Aircraft Leasing Ireland
Ibec

In partnership with
OliverWyman | University of Limerick
Ollscoil Luimnigh

Aviation Sustainability

OUR FUTURE

January 2022

CONTENTS

FOREWORD

Aircraft Leasing Ireland (ALI) is the trade association for the aircraft leasing community in Ireland. The association represents 31 aircraft lessors, including 18 of the world's top 20 and the majority of the global lessor-owned fleet. Ireland is the leading centre for aircraft leasing globally and ALI is dedicated to the continued development and success of the country's aviation industry generally and its aircraft leasing sector in particular.

ESG has rightfully come to the forefront of consciousness in recent years. The three pillars — environment, social and governance — are all very important and are discussed in this narrative, but the environmental dimension is our main focus with regard to aviation. The environmental threat facing our world, and therefore our sector, is existential. To that end, ALI commits to supporting the Fly Net Zero pledge made by the airline industry to achieve net zero carbon emissions by 2050, as approved by IATA at its October 2021 AGM. ALI and its members are committed to driving sustainability across the entire lifecycle of an aircraft.

Air travel has transformed the world. It is a catalyst for global economic growth and enhances our quality of life by allowing us to explore the world. Aviation is continuing to grow at an impressive rate, despite COVID-19, and given the "hard to abate" nature of aviation, this growth puts even stronger pressure on us to take action now to address the environmental challenges facing our sector.

Aviation is a complex industry governed by an extensive regulatory environment. This means that the technological leaps required to address the climate threat are measured in decades rather than years. This in turn means that our transition to carbon neutrality by 2050 is critically dependent on actions taken today, even though the results of those actions are not immediately apparent.

Many actions are already underway to address aviation emissions through improvements in aircraft design and operational efficiency. Emerging technologies such as Sustainable Aviation Fuel (SAF) are already beyond the pilot stage and beginning to scale. Step changes in technology such as electric or hydrogen propulsion are in progress but are a long way from realisation due to the complexities involved.

The scope of this narrative is two-fold. First, to provide an overview of aviation's pathways to achieve net zero by 2050 through aircraft design changes, operational improvements, SAF, electrical/hydrogen propulsion, and recycling. And second, to outline how ALI and its members can use their influence as owners of the majority of the global leased aircraft fleet to lead and drive aviation towards a sustainable future through tangible actions, as outlined in Section 12.

The most immediate of these actions is the development of a charter for aircraft leasing. This charter will be developed in parallel with other key actions, including collaboration with relevant stakeholder groups on matters such as the EU taxonomy and sustainable financing, working with members to implement sustainability initiatives, and collaborating with universities to advance sustainability for aviation.

In preparing this narrative, ALI has benefitted from and is very grateful for contributions from a number of industry thought leaders:

Robbie Bourke
Partner, Oliver Wyman, London

Professor Arvind Gangoli Rao
Delft University of Technology, The Netherlands

Professor Trevor Young
University of Limerick, Ireland

Aircraft Leasing Ireland

Declan Kelly
Chair

Marie-Louise Kelly
Vice Chair

Aircraft Leasing Ireland Sustainability Working Group

Jan Melgaard
FPG Amentum

Robert Downes
Aviation Capital Group

Michael Dowling
DAE Capital

Shane O'Reilly
KPMG

Audrey Crummy
Aircraft Leasing Ireland

Section 1

ESG: ENVIRONMENTAL, SOCIAL AND GOVERNANCE

ESG refers to the three key pillars of corporate activities driving the long-term sustainability of a business, the surrounding environment, and the larger society (Exhibit 1). The emergence of ESG requirements for corporations has increasingly drawn attention to the need to understand the different factors that impact sustainability and social responsibility.

Exhibit 1: Three key ESG pillars of corporate activities driving long-term sustainability

Long-term sustainable business

Environment: Preserving nature and ensuring resource efficiency

Low carbon/No carbon world
Commitment to transition to a low-carbon future, to achieve carbon neutrality

Water conservation
Minimise usage of fresh water in water-scarce catchments

Building biodiversity
Promote conservation of biodiversity

Enhancing energy efficiency, building the circular economy
Minimise energy usage throughout the value chain and maximise reuse, sharing, and recycling

Social: Building safe, inclusive and empowered communities

Education
Empower communities and support sustainable job creation through skills training

Health
Promote the wellbeing of employees and support community health initiatives

Livelihood
Stimulate local economies, promoting local and inclusive development

Governance: Responsible corporates and policies

Ethical policies
Take charge of implementing policies that support/reinforce positive human rights and sustainability outcomes

Build coalitions to deliver impact
Partner with/employ third parties (NGOs, universities, etc.) to help define and measure sustainability goals

Accountability to local stakeholders
Build strong relationship based on trust and responsibility between industry and communities, and wider society

ESG Enablers

Performance management
Robust assessment of activities and outputs to ensure goals are met in effective manner

Organisation structure
Effective governance that facilitate effective management

Communication
Effective communication channels to facilitate learning and feedback

Source: Oliver Wyman analysis

Not only does the world consider a focus on ESG principles to be the right thing to do for humanity and the planet, but financial, reputational and regulatory pressures are combining to force organisations to deliver positive ESG outcomes. Additionally, consumers are increasingly favouring more sustainable products and services.

The focus for this document is primarily on the environmental aspects of ESG, and specifically on the carbon emissions impacts of the aviation industry. It is important, however, to consider that when defining a comprehensive sustainability agenda, all dimensions of ESG must be considered. External ESG ratings agencies, such as MSCI, are monitoring companies' activities across these dimensions to develop a comprehensive view of their sustainability.

Managing Risk

In the World Economic Forum's 2021 Global Risks Report [1], respondents ranked environmental risks as four of the top five global risks in terms of likelihood, while the UN Principles for Responsible Investment [2] considers climate change to be the "highest priority ESG issue facing investors." The World Economic Forum report suggests that prioritising actions for the environment cannot be delayed until economies have fully recovered from the effects of COVID-19, and that the lessons learned from what the global community can achieve in the face of a global emergency like a pandemic should be implemented as soon as possible.

Investors also are driving companies towards a more ESG focused outlook. Climate impact is increasingly being considered in investment strategies and overall portfolio management. ESG scores and factors are now viewed as financial risk topics, with climate risk and sustainability being major considerations. This is leading to the emergence of specialised Sustainable Finance products. Furthermore, investors may soon price airline and aviation investments as higher risk if sector decarbonisation is not addressed effectively.

Financial Disclosures

In addition to ESG reporting, additional climate-related reporting [3] will be mandated in the coming years. The Task Force on Climate-Related Financial Disclosures (TCFD) is a market-driven initiative to develop recommendations for voluntary and consistent climate-related financial risk disclosures in mainstream corporate filings. Increasingly, access to, and the cost of capital is likely to be linked to the level of climate risk and progress towards sustainability.

There is worldwide support for the TCFD, with approximately 60% of the world's 100 largest public companies supporting it. The UK is leading the way by introducing TCFD disclosures for large organisations from April 2022 [3]. Most lessors in Ireland will also be obliged to report on ESG via the Corporate Sustainability Reporting Directive from 2023 [4].

The aviation sector is a challenging sector to decarbonise, as we shall see in later sections. As such, it is experiencing heightened attention from investors and other key stakeholders.

Capital Reallocation

The emergence of the Glasgow Financial Alliance for Net Zero (GFANZ) initiative is noteworthy as a signal of intent from the mainstream global financial system to reallocate capital towards technologies and businesses that can drive decarbonisation across industries, including aviation. GFANZ is a sector-wide coalition in collaboration with the UN's Race to Zero. Members include more than 450 financial firms from 45 countries, responsible for assets of over $130 trillion [5].

Each member has made its own specific net zero commitments. Within banking, for instance, the Net Zero Banking Alliance requires members to measure the emissions associated with their financing activities, and to set targets for the reduction of those "financed emissions" at a rate consistent with reaching Net Zero by 2050.

Aviation Sector Working Together

Aviation is highlighted as a priority GFANZ sector for investigation in 2022, including engagement with industry initiatives such as Clean Skies for Tomorrow and Destination 2050. An agreed pathway for aviation is yet to be established but will likely include investments in green technologies. It will be critically important for aircraft leasing organisations to be involved in these conversations.

Recent announcements underscore how sustainability is gaining more focus in aviation industry boardrooms. Cooperation and partnerships among stakeholders are vital to making progress. Recent examples include initiatives such as the UN's Net-Zero Banking Alliance, RMI's Sustainable Aviation Buyers Alliance (SABA) [6], and the Aviation Climate Taskforce (ACT), which is a global collection of aviation leaders seeking to accelerate emerging technologies through a dedicated investment fund [7].

RMI is a US-based climate NGO working to reduce emissions to a 1.5°C trajectory. Its key focus is energy transition, and includes initiatives through its Center for Climate Aligned Finance to use the financial system to drive decarbonization. RMI is working across two main operating platforms for aviation, the Clean Skies for Tomorrow Coalition [8] and the Sustainable Aviation Buyer's Alliance [6], which covers the entire aviation value chain including banks, fuel producers, manufacturers, airlines, airports, consumers, NGO's, and policy makers, developing an ecosystem of frameworks and guidance tools.

According to RMI, a key end goal for the aviation sector could be the introduction of a similar agreement to that of the global framework for responsible ship finance, The Poseidon Principles [9], but tailored to aviation to help coordinate transparency, disclosure and target setting for lenders to aviation.

Aircraft leasing companies can use their position of influence to ensure awareness and stimulate action across their customer base and, together with OEMs, drive progress towards a lower carbon aviation industry. Furthermore, leasing companies have a clear interest in working with other stakeholders, especially on the financing of aircraft.

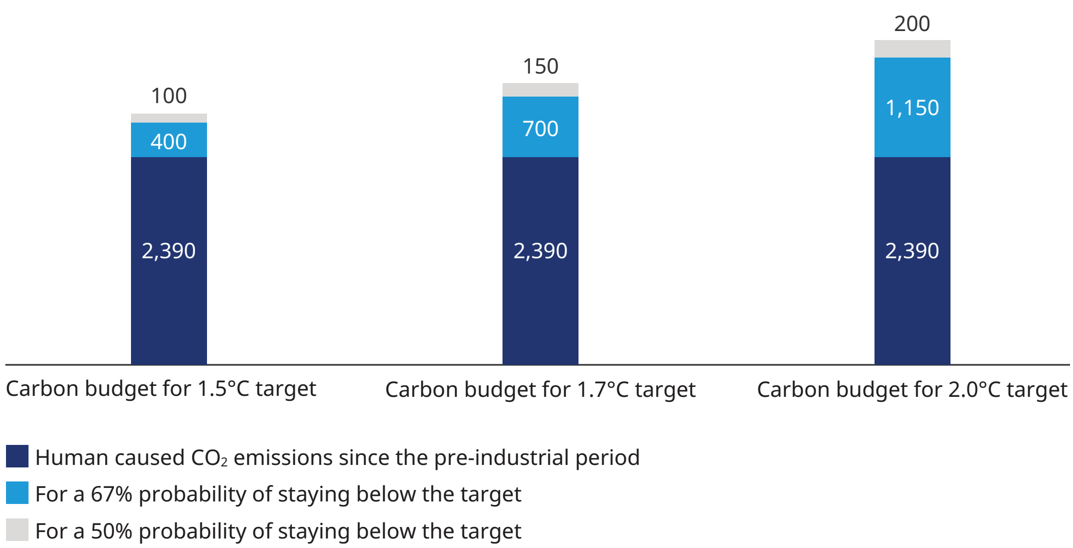
Section 2

NET ZERO CARBON EMISSIONS BY 2050

The conclusion of the United Nations Conference of Parties climate change conference (COP26) in November 2021 has accelerated action towards global net zero emissions by 2050, with the goal of limiting global warming to 1.5°C. This is one of the targets set out in the UN Sustainable Development Goals (SDGs), which have ESG at their core [10]. The specific objective to limit warming to 1.5°C, which was originally adopted in the Paris Agreement treaty in 2015 [11], requires a shift from commitments to real actions.

The 1.5°C warming limit can be achieved by reducing greenhouse gas emissions and staying below a specified global carbon budget, as calculated by the Intergovernmental Panel on Climate Change (IPCC).

Exhibit 2: Global carbon budget overview



Source: Adapted from IPCC "Climate Change 2021" [12]

According to the IPCC's latest 2021 report [12], the remaining carbon budget to stay within 1.5°C is between 400-500 $GtCO_2$ in total (as shown in Exhibit 2). However, with global carbon emissions already reaching 40.8 $GtCO_2$[1] in 2019, we will reach the 1.5°C limit within just 10 years if we continue at that rate. The actions taken by businesses and governments between now and 2030 will be critical for the 2050 target to be met and were a key focus for COP26 [13]. Staying within 1.5°C will require a global reduction in CO_2 emissions of between 40–50% by 2030, and more than 80% by 2040.

To align with the Paris Agreement, the International Air Transport Association (IATA) 77th Annual General Meeting on 4th October 2021 approved a resolution for the global air transport industry to achieve net zero carbon emissions by 2050. The resolution also documented a strategy for the achievement of the target, including a set of milestones to be reached between now and 2050 [14].

More specific technology pathways for achieving net zero, including aircraft design, operational efficiencies, new propulsion technology and sustainable aviation fuels (SAF) are illustrated in the Air Transport Action Group (ATAG) Waypoint 2050 report [15]. These pathways are considered throughout this document.

Aviation Emissions

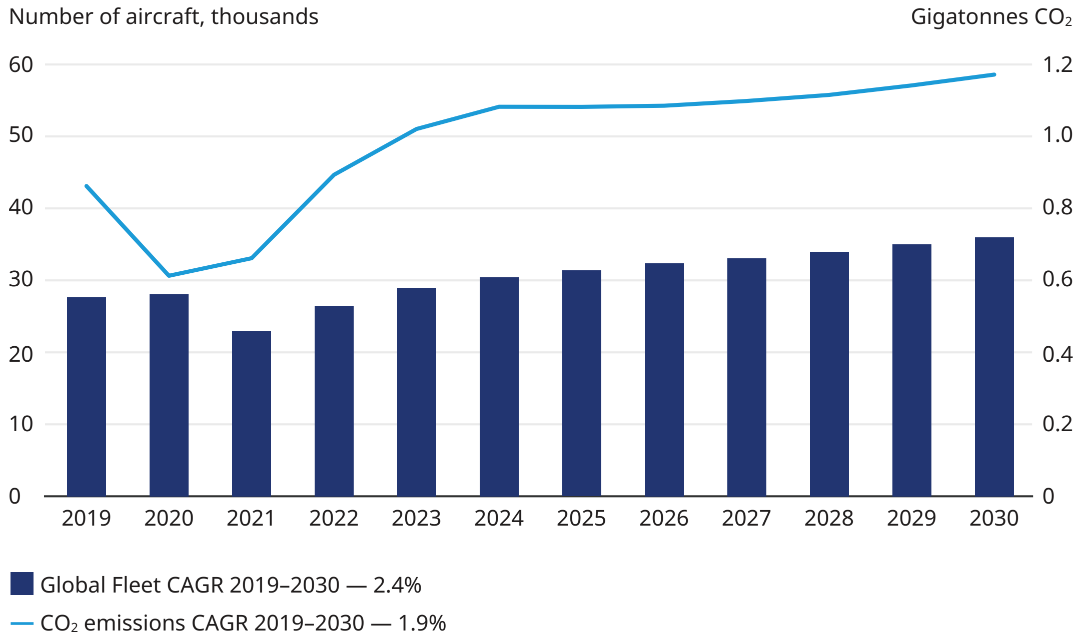
In 2019, aviation accounted for approximately 2.3% of global greenhouse gas emissions, with global commercial fleet CO_2 emissions totalling 0.918 Gt [16]. While the absolute CO_2 emissions have increased in line with the growth of the global fleet, significant improvements in aircraft efficiency have limited the impact. Emissions have been reduced by over 50% per seat kilometre through improvements in aircraft design, aerodynamics, materials, and operating efficiencies [17].

Despite reductions in air travel demand seen globally due to COVID-19, growth for the global commercial aviation industry is forecast to remain strong over the current decade. Driven by growing global GDP and a continuing increase in global middle classes, IATA is projecting 3.3% annual compound growth in passenger demand to 2040 [18], while major OEMs are projecting closer to 4% in this timeframe.

The required fleet to facilitate this growth is likely to reach over 35,000 commercial aircraft by 2030 [19], as shown in Exhibit 3, and grow to more than 50,000 aircraft by 2050, according to IATA projections [20]. IATA believes CO_2 emissions will increase from just below 1.2 Gt in 2030 to 1.8 Gt [21] by 2050, should no mitigating actions be taken. That projection represents the baseline for our analysis throughout this document.

1 Emissions are generally quoted in CO_2 or CO_2e; CO_2 is the actual CO_2 emissions, while CO_2e or CO_2 equivalent is a measure of all greenhouse gases (including gases such as methane and nitrogen oxides) converted to an equivalent CO_2 value based on global warming potential to allow ease of comparisons.

Exhibit 3: Global commercial fleet growth and associated CO_2 emissions growth to 2030



Source: Oliver Wyman Fleet and MRO Forecast [19], Oliver Wyman analysis

As governments and industries drive decarbonisation in the near term, it is expected that aviation's current 2.3% share of emissions will increase significantly as that of other sectors decline due to their decarbonisation efforts.

Decarbonisation Pathways

To enable the aviation industry to meet the 2050 net zero target, a combination of pathways will be required, with the entire aircraft lifecycle taken into consideration. Because the major share of all aircraft lifecycle carbon emissions takes place during flight, priority needs to be placed on fuel and propulsion. Decarbonisation pathways differ for different aircraft categories and should be prioritised in that way as well.

The ATAG Waypoint 2050 report lays out the following pathways [15], with applicable aircraft categories shown in Exhibit 4.

Exhibit 4: Indicative overview of where low- and zero-carbon energy could be deployed in commercial aviation

	2020	2025	2030	2035	2040	2045	2050
Commuter 9–19 seats <60 minute flights <1% of industry CO_2	SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF
Regional 50–100 seats 30–90 minute flights ~3% of industry CO_2	SAF	SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF
Short haul 100–150 seats 45–120 minute flights ~24% of industry CO_2	SAF	SAF	SAF	SAF potentially some Hydrogen	Hydrogen and/or SAF	Hydrogen and/or SAF	Hydrogen and/or SAF
Medium haul 100–250 seats 60–150 minute flights ~43% of industry CO_2	SAF	SAF	SAF	SAF	SAF potentially some Hydrogen	SAF potentially some Hydrogen	SAF potentially some Hydrogen
Long haul 250+ seats 150 minute + flights ~30% of industry CO_2	SAF	SAF	SAF	SAF	SAF	SAF	SAF

Source: Air Transport Action Group, "Waypoint 2050," [15]

- **Sustainable aviation fuels (SAF):** applicable to each aircraft type due to being a drop-in fuel[2]
- **Electric propulsion:** applicable to small aircraft platforms with short range, with technology being available in limited applications by 2025, but with increasing application to larger aircraft in subsequent decades
- **Hydrogen propulsion:** applicable to small and medium sized aircraft platforms, with fuel cells generating electrical power being developed by 2030, and hydrogen combustion engines and cryogenic fuel storage becoming available in the late 2030s or early 2040s

In addition to these pathways, aggressive actions will be required in relation to operational improvements around aircraft design and technologies, air traffic management, and flight operations.

When looking at the likely impact of each of these pathways on CO_2 emissions, operational improvements and SAF are the primary levers for the industry in the short and medium term. Propulsion levers will become more relevant in the longer term and ultimately more significant beyond 2050.

2 Drop in fuel: A fuel that can use current infrastructure and processed to be a direct replacement for jet fuel, without the need for changes to the aircraft or associated infrastructure.

Exhibit 5: Categorisation of different aviation decarbonisation pathways by 2050

Pathway		**Next steps or examples**	**Improvement**	**Difficulty**	**Potential by 2050**	**Timeline**
Aircraft design and operational improvements	Aircraft design and technologies [Section 3]	Winglets Light weight seating/cabin Current generation engine improvements Load alleviation	1.2% improvement per annum from 2022 to 2040 (25% total improvement) (Historical improvements have been 1.5–2%)		~25%	Some already available/ ongoing operational improvement; Continuous technology improvement with OEM's across airframe and engines
	Flight operations (including ATM) [Section 4]	Performance based navigation Perfect flight partnerships Formation flight Flight planning	Improvements of approximately 3% from air traffic management		~3%	Some already available; 2030 — ANSPs fully implemented ICAO Aviation System Block upgrades and regional programmes
	Other operational improvements [Section 4]	Electric ground power Airport infrastructure Flight planning	Marginal improvements with most potential in infrastructure renewables		<2%	Some already available; Increase in electrical storage and renewables are key enablers
Sustainable aviation fuels	HEFA Gasification/FT Alcohol to jet (AtJ) Power to liquid (PtL) [Section 5]	Investment in production Pricing Prioritisation and scale of feedstocks Airline offtake commitments Government policy/incentives	Potential to have up to 25 Mt of SAF by 2030, unlimited supply by 2050		55-60%	Some pathways already available; a number in the pipeline over the next 3–5 years at scale Power to Liquid pathway still in development, estimated for 2030+ at scale
Electric propulsion	[Section 6]	Electric and hybrid electric development well under way Battery development	Deployment in 2025 on commuter and 2030 on regional aircraft test aircraft, but small aircraft volume limiting potential		~2%	Commuter aircraft flying test beds available 2025, regional by 2030; aircraft in production from 2030+
Hydrogen propulsion	[Section 7]	Hydrogen flying test beds Infrastructure development Hydrogen fuel cells and conversion kits Hydrogen combustion engines	Deployment in 2035 on regional aircraft and 2040 on short/ medium haul driving most of improvement. But challenges on larger aircraft and slow ramp up as fleet transition required		~12%	Regional aircraft available 2035 Short/medium haul aircraft available 2040

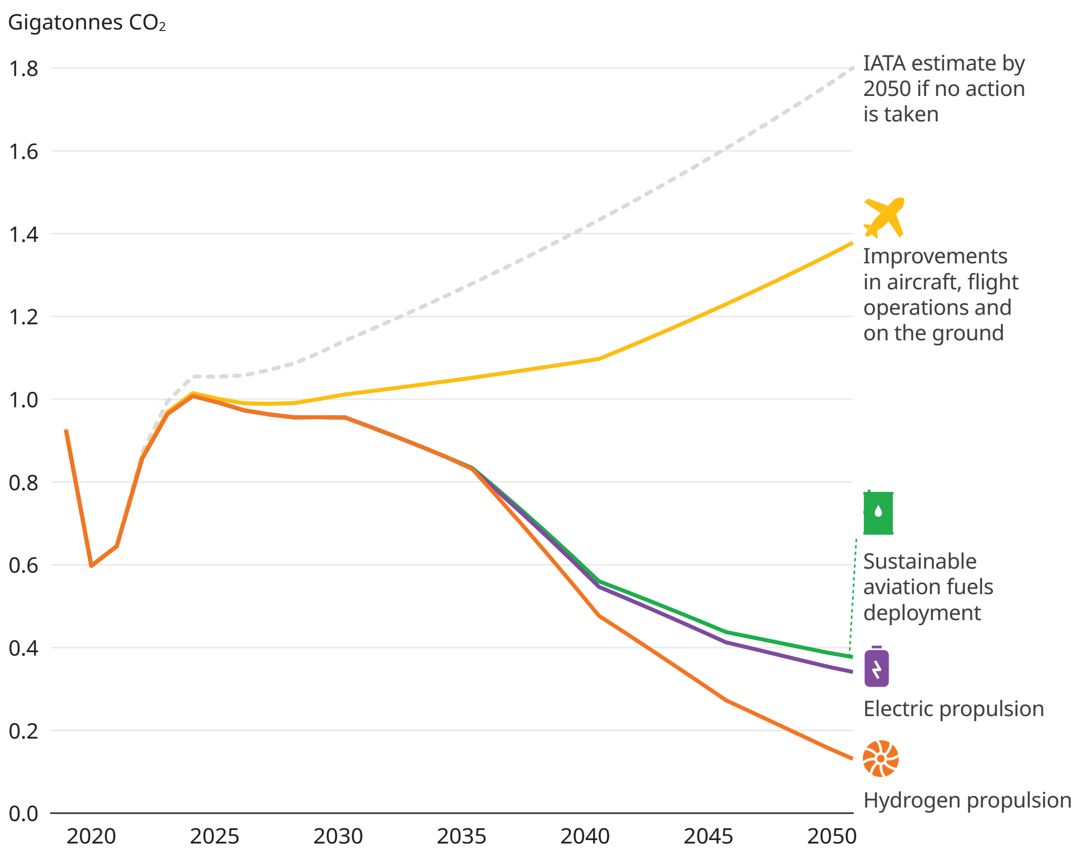
Source: ALI, Oliver Wyman and University of Limerick analysis

Using the IATA estimate of 1.8 Gt of emissions by 2050 in the base case (where no changes are implemented), estimates of the impact that each pathway and lever will have on emissions over the next 30 years have been developed (Exhibit 6). The details and assumptions are laid out in the following sections.

Operational and design improvements will play an immediate role in minimising aviation's net increase in emissions, with between 25–30% of the required 1.8 Gt reduction in emissions coming from this pathway.

SAF will be the primary lever for reducing emissions during the next 30 years, with the potential to achieve more than 55% of the 2050 requirement. Electric and hydrogen propulsion are expected to have limited impacts until post-2040, with current emissions reduction potential estimated at 2% and 12%, respectively.

Exhibit 6: Aviation carbon emissions forecast by scenario



Source: ALI, Oliver Wyman and University of Limerick analysis

While this base case falls short of zero emissions by 2050, the four primary pathways have the potential to achieve net zero by 2050 with the aggressive adoption of synthetic fuels from the power-to-liquid pathway (synfuel, PtL or e-fuels) or hydrogen propulsion, although both options will require significant capital investment to scale at the rate required.

The challenge in the short term is that 65% of the emissions reduction technology in the base case is either not commercially developed or is at an early pilot stage at present.

There are a wide variety of forces at play that could ultimately change the anticipated pathways and this baseline over the next 30 years. These factors include:

- Rapid scaling and cost reduction of the power-to-liquid SAF pathway
- Technology breakthroughs for the deployment of hydrogen
- Rapid development of renewable energy sources, particularly green hydrogen
- Large shifts in aircraft technology, either to a scale or of a type not currently predicted
- Aggressive changes in carbon pricing, driving quicker scaling of technology across potential levers

While these examples are not exhaustive, it is clear that there is a lot to play for in decarbonising aviation, with the overriding factors being the speed of technology development and the capital investment required to scale them, as well as the certification process for new technologies.

In the following sections, the document expands on the four primary pathways to achieve net zero by 2050.

Section 3

AIRCRAFT EFFICIENCY IMPROVEMENTS

Aviation has a strong track record of producing incremental improvements in energy efficiency. These improvements relate to (1) aircraft technologies and (2) flight and ground operations (discussed in Section 4).

Fuel efficiency improvements, in general, can be attributed to improved engine performance, better lift-to-drag ratio in cruise, and reduced airframe structural and systems weights.

Propulsion system improvements — which have played the leading role in past aircraft efficiency gains — are due to improved thermal efficiencies such as increased overall pressure ratios associated with increases in engine core operating temperatures, and improved propulsive efficiencies which are strongly connected with the engine bypass ratio.

Improved aerodynamic efficiencies have come from superior wing designs including advanced supercritical aerofoils, winglets, high aspect ratio wings, and reduced drag.

Airframe structural weight has been steadily reduced through the use of new materials such as carbon fibre composites and aluminium lithium alloy, and through better understanding of flight loads and structural behaviour. Reducing the weight of non-airframe components including seats, cabin partitions, and on-board systems has also yielded significant benefits.

Historical Improvements

When assessing the environmental impact of commercial aviation, both passenger and freight, different metrics have been used historically to quantify aircraft efficiency. One of the more useful metrics to assess aircraft efficiency is block fuel intensity. This can be defined as block fuel consumed per RTK (revenue-tonne-kilometre) or per RPK (revenue-passenger-kilometre). Block fuel consumption can be directly translated to CO_2 emissions, as 3.16 kg of CO_2 is produced for each 1 kg of jet fuel combusted.

The average block fuel intensity (kg per RTK) of new aircraft decreased by 41% from 1970 to 2019, equivalent to 1% a year on average, according to a recently published study by the International Council on Clean Transportation (ICCT) [22]. When the 1960s were included in the assessment, the average annual reduction in fuel intensity increased to 1.3%.

Notably, some time periods have seen a greater reduction in fuel intensity than others; for example, block fuel intensity fell by an average of 2.8% per year in the 1980s [22], but improvement slowed during the 1990s and 2000s. In the past decade, the rate of improvement has increased again with the introduction of newer fuel-efficient aircraft types.

Future Projected Improvements

Looking ahead to the short- and medium-term future, it is expected that the technologies that drove historical fuel efficiency improvements will continue to produce ever-more efficient designs, with some of these technologies already being deployed with increasing penetration. Geared turbofans (for widebodies), ultra-high bypass ratio and open rotor engine concepts are expected to yield significant fuel efficiency benefits. Improved aerodynamic efficiency is likely to come from highly optimised wing designs with higher aspect ratios and reduced drag, through laminar flow control for example, and gust load alleviation. Airframe structural weights are expected to continue their downward trend, due to innovative materials such as thermoplastic carbon fibre composites, and new manufacturing and assembly techniques including additive manufacturing and welded composite structures.

The ICAO, in its periodic assessments of the environmental impact of air travel, has assumed — for forecasting purposes — an aggregate annual fuel efficiency improvement of between 1% and 1.5% for aircraft technology and operational improvements with the higher value corresponding to an “optimistic” scenario [23]. Set against the historical gains achieved over the past 50 years, the “aspirational” target of 2% annual efficiency improvement, as adopted by the ICAO assembly in 2016 [23], represents a considerable challenge to the industry.

Using these forecasts as a proxy, the baseline scenario laid out in this document assumes that efficiency improvements of 1.2% per year from 2022 to 2040 are realistic and feasible, particularly given the technology improvements already achieved in current generation aircraft compared to older generations (e.g., A320 NEO vs A320 CEO; B777X vs B777-200). However, this annual improvement will reach diminishing returns without a technological step change and is therefore likely to tail off around 2040.

Section 4

FLIGHT AND GROUND OPERATIONAL IMPROVEMENTS

Driving efficiency improvement through aircraft technologies is the primary route for reducing carbon emissions across the global fleet both in the near and long term. But optimising flight, ground operations and air traffic management (ATM) in particular is another area of focus for the short term, with significant efforts already underway. Greater operational efficiency can ultimately drive small but material reductions in carbon emissions.

Flight Operations

Flight operations improvements can be categorised as those within the aircraft operator's control (airline flight ops), and those outside of it (largely ATM). Airline flight operations efficiencies have been the focus of fuel and flight ops teams within airlines for decades and are well understood, with ongoing progress. ATM efficiencies still have some way to go, and as traffic continues to grow over the next decade and beyond, it will be necessary to invest in ATM technologies and make greater efficiency improvements to airspace infrastructure to ensure in-flight emissions are kept to a minimum.

By delivering and implementing the range of ATM improvement technologies currently available and concepts being developed globally, ATM has the potential to materially reduce CO_2 emissions over the next decade. In the baseline for this report, flight operations emission improvements are estimated to account for a 3% reduction in total emissions by 2050. According to the EU Destination 2050 Report [24], there is a marked difference between Europe and the rest of the world, with improvements in Europe expected to be 5.1% from ATM by 2035 compared to 2.1% outside of Europe by 2040.

Examples of work already underway include:

Opportunity	Description	Current Progress	Difficulty
Performance-based navigation (PBN)	• Moving away from sensor-based navigation, PBN allows flexibility of flight path planning for efficiency • RNAV (area navigation) or RNP technology is used to enhance flight trajectory • Operators are responsible for achieving flight performance	• Implementation currently in progress globally • All ICAO states should now have a PBN plan in place as required by ICAO by Dec 2020 • EU migrating to all approaches and SIDs by PBN by 2030	
Continuous climb/descent operations (CCOs/CDOs)	• Flight path operation where a continuous climb path is followed for optimal fuel consumption and cruise altitude is reached with optimum air speed and thrust and/or a continuous descent path is followed, reducing thrust and drag	• Already implemented and continuously improving • Further opportunities for improvement through RNP • Limitations in high-traffic areas due to safety	
Trajectory-based operations (TBO)	• Concept based on strategically planning and managing in-flight trajectory by sharing data across network (flight ops, pilot, ATC, etc.) • Optimum efficiency flight with minimal deviation from flight trajectory by balancing capacity and demand	• Contributors to TBO starting to be implemented in EU and US but will require a gradual global transition to full TBO • Enhanced data and information sharing required	
Required navigation performance (RNP)	• Navigation specific component of PBN, allowing for accurate and precise flight paths to be followed in more locations • Facilitates more efficient CDOs	• Progressive implementation in progress, including aircraft equipment and pilot training • Navigation separation standards provide opportunities to enhance utilisation	
Automatic dependent surveillance-broadcast (ADS-B)	• Space-based ADS-B surveillance allows global tracking in non-radar-controlled airspace, enabling increased capacity and fuel efficient routes	• In implementation since 2019 • Now mandatory in US, Canada and European airspace	
Flexible tracks/ free route	• Improved navigation systems can analyse weather conditions and trajectory to reroute flights along a more flexible and efficient path	• Dynamic airborne reroute procedures are currently available over the North and South Pacific region	

Source: Adapted from Waypoint 2050 Report [15]

In addition to current technologies and initiatives already being implemented, further technological developments are expected to provide additional emissions reductions. For example, wake-energy retrieval concepts, such as the Airbus fello'fly project [25] and a component of Boeing's ecoDemonstrator programme [26], are anticipated to be adopted by 2040, potentially reducing CO_2 emissions by up to an additional 3% [24]. By 2030, 4D trajectory-based operation (TBO) is expected to be implemented, where flight paths follow an optimum, unrestricted trajectory but must arrive at designated points at pre-determined times [15].

To enable these ATM initiatives to be safely and effectively implemented across wide areas of airspace, cooperation between governments and organisations is essential. There are existing approaches to this, including the Single European Sky initiative collaborating on ATM across and surrounding Europe, and the NextGen programme collaborating with stakeholders across the US to progress ATM technologies. Broader coordinated global initiatives remain limited, however.

Ground and Other Carbon Emissions Operational Improvements

For aircraft operators today, ground and other improvements offer the most immediate improvement but also likely the smallest reduction in CO_2 emissions. This includes everything from electric ground power to airport energy supply, to fuel and water uplift procedures, to waste recycling onboard. Each of these areas are relevant in their own right and can have a positive benefit for overall emissions reduction despite being relatively small, but most importantly present opportunities to act immediately.

The biggest single impact that can be achieved here is likely to be a switch to renewable electrical energy supplies at airports. This includes providing reliable renewable energy infrastructure for passengers and aircraft, as well as electricity storage capabilities. Moreover, programmes such as Airport Collaborative Decision Making (ACDM) [27] can help significantly reduce emissions and congestion arising from aircraft taxiing.

Airline initiatives such as removal of single use plastics and reduction of packaging for catering have been underway for some time but have been challenging to implement and maintain during COVID-19. Clear focus and workstreams within airlines will be required to ensure that waste reduction programmes are underway and delivering while still maintaining the required customer experience.

Section 5

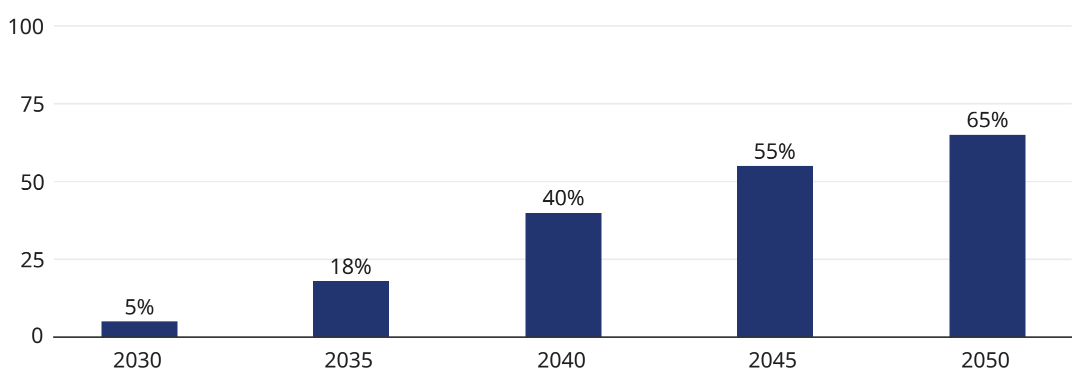
SUSTAINABLE AVIATION FUEL (SAF)

SAF refers to aviation fuel that is derived from non-fossil fuel sources and is seen by most stakeholders as a core technology in driving sector decarbonisation. SAF is already in production and is being used in limited cases around the globe. It can be used immediately on commercial aircraft, as it is a drop-in fuel when produced to the approved standard (ASTM D7566), with no changes required to either the aircraft or infrastructure. Currently, SAF can be blended with jet fuel up to 50% by volume, but trials have been undertaken recently with 100% SAF fuelling long haul flights.

SAF was first used in the late 2000s using an older generation biofuel, and in 2009 the first SAF pathway was approved [28]. Subsequently, many more pathways and sources of SAF have been developed and approved under the same standard. Longer term, the speed of continued development and scaling of these pathways and feedstocks will determine just how influential SAF will be in decarbonising the sector in the next few decades.

IATA's stated objectives and commitments are to reach net zero carbon emissions by 2050, with a specific significant commitment related to SAF usage, as shown in Exhibit 7:

Exhibit 7: IATA commitment for SAF usage through to 2050



Source: IATA, "Net-Zero Carbon Emissions by 2050," Press Release No: 66, 4 October 2021 [21]

Pathways for SAF production

There are four pathways for SAF development, as outlined in the WEF report [8]: Hydroprocessed fatty acids esters and fatty acids (HEFA), Gasification/Fische-Tropsch (FT), Alcohol to jet (AtJ), and Power to liquid (PtL).

Today, there are 17 sites globally producing SAF, mostly via the HEFA pathway. While these are spread across North America, Europe and Asia, most sites are concentrated in Europe and North America. By the end of 2023, however, Singapore's Neste facility is expected to have become the largest single producer by volume.

More than 80 additional SAF production sites are planned around the world at present, according to the ICAO [15]. Should these run to full publicly announced capacity and produce SAF exclusively, they would meet the needs of aviation by 2050. However, the raw material for SAF is in demand by other sectors as well, including renewable diesel, which is cheaper to produce, and currently delivers a higher margin due to incentives. In practice, this means that publicly announced SAF sites may fall short of meeting demand from the aviation sector. That said, feedstock competition may wane as hydrogen and battery power for trucks and buses becomes more common. In addition, more SAF production sites are likely to be announced in the coming years.

Exhibit 8: Primary SAF pathways with feedstocks and potential

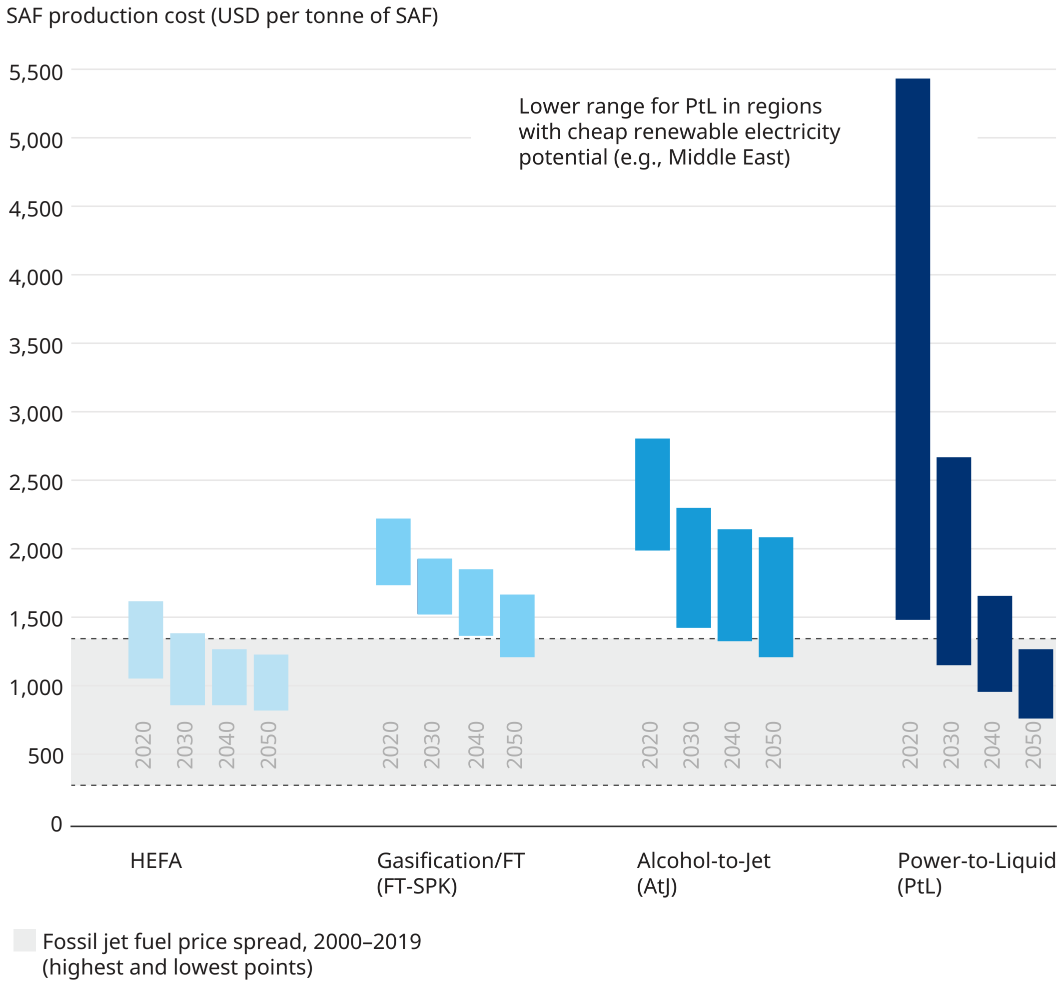
	HEFA	Gasification/FT	Alcohol to Jet	Power-to-Liquid
Description	Production of jet fuel through extraction of oils from waste and residue lipids and purposely grown energy plants	Production of fuel using any carbon containing materials including Agri and Forestry residues and Municipal solid waste	Extraction of ethanol and iso-butanol typically sourced from biomass	Conversion of captured CO_2 to synthetic fuel through electrolysis with Green Hydrogen
Feedstock (examples)	Used cooking oils; waste oils; animal fats (tallow); tall oil; fish oil	Municipal solid waste, wood processing (saw dust, slabs, wood chip), forestry residues (leaves, lops, tops, stem wood), Rice straw, cereal residues; industrial waste gas	Forestry residues, wood-processing and agricultural residues, purposely grown non-edible energy cover crops; industrial waste gas	Captured carbon either from Industrial site capture, sustainable biomass; or direct air capture (DAC)
GHG reduction	~80%	80–90%	80–90%	95%+[2]
Yield	90%	20%	13%	17%
Maturity 2021	In production	Commercial pilot sites	Commercial pilot sites	Emerging pilot sites, but 8–10 years from in production
Potential Fuel 2030	2 Mt[1]	2 Mt[1]	2 Mt[1]	0% <0.1 Mt
Potential Fuel 2050	30 Mt Could be as high as 85Mt but uncertainty over some feedstocks	200 Mt Only 20% yield; could be as high as 460 Mt if cover crops included and full access to feedstock is possible	70 Mt 13% yield on agri, forestry, wood processing	Unlimited

1. Extrapolated from Announced SAF capacity between 2021 and 2025; ATAG Waypoint 2050, Fuelling Net Zero
2. Carbon sourced from industrial plants should not be seen as carbon neutral; feedstock from air is negative
Source: Adapted from World Economic Forum "Clean Skies for Tomorrow" [8]

Headwinds for SAF Development

Feedstocks from the HEFA pathway will be limited to less than 10% of future SAF demand. The AtJ and FT pathways have significantly greater potential in terms of volume, although at a much lower yield of feedstock to fuel. Examples such as municipal solid waste offer huge opportunities for scaling. There is potential for nearly 1,000 Mt of waste material where approximately 80% is usable for the FT pathway, to produce 160 Mt of fuel [8]. However, the dispersed nature of this feedstock (aggregated and disposed of at the local authority level) means that realistically only 50% of municipal waste is likely to be available for production facilities.

Exhibit 9: Cost profile of SAF pathways between 2020 and 2050



Source: Adapted from World Economic Forum "Clean Skies for Tomorrow" [8]

The cost of producing SAF is currently significantly higher than traditional jet fuel, with the HEFA pathway currently wholesaling at three times the price of jet fuel. While it is unlikely that this price differential will continue to apply as HEFA supply ramps up, it is still likely that the cost of unsubsidised SAF will stabilise at 1.5 times current fuel prices, but that falls within the range of the top end of fuel prices in the recent past (Exhibit 9). Also, the general cost of carbon and associated carbon pricing is likely to indirectly make SAF costs more comparable to traditional jet fuel in the years to come.

For the other pathways, there is a lot of work to be done to scale these and achieve cost reductions to bring them in line with acceptable long-term price levels. However, different feedstocks and pathways have their own cost drivers that need to be addressed.

For example, in the case of municipal solid waste, capital expenditure for plant development is the primary cost driver, while the feedstock currently has no marketplace and therefore no cost. Development costs will come down, but feedstock costs will likely go up as demand is created.

Power-to-Liquid Long-Term Potential

The PtL pathway is the furthest away in terms of maturity but has the highest potential. The PtL process extracts carbon from the atmosphere, either directly from the air or from emissions from industrial processing and produces synthetic fuel using an electrolytic process. In effect, feedstocks are unlimited, but the cost of acquiring the carbon is currently quite high such as with direct air capture (DAC) technology, which requires large volumes of air to produce the carbon in sufficient volumes. Point source capture (PS), largely from industrial sites, has a much higher carbon concentration, but simply recycles carbon emissions rather than achieving truly net zero carbon emissions. Furthermore, the availability of carbon from this source will fall over time as industries decarbonise.

Regardless of the source of carbon, the process requires abundant access to green hydrogen, which is currently in short supply[3]. However, as other industries invest in and scale up the supply of green hydrogen, the expected reduced cost will dramatically change the economics associated with jet fuel production where carbon is the feedstock. This source of SAF has the potential to combine the highest volume with a reasonable price, at scale, while also providing the largest percentage reduction in greenhouse gasses.

Supply and Demand to Scale SAF

In the near term, the biggest issue related to the supply of SAF is demand in terms of signed commitments (offtake agreements). IATA has committed to 5% SAF by 2030, and over 70 airlines worldwide have committed to some SAF usage by 2030, while over 50% of the world's airlines have committed to be net zero by 2050. Airlines have started entering into offtake agreements, but many more are needed to allow the energy companies to justify the capital commitments required to drive an aggressive ramp up of SAF production.

Energy companies are focusing on the production of other renewable fuels where the incentives are higher, capital expenditure is lower, and margins are better. While this may be a short to medium term phenomenon, as fuels such as renewable diesel are likely to be replaced by other energy sources in the long term, it is having a material effect on limiting current investment in SAF and therefore the timeline for scaling production.

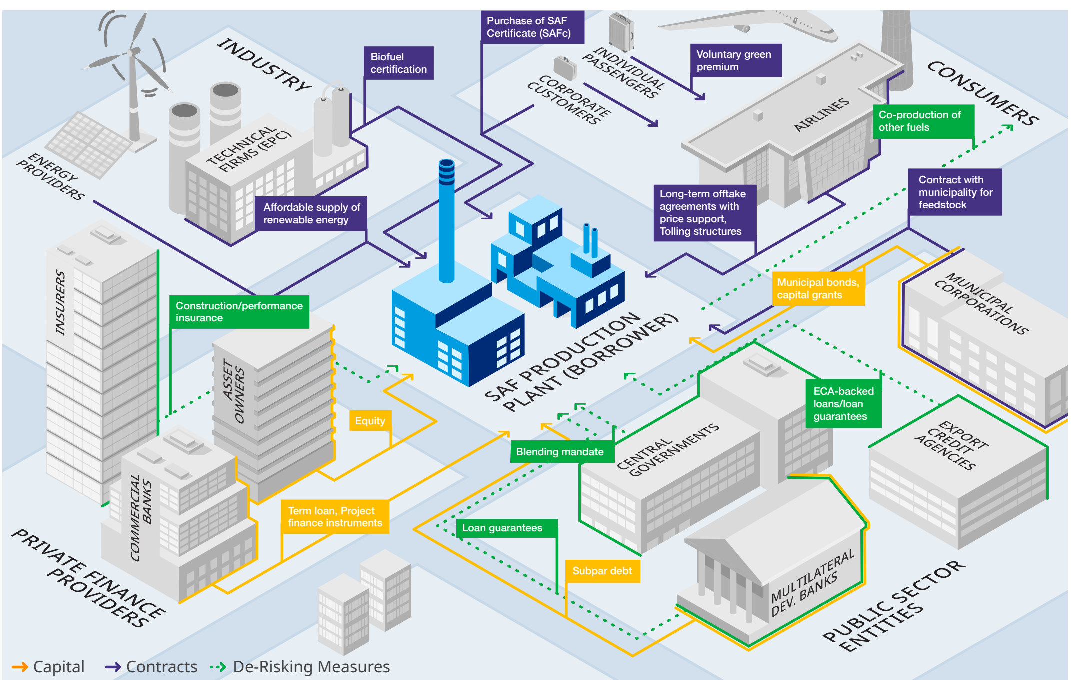
3 Green hydrogen refers to hydrogen that is generated entirely by renewable energy.

To “square this circle,” a combination of factors will need to be addressed through specific actions, many of which are laid out in the ATAG Waypoint 2050 Report [15]. As we consider how these different requirements and actions come together, we need to ensure that all parties understand their role. The speed of deployment and scaling of SAF will be dependent on the full ecosystem coming together (see Exhibit 10). Whether it is the energy sector driving investment and scaling at the right price; the consumers (airlines) making commitments in offtake agreements; passengers willing to pay a green premium; the public sector (governments) establishing direct incentives, mandates or grants for SAF; or financiers (including aircraft lessors) investing in SAF and enabling technology such as green hydrogen.

SAF deployment is estimated to deliver over 50% of the decarbonisation potential from the baseline outlined in Section 2. The largest proportion of this reduction will come through PtL sources post 2035, with more than a third of all future emissions reductions coming through this pathway. The other SAF pathways will deliver another 20% of emissions reductions based on the baseline assumptions.

Exhibit 10: SAF Production and Deployment

Enabling aviation decarbonisation



Source: World Economic Forum and Oliver Wyman, based on industry input

Section 6

ELECTRIC AND HYBRID-ELECTRIC PROPULSION

There are several options for the electrification of aviation propulsion systems. In broad terms, they can be divided into three categories: all electric, hybrid-electric, and turbo-electric. All-electric propulsion is only suitable today for small general aviation aircraft undertaking short journeys, based on current state-of-the-art battery technology. Greater payload/range performance is achievable with hybrid-electric propulsion systems, which rely on a mix of stored electrical and fuel energy. The term turbo-electric is used to describe a propulsion system in which an electric propulsor, an electric motor driving a fan/propeller, is powered by a turbogenerator burning fuel such as kerosene.

The Challenge of Battery Energy

Switching from burning kerosene to consuming electrical energy stored in batteries on an aircraft will in almost all cases increase the total energy required for a flight. Achieving a net environmental benefit is thus predicated on the availability of low or zero CO_2 electrical energy for battery recharging. The increase in total energy is primarily driven by two factors: the specific energy density (SED) of batteries is an order of magnitude less than kerosene, so the aircraft empty weight would be considerably heavier; and the total weight of the energy “store” does not decrease during flight with batteries while a plane’s weight falls as jet fuel is consumed.

The second point is important, as energy consumption per flight-hour is proportional to the aircraft’s gross (instantaneous) weight. This goes some way to explaining why the design of an all-electric aircraft capable of flying more than a few hours is so difficult. It is also evident that reducing aircraft weight and improving aerodynamic and propulsive efficiencies is critical to the successful achievement of net zero flight.

The range of an all-electric aircraft depends directly on battery SED and total battery mass. The SED of today’s lithium-ion batteries is about 100 to 265 Whr/kg [29]. Projections on how battery energy density will improve with time vary considerably. It is considered likely that battery SED will reach 400 to 600 Whr/kg by 2035 [30]. Several design studies have assumed that 1,000 Whr/kg batteries will be available by that date [31]. Nonetheless, when compared to kerosene, which has a SED of 11,900 Whr/kg, the limitations of all-battery operations become apparent. It therefore seems reasonable to conclude that all-electric propulsion will be restricted to short-haul aircraft applications in the short- to medium-term future.

Advantages of Electric Propulsion

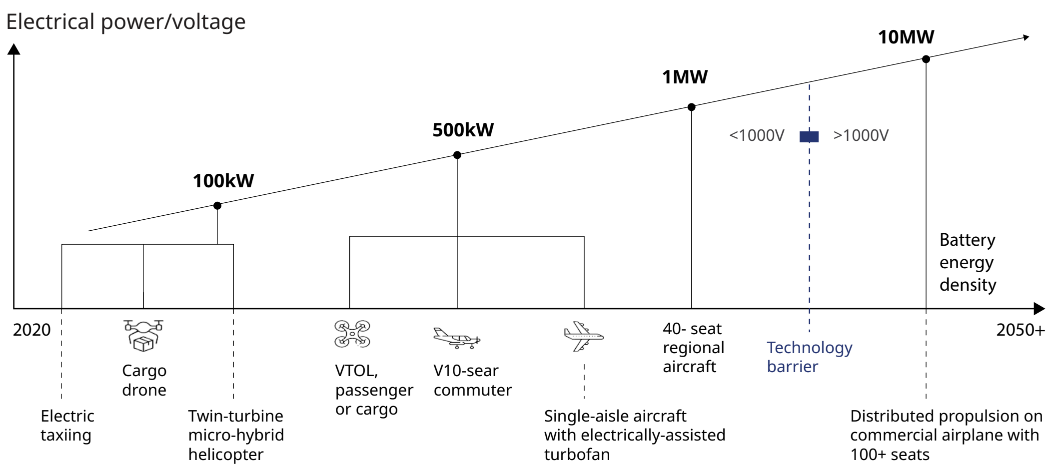
Electric propulsors have some exciting advantages over fuel-burning turbine powerplants. When scaled down in size, combustion engines generally incur performance, weight and efficiency penalties, while electric motors do not [32]. This opens up a new design space for manufacturers, allowing for the placement of smaller electric propulsors along the wing and at the wingtip[4]. This is known as distributed electric propulsion (DEP). The coupling of such electric propulsion with aerodynamic and flight control disciplines can yield improvements in overall aircraft fuel efficiency.

Turbo-electric and certain hybrid-electric propulsion architectures allow fan and turbine speeds to be decoupled, enabling both to be operated at their optimum speeds, achieving similar benefits to a geared turbofan (GTF). Another advantage of electric propulsion is that electric powerplants driven by batteries will not suffer power lapses with altitude.

Electric propulsion does come with significant engineering challenges, however. High on the list is thermal management. Even a small percentage of energy lost as waste heat can amount to a significant design challenge. Superconducting electrical power transmission eliminates electrical resistance heating but requires cooling.

Another engineering challenge concerns the installation of high voltage electrical systems and the hazards associated with short circuits and arcing. There is an emerging confidence that these problems can be solved, but it will take time. Forecasts for entry into service of electric-powered aircraft vary. One scenario is provided in Exhibit 11, which illustrates a progressive increase in installed electrical power.

Exhibit 11: Penetration of electrically powered aircraft into the market



Source: Oliver Wyman analysis

4 The propulsors accelerate the air over the upper wing surface, enabling changes to the aerodynamic design of the wing. For example, high lift augmentation facilitates higher wing loading, which can translate to an improved lift-to-drag ratio in cruise. In addition, propulsors installed at the wingtip can reduce wingtip vortices, yielding drag benefits. They also provide bending moment relief, reducing the stresses at the wing root. Yaw control can be provided through differential thrust, which can have an influence on the sizing of the vertical tailplane, for example.

System Design

Several different hybrid-electric propulsion system architectures have been developed, depending on how the power is delivered to the propulsors and on the power split between electrical and fuel. In recent years, there has been considerable interest in electrically assisted propulsion systems (EAPS), which employ an electrical system in parallel to assist fuel-burning gas turbines at certain stages of a flight. The advantage of EAPS is that turbofans can be optimally sized for specific flight phases such as cruising, while the electrical system provides power for taxiing, which is notoriously inefficient for a turbofan, and assists the turbofan during take-off and climb. Such EAPS concepts have the potential to reduce CO_2 emissions by about 7.5% and total energy consumption by around 2% for an A320 class aircraft on a 1,000 km mission [33].The immediate and short-term application of all-electric and hybrid-electric propulsion systems is already in evidence in the emerging market of advanced air mobility (AAM), as well as general aviation and commuter applications, where the Technology Readiness Level (TRL)[5] of key technologies is quite advanced at between TRL 6 and TRL 8. The TRL for electric propulsion systems suitable for regional aircraft is, however, much lower (between TRL 4 and 5) and 40-70 seat aircraft with hybrid-electric architectures and hydrogen fuel cells are not likely to enter service until the 2030s.

The technical challenges to be overcome for single-aisle aircraft of 100-150 seats, where significant amounts of energy will need to be stored electrically, are considerably greater and the TRL is between 3 and 4.

The baseline assumptions in Section 2 project a 2% reduction in emissions arising from electric/hybrid propulsion systems in 2050. This will come exclusively from commuter and regional aircraft coming into service from 2035 onwards.

5 TRL is a system used to estimate technology maturity, based on a scale of 1 to 9, with 9 being the most mature technology.

Section 7

HYDROGEN PROPULSION

Hydrogen, as a fuel source, has a strong appeal for use in both surface and air transportation, as it contains no carbon. It can be combusted in a turbine powerplant or consumed in fuel cells to generate electricity to drive electric propulsors. The latter option, which will utilise hydrogen-electric powertrains, is considered to be a good solution for commuter and short-haul regional aircraft. Combusting liquid hydrogen in gas turbines, however, is the most efficient route for larger aircraft, as bigger gas turbines are equally or more efficient than fuel cells and provide a very high power-to-weight ratio.

Comparison of Hydrogen to Existing Fuels

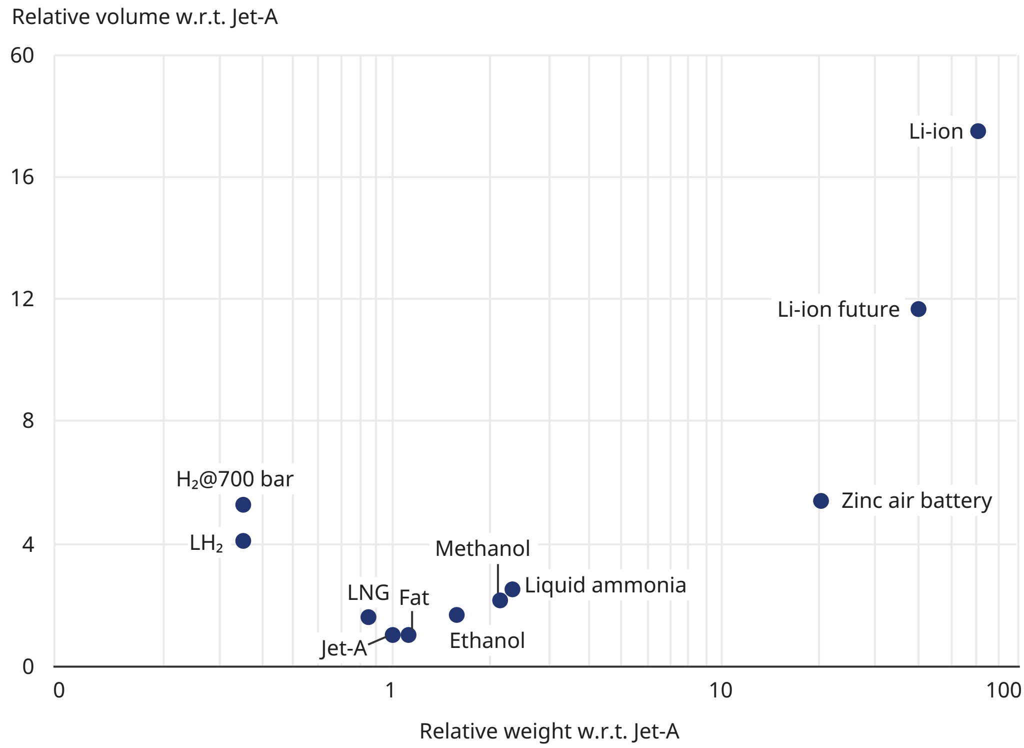
What makes hydrogen different from kerosene is its energy density. To understand how this will impact the design of future hydrogen-powered aircraft, we need to consider energy density, both per unit mass (SED) and unit volume (volumetric energy density or VED). Both will impact the design of new aircraft, but in different ways.

Exhibit 12 shows several fuels/energy carriers in terms of their SED and VED. It can be seen that Jet-A has good SED and VED — that is, it delivers sufficient energy for its weight and volume to make it well suited to aviation applications. While biofuels and synthetic kerosene have similar energy densities, and therefore are ideal from an energy carrier point of view, their availability and cost currently limit widescale deployment (as discussed in Section 5).

Gaseous hydrogen takes up far more volume than kerosene to deliver the same amount of energy (a VED of 0.01 MJ/L, compared to 35 MJ/L for kerosene). It is possible to store smaller amounts of hydrogen in pressurised tanks, which would be suitable for smaller aircraft operating over shorter distances.

For large quantities of hydrogen, however, it is better to store it as cryogenic liquid hydrogen (LH_2), which has a higher VED (8.5 MJ/L). The major disadvantage is that liquid hydrogen needs to be stored at -253°C. And since the VED of LH_2 is still about four times lower than kerosene, much larger fuel storage tanks are needed, which, of course, must be very well insulated. On the positive side, the weight of LH_2 is only one-third of that of kerosene for the same energy content.

Exhibit 12: Comparison of various energy sources for aviation with respect to Jet-A



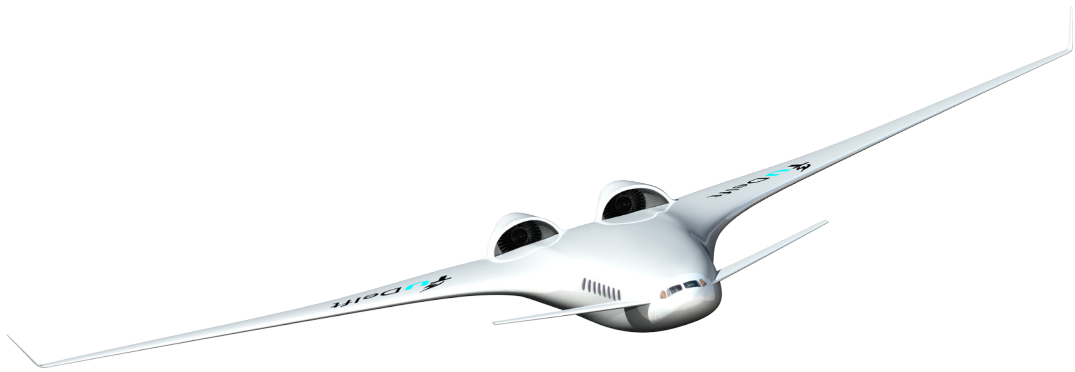
Source: Adapted from "A hybrid engine concept for multi-fuel blended wing body" [34]

Aircraft Design Implications

The storage of liquid hydrogen on aircraft poses several major engineering challenges. LH_2 has an extremely low boiling temperature (-253°C). The tanks need to be heavily insulated to prevent the LH_2 from evaporating as it absorbs heat and expands rapidly; thus, venting is necessary to prevent tanks from exploding. Hydrogen tanks have a propensity to leak as the gas can seep through even minute pores in welded seams. Furthermore, metals exposed to extreme cold become brittle. The safety of operations and usage in an airport environment will also be extremely challenging. And solutions to the refuelling and containment problems associated with cryogenic LH_2 are at a very low TRL currently.

Looking ahead to practical applications, the ratio of the weight of hydrogen to the weight of the tank improves with increased capacity. It is thus better to use fewer, large tanks than many smaller ones. Tank design and placement are thus critical considerations in the development of new hydrogen powered aircraft. The fuel will likely need to be stored in the fuselage or in external underwing pods. Consequently, we may see aircraft developed with novel configurations, such as the blended wing body (BWB), which has the potential to deliver superior overall performance compared to the classical "tube and wing" layout seen in all passenger transport aircraft today.

Exhibit 13: Blended Wing Body (BWB) concept developed for the AHEAD project (funded under FP7 by the EC)



Source: Professor Arvind Gangoli Rao, Delft University of Technology

BWB configurations (illustrated in Exhibit 13) are aerodynamically efficient and provide a large internal volume, ideal for storing fuels with low VED. Such developments will require considerable engineering effort and investment. Innovative architectures will also present new challenges for aircraft certification. A more immediate pathway for hydrogen utilisation will be in the short-haul commuter and regional aircraft sectors, with the retrofitting of turboprops with hydrogen-electric powertrains employing fuel cells, electric propulsors and gaseous H_2 storage.

Key Benefits of Hydrogen Fuel

The most appealing aspect of using hydrogen as an aircraft fuel is that no CO_2 is emitted. There are also other benefits of using LH_2 compared to kerosene, including the absence of secondary emissions such as soot, carbon monoxide, unburnt hydrocarbons, and volatile organic compounds. Furthermore, the use of a cryogenic heat sink can substantially increase turbofan engine thermal efficiency. The fuel also offers improved combustion range and flammability limits, and it is less prone to combustion instabilities when compared to alternatives [35].

Hydrogen-powered aircraft would, however, emit NOx (nitrogen oxides), but these are thought to be of the order of 50% lower than that from kerosene combustion. Another factor to be considered is that burning hydrogen would generate substantially more water than the current generation of jet aircraft, and water is a greenhouse gas at altitudes above about 10 km.

Production Challenges

The current TRL is low (TRL 1 to TRL 3) for many of the key technologies required to realise a liquid-hydrogen-powered passenger transport aircraft that can operate safely and reliably. Considerable resources will be needed to mature these technologies to a level comparable to those employed in current aircraft.

The problems associated with the sustainable production of hydrogen are, of course, not specific to the aviation industry. The worldwide production capacity for green hydrogen is wholly inadequate to contemplate a near-term transition to hydrogen for large segments of the transport industry. Currently, hydrogen costs considerably more than kerosene (per unit energy); although this is expected to fall as demand increases. Infrastructure will be needed to deliver and store hydrogen at airports, or — as some have suggested — to produce hydrogen locally. Because of these factors, while we might see flying test beds before the end of the 2030s, it is unlikely that we will see production aircraft until 2040 or later. And as production will roll out slowly, transitioning the global fleet to hydrogen will take time.

The ultimate penetration of hydrogen as a decarbonisation pathway by 2050 will rely heavily on how quickly the key technologies can be developed and adapted from other sectors like space for commercial aviation. A reliable supply of green hydrogen is the other critically important factor. The baseline assumptions in Section 2 project an 11% reduction in emissions in 2050 due to hydrogen, with stronger penetration in Europe, North America, and Asia. This reduction will commence from about 2035 for regional and smaller aircraft, with larger aircraft coming online after 2040 in a gradual way.

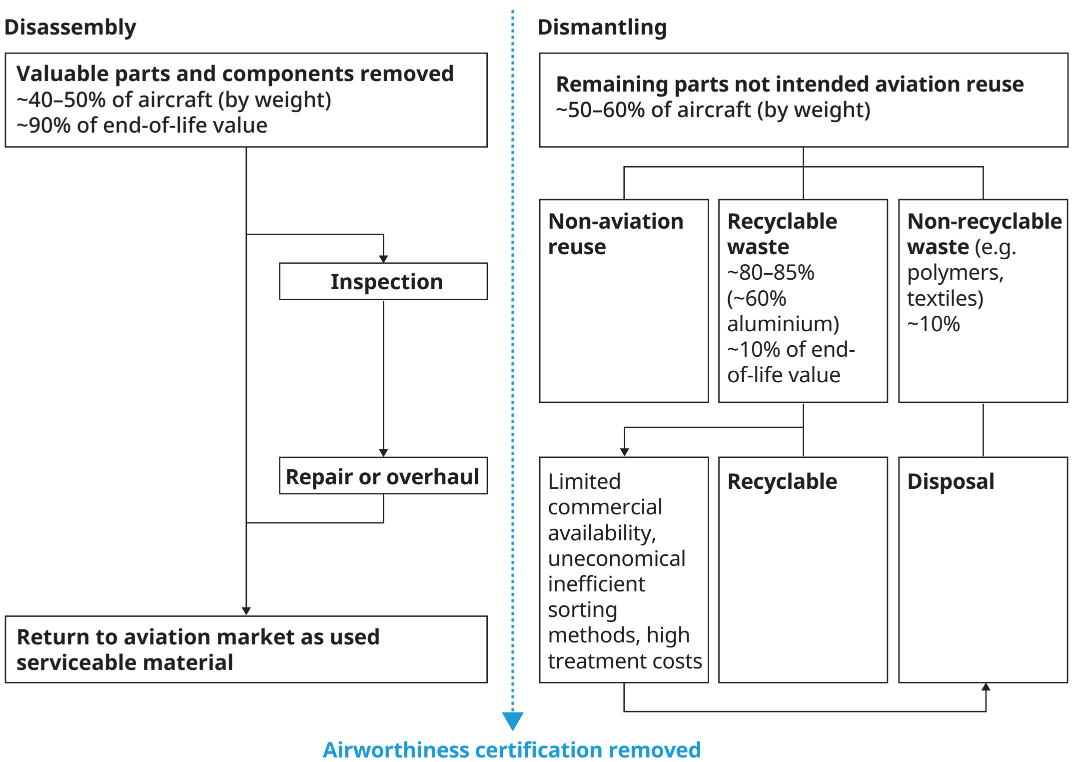
Section 8

RECYCLING OF AIRCRAFT

Although the primary environmental factors facing the industry are fuel burn related and laid out as pathways to reduce carbon emissions in the previous sections, it is important to consider the environmental impact of an aircraft across its full lifecycle, including at end of life. Decisions related to aircraft retirement and replacement with new aircraft increasingly require economic and sustainability trade-offs.

From 2010 to 2019, an average of 664 aircraft were retired each year. COVID-19 caused increased activity in 2020, with an estimated 1,287 aircraft retired. While many have yet to be disassembled, these aircraft are unlikely to ever return to service. From 2022-2030, annual retirements are expected to average 784 per year, with the average age of the global fleet declining as a result [19]. The energy intensity of the global fleet will decline as new aircraft replace older models. Improved recycling processes for aircraft in terms of both volume and value will be important in driving the principle of a circular economy.

Exhibit 14: Aircraft end-of-life process (adapted from Best Industry Practices for Aircraft Decommissioning [36])



Source: IATA, "Best Industry Practices for Aircraft Decommissioning (BIPAD) 1st Edition" [36]

Disassembly and Used Serviceable Material

During aircraft disassembly, valuable parts and components are removed and recertified to be returned to the aviation materials market. The conversion of dismantled parts to used serviceable material (USM) is driven by demand, disassembly capacity and the complexity of decommissions. Aircraft owners and operators have increasingly accepted USM as a reliable alternative to OEM material and disassembly capacity is growing along with USM supply, with close to 50% of all parts now being returned to the production pipeline [36]. The market demand for USM is likely to remain strong in the long term, providing a ready marketplace for this recycling activity.

Dismantling and Recycling or Disposal

During the dismantling process, the remaining parts and components that can no longer be reused within aviation may be repurposed. Most of the remaining materials can be recycled [37] and returned to the supply chain as raw material. Depending on the vintage of the aircraft, up to 60% of the remaining aircraft materials could consist of aluminium, which is fully recyclable with many further uses, including industrial and commercial applications. Commercial recycling solutions for the remaining recyclable polymers and composite materials are constantly developing and evolving, and availability should continue to improve.

Whether by integrating recycling requirements into the initial aircraft design and material selection, or further developing cost effective disassembly processes for harder to recycle materials, embedding circular economy principles into the aviation value chain will be important for future sustainability.

For the approximately 10% of aircraft parts, components and materials that cannot be recycled or reused, predominantly carbon fibre components, disposal is unavoidable. It is necessary to consider environmental impacts when disposal takes place, particularly in terms of hazardous materials and the contamination of natural resources.

The percentage of such materials is likely to reduce over time as it is expected that cost reductions and manufacturing innovations will lead to a significant increase in the amount of thermoplastic materials used in airframe structures. Unlike thermoset composite materials, thermoplastics can be melted down and easily recycled.

Section 9

CLIMATE CHANGE AND NON-CO_2 CONSIDERATIONS

Over the past few decades, climate scientists have steadily improved our understanding of how global aviation contributes to anthropogenic climate change. Mathematical models have been developed to describe the contribution of aviation to climate change and to provide a means to assess future scenarios such as changes to passenger demand, aircraft technologies, and operations. The mechanisms by which flight operations impact climate is associated with (a) the creation of greenhouse gasses, (b) the formation of nitrogen oxides that impact greenhouse gasses, and (c) the emission of minute solid and liquid particles that can scatter solar radiation and aid in the formation of contrails (illustrated in Exhibit 15).

Background to Climate Forcing Agents

Aviation's climate impacts can be divided into two overall categories: those resulting from CO_2 emissions and those resulting from non-CO_2 causes. CO_2 is a product of the combustion of hydrocarbon fuels, such as kerosene, and is a powerful greenhouse gas. Non-CO_2 causes include nitrogen oxides, water vapour, soot and sulphate aerosols, and contrails and the cirrus cloudiness that arises from them. Nitrogen oxides (NOx), created through fuel combustion, contribute to acid rain and smog and act as a catalyst to change the levels of ozone (O_3) and methane (CH_4) in the atmosphere.

For aviation, CO_2 has historically been considered to yield the largest sustained impact of any "climate forcing" agent. This document has been written from this perspective, based on the resolution approved at the 77th IATA AGM in 2021 [14]. Recent studies, however, have shown that non-CO_2 agents could be very significant in global warming effects, and could potentially have a greater near-term impact than CO_2.

As previously stated, global aviation CO_2 emissions represent about 2.3% of total CO_2 emissions created by human activity. The underlying science that explains how CO_2 emissions influence the earth's climate system is well understood and the level of uncertainty in modelled predictions is therefore quite small.

For non-CO_2 causes of climate forcing, scientific understanding of the complex underlying processes involved remains incomplete. Modelled climate forcing computations are consequently associated with high levels of uncertainty. The most recent comprehensive analysis of global aviation's contribution to climate forcing[6] [38], concludes that non-CO_2 factors produce a net positive (warming) impact that accounts for almost two-thirds of aviation's net climate forcing.

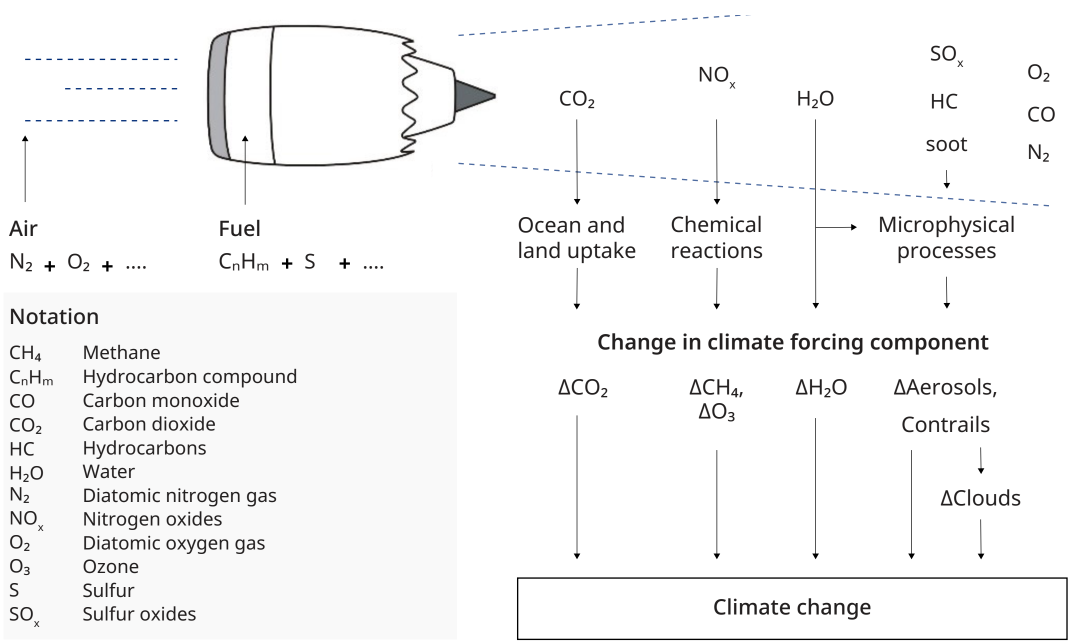
6 A climate forcing factor will change the Earth's climate system by altering the balance between incoming and outcoming energy.

Combating Non-CO_2 Impacts

Contrails form in cold ice-supersaturated air. Sometimes they dissipate quickly, but they can also persist and spread out to combine with naturally occurring cirrus clouds. Avoiding flights at altitudes or time of day associated with persistent contrail formation will reduce the climate forcing associated with air transportation.

Experimental research [39] [40] conducted recently by the DLR (German Aerospace Centre) and NASA into the combustion of SAF in atmospheric conditions known to produce contrails has yielded interesting results. SAF is a hydrocarbon fuel, similar to crude oil-based kerosene, but the two are not identical; when SAF is combusted in flight, it produces lower soot emissions and alters contrail properties. Experimental results indicate that burning low aromatic[7] SAF (e.g., HEFA) "can result in a 50% to 70% reduction in soot and ice number concentrations and an increase in ice crystal size. Reduced contrail ice numbers cause less energy deposition in the atmosphere and less warming" [39]. This benefit is slightly reduced in a complete climate forcing assessment, as soot and other emitted particles reflect incoming solar radiation, which has a planetary cooling effect. Nonetheless, the widespread adoption of SAF could yield meaningful reductions in aviation's non-CO_2 climate impacts [39]. Addressing soot and other particle emissions will only mitigate a portion of the non-CO_2 challenge however. More cross industry research is required to fully understand and address the challenges of non-CO_2 emissions.

Exhibit 15: Schematic representation of principal aircraft emissions and their causal linkages to climate change [41]



Source: Professor Trevor Young, University of Limerick

7 Aromatics, which are a base component of fuels derived from crude oil, are comparatively heavy hydrocarbon molecules, which produce soot when combusted.

Section 10

SOCIAL CONSIDERATIONS

In addition to considerations directly related to the environment, organisational decisions need to appropriately consider contributions to building safe, inclusive, and empowered communities as part of their social responsibility.

Air transport is a global connector that facilitates GDP growth and globalisation. It is a significant contributor to global economic and social development. It enables the flow of goods and services to support international trade, and the movement of people to support global mobility.

According to IATA, in 2019, the worldwide airline industry moved 4.5 billion people on scheduled services and contributed 1% to global GDP, with 2.9 million people employed directly by airlines around the world and a further 87.3 million jobs supported directly and indirectly by the air transport sector [42].

Air transport also plays a vital role in facilitating the reduction of both local and global inequality. Locally, air transport enables efficient connectivity to remote areas suffering from physical geographical barriers to transport or underdeveloped surface transport infrastructure. Air transport enables essential medical and other services or supplies to be accessed in remote areas. At a global level, air transport enables developing nations to access markets for goods and services, thereby accelerating development of these poorer regions.

Demand for air transport is continuing to rise as GDP increases and global middle classes expand. Conversely, increasing GHG emissions and associated climate change disproportionately impacts developing countries. So, as investments in carbon-reducing initiatives and technologies accelerate, it is important to recognise that developing countries with historically low carbon emissions and that are most at risk from the impacts of climate change will require additional finance to enable investment in reducing carbon emissions. At COP26, $413 million was committed to the Least Developed Countries Fund (LDCF) by donor governments [43] [44].

As an industry, there are many ways in which aviation can further contribute to the social aspects of sustainable development. Indeed, ATAG has indicated that the global air transport industry can support 15 out of the 17 UN Sustainable Development Goals [45]. Those particularly relevant to the global aviation industry as presented by ATAG include:

- Gender equality
- Affordable and clean energy
- Decent work and economic growth
- Industry, innovation, and infrastructure
- Reduced societal inequalities
- Responsible consumption and production
- Climate action

Increasing female participation has been challenging in the aviation industry. Airlines continue to have one of the poorest gender balances of all industries with IATA estimating that women globally only represent c. 5% of the global pilot population and c. 3% of airline CEOs. In 2019, IATA launched its gender diversity initiative 25by2025, a voluntary programme to improve female representation at senior levels to 25% [46]. The campaign is an initial step towards achieving greater gender balance in the aviation industry. The initiative now has 86 signatories across airlines, OEMs, and associated companies. While it is too early to produce data to measure the success of the programme, it has created momentum amongst member organisations to implement programmes that will drive change.

Gender participation in the aviation industry, including aircraft leasing, is measured annually in a survey carried out by Mason Hayes & Curran [47]. In 2020, the survey found that there had been an increase to greater than 30% in the number of females in senior management roles. Diversity is still lacking at board level, however.

But the industry does recognise the need for change and 47% of those surveyed reported that their organisation had a Diversity & Inclusion Committee. A number of different organisations including Women in Aviation International (WAI), Advancing Women in Aviation Roundtable (AWAR) and PropelHer have been established to create awareness of the challenges that face women wishing to progress to senior levels. In addition, ALI has made equality, diversity and inclusion (EDI) a priority issue.

Aircraft noise exposure also is a significant social consideration, as has been the case for the past 50 years. Although modern aircraft are much quieter today than their predecessors, the continuing increase in commercial air traffic means that noise is still a major societal concern, one that warrants further research and innovation to reduce its impact.

As the development of AAM vehicles, such as drones and air taxi's, has recently seen rapid growth, these new commercial operations are expected to become commonplace in many cities around the world in the coming years. Consequently, AAM vehicles may impact areas not previously exposed to aircraft noise. Societal acceptance of this noise source is considered critical to the successful integration of this new mode into the air transport system [48].

The leasing sector can make significant contributions to the local community and society in general. A recent positive example of this is the provision of €1M in funding, via ALI, to COVID-19 related initiatives in Ireland during 2020. In addition to the provision of funding, the support included the facilitation of three charter flights to transport PPE for healthcare workers, demonstrating how the industry can use its position of influence in the sector to deliver meaningful benefits for our community.

Section 11

GOVERNANCE CONSIDERATIONS

ESG reporting and financial reporting related to ESG is becoming increasingly important, with frameworks such as TCFD being required to gain access to sustainability linked funding. Investors are increasingly looking for responsible policies and governance within these reports to demonstrate and track positive progress. This governance allows companies to take actions that support sustainable outcomes while engaging communities and building coalitions and partnerships.

Within aviation, the development of sustainable coalitions such as the ICAO Global Coalition for Sustainable Aviation, Aviation Climate Taskforce (ACT), and ATAG (Air Transport Action Group) as well as initiatives driven by global bodies such as IATA, are pushing ownership and awareness of these issues to a position where companies have little choice but to act.

However, while actions within the aviation sector are becoming more coordinated, other industries have developed strong governance playbooks that are worthy of attention. Good examples exist in industries where the development of charters and governance frameworks have been successful. These charters benchmark responsible sustainability actions in a broad sense and provide guidance to signatories on such actions.

One example of this is the Poseidon Principles framework for responsible investment by financial institutions in the global shipping and maritime industry. Signatories include lenders, lessors, and financial guarantors. By assessing and annually reporting the climate alignment of ship finance portfolios, the signatories are encouraged to ensure their portfolios conform with the responsible environmental behaviours outlined in the framework. This in turn incentivises the decarbonisation of the shipping sector. At time of writing, 28 institutions representing nearly 50% of the global ship finance market had signed up to the framework.

There is an opportunity for ALI to develop a governance framework that will lead to actions and commitments on the part of its members and the broader supply chain that will ensure a more sustainable future for aviation.

One specific action that can be taken is to develop and implement an Aircraft Leasing Charter, as discussed in Section 12. The objective of this Charter would be to establish a framework for assessing and disclosing sustainability alignment for leasing portfolio and provide actionable guidance on how to achieve GHG reduction ambitions.

Section 12

AIRCRAFT LEASING IRELAND'S ACTIONS FOR THE ENVIRONMENT

ALI commits to be the world's leading aircraft lessor organisation on sustainability and to work to enhance and support the Fly Net Zero commitment from airlines to achieve net zero carbon by 2050 (IATA AGM Oct-21 [14]). ALI and its members are committed to driving sustainability across the entire aircraft lifecycle. Action areas for ALI include:

- Sustainability is a prerequisite for the continued long-term growth and success of the sector. ALI's members are committed to developing a charter during 2022, which based upon aviation's pathway to net zero in 2050, will cover the entire spectrum of ESG, including demonstration of leadership in carbon disclosures and accelerating progress in future aircraft and low carbon technologies
- To work in a proactive manner with the EU during the development of the upcoming Taxonomy for Aviation. ALI views this taxonomy as critically important for capital providers investing in the "hard to abate" aviation industry
- To establish a sustainability committee, where the scope includes sharing best practices among members with respect to sustainability, and to establish an ALI Sustainability Award to promote the sustainability agenda within its membership
- To commit to inaugurating an Aviation Sustainability Day in Ireland during 2022, inviting relevant stakeholders to further discussion and progress towards net zero by 2050
- To work actively with the University of Limerick with respect to leadership of sustainability initiatives and to expand involvement with other Irish universities in a collaborative effort to drive sustainability via curriculum development and the continued evolution of thought leadership
- To actively encourage its members to act on the environment today, ranging from arrangements to ensure that employees choose travel service providers based on sustainability credentials, steering investments towards aircraft with low energy intensity, expanding the recycling of aircraft, and growing members' value chain to encompass sustainable investments including SAF and electric or hydrogen-based propulsion projects
- To take an active role in international talks on aviation sustainability and to seek to foster partnerships with other relevant stakeholders in the sector
- To encourage and assist members to use their position of influence with their airline customer base to promote awareness and action around sustainability leading to a lower carbon aviation industry
- As buyers of more than [50%] of the world's new aircraft, to represent, encourage and assist members to use their very significant buying power and influence with original equipment manufacturers (OEMs), to demand an aggressive step change and acceleration in technology development, to ensure that the industry can achieve Net Zero by 2050

Aircraft Leasing Ireland will through its actions manifest its determination to be a driving force in the improved sustainability performance of the global aviation industry.

REFERENCES

1	World Economic Forum, "The Global Risks Report 2021, 16th Edition," World Economic Forum, 2021.
2	Principles for Responsible Investment, "PRI | Climate Change," Principles for Responsible Investment, 2021. [Online]. Available: www.unpri.org/sustainability-issues/climate-change.
3	Task Force on Climate-related Financial Disclosures, "Task Force on Climate-related Financial Disclosures 2021 Status Report," 2021.
4	KPMG Sustainable Futures, "Ready for the change? An Analysis of Irish Companies ESG Reporting Readiness," KPMG's Creative Services, 2021.
5	Glasgow Financial Alliance for Net Zero, "The Glasgow Financial Alliance for Net Zero Our progress and plan towards a net-zero global economy," 2021.
6	RMI, "Sustainable Aviation Buyers Allowance," RMI, 2021. [Online]. Available: https:rmi.org/saba/.
7	Aviation Climate Taskforce, "Accelerating breakthroughs in emerging technology to decarbonize aviation," Aviation Climate Taskforce, 2021. [Online]. Available: https:aviationclimatetaskforce.com/.
8	World Economic Forum, "Clean Skies for Tomorrow Sustainable Aviation — Fuels as a Pathway to Net-Zero Aviation," 2020.
9	Poseidon Principles for Financial Institutions, "A global framework for responsible ship finance," 2021. [Online]. Available: https:www.poseidonprinciples.org/.
10	United Nations, "The 17 Goals," United Nations Department of Economic and Social Affairs Sustainable Development, 2021. [Online]. Available: https:sdgs.un.org/goals.
11	United Nations Framework Convention on Climate Change (UNFCCC), The Paris Agreement, 2016.
12	IPCC, "Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change," Cambridge University Press. In Press., [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)], 2021.
13	United Nations Climate Change, "UN Climate Change Conference UK 2021 in Partnership with Italy — COP26 Goals," 2021. [Online]. Available: https:ukcop26.org/cop26-goals/.
14	IATA, "Resolution on the Industry's Commitment to Reach Net Zero Carbon Emissions by 2050," IATA, 2021.
15	Air Transport Action Group, "Waypoint 2050," 2nd Edition, 2021.
16	B. Graver, D. Rutherford and S. Zheng, "CO_2 Emissions from Commercial Aviation — 2013, 2018 and 2019," International Council on Clean Transportation, Washington, DC, 2020.
17	"Air Transport Action Group Global Fact Sheet," September 2020. [Online]. Available: https:www.atag.org/component/attachments/attachments.html?id=933.
18	International Air Transport Association (IATA), "20 Year Passenger Forecast," IATA, 2021. [Online]. Available: https:www.iata.org/pax-forecast/.
19	Oliver Wyman, "Global Fleet and MRO Market Forecast," 2021.
20	IATA, "Aircraft Technology Roadmap to 2050," 2019.
21	IATA, "Net-Zero Carbon Emissions by 2050," Press Release No: 66, 4 October 2021. [Online]. Available: https:www.iata.org/en/pressroom/2021-releases/2021-10-04-03/.
22	X. S. Zheng and D. Rutherford, "Fuel burn of new commercial jet aircraft: 1960 to 2019," Washington, DC: The International Council on Clean Transportation, Sept. 2020.
23	ICAO, "Environmental report 2016: Aviation and climate change," Montréal, Canada: Environment Branch, International Civil Aviation Organization, 2016.
24	Royal Netherlands Aerospace Centre, SEO Amsterdam Economics, "Destination 2050 — A route to net zero European aviation," Amsterdam, The Netherlands, 2021.
25	Airbus, "fello'fly Wake-energy retrieval to boost environmental performance," 2021. [Online]. Available: https:www.airbus.com/en/innovation/disruptive-concepts/biomimicry/fellofly.

26	Boeing, "Sustainability and Innovation for the Future — Introducing the Boeing ecoDemonstrator Program," 2021. [Online]. Available: https:www.boeing.com/principles/environment/ecodemonstrator.
27	Eurocontrol, "A-CDM Airport Collaborative Decision-Making," 2021. [Online]. Available: https:www.eurocontrol.int/concept/airport-collaborative-decision-making.
28	ASTM Standards, Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons, ASTM D7566-21, 2021.
29	Clean Energy Institute, "Lithium-ion battery," University of Washington, 2021. [Online]. Available: https:www.cei.washington.edu/education/science-of-solar/battery-technology/.
30	K. Thole, W. J. Whitlow, M. Benzakein et al., Commercial aircraft propulsion and energy systems research: Reducing global carbon emissions, Washington, DC: The National Academies Press, 2016.
31	B. Brelje and J. Martins, "Electric, hybrid, and turboelectric fixed-wing aircraft: A review of concepts, models, and design approaches," Progress in Aerospace Sciences, vol. 104, pp. 1-19, 2019. DOI: 10.1016/j.paerosci.2018.06.004.
32	M. Moore and B. Fredericks, "Misconceptions of electric propulsion aircraft and the emergent aviation markets," in AIAA SciTech: 52nd Aerospace Sciences Meeting, National Harbor, MD, 2014.
33	A. Ang, A. Rao, T. Kanakis and W. Lammen, "Performance analysis of an electrically assisted propulsion system for a short-range civil aircraft," Proc IMechE Part G: J Aerospace Engineering, vol. 233, no. 4, p. 1490 — 1502, 2019. DOI: 10.1177/0954410017754146.
34	A. G. Rao, F. Yin and J. van Buijtenen, "A hybrid engine concept for multi-fuel blended wing body," Aircraft Engin. and Aeros. Techn., vol. 86, no. 6, p. 483 — 493, 2014.
35	A. G. Rao, F. Yin and H. G. Werij, "Energy transition in aviation: The role of cryogenic fuels," Aerospace, vol. 7, no. 181, 2020. DOI: 10.3390/aerospace7120181.
36	International Air Transport Association, "Best Industry Practices for Aircraft Decommissioning (BIPAD) 1st Edition," Montreal — Geneva, 2018.
37	E. Grey, "Aircraft recycling: up to the challenge," Airport Technology, 17 April 2020. [Online]. Available: https:www.airport-technology.com/features/featureaircraft-recycling-up-to-the-challenge-5710942.
38	D. Lee, D. Fahey, A. Skowron et al., "The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018," Atmospheric Environment, no. 244, pp. 1-29, 2021. DOI: 10.1016/j.atmosenv.2020.117834.
39	C. Voigt, J. Kleine, D. Sauer et al., "Cleaner burning aviation fuels can reduce contrail cloudiness," Commun. Earth Environ., vol. 2, no. 114, 2021. DOI: 10.1038/s43247-021-00174-y.
40	T. Bräuer, C. Voigt, D. Sauer et al., "Reduced ice number concentrations in contrails from low-aromatic biofuel blends," Atmos. Chem. Phys., vol. 21, 2021. DOI: 10.5194/acp-21-16817-2021.
41	T. Young, Performance of the jet transport airplane: Analysis methods, flight operations, and regulations, Hoboken, NJ: Wiley, 2018.
42	International Air Transport Association, "Economic Performance of the Airline Industry — End-year Report," IATA Economics, 2021.
43	UNFCCC, "US$ 413 Million Pledged for Most Vulnerable Countries at COP26," 2021. [Online]. Available: https:unfccc.int/news/us-413-million-pledged-for-most-vulnerable-countries-at-cop26.
44	GEF, "Least Developed Countries Fund — LDCF," 2021. [Online]. Available: https:www.thegef.org/what-we-do/topics/least-developed-countries-fund-ldcf.
45	Air Transport Action Group, "Flying in Formation — Air Transport and the Sustainable Development Goals," Aviation Benefits Beyond Borders, 2017.
46	"IATA Future of Airlines 25 by 2025," [Online]. Available: https:www.iata.org/en/policy/future-of-airlines-2035/25-by-2025/.
47	Mason Hayes and Curran, "5th Annual Gender Diversity in Aviation Survey," Dublin, Ireland, 2021.
48	S. Rizzi, D. Huff, D. J. Boyd et al., Urban air mobility noise: Current practice, gaps, and recommendations, VA: NASA/TP-2020-5007433, Langley Research Center, 2020.

ABBREVIATIONS AND ACRONYMS

AAM	Advanced Air Mobility
ACDM	Airport Collaborative Decision Making
ACT	Aviation Climate Taskforce
ADS-B	Automatic Dependent Surveillance-Broadcast
ALI	Aircraft Leasing Ireland
ANSP	Air Navigation Service Provider
ASTM	American Society of Testing and Materials
ATAG	Air Transport Action Group
ATC	Air Traffic Control
AtJ	Alcohol to Jet
ATM	Air Traffic Management
BWB	Blended Wing Body
CCOs	Continuous Climb Operations
CDOs	Continuous Descent Operations
COP26	Conference of the Parties — 26th United Nations Climate Change Conference, November 2021
DAC	Direct Air Capture
DEP	Distributed Electric Propulsion
DLR	German Aerospace Centre
EAPS	Electrically Assisted Propulsion Systems
ESG	Environmental, Social and Governance
FT	Fischer-Tropsch
GDP	Gross Domestic Product
GFANZ	Glasgow Financial Alliance for Net Zero
GHG	Greenhouse Gas
GTF	Geared Turbofan
HEFA	Hydroprocessed Esters and Fatty Acids
IATA	International Air Transport Association
IATA AGM	IATA Annual General Meeting
ICAO	International Civil Aviation Organization
ICCT	International Council on Clean Transportation
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LDCF	Least Developed Countries Fund
NASA	National Aeronautics and Space Administration (US)
OEM	Original Equipment Manufacturer
PBN	Performance-Based Navigation
PPE	Personal Protective Equipment
PS	Point Source Capture
PtL	Power to Liquid
RNAV	Area Navigation
RNP	Required Navigation Performance

RPK	Revenue-Passenger-Kilometre
RTK	Revenue-Tonne-Kilometre
SABA	Sustainable Aviation Buyers Alliance
SAF	Sustainable Aviation Fuel
SED	Specific Energy Density
SID	Standard Instrument Departure
TBO	Trajectory-Based Operations
TCFD	Task Force on Climate-Related Financial Disclosures
TRL	Technology Readiness Level
UN	United Nations
USM	Used Serviceable Material
VED	Volumetric Energy Density
WEF	World Economic Forum

CONTRIBUTORS

Arvind Gangoli Rao

Associate Professor, Faculty of Aerospace Engineering,
Delft University of Technology, The Netherlands

James Davis

Partner, Oliver Wyman, London

Michael Dowling

Chief Risk Officer, DAE Capital, Dublin

Robert Downes

SVP, Head of Aircraft Trading;
Managing Director, ACG Ireland

Trevor Young

Associate Professor Aircraft Design
School of Engineering, University of Limerick, Ireland

David Knipe

Partner, Oliver Wyman, London

Jan Melgaard

Executive Chairman, FPG Amentum Limited, Dublin

Robbie Bourke

Partner, Oliver Wyman, London

Shane O'Reilly

Director, KPMG Sustainable Futures, Dublin