

MAKING NET-ZERO AVIATION POSSIBLE

An industry-backed, 1.5°C-aligned transition strategy

EXECUTIVE SUMMARY / JULY 2022



**MISSION
POSSIBLE
PARTNERSHIP**

Sponsored by



Energy
Transitions
Commission



Supported
by knowledge
partner
McKinsey
& Company



THE MISSION POSSIBLE PARTNERSHIP

At current emissions levels, staying within the global carbon budget for 1.5°C might slip out of reach in this decade. Yet efforts to slow climate change by reducing greenhouse gas (GHG) emissions run into a central challenge: some of the biggest emitters of greenhouse gases into the atmosphere – transportation sectors like aviation, shipping and trucking, and heavy industries like steel, aluminium, cement/concrete, and chemicals manufacturing – are the hardest to abate. Transitioning these industries to climate-neutral energy sources requires complex, costly, and sometimes immature technologies, as well as direct collaboration across the whole value chain, including companies, suppliers, customers, banks, institutional investors, and governments.

Catalysing these changes is the goal of the Mission Possible Partnership (MPP), an alliance of climate leaders focused on supercharging efforts to decarbonise these industries. Our objective is to propel a committed community of CEOs from carbon-intensive industries, together with their financiers, customers, and suppliers, to agree and, more importantly, to act on the essential decisions required for decarbonising heavy industry and transport. Led by the Energy Transitions Commission, the Rocky Mountain Institute, the We Mean Business Coalition, and the World Economic Forum, MPP will orchestrate high-ambition disruption through net-zero industry platforms for seven of the world’s most hard-to-abate sectors: aviation, shipping, trucking, steel, aluminium, cement/concrete, and chemicals.

The foundation of MPP’s approach: 7 Sector Transition Strategies

Transitioning heavy industry and transport to net-zero GHG emissions by 2050 – while complying with a target of limiting global warming to 1.5°C from preindustrial levels – will require significant changes in how those sectors operate. MPP facilitates this process by developing **Sector Transition Strategies** for all seven hard-to-abate sectors.

A Sector Transition Strategy
is a suite of user-friendly tools
(including a report, an online explorer, and an open-source model)
aiming to inform decision makers
from the public and private sectors
about the nature, timing, cost, and scale of actions necessary to deliver net zero within the sector by 2050 and to comply with a 1.5°C target.



In line with industry-specific replacement cycles of existing assets (like steel plants or aircraft) and the projected increase in demand, the market penetration of viable decarbonisation measures each sector can draw on is modelled.

The objectives of the MPP Sector Transition Strategies are:

- 1. To demonstrate industry-backed, 1.5°C-compliant pathways to net zero**, focusing on in-sector decarbonisation and galvanising industry buy-in across the value chain.
- 2. To be action-oriented with clear 2030 milestones:** By quantifying critical milestones for each sector in terms of its required final energy demand, upstream feedstock resources, and capital investments, MPP wants to lay the foundation for tangible, quantitative recommendations of ways to reach these milestones through collaboration among industry, policymakers, investors, and customers.
- 3. To be transparent and open:** MPP's long-term goal is to fully lay open the internal machinery of the Sector Transition Strategies, that is, to make its Python models open source and all data inputs open access. In addition, MPP is developing online explorers that bring the Sector Transition Strategy reports to life: individual users will be able to explore the results of the reports and to customize model input assumptions, study the impact of individual levers, and dive deeper into regional insights.
- 4. To break free from siloed thinking:** The transition of a sector to net zero cannot be planned in isolation since it involves interactions with the broader energy system, for instance, via competing demands for resources from multiple sectors. All MPP Sector Transition Strategies are based on similar assumptions about the availability and costs of technologies and resources like electricity, hydrogen, or sustainable biomass. By providing a harmonized, cross-sectoral perspective, we intend to inform decision makers with a fair, comparable assessment of transition strategies for all seven sectors.

On the basis of its Sector Transition Strategies, MPP intends to develop practical resources and toolkits to help operationalize industry commitments in line with a 1.5°C target. Among others, the quantitative results of the Sector Transition Strategies will inform the creation of standards, investment principles, policy recommendations, industry collaboration blueprints, and the monitoring of commitments. These will be developed to expedite innovation, investments, and policies to support the transition.

Goals of the MPP Aviation Transition Strategy

This publication builds on the work of other aviation organizations that have announced initiatives to reduce emissions. In particular, we acknowledge and appreciate the following important building blocks to shape the aviation sector's decarbonisation path:

- *Waypoint 2050* by the Air Transport Action Group (ATAG) and its accompanying ICF report, *Fueling Net Zero*ⁱ
- *Report on the Feasibility of a Long-Term Aspirational Goal (LTAG) for International Civil Aviation CO₂ Emission Reductions* by the International Civil Aviation Organization (ICAO)
- *Decarbonising Air Transport* by the International Transport Forum (ITF) and the Organisation for Economic Co-operation and Development (OECD)
- *Horizon 2050: A Flight Plan for the Future of Sustainable Aviation* by the Aerospace Industries Association (AIA) and Accenture
- *Destination 2050* by European aviation industry associations
- *2021 Aviation Climate Action Plan* by the US Federal Aviation Administration
- *PtL Roadmap* by the government of Germany
- *Decarbonisation Road-Map* by Sustainable Aviation for the United Kingdom
- *Roadmap to Climate Neutral Aviation in Europe* by Transport & Environment

Through the support of industry stakeholders from the Clean Skies for Tomorrow (CST) and Target True Zero (TTZ) initiatives,ⁱ MPP has considered the different perspectives of the roadmaps above and has developed **an industry-backed Sector Transition Strategy** that outlines how the global aviation sector can reach net-zero GHG emissions by 2050 while also complying with a 1.5°C target. Beyond that, **it takes the next step from strategic thinking to near-term milestones and provides recommendations for action for industry, policymakers, and financial institutions on ways to unlock the transition in this decade.**

ⁱ The Clean Skies for Tomorrow (CST) and the Target True Zero (TTZ) initiatives of the World Economic Forum convene top executives and public leaders, across and beyond the aviation value chain, to accelerate the uptake of Sustainable Aviation Fuels and novel propulsion aircraft.



Industry support for MPP's Aviation Transition Strategy

This report constitutes a collective view of participating organizations in the Aviation Transition Strategy, foremost the CST and TTZ community. Participants have validated the model inputs and architecture, and endorse the general thrust of the arguments made in this report, but their endorsement should not be taken as agreeing with every finding or recommendation. These companies agree on the importance of limiting global warming to 1.5°C and the importance of reaching net-zero GHG emissions in heavy industry and transport by mid-century, and they share a broad vision of how

the transition can be achieved. The fact that this agreement is possible among the industry leaders listed below should give decision makers across the world confidence that it is possible to meet simultaneously rising air travel demand, reduce emissions from the sector to net zero by 2050, and comply with a 1.5°C target. It should also provide assurance that the critical actions required in the 2020s to set the sector on the right path are clear and can be pursued without delay, and that the industry is ready to collaborate with its value chain to achieve those goals.

1. ACI
2. Aena
3. AeroMéxico
4. Aeroporto di Roma
5. Air France–KLM Group
6. Air France
7. Air New Zealand
8. Airbus
9. Alaska Airlines
10. Amelia International
11. American Airlines
12. American Express Global Business Travel
13. ASL Aviation
14. Boeing
15. Boom Supersonic
16. bp
17. Brisbane Airport Corporation
18. Caphenia
19. Carbon Engineering
20. Cargolux
21. Cathay Pacific
22. Choose
23. Dubai Airports
24. EasyJet
25. EDL Anlagenbau Gesellschaft mbH
26. Embraer Commercial Aviation
27. Eve Air Mobility
28. Faradair Aerospace Limited
29. Fly Victor
30. Fraport
31. GenZero
32. Gol Linhas Aéreas
33. Heathrow Airport
34. Honeywell
35. IAG
36. Japan Airlines
37. KLM
38. LanzaJet
39. LanzaTech
40. Loganair
41. Lydian
42. Maeve Aerospace B.V
43. McKinsey & Company
44. Menzies
45. Microsoft
46. Neste
47. Norsk e-Fuel
48. Novo Nordisk
49. Occidental Petroleum
50. Oneworld Alliance
51. Praj
52. Prometheus
53. Qatar Airways
54. Repsol
55. Royal Schiphol Group
56. SAF+ Consortium
57. Shell
58. SkyNRG
59. Sounds Air
60. Sunfire
61. SYSTEMIQ
62. Twelve
63. Vancouver Airport Authority
64. Varo Energy
65. Velocys
66. Virgin Atlantic
67. VoltAero
68. Widerøe Zero
69. Wright Electric



AUTHORS & ACKNOWLEDGEMENTS

This report was prepared by the Mission Possible Partnership aviation team, led by a steering committee of:

Lauren Uppink (World Economic Forum, MPP Aviation Sector Lead)
Manosij Ganguli (Energy Transitions Commission, ETC)
Robin Riedel (McKinsey & Company)

The coordination of the report, analysis, and stakeholder engagement was led by:

Maximilian Held (ETC)
Laia Barbarà (World Economic Forum)

and supported by:

Elena Gerasimova (McKinsey)
Kritika Rastogi (McKinsey)
David Hyde (World Economic Forum)

The model and analytics effort was led by **Maximilian Held** (ETC) and driven by:

Andrea Bath (ETC)
Charlotte Bricheux (McKinsey)
Jason Martins (ETC)
Morgan Matranga (McKinsey)
Timon Rückel (ETC)
Austin Welch (McKinsey)

Steering and guidance were provided by MPP leadership who oversee the development of all the MPP Sector Transition Strategies:

Faustine Delasalle (Executive Director, MPP)
Eveline Speelman (ETC)

We thank Carlos Agnes, Kash Burchett, Henry Gilks, Alasdair Graham, Andrew Isabirye, Ita Kettleborough, Aparajit Pandey, Lloyd Pinnell, Manuel Schrenk, Trishla Shah, Adair Turner, Marco van Veen, Laëtitia de Villepin, Maaïke Witteveen (all from ETC), Peter Cooper, Axel Esque, Guenter Fuchs, Julian Hölzen, Nathan Lash, Agata Mucha, Jesse Noffsinger, Daniel Riefer, Brandon Stackhouse (all from McKinsey), the McKinsey Energy Insights and Hydrogen Insights teams, and other collaborators for providing valuable contributions to this project. The report was edited and designed by M. Harris & Company.





Mission Possible Partnership (MPP)

Led by the ETC, RMI, the We Mean Business Coalition, and the World Economic Forum, the Mission Possible Partnership (MPP) is an alliance of climate leaders focused on supercharging the decarbonisation of seven global industries representing 30% of emissions: aviation, shipping, trucking, steel, aluminium, cement/concrete, and chemicals. Without immediate action, these sectors alone are projected to exceed the world's remaining 1.5°C carbon budget by 2030 in a Business-as-Usual scenario. MPP brings together the world's most influential leaders across finance, policy, industry, and business. MPP is focused on activating the entire ecosystem of stakeholders across the entire value chain required to move global industries to net-zero. www.missionpossiblepartnership.org



Energy Transitions Commission

Energy Transitions Commission (ETC)

ETC is a global coalition of leaders from across the energy landscape committed to achieving net-zero emissions by mid-century, in line with the Paris climate objective of limiting global warming to well below 2°C and ideally to 1.5°C. Our commissioners come from a range of organizations – energy producers, energy-intensive industries, technology providers, finance players, and environmental NGOs – which operate across developed and developing countries and play different roles in the energy transition. This diversity of viewpoints informs our work: our analyses are developed with a systems perspective through extensive exchanges with experts and practitioners. www.energy-transitions.org

McKinsey & Company

McKinsey & Company is a global management consulting firm committed to helping organizations create Change that Matters. In more than 130 cities and 65 countries, their teams help clients across the private, public, and social sectors shape bold strategies and transform the way we work, embed technology where it unlocks value, and build capabilities to sustain the change. Not just any change, but Change that Matters – for their organizations, their people, and in turn society at large. McKinsey & Company is a knowledge partner for the Mission Possible Partnership and provided fact-based analysis for this report. Learn more at www.mckinsey.com.



Clean Skies for Tomorrow (CST)

The Clean Skies for Tomorrow (CST) Coalition provides a crucial global mechanism for top executives and public leaders, across and beyond the aviation value chain, to align on a transition to sustainable aviation fuels as part of a meaningful and proactive pathway for the industry to achieve carbon-neutral flying. The Clean Skies for Tomorrow Coalition is led by the World Economic Forum in collaboration with RMI and the Energy Transitions Commission. Learn more at www.weforum.org/cleanskies.



World Economic Forum

The World Economic Forum is the international organization for public-private cooperation. The Forum engages the foremost political, business, cultural, and other leaders of society to shape global, regional, and industry agendas. Learn more at www.weforum.org.

SUPPORTED BY



Target True Zero Coalition

The Target True Zero Coalition, led by the World Economic Forum, brings together leaders from across the aviation sector to understand the role that new technologies such as electric and hydrogen aircraft can play in delivering flying with a true zero climate impact. The coalition works to establish consensus on the key issues that will be required to realize the benefits of alternative propulsion in aviation and identify unlocks to accelerate the development and deployment of technologies with reduced climate impact. Learn more at www.weforum.org/agenda/2021/07/targeting-true-net-zero-aviation/.



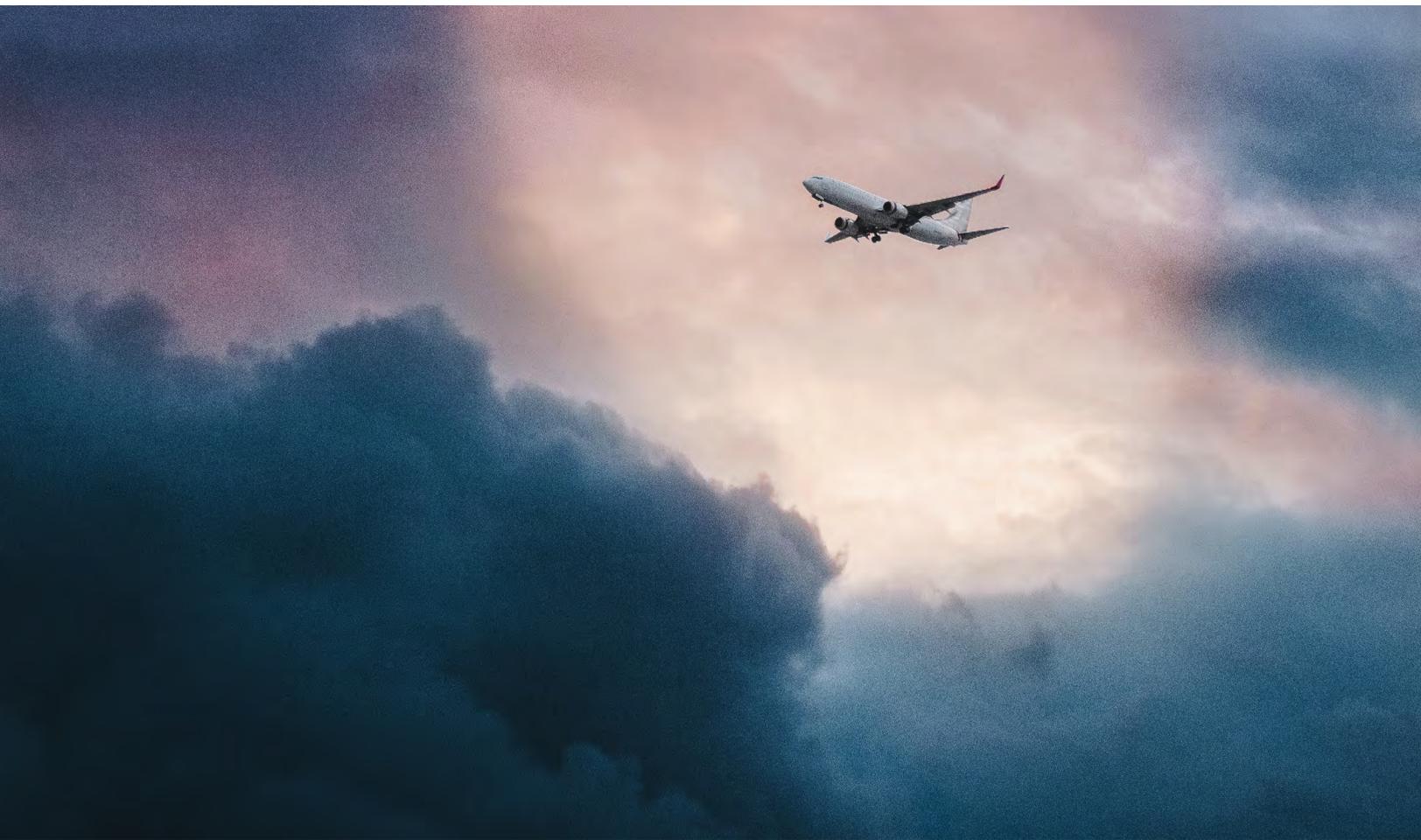
ELEVEN CRITICAL INSIGHTS ON THE PATH TO A NET-ZERO AVIATION SECTOR



1. Bringing aviation on a path to net-zero emissions by 2050 requires a doubling of historical fuel efficiency gains of aircraft, a rapid roll-out of Sustainable Aviation Fuels (SAFs), and the market entry of novel propulsion aircraft in the mid-2030s.

In 2019, global aviation was responsible for GHG emissions of 1.2 Gt CO₂eⁱⁱ – about 2% of global anthropogenic GHG emissions and 3.5% of the anthropogenic climate impact (measured in net effective radiative forcing). In contrast to a Business-as-Usual (BAU) scenario, two net-zero scenarios combine a different set of decarbonisation measures to reach net zero by 2050 (Exhibit A). The main difference between the Prudent (PRU) scenario and

the Optimistic Renewable Electricity (ORE) scenario is that the latter assumes a faster cost decline of renewable electricity and hence, more favorable economic conditions for electricity-based technologies. As a result, SAFs produced from electricity (Power-to-Liquids, PtL) as well as hydrogen and battery-electric aircraft enter the market earlier and at a larger scale – in contrast to the PRU scenario in which biofuels prevail.



ii Global aviation includes commercial passenger, commercial cargo, public sector, and general aviation. In 2019, the total emissions of global aviation of 1.24 gigatonnes (Gt) CO₂-equivalent (CO₂e) consisted of 1.02 Gt CO₂ tank-to-wake and 0.22 Gt CO₂e upstream (well-to-tank) emissions.

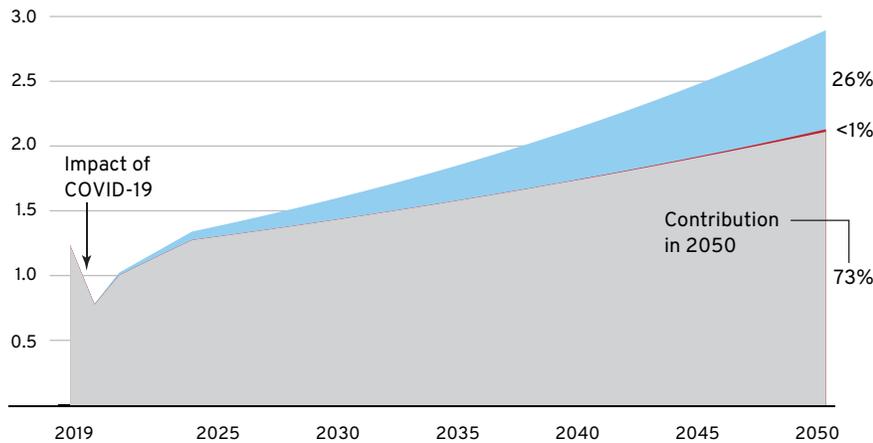


A combination of GHG reduction levers can make net-zero aviation a reality

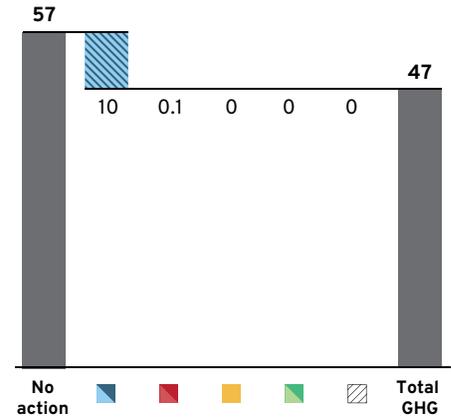


Business-as-Usual scenario

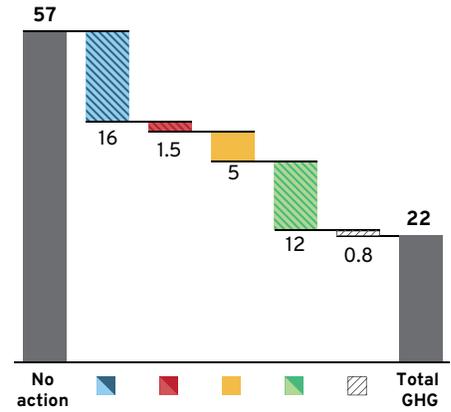
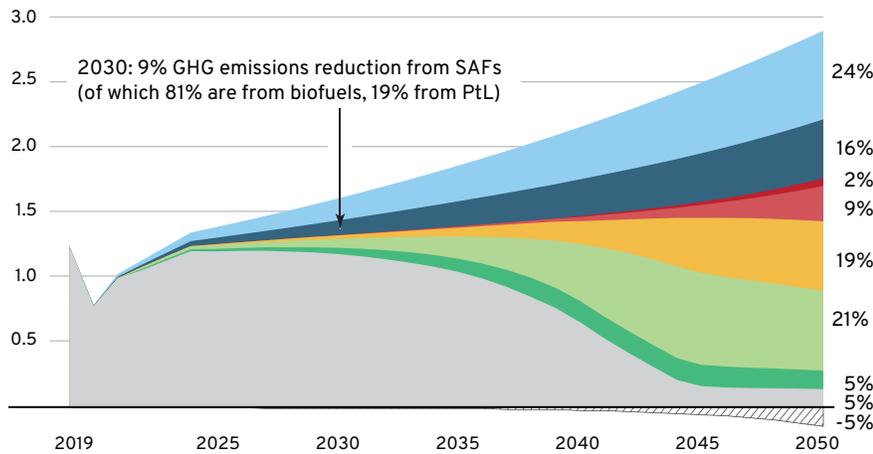
GHG emissions reduction, Gt CO₂e (billion tonnes)



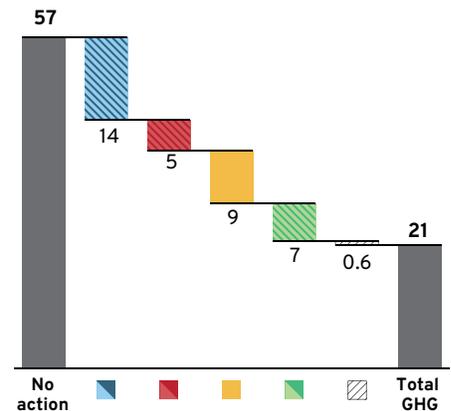
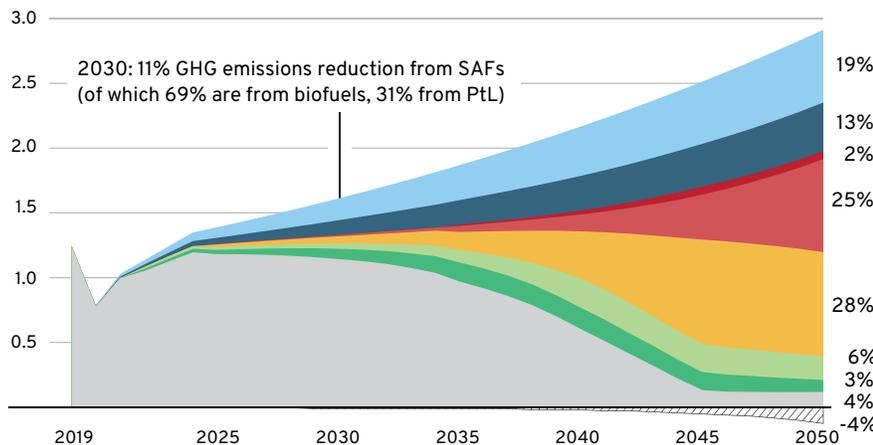
Cumulative GHG emissions between 2022 and 2050, Gt CO₂e



Prudent scenario



Optimistic Renewable Electricity scenario



Note: Sums in contributions to 2050 GHG emissions may not total 100 due to rounding.

Source: MPP analysis



For both net-zero scenarios, fuel efficiency improvements of aircraft and SAFs play the largest role in reducing emissions. Doubling the annual fuel efficiency gains compared with historical developments could avoid about 14–16 Gt CO₂e between 2022 and 2050 compared with a future without any climate action. SAFs can further reduce emissions by 16–17 Gt CO₂e.

Common ground between two net-zero scenarios

Carbon-neutral growth until 2030 is feasible (Exhibit B) if yearly fuel efficiency gains can be doubled compared with historical gains and if the production capacity of Sustainable Aviation Fuels (SAF) can be ramped up by a factor of 5–6 compared with existing and planned plants. Demand reduction triggered

by a shift of short-haul flights to high-speed rail and behaviour changes (e.g., reduced business travel due to videoconferencing) could save an additional 5 megatonnes (Mt) CO₂e in 2030 if the required high-speed rail network were available.

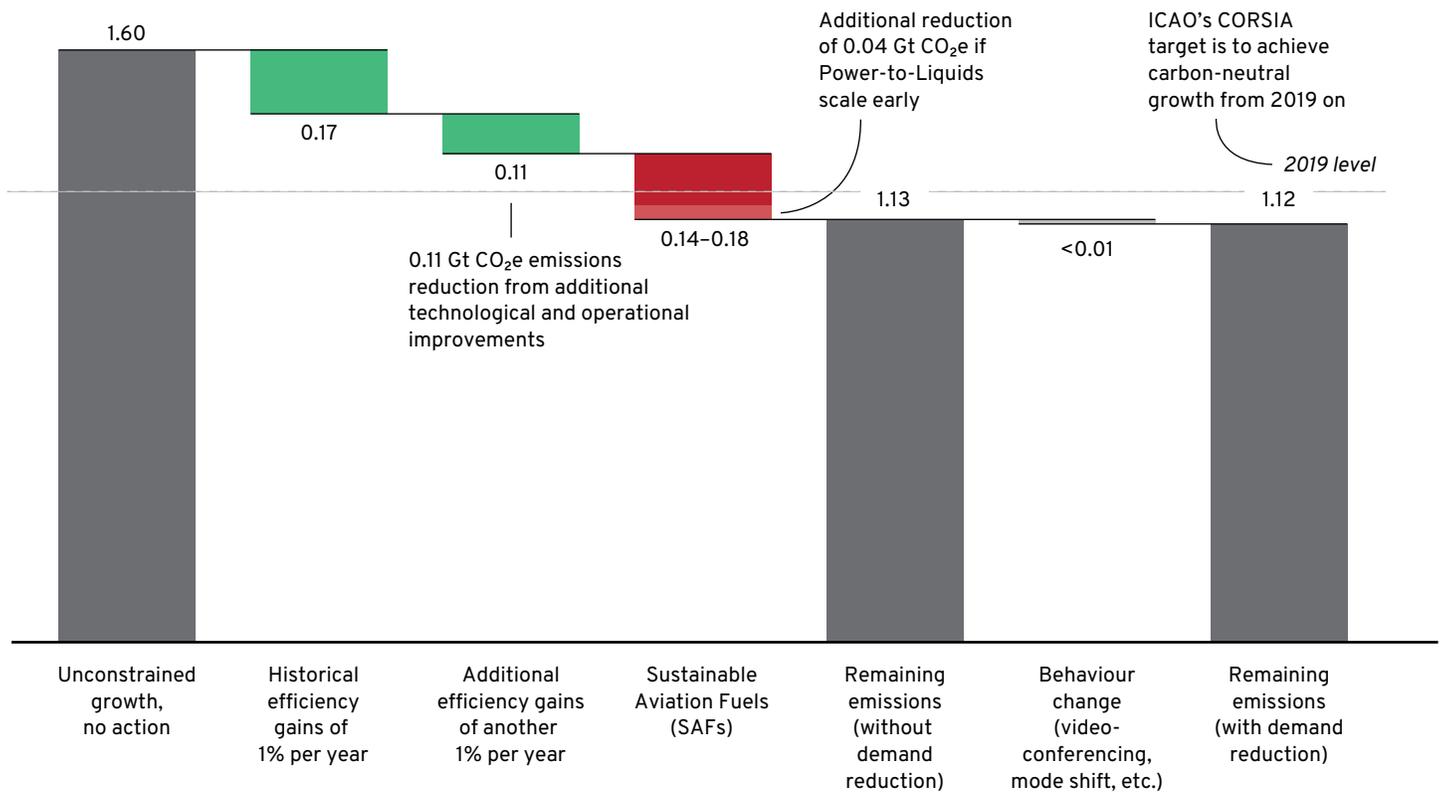
Net-zero emissions by 2050 are feasible (Exhibit C) if yearly fuel efficiency gains can be doubled compared with average historical gains; SAF production capacity can be scaled up by a factor of 35–45 compared with existing or planned plants; hydrogen, battery-electric, and hybrid-electric aircraft enter the market in the mid-2030s; and carbon dioxide removals (CDR) counterbalance the residual emissions of renewable fuels by 2050, which can reduce GHG emissions compared with fossil jet fuel by about 75%–95% but not 100%. Demand reduction could cut the amount of SAF needed in 2050 by about 10%–15%.

EXHIBIT B

How carbon-neutral growth until 2030 could be achieved

GHG emissions in 2030, Gt CO₂e

■ Negative abatement costs of -US\$300–\$0/t CO₂ ■ High abatement costs of \$200–\$600/t CO₂



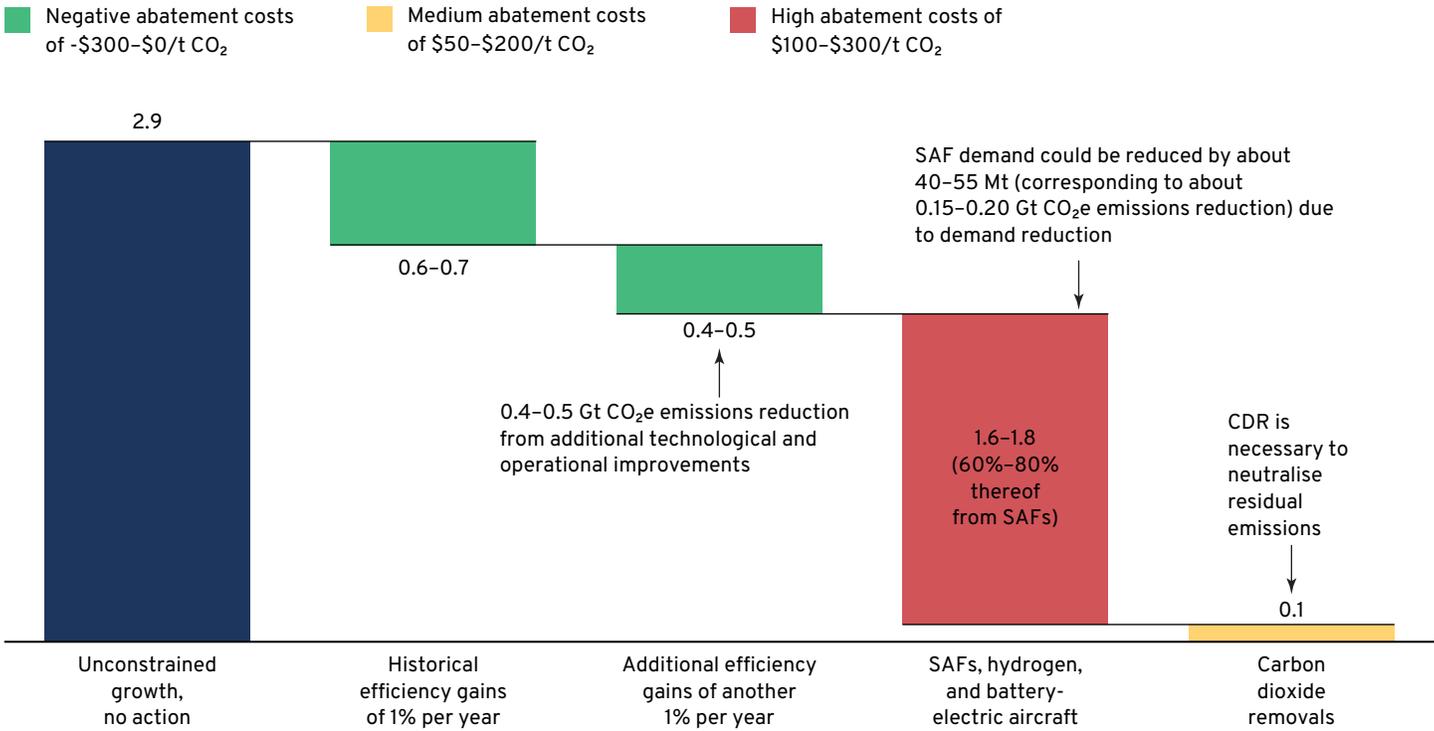
Note: Totals may not equal sums due to rounding.

Source: MPP analysis



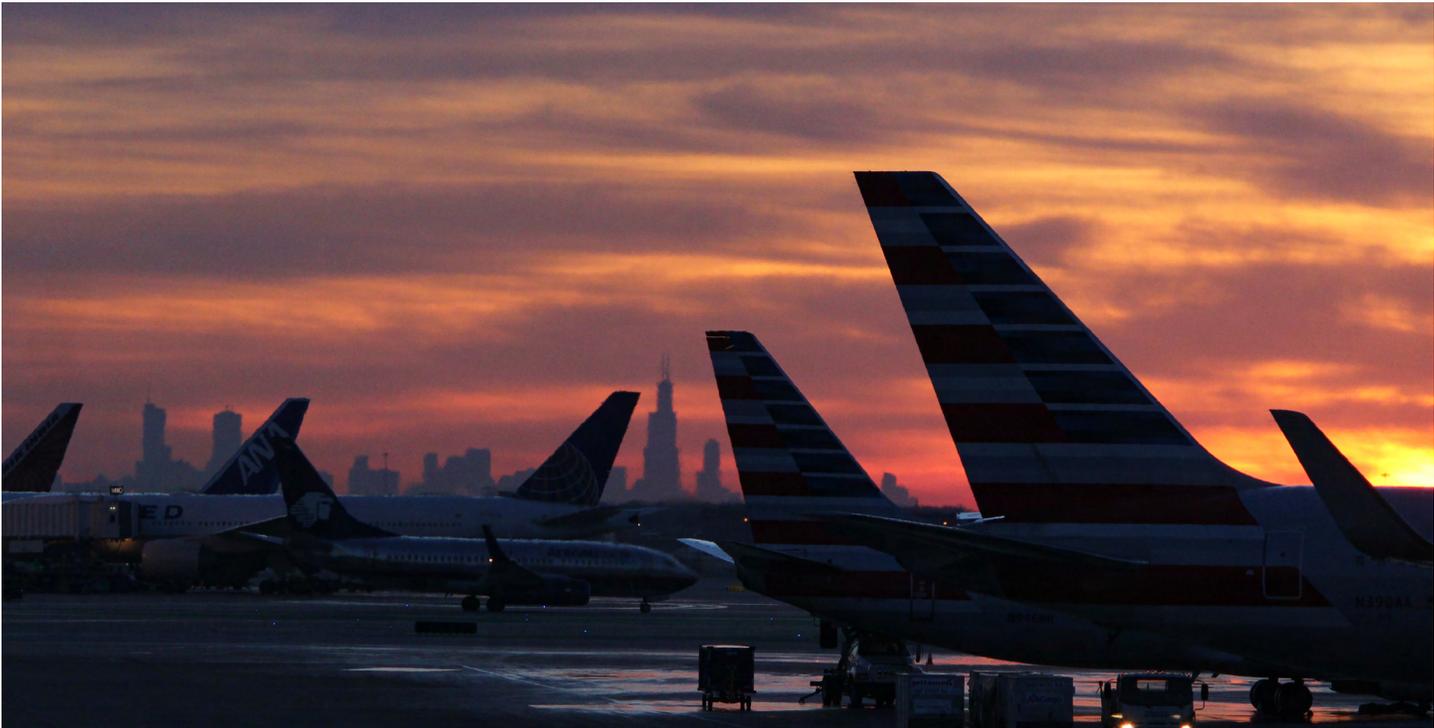
How net zero by 2050 could be achieved

GHG emissions in 2050, Gt CO₂e (billion tonnes)



Note: Totals may not equal sums due to rounding.

Source: MPP analysis



2. Aviation can comply with a sectoral 1.5°C carbon budget if all levers are pulled. Achieving net zero by mid-century avoids cumulative GHG emissions of 25–26 Gt CO₂e.

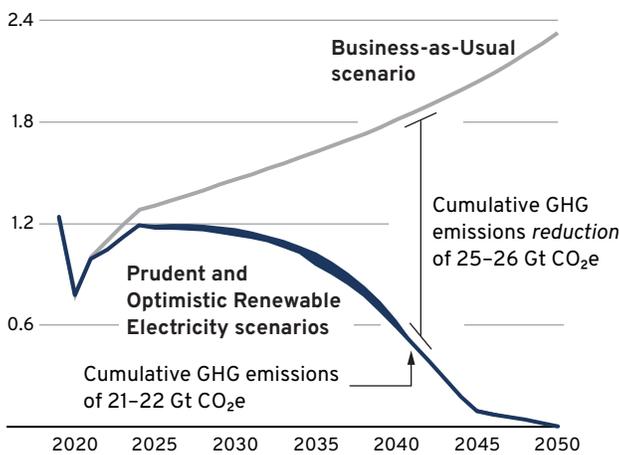
In a BAU scenario, cumulative GHG emissions between 2022 and 2050 sum to 47 Gt CO₂e, of which roughly 39 Gt are from in-flight CO₂ emissions (Exhibit D) – an overshoot of more than 100% against a 1.5°C carbon budget for global aviation of about 18 Gt CO₂.ⁱⁱⁱ In contrast, the two net-zero scenarios are

roughly in line with a 1.5°C carbon budget, being responsible for cumulative GHG emissions of only 21–22 Gt CO₂e, of which about 18 Gt CO₂ are in-flight CO₂ emissions and life-cycle CO₂ emissions of renewable fuels.

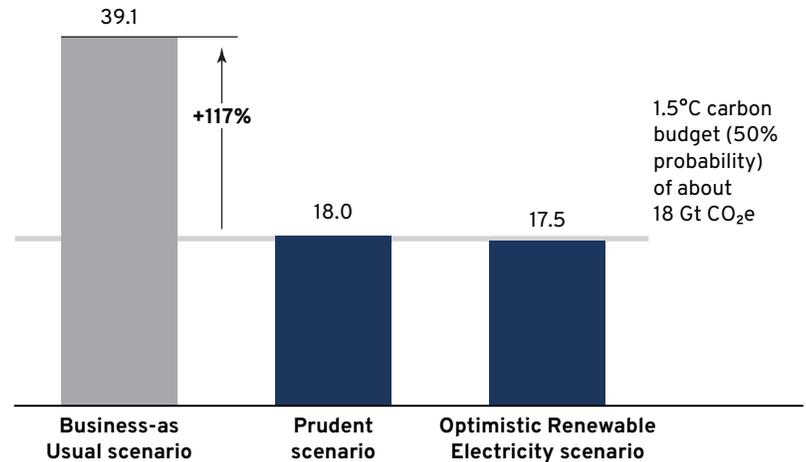
Both net-zero scenarios halve the cumulative GHG emissions of the BAU scenario

EXHIBIT D

Annual GHG emissions, Gt CO₂e per year



Cumulative CO₂ emissions between 2022 and 2050, Gt CO₂ per year



Note: For the carbon budget comparison, only CO₂ emissions are compared (not GHG emissions) since the 1.5°C carbon budget is defined for CO₂ only, while it assumes a similar emissions reduction trajectory for non-CO₂ emissions. Similarly, we assume here that non-CO₂ emissions from aviation are reduced in a similar trajectory as CO₂ emissions. For the cumulative emissions, we have accounted for tank-to-wake CO₂ emissions of fossil jet fuel and life-cycle CO₂ emissions (incl. Scope 1 and Scope 3) for renewable fuels. Based on industry expertise and Chipindula et al. (2018), we have assumed that 95% of the assumed life-cycle GHG emissions are CO₂, the rest from non-CO₂ species. Only for waste-based fuels (e.g., used in G/FT or AtJ processes), we have assumed that 90% of the life-cycle GHG emissions are CO₂. The cumulative emission figures include emissions reductions from CDR.

Source: MPP analysis; Jesuina Chipindula et al., “Life Cycle Environmental Impact of Onshore and Offshore Wind Farms in Texas”, *Sustainability* 10, no. 6 (June 2018)

iii The sectoral 1.5°C carbon budget is calculated as of the beginning of 2022 at a 50% probability of achieving a 1.5°C target. It has been broken down from a global carbon budget from the IPCC to individual sectors following an average of the sectoral allocations of BNEF NEO and IEA NZE reports. The methodology is documented in Box 1 (main text) and the *Technical Appendix*. See IPCC, “Summary for Policymakers”, in *Global Warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*, eds. Valérie Masson-Delmotte et al. (2018); BloombergNEF, *New Energy Outlook 2021 Executive Summary*, July 2021; and IEA, *Net Zero by 2050: A Roadmap for the Global Energy Sector*, May 2021. NZE refers to the “Net Zero Emissions by 2050 Scenario” of the IEA.



3. Average annual investments between 2022 and 2050 to get global aviation to net zero are estimated at about US\$175 billion, about 95% of which would be required for fuel production and upstream assets.

Achieving carbon-neutral growth till 2030 (that is, maintaining the same levels of emissions as in 2019) would need average annual investments of about \$40 billion to \$50 billion in this decade. Until mid-century, a total annual capital investment of about \$175 billion would be required (Exhibit E). This compares with aviation’s yearly contribution to global GDP of roughly \$2 trillion.

Of these investments, 92%–96% are required for the production of renewable fuels – including not only the final fuel production but also all upstream assets: about 30%–50% of that capital is required for new SAF production plants, about 35%–50% for

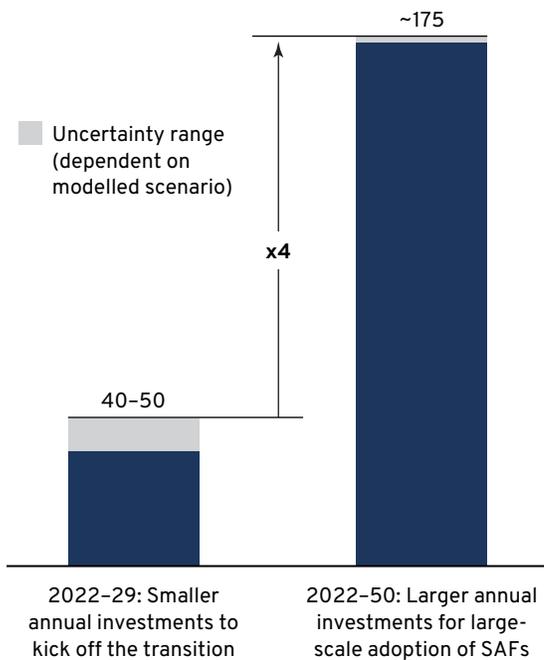
new renewable electricity generation capacity, and the rest for CO₂ capture plants and electrolysers.

The remaining 4%–8% of the total investment requirement flows into the development of battery-electric, hybrid-electric, and hydrogen aircraft. The total annual capital investments do not include the capital cost of new conventional jet aircraft that would also be required for a regular fleet substitution/ expansion without decarbonising. Since SAFs can simply be blended to fossil jet fuel as drop-in fuels, their impact on aircraft capital costs is negligible compared with investments required in the fuel production chain.

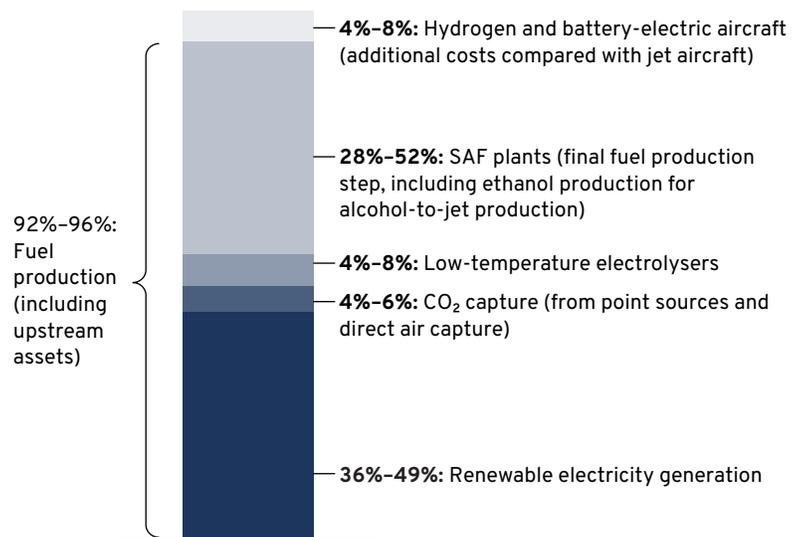
Investments to bring global aviation to net zero

EXHIBIT E

Annual investments across the whole value chain, billion \$ per year, required for net zero by 2050



Breakdown of capital requirements across value chain, Percentage ranges dependent on modelled scenario



Source: MPP analysis



4. Current project pipelines for SAF production are insufficient and need to be scaled up by a factor of 5–6 until 2030.

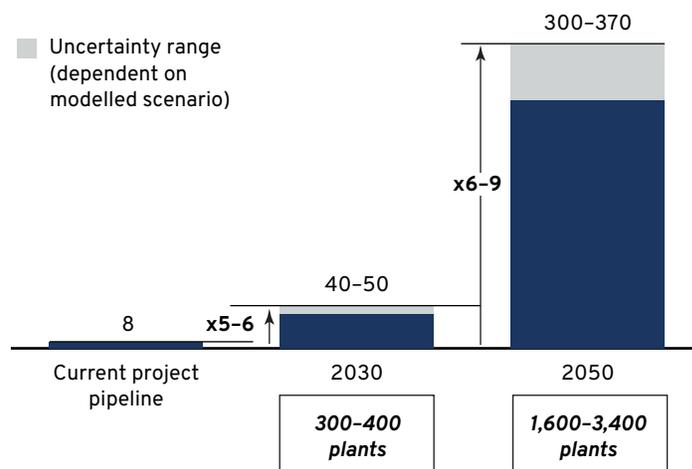
Sustainable bio-jet fuel and electricity-based (PtL) fuels need to be brought to market by 2030 to enable the massive scale-up in the 2030s that will be required to achieve net zero by 2050. To achieve SAF production levels of 40–50 Mt by 2030, investments into about 300–400 new fuel production plants and associated upstream infrastructure need to be made (Exhibit F). In particular, this 2030 target will be a challenge considering that it takes at least five years to build a new SAF plant and get it to full operation. With eight years left until 2030, new SAF plants need to be planned within the next two to three years if they are meant to meet 2030 targets.

Since the availability of sustainable biomass resources is limited, policies should incentivise priority use of biomass for sectors like aviation that have few other alternatives to decarbonise. To accelerate the scale-up of bio-jet fuel production, ethanol production volumes currently supplying the road transport sector could be redirected to the aviation sector. The electrification of cars will most likely free up certain ethanol volumes that can be transformed into bio-jet fuel via the alcohol-to-jet process. In addition, HEFA (hydroprocessed esters and fatty acids) plants could decrease their diesel outputs in favour of jet fuel. Both measures combined could unlock additional SAF supply of 14–22 Mt by 2030, about 25%–50% of the SAF demand in that year.

How SAF project pipeline needs to be scaled

EXHIBIT F

SAF production volumes in net-zero scenarios, Mt



Assumed plant sizes: SAF output capacities of 0.3 Mt/y for PtL and HEFA, 0.065 Mt SAF/y for other biofuels.

Source: MPP analysis

5. The faster the cost decline in renewable electricity generation, the higher the expected market share of PtL. In contrast, if electricity costs do not drop as rapidly, biofuels are likely to dominate the market.

To decarbonise aviation, a combination of different renewable fuels will be required, foremost biofuels, PtL, and hydrogen. In particular, there is a trade-off between the use of sustainable biomass on one hand and renewable electricity and green hydrogen on the other. While biofuels are the only SAF option today, PtL is projected to enter the market on a large scale in the late 2020s and become cheaper in the mid-2030s. The PtL market share by 2050 depends on how fast the levelised cost of electricity will fall in the next 15 years. Low electricity costs will lead to low green hydrogen production costs and finally low PtL costs that outcompete biofuels. Such a situation is reflected

in our ORE scenario, in which PtL constitutes the main SAF type from around 2040 onwards. However, if the cost decline of renewable electricity generation is slower, biofuels are expected to dominate the market in 2050 if (and only if) sufficient volumes of sustainable biomass – which is subject to global resource constraints – can be directed to the aviation sector. This is reflected in the PRU scenario. Although the future might lie between those two scenarios, the high demand volumes of SAF will in any case require both fuel production pathways to deliver SAF.



6. Hydrogen and battery-electric aircraft can make global aviation more efficient starting in the late 2030s and supply up to a third of the final energy demand in 2050.

Hydrogen aircraft could enter the market in the 2030s and scale up through 2050 to reach as much as roughly a third of aviation’s final energy demand by then (Exhibit G). With current aircraft designs, hydrogen aircraft could be range limited to about 2,500 km because storing hydrogen compared with jet fuel currently requires at least five times more volume to carry the same amount of energy. A redesign of airframes and storage technology innovation could, however, unlock longer ranges without reducing the number of available seats. If hydrogen aircraft were to enter the market around 2035 and achieve high ranges, they could gain a market share of about 32% by 2050 in terms of aviation’s final energy demand. If they enter the market only at around 2040 and achieve lower ranges, their impact

will be lower and rank at about 13% of the final energy demand by 2050.

Assuming breakthroughs in battery chemistries, battery-electric aircraft could potentially power regional aircraft on flights up to about 1,000 km by mid-century. Although they could replace more than 15% of the global jet aircraft fleet through 2050, they would contribute to only about 2% GHG emissions reduction because of their range limitation.

“Green corridors” could kick off the introduction of hydrogen and battery-electric aircraft, providing the necessary refuelling/recharging infrastructure at two dedicated airports with regular operations between them.

The technological potential of renewable fuels

EXHIBIT G

Best Medium Worst

	Battery-electric	Hydrogen	SAFs
Efficiency of fuel production and propulsion system	~60%	~25%	~15%
Maximum range in 2050	Few 100s km up to 1,000 km	2,500 km up to no limitation	No limitation
Expected large-scale market entry	Around 2035–40		<2030
Share of cumulative GHG emissions reduction from renewable fuels (2022–50)	2%–3%	8%–22%	75%–91%
Share of final energy demand in 2050	~2%	13%–32%	65%–85%

Hydrogen and battery-electric aircraft are more efficient than jet fuel-powered aircraft, but can only perform short- to mid-haul flights.

SAFs enter the market earlier and therefore have a larger impact on GHG emissions reduction.

Note: The GHG reduction potential of renewable fuels (SAFs and hydrogen and battery-electric aircraft) is defined by a trade-off between maximum aircraft range, expected market entry, and well-to-wake efficiency.

Source: MPP analysis





7. By 2050, net-zero aviation could require an additional 5,850 terawatt-hours (TWh) of renewable electricity (5% of the expected global demand), 95 million tonnes of hydrogen (10%–20% of the expected global demand), and 12 exajoules (EJ) of sustainable biomass (10%–25% of the expected global sustainable biomass availability) per year in the PRU scenario – or about double the electricity and hydrogen but only one-third of the biomass in the ORE scenario.

Decarbonising air transport has massive implications for global energy system resources (Exhibit H) – in particular for sustainable biomass (for biofuel production) as well as renewable electricity and green hydrogen (for PtL production and the direct use of hydrogen in hydrogen aircraft). One tonne of jet fuel can be produced by (1) about 1.1–1.2 tonnes of used cooking oil, (2) about 5–8 tonnes of municipal solid

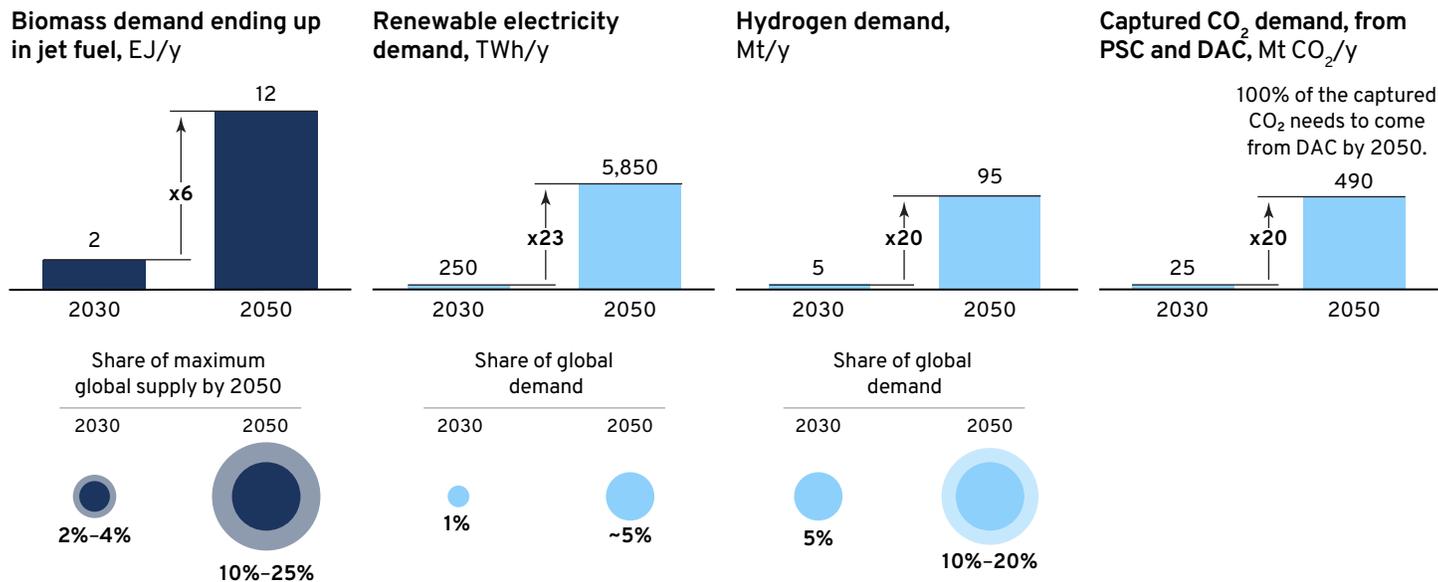
waste (MSW), agricultural/forestry residues, or nonfood energy crops, or (3) about 24–31 megawatt-hours (MWh) of renewable electricity (to yield about 0.5 tonne of hydrogen and to capture about 3.3 tonnes of CO₂). CO₂ can be sourced from point source capture (PSC) in the near term to scale up PtL production, but needs to come from direct air capture (DAC) in the long term.



Resource demand of global aviation in 2030 and 2050

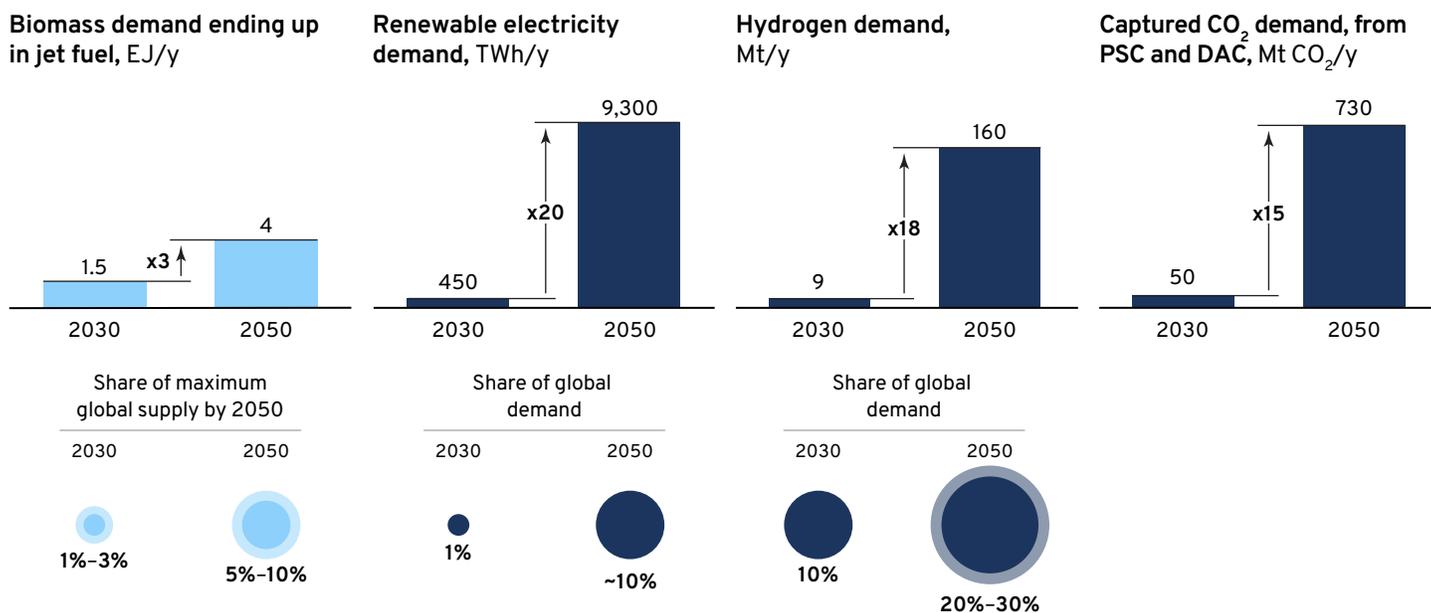
PRUDENT SCENARIO

A key challenge of a biofuel-dominated scenario is the sufficient supply of sustainable biomass, in light of the competition for this limited resource from other sectors. However, such a scenario will require only about half the electricity, H₂, and captured CO₂ of a PtL-dominated one by 2050.



OPTIMISTIC RENEWABLE ELECTRICITY SCENARIO

A key challenge of a PtL-dominated scenario will be the sufficient supply of renewable electricity, H₂, and captured CO₂, in light of growing global demand also from other sectors. However, such a scenario will require only one-third of the sustainable biomass of a biofuel-dominated one by 2050.



Source: MPP analysis



In 2030, aviation could demand 5 million–9 million tonnes of hydrogen, suggesting a share of 5%–10% of indicative global demand projections of the Energy Transitions Commission of 90 Mt. It could require 250–450 TWh of additional renewable electricity, suggesting a share of about 1% of indicative global demand projections of the Energy Transitions Commission of 35,000 TWh, depending on how fast PtL enters the market.

In a scenario where PtL and hydrogen dominate the energy mix in 2050 (ORE), up to 9,300 TWh in additional renewable electricity production capacity would be required. Supplied by up to 4 TW of renewable electricity generation capacity, aviation could thereby demand up to 10% (9,300 TWh) of the indicative expected global electricity production of 90,000–130,000 TWh in 2050, suggested by the Energy Transitions Commission. In addition, the production of about 160 Mt hydrogen would require an installed electrolyser capacity of up to about 2 TW.

In a scenario more reliant on biofuels (PRU), 12 EJ of biomass could be required for the aviation sector, demanding 10%–25% of the indicative global availability of sustainable biomass by 2050. The conversion of 12 EJ sustainable biomass to biofuels will simultaneously entail the production of by-products like diesel/gasoline or naphtha, which will demand an additional 8 EJ.^{iv} Therefore, 20%–40% of the indicative globally available sustainable biomass would be used in biofuel production facilities, to primarily serve the aviation sector.

In the face of competing demand for these resources, also from other sectors, ramping up sufficient capacity will be critical in order to decarbonise aviation and our global economy. Sustainable biomass should be redirected from current sectoral use cases where alternative decarbonisation solutions exist (e.g., in road transport or shipping) to the aviation sector.



iv These by-products can decarbonise other sectors, wherefore the additional 8 EJ should not be attributed to aviation per se.



8. Aircraft fuel efficiency gains and operational measures could avoid over 15 Gt CO₂e of cumulative GHG emissions at zero or even negative abatement costs.

Sustainable biofuels and PtL will most likely enter the market at large scales only around 2030, and hydrogen and battery-electric aircraft even later in the 2030s. However, other measures can reduce emissions more quickly. The industry should keep investing in fuel efficiency gains for conventional engines, along with improved airframe design, ground operations, air traffic management, and route planning. These measures could improve fuel efficiency by 2% per year (see *Technical Appendix* for more detail), or about 40% by 2050 compared with 2019. Replacing the current commercial aircraft fleet with the most fuel-efficient aircraft that are in service today would already reduce fuel consumption by about 20%. Cumulatively between 2022 and 2050, efficiency measures

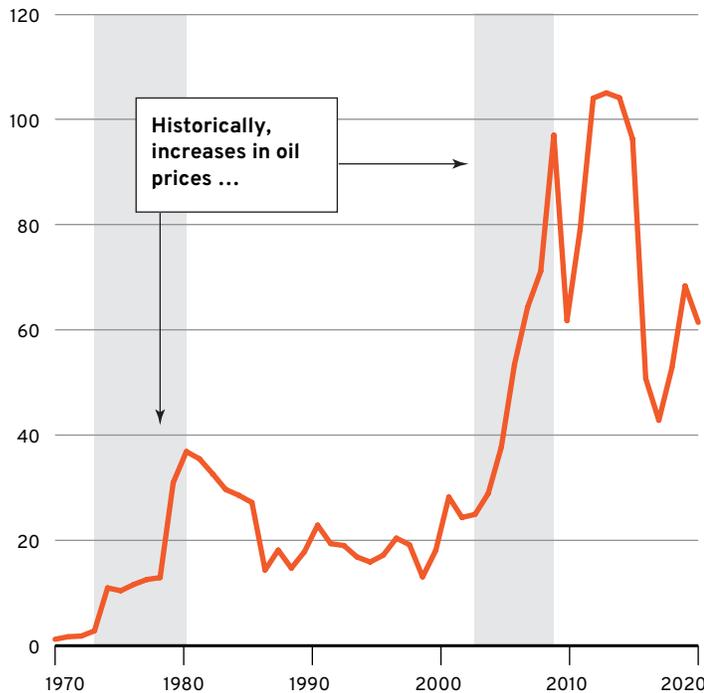
could abate about 15 Gt CO₂e at far lower costs than other measures – often even at negative marginal abatement costs compared with current abatement costs of more than \$200 per tonne of CO₂e for SAFs.

Historically, average efficiency gains of 1% per year have been recorded. However, in two periods in the 1980s and the 2010s, surging aviation fuel costs led to increased fuel efficiency measures of 1.5%–2.8% per year to save on fuel costs (Exhibit I). The prospect of future fuel cost increases due to the switch to SAFs could again be a key driver for increased fuel efficiency efforts.

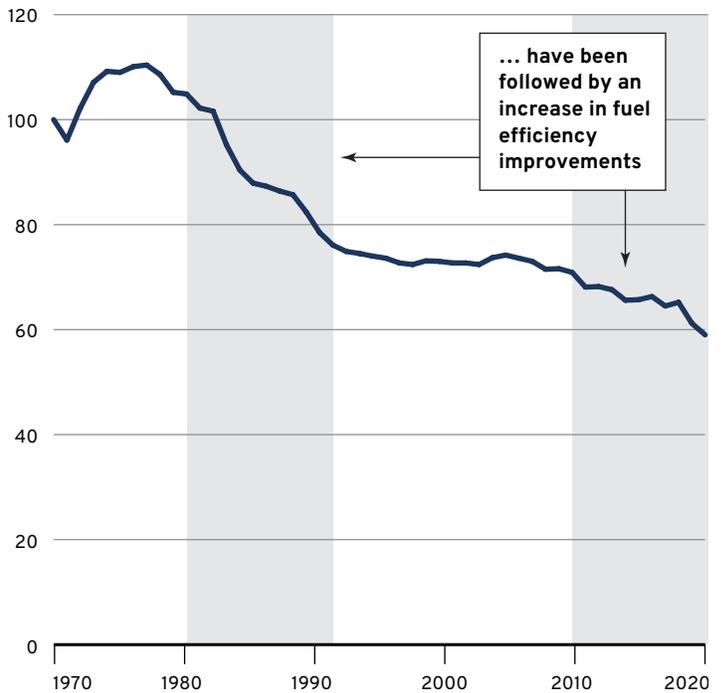
EXHIBIT I

Historically, aircraft fuel efficiency gains followed high oil prices

Oil price, \$/barrel



Fuel economy,* fuel/tonne-km



* Relative to 1970 (1970 = 100%)

Source: MPP analysis, based on World Bank and ICCT



9. Although average fuel costs are increasing in the net-zero scenarios, the cost of flying could remain stable, being counterbalanced by efficiency gains.

SAFs are currently 2–5 times more expensive than fossil jet fuel, and even in the long run, SAFs are likely to come at a premium, even though high oil prices could reduce this premium considerably.

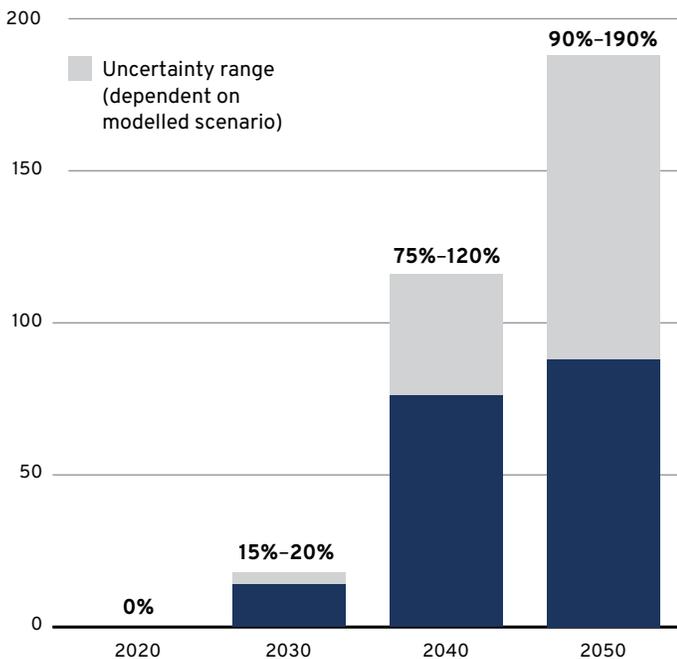
The average energy cost for global aviation will depend on (1) the market share of renewable fuels, which will increase over time, (2) their production costs, which will decline over time (because of technology innovation, economies of scale, and/or carbon pricing schemes), and (3) the fuel efficiency of aircraft, which will increase over time. As a result of (1) and (2), a share of 13%–15% of SAFs by 2030 could increase the average cost of fuel by about 15%–20%. However, considering fuel efficiency gains of aircraft, the average cost increase per revenue passenger kilometre (RPK) could be negligible.

By 2050, average fuel costs for a fully decarbonised aviation sector could increase by about 90%–190% compared with projected fossil jet fuel costs (before considering any carbon pricing on top of fossil jet fuel costs). Average costs per RPK could, however, rise by only about 5%. Further technology improvements, economies of scale, and the introduction of more efficient hydrogen and battery-electric aircraft could even lead to a decrease of about 5% (Exhibit J) in the costs per RPK. Although these values are only indicative and it is unclear how individual segments of the value chain will react to increased fuel costs, efficiency gains could enable airlines to compensate for large parts of the economic impact of increased fuel costs.

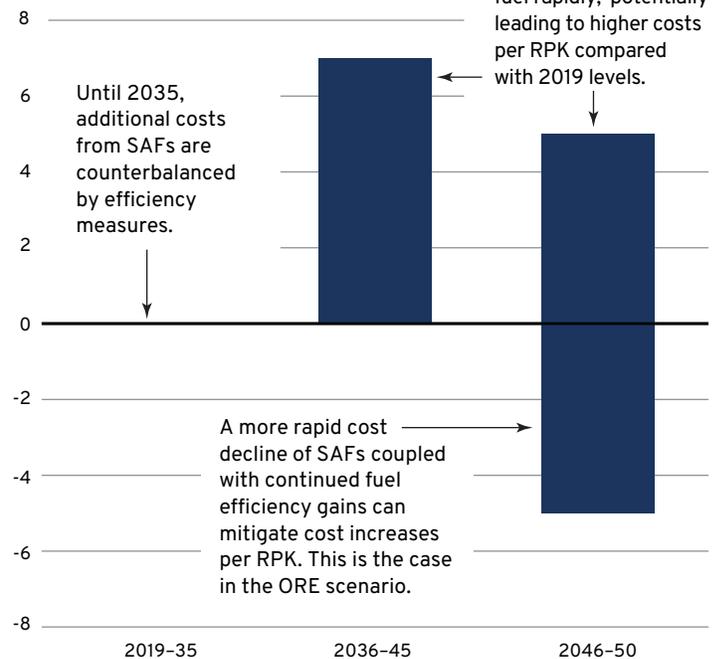
EXHIBIT J

Increasing fuel costs could be balanced with fuel efficiency gains

Average aviation fuel cost increase compared with fossil jet fuel costs, %



Indicative cost increase per RPK, percentage, compared with 2019 baseline



Source: MPP analysis



10. Carbon dioxide removal (CDR) solutions are needed to remove residual emissions from renewable fuels but are not a replacement for deep and rapid in-sector decarbonisation.

CDR solutions are necessary in addition to, and not instead of, deep and rapid in-sector decarbonisation.

Renewable fuels reduce GHG emissions by about 75%–95% compared with fossil jet fuel. The GHG emissions reduction of biofuels can vary considerably depending on the biomass feedstock. For PtL, hydrogen, and battery-electric aircraft, the GHG emissions reduction potential depends on the embedded emissions in renewable electricity generation assets and is therefore expected to increase in parallel to the decarbonisation of the manufacturing industry.

Still, renewable fuels rarely reduce GHG emissions by 100%, and unabated residual emissions of about 120–140 Mt CO₂e will remain in 2050. Those will need to be mitigated by CDR solutions, including, for example: natural climate solutions (NCS); hybrid solutions like biochar or bioenergy with carbon capture and storage (BECCS); and engineered solutions like direct air carbon capture and storage (DACCS). Counterbalancing the residual emissions would cost an additional \$15 billion–\$18 billion in 2050 alone at an average abatement cost of \$125 per tonne of CO₂. Investments in CDR should start immediately to be able to sequester 120–140 Mt CO₂e by 2050.



11. Policymakers must create a level playing field between fossil jet fuel and SAFs. Industry collaboration across the value chain can ramp up SAF demand and supply, as well as trigger technological innovation. Financial institutions must direct capital to SAF plants.

A tailored and robust set of policies will be needed to overcome the technological and economic challenges that have been preventing SAFs from scaling (Exhibit K).^v In this decade, policymakers should (1) de-risk private investments for new SAF production pathways, (2) bridge their cost differential compared with fossil jet fuel, and (3) direct sustainable feedstock to the aviation sector. Simultaneously, the way for hydrogen/battery-electric aircraft can be paved by supporting R&D and ensuring future accessibility to renewable electricity and green hydrogen at scale.



Key policy milestones in this decade

EXHIBIT K

Global milestones



Create demand for decarbonisation measures: ICAO commits to net zero by 2050 and adopts a long-term global aspirational goal (LTAG), e.g., in form of GHG emissions intensity reduction targets in line with this report.



Create enabling conditions: A functional, global book-and-claim system is established by 2025.

National/regional supply incentives



Change incentive schemes for renewable fuel production to redirect biomass use from road transport (biodiesel) to aviation (bio-jet fuel).



Support R&D of new SAF pathways and hydrogen/battery-electric aircraft.



De-risk projects, e.g., via blended finance, capital grants, concessional/low-interest loans, or long-term guarantees.

National/regional demand incentives



Impose 5%–7% blending mandates for SAFs by 2025 and 10%–15% by 2030, and reduce the cost differential between SAFs and fossil jet fuel, e.g., by direct or indirect subsidies (like a blender's tax credit).



Use green public procurement to supply 20% of public-sector air travel with SAF by 2030.



Tighten emissions trading schemes.

Note: List is not mutually exclusive, nor collectively exhaustive; national policy packages should be tailored to the specific country and region.

Source: MPP analysis

^v See overview of policy options to support the market entry and scaling of SAFs developed by the Clean Skies for Tomorrow Initiative, the Mission Possible Partnership, and the Energy Transitions Commission, *Clean Skies for Tomorrow: Sustainable Aviation Fuel Policy Toolkit*, November 2021, www.energy-transitions.org/wp-content/uploads/2021/11/Clean_Skies_for_Tomorrow_Sustainable_Aviation_Fuel_Policy_Toolkit_2021.pdf.



From an industry perspective, the market entry and scale-up of SAFs require radical collaboration across the value chain in this critical decade to overcome the chicken-and-egg problem between demand and supply of SAFs and to bridge their initially high cost differential compared with fossil jet fuel (Exhibit L).

Banks, institutional investors, and public-sector banks can collectively make commitments to invest in SAF plants and upstream energy infrastructure to unlock the annual capital requirements of \$40 billion–\$50 billion in this decade. Financial institutions should signal capital flow commitments early on to de-risk projects (Exhibit M). Besides SAF plants, novel propulsion aircraft should also receive investment support to increase their technology readiness level (TRL).

Key industry milestones in this decade

EXHIBIT L

Demand creation via offtake agreements



Current offtake agreement volumes – a cumulative 21 Mt SAF for varying offtake durations of 0.5–20 years – between SAF producers and customers (airlines, corporations, governments, etc.) are doubled by 2025 and increased by a factor of 5 until 2030 to overcome the chicken-and-egg problem between demand and supply.



Offtake agreements focus on this decade to scale up near-term supply of SAFs and meet the yearly demand for about 40–50 Mt SAFs by 2030. Advanced market commitments and initiatives like the First Movers Coalition provide similar powerful demand signals.

Supply changes in reaction to policy revisions



Triggered by revised biofuel policies, existing HEFA plants reduce their diesel output in favour of jet fuel: doubling the jet fuel share to 36% unlocks additional 7 Mt jet fuel by 2030. Increasing the jet fuel share to a maximum of 55% would unlock an additional 8 Mt.



Triggered by revised biofuel policies, 10% of global bioethanol supply (9 Mt) is redirected from road transport to aviation to produce 6–7 Mt of SAF by 2030.

Industry consortia



Cross-value chain consortia have de-risked currently low-TRL PtL production pathways and brought first-of-a-kind (FOAK) PtL plants to the market by 2025 and larger-scale second-of-a-kind (SOAK) PtL plants by 2030.



Cross-value chain consortia have de-risked the development of hydrogen and battery-electric aircraft, which enter the real-world test phase by 2030.

Note: List is not mutually exclusive, nor collectively exhaustive; industry action should be tailored to the national policy environment and region.

Source: MPP analysis

Key finance milestones in this decade

EXHIBIT M

Climate-aligned investment principles



By 2030, banks, institutional investors, and public-sector banks commit 100% of their investments to infrastructure assets and companies that comply with 1.5°C targets (similar to Poseidon Principles in shipping).

In collaboration with the financial sector, investment principles are established until 2023 to define sustainability criteria for infrastructure assets, companies' and financial institutions' aviation- and fuel-related portfolios. Investment principles should:



Encourage an engagement of investors and industry corporations

- To incentivise and facilitate 1.5°C-aligned target-setting;
- To develop best practices of new financing instruments tailored to make projects related to SAFs, efficiency measures, and novel propulsion aircraft investable, and
- To develop quantitative analyses on ways to de-risk such projects for financial institutions.



Mandate beneficiaries of any form of climate-aligned finance to disclose annual metrics to track their progress on decarbonisation targets.



Include exclusion criteria to trigger divestments from non-1.5°C-aligned assets and companies, e.g., banks do not provide loans to aviation companies that do not meet minimum 1.5°C-aligned criteria by 2030.



Include inclusion criteria (e.g., existing target to reduce GHG intensity per RPK by 20%–25% until 2030 for airlines, or a commitment to use 10%–15% SAF by 2030 for airlines and corporate customers, or the target of min. 85% GHG reduction compared with fossil jet fuel for a new SAF plant) to trigger new investments in 1.5°C-aligned assets and companies.

Public-private partnerships can de-risk technology projects of low maturity



Consortium of capital providers to share risk.



Public-sector banks to de-risk projects, e.g., via blended finance, concessional loans, capital grants, or long-term guarantees.

Note: List is not mutually exclusive, nor collectively exhaustive; finance action should be tailored to type of financial institution, their portfolios, the size of the companies that require capital for low-carbon technologies, and the technologies' maturity.

Source: MPP analysis



CONCLUSION

Bringing global aviation on a 1.5°C-aligned path to net zero is possible. It will require substantial annual investments in the order of \$175 billion, of which about 95% would be in renewable fuel production, and entail large-scale implications for the energy system. Aviation demand could represent up to 10% of the expected global electricity demand and up to 30% of the expected global green hydrogen demand by 2050.

Policymakers, financial institutions, and industry leaders need to collaborate to set the course towards 1.5°C and net zero. Early action in this decade is required to unlock technological innovation and economies of scale and to enable large-scale GHG emissions reductions in the 2030s and 2040s.

In a joint effort by actors across the value chain, we can make this mission possible.





**MISSION
POSSIBLE
PARTNERSHIP**

The Mission Possible Partnership is an alliance of climate leaders focused on supercharging efforts to decarbonise some of the world's highest-emitting industries in the next 10 years.

© COPYRIGHT 2022 MISSION POSSIBLE PARTNERSHIP