduce price premiums as well as make the business case for SAF to be produced in emerging economies. » Enhance policy frameworks that prevent SAF costs from falling disproportionately on airlines and passengers. » Explore innovative local policy actions to incentivise the use of SAF, particularly in a national or city-level context where existing regulations (for example on local air quality) could have a SAF incentive structure considered. » Identify opportunities presented by SAF and its feedstocks to support regional energy autonomy and resilience goals.
Invest in SAF	» Bridge investment risks across both demand (short-term offtakes) and supply (long-term facilities) by supporting the growth of a national SAF industry. This includes attracting capital for new capacity through loan guarantees, revenue certainty mechanisms, and policy stability, while also advancing research into local SAF pathways and related clean energy industries. » Demonstrate leadership with a commitment for government travel to be undertaken on SAF.

»

Support the technical development of SAF	» Adopt globally-recognised sustainability standards and work to harmonise global standards including through ICAO.
Demonstrate recognition of sustainable aviation fuel (SAF) as the primary driver of aviation decarbonisation to 2050	» Recognise aviation as a priority end-use sector due to the limited cost-effective alternatives to liquid fuels and prioritise feedstock. » Develop durable and long-lasting policies that put SAF on a more level playing field with fossil fuel options, such as providing incentives for production, blending and use of SAF, differentiating SAF from other alternative transport fuels. » Redirect fossil fuel subsidies — estimated to be anywhere between $1 trillion (IEA[64]) and $7 trillion (IMF[65]) a year — towards supporting low-carbon and renewable energy scale-up, including SAF and reinvest sector-generated funds directly into research and development for sustainable aviation technologies, particularly in emerging economies.

Research institutions

Implement SAF research programmes	» Implement SAF research programmes into innovative technology pathways, feedstock and emissions reduction factor improvements and production efficiency improvements.

Energy industry

Demonstrate substantial and long-term commitment to SAF production	» Demonstrate substantial and long-term commitment to SAF production and scale-up across regions, including living up to announcements on SAF, on both capacity and timing through coordinated planning with fuel suppliers, airports, and regulators. » Review long-term corporate planning and strategy in line with the opportunities provided by the SAF market and demonstrate commitment to the transition. As global refinery capacity declines due to the expected decrease in fuel demand of road transport, existing refineries to transition to lower-carbon fuels production through repurposing and co-processing, provided that the right policies are in place.
Commit to predictable supply of SAF at an affordable cost	» Commit to predictable supply at an affordable cost for SAF, enabled by policy incentives and fuel industry scale-up. » Provide price transparency for SAF buyers and air transport customers in voluntary and regulated SAF environments (such as ReFuel EU) - fuel suppliers must be both transparent to governments, airlines and consumers in their choice and cost pass-through of SAF. Airlines also must have timely access to sustainability documentation from SAF use.
Guarantee access to airport fuelling infrastructure	» Commit to guaranteeing access to airport fuelling infrastructure to help avoid the need for regulatory action to enable SAF supply into airports and ensure equitable availability across regions.

Finance community

Focus on funding SAF opportunities worldwide	» Mobilise funding for SAF opportunities worldwide, covering feedstock supply chains, production, distribution, and enabling infrastructure while deploying innovative financing tools such as blended finance and novel offtake structures to unlock projects all over the world.
Investigate innovative financing mechanisms	» Consider using the ICAO Finvest Hub platform to support maturation and launch of SAF projects.
Re-evaluate conventional project risk tolerance assumptions	» Re-evaluate conventional project risk tolerance assumptions including relationship to climate risks. » Aircraft financiers should consider SAF investments as complement to and risk mitigation for aircraft investment portfolios.

Other stakeholders

Other transport modes and energy sectors should prioritise best available energy options such as electrification	» Other transport modes and energy sectors should prioritise best available energy options such as electrification (passenger road transport, residential heating).

MEASURE 4: MARKET-BASED MEASURES

While the global aviation sector aims to decarbonise as much as technically feasible through technology, operations, infrastructure improvements, and SAF, residual carbon will need to be addressed through measures targeting the remaining emissions.

Net zero carbon aviation requires emissions to be cut within the sector to the maximum extent feasible, with the 'net' referring solely to removals of the hardest-to-abate residual emissions. SAF has the same combustion emissions as conventional jet fuel, yet its upstream lifecycle emissions benefits are treated as an 'in-sector' reduction since SAF is manufactured specifically for aviation use.

Market-based measures to mitigate residual carbon emissions will play a particularly critical role in aviation's path to net zero 2050, because most other sectors have far more accessible in-sector mitigation options. The path towards decarbonisation by 2050 will rely on the supply of emissions reductions and avoidance (offsets) in the near- and mid-terms towards increasing supply and use of carbon dioxide removals and ultimately 100% CDRs by 2050. In each of scenarios 0-2, *Waypoint 2050* has identified the measures to reduce emissions. However, there is a range of 400 to 1,350 MtCO_2 of residual or remaining carbon emissions mitigation in 2050 that will be required through carbon removals.

Current policy: CORSIA

In 2016, governments meeting at ICAO agreed to establish CORSIA, the world's first climate pricing mechanism for any single global sector, to offset the growth in international aviation CO_2 emissions from 2019 levels. CORSIA does not cover domestic air transport operations, as these are subject to national action under the 'nationally determined contributions' outlined in the Paris Agreement.

CORSIA is intended to offset the growth in emissions from international aviation, which is not covered under the Paris Agreement. Similar to the Paris Agreement, CORSIA is initially a voluntary scheme, with States deciding if their country will be included. In later years, it becomes mandatory for all with the exception of small and developing countries or States with low level of aviation activities.

In order to address the concerns of developing States and to take into account the special circumstances and respective capabilities of States, CORSIA is being implemented in phases. From 2021 until 2026, only flights between volunteering States will be subject to offsetting requirements. Starting 2027, all flights will be subject to offsetting, with the exception of flights to/from Least Developed Countries (LDCs), Small Island Developing States (SIDS), Landlocked Developing Countries (LLDCs) and small aviation markets, unless they volunteer to participate.

Since 2021, the number of participating States has steadily increased from 88 States to 115 in 2023 and 130 today.

Due to the impacts of Covid-19 on international aviation, its CO_2 emissions remained below the CORSIA sector baseline (based on 100% of 2019 emissions subject to offsetting requirements). As such, there was no offsetting required during the Pilot Phase.

During the 41st Assembly, ICAO agreed to adjust the CORSIA sector baseline to 85% of 2019 emissions subject to offsetting requirements from 2024 onward. This lower baseline is expected to result in greater future offsetting requirements and thereby increasing the ambition of CORSIA.

In 2025, the ICAO Council finalised its periodic review of CORSIA, evaluating the pilot phase (2021-2023) and updating projections for international aviation's offsetting requirements. Offsetting began in 2024 and will continue through to at least 2035, addressing emissions growth above 85% of 2019 levels.

According to ICAO Assembly Resolution A41-22, a special review is expected by the end of 2032 on the future shape of the scheme beyond 2035.

CORSIA provides a robust framework currently recognising programmes that generate units emissions from (1) reductions, (2) avoidance, and (3) removals and meet the CORSIA emissions unit eligibility criteria[66].

Near-term actions *to accelerate progress towards the 2050 goal:*

- *Reaffirm support to CORSIA as the only global market-based measure for international aviation.*
- *Continue to support the implementation of CORSIA especially as it transitions to an active phase of claiming of emissions reductions from CORSIA eligible fuels and cancellation of CORSIA eligible emissions units starting in 2024.*
- *Accelerate the implementation and release of letters of authorisation (LoAs) for CORSIA eligible emissions units to ensure enough supply for the first phase (2024-2026).*

Current policy: EU ETS

The European Union Emissions Trading Scheme (EU ETS) is a carbon market, also known as a "cap and trade" system, designed to reduce greenhouse gas emissions in line with European Union climate objectives. For aviation, it requires airlines and certain private aircraft operating within the European Economic Area (EEA) to monitor, report, and surrender allowances for their CO_2 emissions, effectively putting a price on carbon and incentivising reductions.

The EU ETS sets a limit (cap) on total greenhouse gas emissions from the aviation sector. Airlines must obtain allowances (permits to emit) for each tonne of CO_2 they release. The EU ETS currently covers flights within the EEA, including those to and from the outermost regions of the EU, and flights departing from the EEA to Switzerland and the UK. Both EU and non-EU airlines operating flights within the specified geographical scope are subject to the EU ETS.

The EU ETS is in its fourth phase (2021-2030) and is continuously being revised to become more stringent.

Recent revisions have included the phasing out of free allowances for aviation, promoting the use of SAF, and reinvestment mechanisms to support SAF production. The price of EU Allowances has fluctuated, but has generally increased in recent years[67], becoming a significant cost factor for airlines. The EU ETS is expected to continue evolving, with potential further expansions of its scope and more stringent measures to reduce emissions.

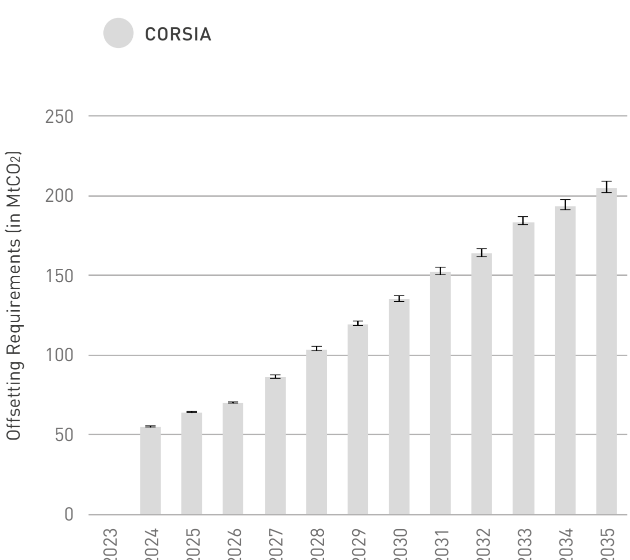
Current policy: other jurisdictions

UK ETS: The UK Emissions Trading Scheme (UK ETS) is a market-based system designed to reduce greenhouse gas emissions, including those from aviation, and is a cornerstone of the UK's net zero strategy. Introduced in 2021 after the UK's departure from the EU ETS, it sets a cap on total emissions for covered sectors, including power, industry, and aviation, with the cap declining over time to encourage decarbonisation. For aviation, the routes covered by the UK ETS include UK domestic flights, flights between the UK and Gibraltar, flights departing the UK to European Economic Area States (and Switzerland) conducted by all included aircraft operators, regardless of nationality. Most aircraft operators have obligations under the UK ETS[68].

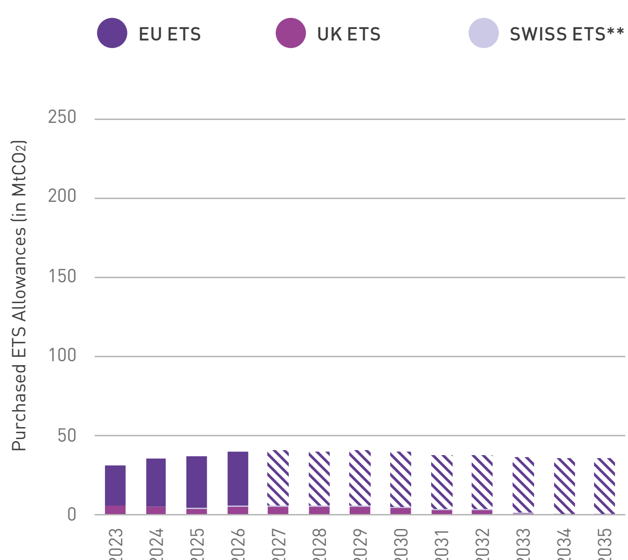
Swiss ETS: The Swiss Emissions Trading System[69] (Swiss ETS or CH-ETS) is a mandatory regulation for aircraft operators to monitor and report CO_2 emissions from flights within Switzerland and between Switzerland and the European Economic Area (EEA) or the United Kingdom, requiring them to cover these emissions with allowances. Since 1 January 2020, the Swiss ETS has been linked to the EU ETS, allowing for the mutual recognition of emission allowances and simplifying compliance for operators who also fall under the EU ETS.

Potential role of market-based measures

Beyond the use of carbon offsets from voluntary actions, those airlines with activity in the covered territories are addressing part of their residual emissions through existing schemes and, from 2024, through CORSIA. Expectations out to 2035 for CORSIA are outlined on the left graph. The following assumptions are made: that EU ETS and Swiss ETS continue in current scope through 2035 (this could evolve as policy discussions shift); that the EU and Swiss ETSs extend to 2035 under the current scope.



Range of offsetting requirements from CORSIA according to Waypoint 2050 scenarios 0-2.

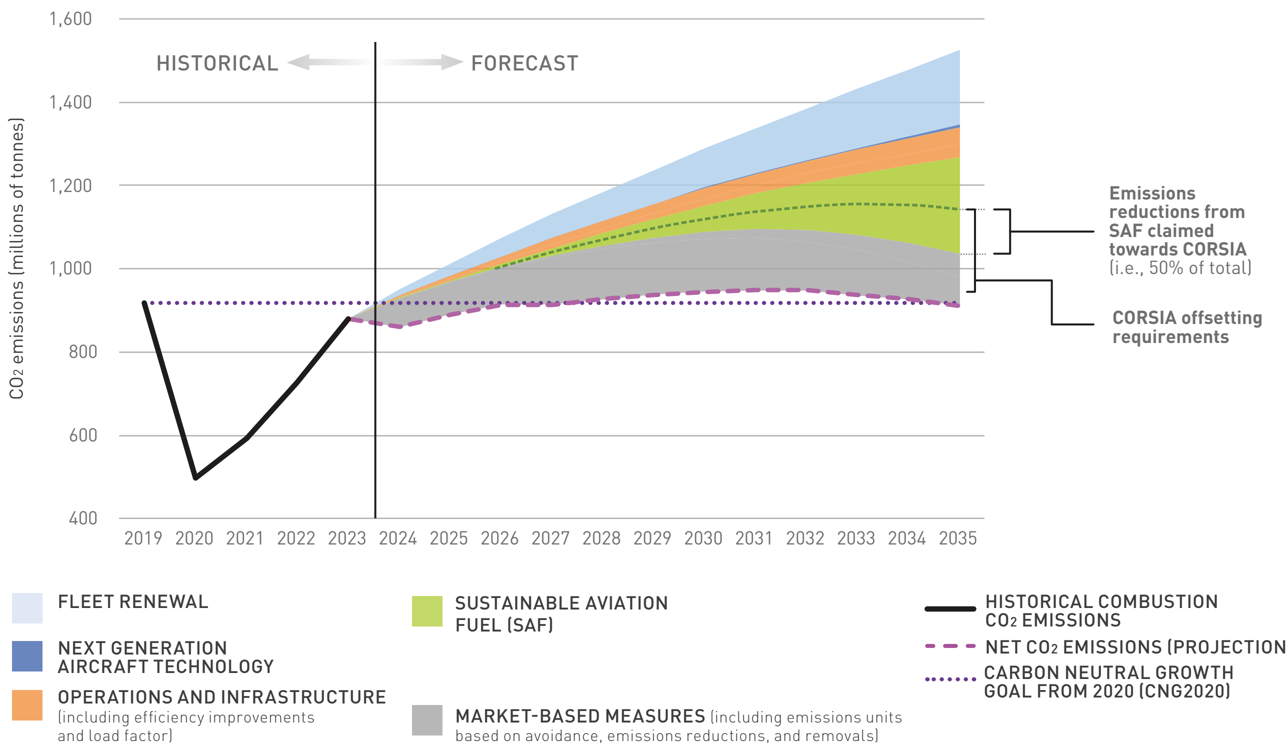


**Through 2026, as assessed in the European Aviation Environmental Report (2025).

Note: For purpose of analysis, the EU and Swiss emissions trading schemes are assumed to extend until 2035.

Contribution of existing policies towards net CO_2 emissions through 2035[70]

Net CO_2 emissions have remained below 2019 levels through 2023. From 2024, the contribution from CORSIA and other emissions trading schemes is expected to maintain net emissions below CNG2020. As CORSIA applies to international aviation (it does not address domestic aviation emissions), net CO_2 emissions may increase in the late 2020s above the CNG2020 level but then stabilise as SAF and carbon removals scale up.



Evolving solutions to residual carbon

Currently, the supply of traditional 'offsets' (short for out-of-sector or indirect emissions mitigation) from carbon markets is dominated by emissions reductions and avoidance, with carbon removals being an emerging and increasingly preferred type of indirect emissions mitigation.

- Emissions reductions credits come from projects which reduce the emissions of any given activity. For example, a renewable energy project to deliver solar electricity equipment to communities which would otherwise have burned coal for power.
- Avoidance credits come from projects which avoid CO_2 being created in the first place, such as deforestation reduction projects.

Historically, these offset credits were created to channel funding from developed-world consumers and businesses towards climate projects in developing nations. Some of these offsets, which are transacted in unregulated voluntary markets, have been the subject of some controversy in recent years.

ICAO's CORSIA framework, bolstered by robust sustainability criteria and rigorous verification, helps ensure high quality emissions units. In 2024, the UNFCCC finalised Article 6 rules under the Paris Agreement, enabling robust offsetting with corresponding adjustments to prevent double-counting, potentially unlocking affordable, verified supply for regulatory markets like CORSIA. However, traditional offsets primarily avoid or reduce emissions that would have occurred elsewhere but do not remove them[71]. For this reason, as the world decarbonises, the supply of quality traditional offsets should diminish and reaching net zero carbon by 2050 will likely be achieved through a transition to CDRs.

CDR potential sources of supply by 2050

Carbon dioxide removal (CDR), also known as carbon removal or negative emissions, refers to anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air capture and storage, but excludes natural CO_2 uptake not directly caused by human activities.

CDR is seen as a critical component in achieving global climate goals, particularly net zero carbon emissions targets. CDR is not a substitute for reducing greenhouse gas emissions in-sector (mitigation), but rather a necessary complement. CDR can help address emissions from sectors where reducing emissions is particularly challenging, such as agriculture and transportation such as the aviation sector.

CDR categorises methods to remove CO_2 from the atmosphere as (1) nature-based and (2) technology-based solutions. Nature-based CDR uses ecosystems like forests and soils for carbon capture and storage, offering co-benefits like biodiversity but often with less durable storage. Technology-based CDR employs engineered systems such as direct air capture and enhanced rock weathering for potentially more permanent removal, though often at higher costs. Both CDR types are needed to meet climate goals.

CDR encompasses a wide array of project types, including (but not limited to):

- Afforestation and reforestation: planting new forests or restoring existing ones to absorb CO_2.
- Biochar: process of heating biomass (like wood, crop residues, or other organic waste) in a low-oxygen environment through pyrolysis where charcoal-like material (biochar) produced is created and used to sequester carbon in the soil, effectively removing it from the atmosphere for extended periods.
- Bioenergy with carbon capture and storage (BECCS): thermal conversion of biomass as dedicated feedstock or waste for energy production and then capturing and storing the resulting CO_2.
- Direct air carbon capture and storage (DACCS): machines directly capture CO_2 from the atmosphere.
- Enhanced weathering: accelerating the natural process of mineral weathering to absorb CO_2.
- Ocean-based CDR: Enhancing or accelerating natural biological or chemical processes to sequester carbon in the ocean.
- Soil carbon sequestration: increasing the amount of carbon stored in soils through improved land management practices – this can also be through peat bog restoration and other.

Approaches to carbon dioxide removals

Carbon dioxide removal (CDR) encompasses various approaches to extract CO_2 from the atmosphere and store it, helping to mitigate climate change. These methods can be broadly categorised into land-based, ocean-based, and technological solutions. Non-exhaustive list. For illustration purposes.

Method	Afforestation, Reforestation	Blue Carbon	Biochar	BECCS	DACCS
Description	Carbon is captured through photosynthesis can stored in wood, roots and soil.	Carbon is stored in coastal and marine ecosystems (e.g., seagrasses, mangroves)	Carbon is stored through pyrolysis from biomass into biochar that is then stored in soils or products	Biogenic carbon is captured from the air by growing biomass, used for energy production, and then stored in soils or products	Carbon is captured directly from the air and stored geologically
Implementation option	Agroforestry, tree planting, timber in construction, bio-based products	Rewetting, revegetation	Cropping and forestry residues, urban and industrial waste	Cropping and forestry residues, urban and industrial waste	Solid sorbent, liquid solvent
Earth system	Land	Ocean	Land	Land	Land
Readiness	High	High	Moderate	Moderate	Moderate
Storage duration	Decades	Decades	Centuries	Millenia	Millenia
Risk of reversal	High	High	Mid	Low	Low

***Near-term actions** to accelerate progress towards the 2050 goal:*

- *Develop and/or support policies that enable the development of technology/solution agnostic and durable carbon dioxide removals (CDRs) that meet leading sustainability criteria.*
- *Incentivise the scale up of the supply of CDRs, paired with robust monitoring, reporting and verification (MRV) to ensure additionality and traceability from capture to storage.*
- *Ensure that the aviation sector will be able to secure a sufficient supply of CDRs to meet its needs given that other sectors are likely going to compete for such supply.*

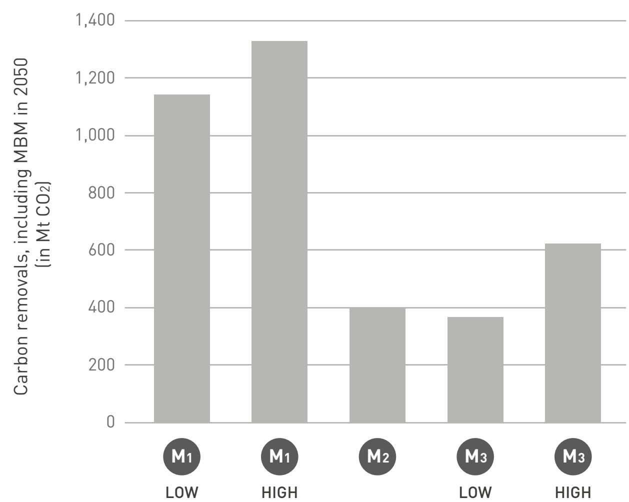
Aviation demand for residual carbon solutions

Based on scenarios 0-2, the potential demand from aviation to address residual CO_2 emissions could reach 400-1,350 $MtCO_2$ by 2050. While these estimates are for 2050 to meet the net zero carbon goal, this demand will not be met instantly at the last minute before 2050. The air transport industry will be competing for a significant share with other economic sectors in the limited expected supply of CDR[72]. Fast and immediate action is required to initiate scale-up and ensure the necessary supply is available[73].

In addition to scaling the supply of carbon removals to reach the 2050 levels, there is the need to develop a viable and credible carbon market now for other emissions reduction and avoidance carbon mitigations use between now and 2050. Without a viable carbon credit market and scalable CDR technologies and supply base, CDRs will not be available for aviation and other sectors in 2050.

Potential demand for CDRs from the global aviation sector by 2050

Potential demand from aviation to address its residual CO_2 emissions could reach from 400 to 1,350 $MtCO_2$ by 2050. Given the need to scale up CDR availability between now and 2050, incentives and/or policy support will be needed to ensure CDRs are available for use in the aviation sector (as well as others) in the lead-up to 2050.



The costs associated with reducing carbon emissions vary significantly across different methods, including emissions units, CDR, and SAF. Cost abatement of CDRs tend to fall between prices of emissions units (based on avoidance and reductions) and the cost abatement of SAF.

CALL TO ACTION: MARKET-BASED MEASURES
(TO ADDRESS RESIDUAL CARBON EMISSIONS)

The aviation sector is considered a "hard-to-abate" sector and despite efforts being made on new technology, energy transition and operational improvements, there will be residual emissions to address in order to meet net zero carbon by 2050.

The table below presents key actions to "**build on current efforts and drive near-/mid-term progress**", "**innovate and develop towards long-term progress**" and "**advocate and collaborate towards joint efforts and progress**" on market-based measures to address residual carbon emissions.

Aviation sector

Continue to implement and strengthen ICAO's CORSIA.	» Continue to implement and strengthen ICAO's CORSIA, including the continued push for availability of CORSIA-Eligible Emissions Units (EEUs). » Promote the publication of a state-of-play report on CORSIA eligible units through ICAO (supply and demand, price, policies, etc).
Recognise the key role of market-based measures.	» Demonstrate the need of the sector for all options of market-based measures, including traditional offsets and carbon removals, associated with supportive policy mechanisms tailored for the aviation sector.
Recognise the key role of carbon removals to reach net zero and start to scale carbon removals.	» Promote and integrate carbon removals into aviation by raising awareness, embedding them in GHG accounting measures (such as ICAO CORSIA and national/regional schemes) and beginning their sourcing and use via fuel pathways or direct emissions units. » Support and collaborate with research institutions and startups in order to develop innovative carbon capture / direct air capture technologies. » Participate in industry-wide initiatives to share expertise, accelerate technology transfer, and signal demand.

Governments and policymakers

Reaffirm support of CORSIA and encourage States to volunteer for CORSIA.	» Reaffirm support of CORSIA as the only global market-based measure for international civil aviation and continue to support the implementation of CORSIA especially as it transitions to an active phase of CORSIA eligible fuels use and offsetting through CORSIA eligible emissions units. » Encourage States to volunteer for CORSIA.
Accelerate the release of letters of authorisation for CORSIA eligible emissions units.	» Accelerate the implementation and release of letters of authorisation for CORSIA eligible emissions units to ensure enough supply for the first phase (2024-2026).
Support and promote the development of carbon capture and removal opportunities.	» Implement measures towards the long-term CO_2 goal through ICAO. » Support and promote the development of carbon capture and removal opportunities, including the development of crucial CO_2 transport and storage infrastructure for CDR, such as CO_2 pipelines and geological storage sites. » Support the development of stable and recognised carbon storage schemes (including through policy and practical challenges such as storage permitting) allowing industry to claim the benefits while limiting risks of reversals. » Implement clear and globally harmonised regulations for CDR technologies (developing MRV for ocean CDR, and establishing accurate measurement methods for biological CDR to broaden the solutions for industry).

»

Ensure that environment taxes and levies support the aviation sector's decarbonisation.	» Ensure that any revenues from environment taxes and levies raised from air transport operations are directed towards initiatives which help reduce emissions from the sector: funding for SAF scale-up, research into new technology options, efficiency incentive programmes, etc.

Research institutions

Accelerate the research into carbon dioxide removal.	» Accelerate the research into carbon dioxide removal across all available and emerging pathways.
Work on carbon storage and carbon recycling technologies.	» Work on carbon storage and carbon recycling technologies.

Energy Industry

Support the financing, development and deployment of CCUS.	» Support the financing, development and deployment of carbon capture utilisation and storage (CCUS) technologies.

Finance community

Fund projects to supply CORSIA emissions units and CDRs.	» Provide funding for projects to supply CORSIA-eligible emissions units and early-stage CDR startups and demonstration projects across a range of CDR technologies, helping overcome the challenges of initial development and attract further investment.
Facilitate the development and operation of carbon markets.	» Facilitate the development and operation of carbon markets, providing liquidity, and helping manage the risks associated with emissions units.
Integrate carbon removals in portfolios for aviation sector decarbonisation.	» Integrate carbon removals in portfolios for decarbonisation of the aviation sector recognising its importance for the sector to attain net zero carbon emissions in 2050.

CONSIDERATION: THE COST OF TRANSITION

> **Any discussion of decarbonising aviation — or the wider economy –inevitably raises questions about cost and affordability, and whether the industry's growth could be jeopardised. Viewed across a global sector and a multi-decade time horizon, the absolute costs can appear large.**
>
> **Yet they must be weighed against regular industry expenditure and, crucially, the potentially far greater costs of inaction. Commercial aviation delivers enormous public value through connectivity; its transition costs need also be placed in context of the immense economic and social benefits of air transport to the wider economy[74].**

Accurately estimating the total cost of aviation's net zero transition is inherently difficult. Working out the full costs of a global long-term climate goal for aviation depends on a range of forecasts, evolving assumptions and many factors that remain unknown today. Spread over 25 years and an entire global sector, these estimates can reach several trillion dollars. Yet, these numbers must be viewed against the costs and investments required to simply operate and renew the global aviation industry over several decades, and against the vastly larger costs of the worldwide energy transition.

Aviation's role in global connectivity

Aviation: Benefits Beyond Borders shows that in 2023, aviation and aviation-enabled tourism supported roughly $4.1 trillion in global GDP (around 3.9%) and 86.5 million jobs worldwide. For developing countries in particular, air transport is a leap-forward opportunity: in 2023 it supported 61 million jobs and contributed about $1.3 trillion in GDP, but forecasts indicate that may grow to 135.4m jobs and $8.5trn in 2043, should the growth in air transport continue as expected.

- **Facilitating trade and high-value goods movement**: Air transport allows rapid shipping of time-sensitive, high-value or perishable goods, enabling developing economies to plug into global supply chains and reach distant markets quickly.
- **Boosting tourism – a key growth engine**: For many emerging economies, tourism is a major source of foreign exchange, jobs and infrastructure investment, and aviation makes tourism possible on a global scale.
- **Enhancing productivity, investment and knowledge exchange**: Connectivity lowers barriers for businesses to access foreign markets, attract talent, share ideas and respond quickly to global demand – which in turn stimulates innovation, investment and economic diversification.
- **Supporting broad employment – directly and indirectly**: Beyond the core aviation jobs, air transport creates ripple-effects across sectors (supply chains, tourism, services), providing livelihoods and economic activity in regions that might otherwise remain isolated.

Air connectivity acts as a multiplier: it doesn't just move people and goods rapidly, it unlocks access, opportunities, and economic transformation. For countries around the world, that can mean accelerated integration into global markets, new sources of jobs and income, and a pathway toward more diversified, resilient economies. Balancing those benefits with the need to curtail CO_2 emissions is an important consideration.

Investment needed to maintain connectivity

Over the next 25 years, the industry will continue to invest in efficiency research and development, including the development of new aircraft types. Airlines will continue to invest in acquiring the latest, most fuel-efficient aircraft available. Global 20-year market forecasts estimate this investment at over $3.3 trillion[75]. For context, the civil aerospace industry is spending around $15 billion a year for efficiency research and development. In addition, in the last decade, airlines have spent over $1 trillion on new aircraft.

In order to scale up SAF in the coming years, investments into SAF facilities will be required and critical. Depending on expectations of typical size of the plants and associated unit capital expenditure, some estimates of total cumulative capex for new renewable fuel plants over 2020-2050 range from $4.2 trillion ($129 billion per year) under the high-SAF yield case, to $8.1 trillion under the low-SAF yield case[76]. For perspective, typical global oil and gas capital expenditure totalled $4.2 trillion over 2014-2021 ($540bn a year on average).

IATA estimated that for the whole transition period, from 2023 to 2050, the cumulative additional (transition) costs for airlines could reach $4.7 trillion[77]. The ICAO LTAG report explores scenarios for international aviation decarbonisation. In the ambitious scenario (IS3), 100% replacement of conventional jet fuel with SAF and other cleaner energies (e.g. hydrogen) achieves 55% emissions reductions at a cumulative cost of $4.0 trillion from 2020-2050[78].

The scenarios underlying the IATA and ICAO LTAG cost estimates are closer to the ATAG W2050 scenario 1 described in the previous chapters of this report. For context, in the last 25 years, airlines have spent $5.5 trillion on fuel. In the last decade, airlines have spent over $1 trillion on new aircraft.

In some parts of the world, particularly mature markets with already low fares, air fares may rise to accommodate the cost of shifting to SAF. Many emerging markets, however, still have significant scope for non-fuel cost related cost reductions that can offset rising energy cost increases. Indeed, the inherent volatility of fossil jet-fuel prices means that today's SAF premium may not remain quite so high in the future – and could even be negligible during periods of elevated crude-oil prices.

Overall operating expenses for the industry will likely rise, but at a slower rate than traffic growth. This means the additional costs can be spread across more passengers and cargo, keeping the per-unit burden manageable. The favourable outcome, however, depends on maximum policy support for SAF, continued advances in aircraft and engine technology and global improvements in air traffic management efficiency to drive down fuel use.

Meeting aviation's climate goals will require concerted action from all stakeholders and will involve significant costs for governments, industry and ultimately, consumers. However, given the scope of the challenge, the multi-decade horizon, the sector's continued growth and the far greater costs of inaction, the industry is confident these costs are manageable – sustaining aviation's vital role in global connectivity whilst effectively addressing its climate impact.

Cost of inaction

Even if aviation were not to pursue decarbonisation, long-term there would ultimately be increases in costs. These include higher capital financing rates, fragmented carbon pricing from uncoordinated climate policies and escalating insurance and adaptation costs driven by climate-related disruptions and infrastructure damage.

Moreover, air traffic growth would likely be subject to artificial constraint, and the industry may also face some shrinking demand as passengers and corporate customers reduce or forgo flying based on climate concerns. The resulting costs would then fall on a smaller customer base, pushing up unit costs for airlines, airports, supply chains and ultimately air fares.

Committing to net zero carbon and pursuing every feasible measure to achieve it is therefore not only an environmental necessity, it is the surest way to safeguard long-term competitiveness and retain the trust of customers, investors, and society at large.

CALL TO ACTION: TRANSITION COSTS

The table below presents key actions to "**build on current efforts and drive near-/mid-term progress**", "**innovate and develop towards long-term progress**" and "**advocate and collaborate towards joint efforts and progress**" on market-based measures to address residual carbon emissions.

Governments and policymakers

Support aviation's decarbonisation.	» Through smart policy and incentives, support the transition costs of the aviation sector to progress towards the net zero goal, based on local conditions. » Ensure positive collaboration between aviation and other stakeholder groups to fairly allocate the costs of transition. » Find ways to offset potential increased energy or other net zero costs by reducing taxes or other costs in a way that ensures airfares can continue to support connectivity improvements.

Finance community

Support the financing of the aviation's decarbonisation.	» Mitigate risk, not just to aviation, but all investments that assume aviation access.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[13] All current SAF production occurs concurrently at the same facilities with renewable diesel production, with SAF production being a minority share at each facility. SAF production growth has come along with an even larger expansion in the combined SAF and renewable diesel production capacity.

[14] One exajoule is equal to 1.0E+18 joule.

[15] ICF analysis with source material including BloombergNEF 2022 Road Fuel Outlook: https://ataglink.org/49RQfP7

[16] The T4 scenario depicts a transition "towards non-drop in energies: electrification, hybrid, zero-emissions aircraft technologies". This scenario reflects the possibility that the 50-100 seat segment could be supported by aircraft powered by hydrogen or electricity which would contribute to ~9% of the emissions reductions by 2050. The majority (~58%) of the emissions reductions by 2050 would originate from the narrow body market segment where ambitious hybridisation and efficiency improvements may be achieved. Building on the T3 scenario with unconventional configurations, the T4 scenario reflects incremental improvements for the mid-market segment that could contribute to ~18% of the emissions reductions by 2050. Hybridisation and efficiency improvements have relatively lower potential for the wide-body aircraft segment that would contribute to ~15% of the emissions reductions by 2050.

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[30] Indicative readiness and timing of technologies based on publicly available information. Final development and entry into service dates and availability across market segments are subject to changes due to the possibility of challenges with development, certification, etc. Illustrative potential electric, hybrid/electric, and/or hydrogen fuel cell powered aircraft or powertrain that may enter service in the ~2025-2035 time frame, include but is not limited to: Heart Aerospace ES-30 (https://ataglink.org/3Y5x6lp), ZeroAvia ZA600, ZA2000 (https://ataglink.org/4pRlmPy) and https://ataglink.org/4pOAFbM.

[31] With the exception of the ICAO LTAG report (2021) integrated scenario 3 (operations 3 scenario) that considered very disruptive technologies and aggressive fleet penetration of technologies.

[32] In its *Global Market Forecast 2023* projections, Airbus considered load factor improvements (which could possibly deliver an additional ~0.2% compound annual growth rate (CAGR) 2019-2050 improvement baseline projection) and rest of operations, including air traffic management (~0.2% CAGR 2019-2050 improvement) that are broadly in line with the *Waypoint 2050* scenarios (load factor and operations 3 scenario). Airbus also estimated that cabin optimisation could also deliver a further ~0.2% CAGR 2019-2050 improvement (baseline projection), compared with the 0.4% historical achievement from 1990 to 2019.

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[40] In this edition of *Waypoint 2050*, the assumption of 90% replacement of conventional jet fuel by SAF in 2050 reflects the ambition and expectation to scale up SAF as much as possible whilst acknowledging that some jet fuel from conventional sources will likely remain in 2050 and beyond.

[41] The F2 scenario does not reflect a range of emissions reductions from SAF as it is based on a single scenario of quantity of SAF associated with a single set of assumptions of emissions reductions factors of SAF. Other SAF scenarios include a range of low to high quantities of SAF. All scenarios are forward-looking and inherently embed uncertainty.

[42] The range of emissions reduction factors reflect ranges of some of the underlying policies and goals. For example, emissions reductions from SAF under Refuel EU Aviation comprise a range from "minimum % emission saving SAF" to "ambitious % emission saving SAF" (EASA, 2025). The SAF Grand Challenge goal also has a minimum of a 50% reduction in life cycle emissions compared to conventional fuel.

[43] Quantity of SAF and/or emissions reductions from SAF based on national or regional policies and, if needed, estimates based on traffic forecasts. **USA:** SAF Grand challenge objective of 3 and 35 billion gallons in 2030 and 2050, respectively. Emissions reduction factor ranging from 50%-100%. **EU:** Refuel EU based on EASA Report 2025 range of emissions reductions based on "Minimum" and "Ambitious" percent Emission Saving from SAF. **UK:** UK Sustainable Aviation SAF mandate. **Norway:** assume alignment with ReFuel EU, although could aim for higher (30% is current goal). **Brazil:** 1% emissions reduction requirement on domestic in 2027, rising to 10% in 2037. **China:** Indication of 10% 2035 feasibility study (-6.5 Mt in 2035 – assume ramp-up). **UAE:** Target of 700 million litres being delivered by 2030. **Canada:** blend mandate out of British Columbia only, very rough estimation of fuel uplift proportion from Vancouver vs other major Canadian airports. **Japan:** International flights only. **India:** International flights only. **Malaysia:** 1% expected for 2030, and goal of 47% by 2050. **Thailand:** 1% expected from 2027, 2030 could be higher. **South Korea:** 1% SAF blend mandate on international flights from 2027. **Indonesia:** 1% SAF on international flights from 2027, rising to 2.5% in 2030 and 30% in 2050. **Egypt:** 2% SAF use included in NDC submitted in 2024, although start date and scope not noted. **Türkiye:** -5% emissions reduction from SAF from 2030 on international and domestic flights.

[44] The US Grand Challenge is a domestic production goal and does not imply that all the SAF will be used by airlines in the United States – some may be exported to other countries.

[45] The *Waypoint 2050* Editions 1 and 2 considered goal driven scenarios that were addressing the question *"how much SAF would be needed to reach the 2050 goal with an aggressive development and contribution from SAF?"*. This was captured as scenarios F2-F4 and assumed a 90% replacement of conventional jet fuel by SAF by 2050. Since 2021, recent decarbonisation studies and/or roadmaps, including the ICAO LTAG report (ICAO, *Long-term global aspirational goal (LTAG) report,* 2022: https://ataglink.org/3XB4ccR) and the IATA SAF roadmap (IATA, *Energy and New Fuels Infrastructure Net Zero Roadmap,* 2024: https://ataglink.org/3Y4zaKv), considered scenarios of replacement of conventional jet fuel with SAF of up to 100% by 2050.

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