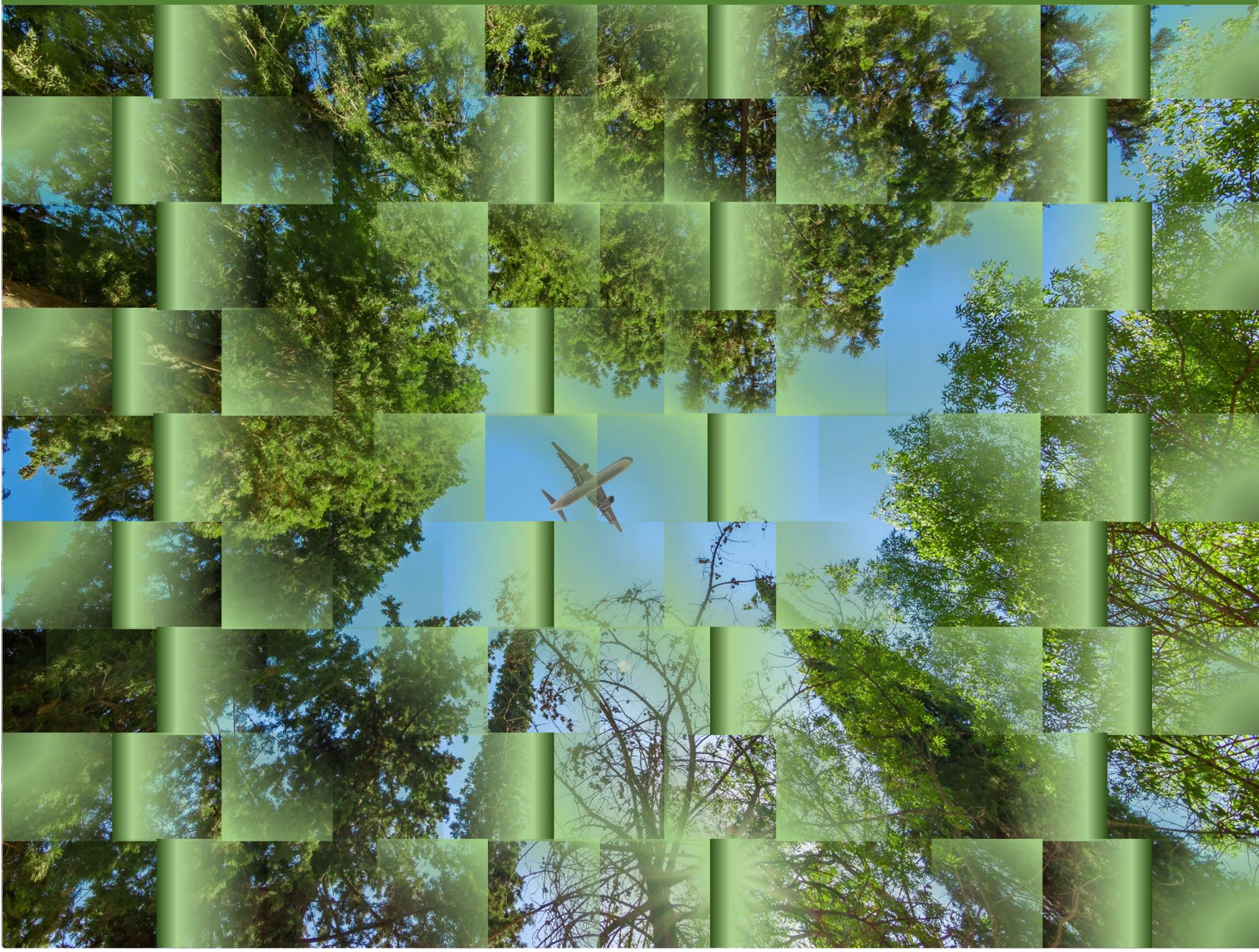
green & sustainable connectivity

GREEN AND SUSTAINABLE CONNECTIVITY



ERA's first sustainability report

european regions airline association

ERA's airline members

ERA (European Regions Airline Association) is the trade association representing more than 60 European airlines and 150 associate members, including manufacturers, airports, suppliers and aviation service providers, across the entire spectrum of the aviation industry. The power of one collective voice, representing multiple businesses, to promote and protect one industry sector is incredibly strong.

ERA works on behalf of its members to represent their interests before Europe's major regulatory bodies, governments and legislators to encourage and develop long-term and sustainable growth for the sector and industry. The association also brings members together to exchange information and learn from each other through events, groups, meetings and forums. A major part of ERA's role is to raise the profile and importance of its members, to champion green and sustainable air connectivity and European air transport.

64 airlines **13 manufacturers** **18 airports** **68 suppliers** **50 aviation services**

COVID-19 disclaimer: The research for this report was gathered prior to the COVID-19 crisis. Therefore, please note, some information regarding technology and the activities of ERA's members may now be outdated and do not reflect current affairs. To find out more about the impact of the COVID-19 crisis on the industry, please click [here](). An updated version of this report will be prepared once the industry moves towards recovery.

For any comments or questions, please contact martina.dipalma@eraa.org

Contents

Glossary

Phrase in full	**Acronym**
Air Transport Action Group	ATAG
Carbon Offsetting and Reduction Scheme for International Aviation	CORSIA
Continuous Climb Operations	CCO
Continuous Descent Operations	CDO
Electronic flight bag	EFB
European Emission Trading Scheme	EU ETS
European Free Trade Association	EFTA
European Union Aviation Safety Agency	EASA
European Union member states (including the UK)	EU28
Federal Aviation Authority (US)	FAA
Greenhouse gas	GHG
Million tonnes	MT
Original equipment manufacturer	OEM
Public service obligation	PSO
Research and development	R&D
Sustainable aviation fuel	SAF

1. Executive summary

This report outlines ERA members' initiatives in the fight against climate change. Green issues are at the top of the agenda for our members and in Europe with the publication of the European Commission's Green Deal in December 2019.

Flying should not be a simple binary choice to fly or not to fly, it is about sustainable flying. The industry takes its responsibility towards sustainable aviation seriously and is working to minimise its impact on the environment as much as possible whilst continuing to deliver essential connectivity and travel opportunities to millions of people across the globe. The aviation sector is approaching the challenge of achieving its climate goals through a multi-pillar strategy: developing new technology, transitioning to sustainable aviation fuels (SAFs), moving to more efficient operations and better use of infrastructure, including defragmentation. ERA is committed to promoting the work and initiatives being carried out to reduce the environmental footprint, as well as challenging governments on their intentions to impose further taxes on aviation and encouraging them to invest in innovation and research.

This Green and Sustainable Connectivity Report, therefore, outlines the work undertaken by regional aviation stakeholders, particularly our airlines, in order to tackle environmental concerns. The regional market presents a different type of demand and services that render regional airlines unique and essential in some regions, for example, where there is no alternative to flying. ERA's airline members provide vital connectivity and support for Europe's regions, promoting social and territorial equality and cohesion as well as contributing to increased tourism and investment. All of this leads to positive social impacts as it facilitates European integration and contributes to sustainable development by providing essential transport links and job creation.

ERA airline members' emissions

This report puts into context ERA airline members' CO_2 emissions. According to EUROCONTROL data, in 2019 ERA airline members accounted for 13.3 million tonnes (Mt) of CO_2 emissions, representing 7.76 per cent of aviation emissions in the EU and 1.43 per cent of the EU's total transport emissions.[1]

Table 1. Global, European and global aviation emissions (2017)

Aviation	Global[2]	Europe[3]	ERA
CO_2 Mt in 2017	859	171[4]	12.7

ERA airline members' efforts to tackle their environmental footprint

As this report outlines the efforts of ERA airlines, we launched a survey in September 2019 which gave us a thorough overview of the emissions, sustainability initiatives and communication efforts of our airline members that helped us inform the paper. The actions already taken by ERA airline members to decarbonise and improve their environmental performance are as follows:

- aircraft weight reduction;
- fleet modernisation;
- use of turboprop aircraft;
- sustainable on-board products;
- waste management, separation of waste from source, reduction of plastic on board;
- introduction of biofuel (i.e. SAF);
- flight operations improvements;
- electronic flight bag (EFB) operations allowing flight decks to be paperless;
- background process optimisation, for example office printing;
- eco flight procedures;
- implementation of fuel management software;
- improved tankering;
- shortening routes;
- optimisation of flights (i.e. CCO/CDO); and
- planning introduction of electric engines.

More about individual ERA members' efforts can be found on page 21 onwards.

Technology review for the regional sector

In addition, a technology review has been undertaken in partnership with ERA member ZeroAvia. The review explores different decarbonisation technologies available for the aviation industry, such as SAFs, hybrid-electric aircraft, battery-electric aircraft and hydrogen electric aircraft. It particularly looks at the most cost-efficient option for the regional sector by focussing on less than 20-seat turboprops, 50–80-seat turboprops and 100–120-seat small, narrow-body regional jets. For the regional sector, electric or zero-emission aircraft have great revenue potential. Based on a survey carried out among ERA airline and manufacturer members, electrification of 20-seat aircraft is expected to be introduced by 2025, for 50–80 seats by 2030 and for 100-seat aircraft not before 2035. Given the nature of regional aviation, characterised by short-haul flights, there is a significant opportunity for ERA airline members to decarbonise with the introduction of new technology, as, apart from decarbonisation, they can also benefit from cost decrease. The regional sector lends itself to new, clean technologies and should, therefore, be the forerunner for testing and selecting the right technology needed to decarbonise the industry.

[1] Based on March 2020 data.
[2] IATA, Industry statistics, Fact sheet (2019).
[3] EASA, Emissions.
[4] 2016 value as latest available data.

2. Introduction

Today, climate change represents one of the biggest threats to the existence of the air transport industry. As it will negatively impact aviation demand patterns, its infrastructure and daily operations,[5] tackling the climate challenge also becomes a question of survival for the aviation sector, particularly for airlines as they are most visible to the consumer.

Moreover, we are experiencing a new political environment in which climate matters are on top of the agenda at both international and European levels. Indeed, governments and international organisations are increasingly encouraging policy measures to mitigate climate change. The ratification of the Paris Agreement in 2016 set new targets for the global community, including maintaining the global temperature increase to well below 2°C above pre-industrial levels and to pursue efforts to keep it below 1.5°C.[6] In 2019, the European Commission presented the European Green Deal, which set a new growth strategy for the European Union with the objective of becoming the first climate-neutral continent by 2050. To achieve such an objective, the European Union is calling on all sectors of the economy and transport modes to take action, and aviation is no exception.

This urgency for the aviation industry to take responsibility has also been increasing due to growing pressures from investors, environmental groups such as Extinction Rebellion and from many public movements arising in Europe, such as 'flygskam' (flight shaming), whereby people are pledging to give up flying and are turning towards other transport modes. Regional airlines are probably the most vulnerable to the increasing pressures from these anti-flying campaigns, despite emitting a small fraction of emissions (less than five per cent of global aviation's share[7]). This is because short-haul flights are easier to replace for the consumer. But shifting towards rail, for instance, is not necessarily the best solution – for many remote European regions, aviation is the only link to the mainland and replacing short-haul routes with trains may be quite carbon intensive if no infrastructure already exists.

We must not forget the socioeconomic benefits of the air transport sector, which are significant, such as ensuring regional connectivity and prosperity for the European regions. Despite these benefits, aviation contributes to the increase in emissions and is perceived as the most pollutant industry by the public.

The sector has always strived to become more sustainable and has made significant progress in mitigating its environmental impact. Airlines have been reducing overall fuel burn for cost reasons, leading also to a reduction of CO_2 emissions as they are directly linked to the fuel burnt. As such, today's aircraft are 80 per cent more fuel efficient than the first jets of 50 years ago[8] and one trip emits 50 per cent less than it would have in the 1990s. Aviation has also been the first industry to set ambitious, global targets for the future, achievable via a set of tools involving new technology deployment, air traffic management improvements and market base measures.

ERA recognises that climate change is a major concern for European citizens and that it must take real climate-preserving action. Contributing to 2–3 per cent of greenhouse gas (GHG) emissions, and with air traffic forecasted to grow in the next decades, the aviation industry is also responsible for its share and needs to ensure sustainable connectivity. The aviation sector, particularly regional aviation, has enormous potential to contribute to the mitigation of climate change. Characterised by short-haul flights, the regional sector lends itself to new and clean technologies and should be the forerunner for testing and selecting the right technology needed to decarbonise the industry.

Not flying is not an option for many people given the benefits that aviation brings, and passengers should not be faced with the dilemma 'to fly or not fly', we should rather strive to fly sustainably.

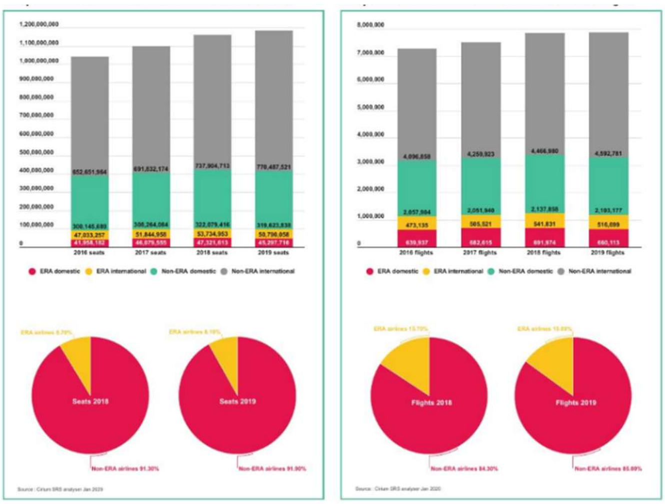
[5] EUROCONTROL, Challenges of Growth (2018).
[6] Paris Agreement (2016).
[7] International Council on Clean Transportation (ICCT), CO_2 emissions from commercial aviation (2018).
[8] Air Transport Action Group (ATAG), Facts and figures.

3. ERA members and the role of regional connectivity

The aviation sector contributes significantly to the European economy and to the competitiveness of the region. With approximately one billion passengers flying on over 8.544 million flights,[9] the European aviation market contributes €823bn to European economic activity – representing 3.3 per cent of all employment and 4.1 per cent of Europe's GDP.

ERA member airlines achieved a 15 per cent market share in 2019, down slightly from 15.7 per cent in 2018 with 56,995 fewer flights and a 4.6 per cent decrease for both domestic and international activity.

Figure 1. European domestic and international market share of seats and flights



Source: Cirium data, ERA Yearbook (2020).

The regional sector, therefore, represents a substantial component of European air transport contributing hugely to economic growth within Europe by:

- carrying 74 million passengers per year;
- operating 1.15 million flights;
- on 1,780 routes;
- supporting 770,000 direct, indirect and induced jobs (of which 290,000 are directly generated by our members); and
- contributing €59bn to Europe's GDP.

Figure 2. ERA contributions to European economy and growth

Table 2. Comparison of global, European and ERA statistics

	Global	European	ERA
Passengers	4.5bn in 2019	1bn	74m
Contribution to GDP	$2.7tr	$823bn	$59bn
Flights	41.9m	8.5m	1.15m per year
Jobs supported	65.5m jobs	12.2m	770,000

In particular, ERA's airlines provide vital connectivity and support for Europe's regions, promoting social and territorial equality and cohesion as well as contributing to increased tourism and investment. All this leads to positive social impacts by facilitating European integration and contributing to sustainable development by providing essential transport links and job creation.

Connecting people and regions

ERA members provide a niche service as they operate in the parts of Europe where air transport is both vital and often the only mode available to inhabitants in remote regions, islands and dispersed areas, such as in the Canary Islands and in the north of Norway. EU member states may award public service obligation (PSO) routes to maintain appropriate schedules for air services on routes which are vital for the economic development of the region they serve. They are crucial as they promote connectivity and ensure territorial cohesion, economic and social development in remote regions and islands on air routes that would otherwise not be economically viable under certain conditions.

This air connectivity allows passengers to travel for business or leisure and to visit friends and family, and many ERA airline members represent the only link to mainland Europe. Given that regional airlines generally have smaller-capacity aircraft, passengers can fly to smaller cities and to main hubs via more direct, point-to-point routes enabling air connectivity and allowing smaller regions to compete within Europe and the rest of the world. Point-to-point routes also represent a more sustainable alternative compared to indirect flights with stopovers, as they result in fewer take offs and landings, which are quite carbon-intense phases of a flight.[10]

ERA's fleet

The fleet of ERA's member airlines is composed of a total of 887 aircraft,[11] the dominant type by market sector being regional turboprops, with 314 aircraft, closely followed by regional jets with 256 in service with member airlines. The most widely-used type is the ATR 72 which accounts for nearly 20 per cent of the entire fleet, closely followed by the DH8-400 with nearly 15 per cent. Regional jets are making inroads into the traditional turboprop market with four Embraer E195 E2s already in service and 53 on order or LOI. In addition, there are 15 Airbus A220-100s order or with LOIs.

[9] ATAG, Aviation Benefits Beyond Borders (2018).
[10] ATAG, Four ways to fly more sustainably (2018).
[11] ERA Yearbook (2020).

Modal shift

The flygskam movement is making people consider alternatives to air transport and rail is one of the most popular at the moment. There are discussions about creating more rail infrastructure, but it is important to bear in mind that rail might not always be the least carbon-intense option. If the rail infrastructure is already in place, you can decarbonise it through renewable energy. However, if more rail infrastructure needs to be built, this will not be the case. To create a huge rail network is will be carbon intensive and requires a lot of steel. In addition, many short-haul air routes cannot be replaced by rail either because of geographic challenges or because development of rail routes would present high costs on such low-frequency routes.[12]

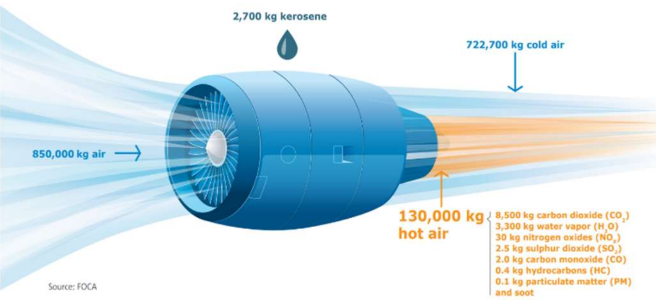
In certain cases, not flying is not an option. We need cleaner aircraft which will allow us to maintain connectivity and regional cohesion, whilst significantly reducing the industry's environmental footprint. Connectivity around Europe is incredibly important. Technology is the solution, not flying less. Regional connectivity is crucial, and it is therefore necessary to invest more in clean transport infrastructure to maintain these vital links.

4. Aviation's emissions in perspective

As outlined previously, environmental factors can play a crucial role in airlines' continued existence. As such, it is important to understand the current environmental impact of the aviation industry, as well as the sector's efforts in mitigating climate change.

Emissions from aircraft are produced from the fuel burned in aircraft engines and the main GHGs emitted by the sector are CO_2 and water vapour (H_2O).[13] As every kilogram of fuel burn produces 3.16kg of CO_2 emissions, CO_2 emissions from aircraft engines are directly related to the fuel efficiency of the aircraft.[14] In addition to CO_2 and water vapour, aviation also emits nitrogen oxides (NOx), methane (CH_4), hydrocarbons (HC), soot, particulate matter (PM) and sulphur oxides (SOx); however, the impact on the environment of these non-CO_2 emissions, as well as of contrails and induced cloud formation, is not fully understood and requires further analysis.[15]

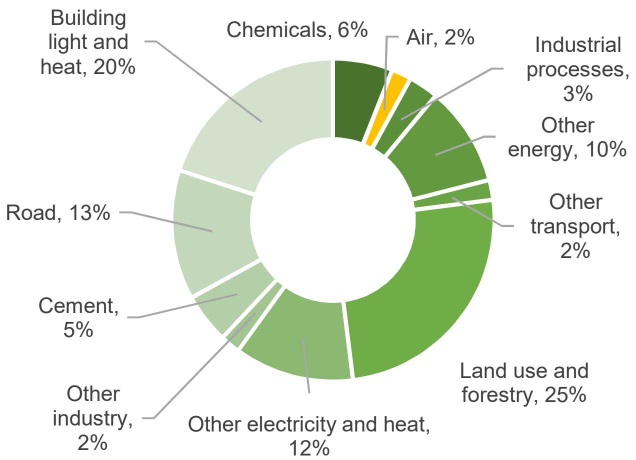
Figure 3. Emissions from a typical two-engine jet aircraft during a one-hour flight with 150 passengers



Source: FOCA.

Globally, aviation is currently responsible for 2–3 per cent of man-made GHG emissions, totalling 915Mt of CO_2 in 2019.[16] Of these, 80 per cent are emitted by international aviation or long-haul flights (over 1,500 km).[17] Out of all transport sources, aviation accounts for 13.4 per cent of CO_2 emissions, compared to 72 per cent from road transport.[18] Figure 4 shows the global breakdown of CO_2 emissions by sector.

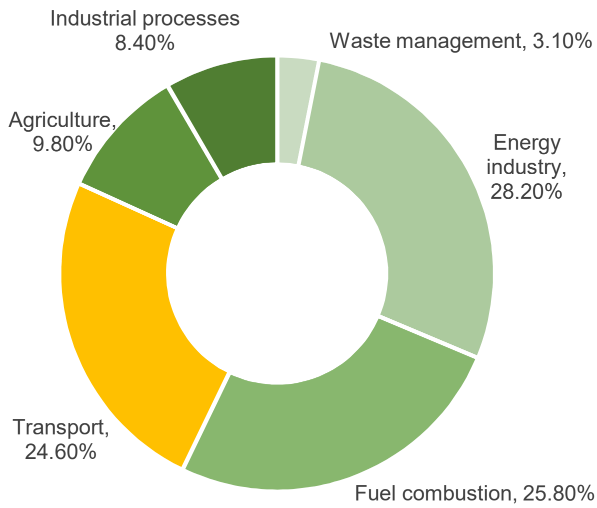
Figure 4. Comparison of GHG emission share by sector



Source: ATAG, 2017

At the European level, aviation accounted for 3.6 per cent of the total EU28 GHG emissions in 2016 and for 13.4 per cent of the emissions from EU transport.[19]

Figure 5: Share of EU GHG emissions by source

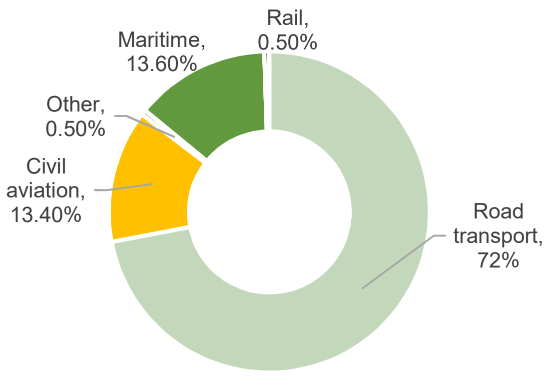


Source: EEA 2019.

[12] Transport & Environment (T&E), Roadmap to decarbonising European aviation (2018).
[13] Intergovernmental Panel on Climate Change (IPCC), Fourth Assessment Report (2004).
[14] European Aviation Safety Agency (EASA), European Aviation Environmental Report (2019).
[15] International Civil Aviation Organisation (ICAO), Introduction to the ICAO basket of measures; EASA, EAER (2019).

[16] International Air Transport Association (IATA), Airline industry economic performance December 2019.
[17] ATAG, Facts & Figures (2020).
[18] ATAG, Facts & Figures (2020).
[19] EASA, European Aviation Environmental report (2019).

Figure 6: Share of EU GHG emissions in transport



Source: EEA 2019

The European Aviation Environmental Report states that in Europe, CO_2 emissions rose by 16 per cent between 2005 and 2017, despite the 24 per cent reduction in fuel consumption per passenger due to new technology developments.[20] Between 2014 and 2017 the number of flights within the EU28 and European Free Trade Association (EU28+EFTA) have increased by eight per cent. Furthermore, forecasts show that the industry will increase its flights by 42 per cent within EU28+EFTA from 2017 to 2040 in the most likely forecast,[21] leading to a consequent increase of CO_2 emissions of at least 21 per cent. This growth will outpace any efficiency improvement achieved thus far via constant introduction of new technology, fleet renewal and operational efficacy.

4.1 ERA airline members' emissions data

According to EUROCONTROL data, in 2019 ERA airline members accounted for 13.3Mt of CO_2 emissions, representing 7.76 per cent of the aviation emissions in the EU and 1.43 per cent of the EU's total transport emissions.[22]

Figure 7. ERA airline member's emissions compared to aviation global and EU European (2017)

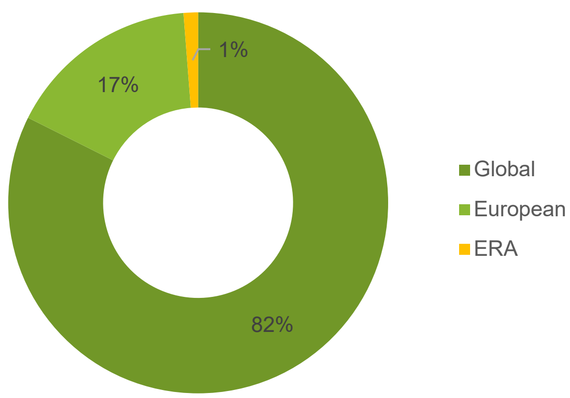


Table 3. Global, European and global aviation emissions (2017)

Aviation	Global[23]	Europe[24]	ERA
CO_2 Mt in 2017	859	171[25]	12.7

Between 2012 and 2017,[26] ERA airline members' CO_2 emissions have seen a growth of 17.1 per cent, totalling an increase of 1.9Mt CO_2. Whereas, between 2017 and 2019 the CO_2 emissions have increased by 4.3 per cent (from 12.7Mt CO_2 in 2017 and 13.3Mt CO_2 in 2019). Interestingly, this growth in CO_2 emissions is not due to an increase in total flights – in fact, total flights in 2019 compared to 2018 have decreased by 5,238. However, total distance flown has increased by 15.4 million km (1.41 per cent) in just one year. Furthermore, it is necessary to compare ERA airline members' emissions growth to the wider EU aviation's growth rate and the increase in all EU's sectors. Both ERA airline members and the EU aviation sector have increased their emissions by, respectively, 17.1 per cent and 9.6 per cent in the same five-year timeframe (see Table 4).

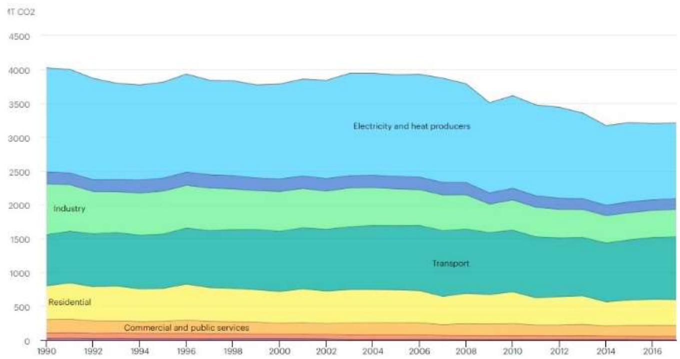
Table 4. EU CO_2 from combustion ($MtCO_2$)

	EU all sectors	EU aviation	ERA
2017	3,209	–	12.7
2016	3,201	171*	11.8
2015	3,216	163	11.4
2014	3,171	159	11.2
2013	3,356	157	10.9
2012	3,441	156	10.9

*latest data available

In contrast, we can see a significant decrease in total CO_2 emissions from all sectors of the EU economy of -6.7 per cent (circa 231Mt CO_2 mitigated). This is most likely due to the decarbonisation efforts of other sectors such as electricity and heat producers[27] (see Figure 8). It is important to bear in mind that aviation is a challenging sector to decarbonise, especially given the long lifespan of aircraft (circa 20–30 years) which slows down the deployment of newer and cleaner technology.

Figure 8. CO_2 emissions by sector, Europe 1990–2017 (IEA)



This trend is not visible at the global level; however, there has been an increase of total CO_2 emissions in all sectors by 3.3 per cent between 2012 and 2017, equivalent to 1.06 billion tonnes CO_2 (see Table 5).

Table 5. Global CO_2 from combustion (Mt CO_2)

	All sectors (global)	Aviation (global)
2017	32,840	859
2016	32,414	811
2015	32,431	770
2014	32,439	733
2013	32,363	710
2012	31,777	694

[20] EASA, European Aviation Environmental Report (2019).
[21] EASA, European Aviation Environmental Report (2019).
[22] Based on March 2020 data.
[23] IATA, Industry statistics, Fact sheet (2019).
[24] EASA, Emissions.
[25] 2016 value as latest available data.
[26] For consistency purposes, 2012 and 2017 chosen based on global and European latest available data.
[27] International Energy Agency (IEA), Data and statistics.

5. Industry targets and achievements in tackling aviation emissions

Along with other sectors, aviation is contributing to emission reductions at the international, European and regional level. In fact, aviation has been decarbonising since 1980, as emissions are a direct function of the amount of kerosene consumed – for an airline, improving overall fuel burn for cost reasons also reduces CO_2 emissions.[28]

The aviation sector has always been concerned about its environmental footprint and, in 2008, it was the first industry to set sector goals for CO_2 emission reductions globally.

These goals include:

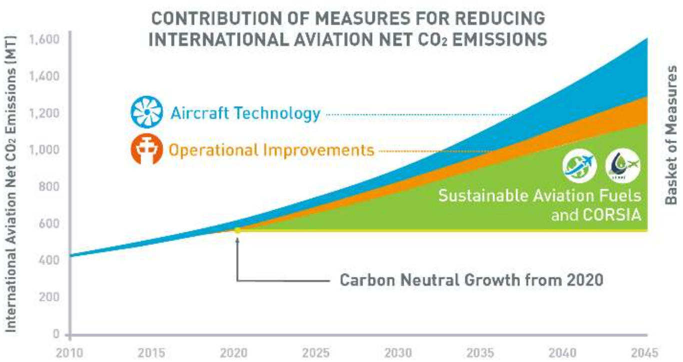
1. Improving fuel efficiency by an average of 1.5 per cent per annum between 2009 and 2020 (currently at 2.1 per cent annual average).
2. Stabilising net CO_2 emissions from 2020 through carbon-neutral growth.
3. Reducing net CO_2 emissions from aviation to half of 2005 levels by 2050.

Since setting these ambitious goals, the industry has continued to improve its environmental efficiency by reducing its average fuel burn by 24 per cent between 2005 and 2017[29] and each new generation of aircraft is on average 20 per cent more fuel efficient than the model it replaces.

To respond to public and political pressures and to achieve these efficiency improvements, the sector has been relying on a four-pillar approach as there is not just one solution to tackle the issue. It is rather a basket of measures that allows the sector and the different market segments within it, to use the most appropriate and feasible solution available to them to address the climate challenge. These measures include:

1. market-based measures;
2. technology improvement;
3. infrastructure and operations improvement; and
4. sustainable aviation fuel.

Figure 9. Contribution of measures for reducing international aviation net CO_2 emissions



Source: ICAO.

As an industry, we are certain that operations, infrastructure and technology measures will allow sustainable growth and provide long-term solutions. However, compared to other sectors of the economy, aviation faces huge challenges to decarbonise. This is mainly due to the relatively long lifespan of aircraft which can remain operational for 25 years, if not more.

For this reason, market-based measures still represent a crucial tool that will help filling the emissions gap in the short and mid-term. Offsetting and cap and trade systems allow the sector to address the gap by compensating the emissions from the industry through reductions that can be achieved more easily in other sectors.

In 2016, the 39th ICAO Assembly adopted the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) to address CO_2 emissions from international aviation. It is the first sector-specific global offsetting mechanism which will address any annual increase in CO_2 emissions of the industry above 2020 levels. It is expected that CORSIA could mitigate circa 2.5 billion tonnes of CO_2 and generate circa $40bn of climate financing by 2035.[30]

Even before CORSIA, the European aviation sector has been tackling its emissions via the European Emission Trading Scheme (EU ETS), applicable to intra-EEA flights. It has been estimated that the net reduction in aviation-related emissions from the EU ETS between the years 2013–2020 will be circa 193 million tonnes of CO_2.[31]

As for operational improvements, a substantial amount of fuel is wasted due to inefficient routing. Better flight routing could reduce inefficient aviation operations growth and cut consumption by 10 per cent according to the International Energy Agency (IEA).[32] Whereas, according to EUROCONTROL's Performance Review Report, the measures could lead to a six per cent emission reduction in Europe.[33] The introduction of free route airspace is estimated to have delivered 2.6 million tonnes of CO_2 emissions reductions since 2014 and the continuous climb and descent operation could reduce CO_2 emissions by 1.1 million tonnes per year.[34]

Technology options and SAFs are analysed in detail in the next section, with a specific focus on the regional sector and ERA members.

[28] Credit Suisse, Summer is coming: Assessing CO_2 emission risks in aviation (2019).
[29] EUROCONTROL, The aviation network – Decarbonisation issues, (2019).
[30] EUROCONTROL, The aviation network – Decarbonisation issues (2019).
[31] EUROCONTROL, The aviation network – Decarbonisation issues (2019).
[32] IEA, Tracking transport – Aviation (2019).
[33] EUROCONTROL, The aviation network – Decarbonisation issues (2019).
[34] EUROCONTROL, The aviation network – Decarbonisation issues (2019).

6. Overview of aviation decarbonisation technologies

Airlines of all sizes as well as aviation manufacturers are looking carefully at all avenues for reducing carbon emissions. Research into efficiency improvements and electric taxiing as well as implementing better air traffic management, for example, should be welcomed and encouraged.

It is important to recognise, however, that propulsion is the key area where innovation is required to truly enable low-carbon and even zero-emission flights.

This research conducted by ERA, in partnership with ZeroAvia, seeks to investigate the viability of decarbonisation technologies that target the propulsion systems of existing aircraft size categories.

As such, this section investigates the following different emissions-reducing propulsion technologies:

- SAFs – bio-based and power-based fuels;
- hybrid-electric aircraft (typically combining a conventional gas turbine with an electric system);
- battery-electric; and
- hydrogen-electric.[35]

The technology composition and time to market will vary greatly by type of aircraft. Therefore, the research focusses on the analysis of three different aircraft types:

- less than 20-seat turboprops;
- 50–80-seat turboprops; and
- small narrow-body regional jets, 100–120 seats.

Each technology will be described, including benefits, barriers to implementation, and the status quo. Then, a timeline to electrified aviation will be presented, followed by key stakeholders across propulsion decarbonisation.

6.1 Reimagining fuel for jet engine propulsion Sustainable aviation fuels

SAFs are a relatively established technology, ready to be used as drop-in replacement fuels for aviation. Given their considerable cost disadvantage in comparison to jet fuel and consumer uncertainty in relation to their environmental impact, questions on how to scale production, how much production will be needed, and who will pay for it, dominate the current discussions within the industry.

SAFs are artificially-produced hydrocarbon fuels from biomass (bio-based fuels) or from CO_2 and hydrogen (power-based fuels, often also called e-fuels, electro fuels), which are then blended with conventional jet fuel.

Bio-based fuels

We are perhaps most familiar with bio-based fuels thanks to the initial interest shown by the automotive industry and its desire to create liquid hydrocarbon fuels from non-fossil sources. Blending mandates have existed since the 2000s in that industry.[36]

However, there is an important distinction between first and second generation. First generation bio-based fuels are typically derived from food crops like rapeseed, palm oil or corn, whereas second-generation bio-based fuels (also known as advanced bio-based fuels) are derived from non-food-based biomass – typically waste-based resources like municipal waste or agroforestry residues.

Benefits

Bio-based fuels are available on the market as a certified drop-in fuel, blended with conventional jet fuel. There are currently six pathways for blending bio-based fuels with conventional aviation fuels that are certified by the American Society for Testing and Materials (ASTM) International, with the maximum blend allowed in these cases being 50 per cent.[37] There is also one more pathway certified for co-processing with fossil-based fuels. While trials have been underway to test 100 per cent bio-based fuels as a fuel source, appetite is muted by existing limits on production of biofuel and the fact that the fuel systems of older aircraft cannot handle the high purity of bio-based fuels.

However, even at a 50 per cent maximum blend, SAFs are crucial as they allow both existing fuel distribution infrastructure and existing propulsion technologies to be used, minimising the capital expenditure required by the industry.

Furthermore, SAFs offer the potential to contribute to a net-zero aviation industry given that lifecycle assessments have shown a possible 80 per cent CO_2 emission reduction from their use. According to SkyNRG, SAFs can improve fuel efficiency by 1–3 per cent, as well as offering a 90 per cent reduction of sulphur oxide and particulate matter emissions,[38] leading to a lower formation of contrails. Another environmental advantage of bio-based fuels is the ability to design the composition of the fuel in the production process, so that turbines could reach higher efficiencies once optimised to the use of designer fuels.

Barriers to implementation

The first barrier is that there is no single, internationally-accepted way of defining SAFs. In 2016, the EU produced a report examining the certification system for bio-based fuels, remarking that "a large volume of biofuel is certified by voluntary schemes" and that the Commission's framework for deciding which voluntary schemes to recognise as sustainable did not include some important sustainability aspects.[39] While the certification pathways are now very clear, industry players will need to decide which bio-based sources are deemed most acceptable to consumers.

Another significant possible barrier in the future will be competition for resources, given that for many industries, advanced bio-based fuels will be the easiest and cheapest decarbonisation solution. Questions have been raised as to

[35] The study will not look at the use of hydrogen as a fuel in gas turbines.
[36] For example EU L123 in 2003.
[37] EASA website.
[38] The Energy Transition, Can flying be made carbon neutral? (2020).
[39] The European Court of Auditors (ECA), The EU system for the certification of sustainable biofuels (2016).

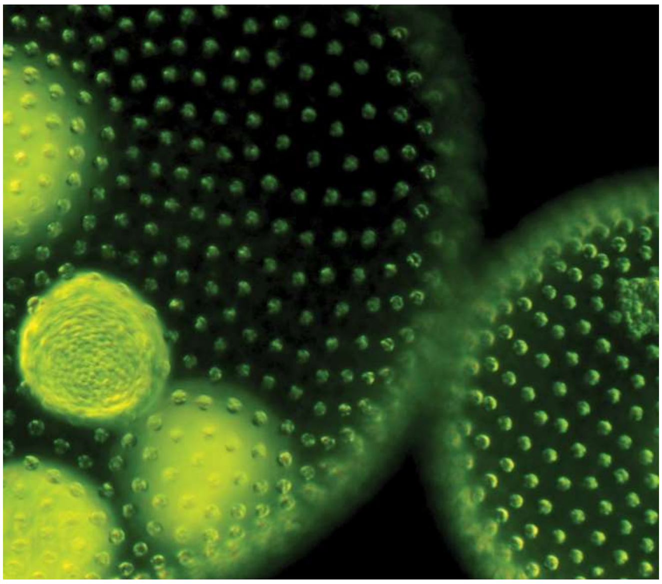
whether second generation bio-based fuels are practical given doubts that sufficient waste-based resources exist to supply the necessary production. However, research has shown that EU member states are likely to have more than enough sustainably available feedstock to meet the advanced biofuel requirement overall, and a majority may have more than 10 times the necessary amount.[40]

In addition, costs are likely to be prohibitive for commercial uptake. The cost of bio-based fuels is estimated as being 3–10 times that of fossil jet fuel according to industry sources.[41] While advanced bio-based fuels may be subject to less price volatility than conventional jet fuel, there is also limited potential for prices to fall significantly as feedstock costs are unlikely to go down with an already efficient process of production. This, of course, raises the question of who should pay the increase in fuel costs with regional airline operators unable to squeeze already tough operating costs and consumers unlikely to want to pay significant additional sums for flights (the level at which budget airlines set their carbon offset fees could be a guide to consumer willingness to pay).

Status quo

Today's production capacity is sufficient for 0.1 per cent of worldwide jet fuel demand. By 2025, capacity could grow to 3.5–6.3 billion litres of jet fuel, which would represent up to one to two per cent of global jet fuel consumption.[42] Therefore, it will most likely be difficult for airlines to drastically increase their use of bio-based fuels over the coming decade.

Governments have, however, shown willingness to back the development of the technology, with Norway mandating targets for blending conventional fuel with SAF for all international and domestic flights (requiring 0.5 per cent this year, with a plan to progressively raise this to 30 per cent by 2030). Several other countries in the EU are following and discussing a unilateral implementation of a SAF blending mandate. In addition to that, all major aviation decarbonisation roadmaps (ATAG, Airlines UK, Delta Airlines) overlap in their assumption that SAFs will contribute significantly to their emissions reduction.



Power-based fuels

Power-based fuels are liquid hydrocarbons created from hydrogen and CO_2. The CO_2 can either be captured from point emissions, for example, from large factories or from direct air capture. Hydrogen should be produced from renewably-powered electrolysis for minimal emissions.

Benefits

There are a number of potential benefits of using power-based fuels as aviation fuel. Firstly, power-based fuels have a theoretically unlimited supply and are thus seen as an important source for meeting fuel demand caused by growing aviation passenger numbers.[43] Proponents of power-based fuels also claim that they need less land area for the same fuel output than bio-based fuels.

Power-based fuels are also, in theory, less subject to price fluctuations than conventional jet fuels. The only major dependency in production is electricity cost, which tends to be fixed for around 30 years in modern power purchase agreements. This provides much higher levels of planning stability for airlines.

Barriers to implementation

One major challenge is the increased costs, with power-based fuels estimated to cost at least twice as much as conventional jet fuel, even at a scaled-up production facility.[44] On the road to these costs, initial production facilities will showcase significantly higher costs, as the economies of scale and learning curves have not yet been established for power-based fuels. Riding down these curves for both hydrogen production and CO_2 capture will prove a key challenge. Of course, if the demand for these fuels does not materialise as predicted, the cost evolution will be much slower.

Furthermore, in spite of first production dating back to the 1960s, the industry for power-based fuel production is still not highly developed and there are, therefore, no at-scale cost verifications. To date, there are only a handful of companies using the greenest form of power-based fuel production through direct air capture. Some have shown promise, including Carbon Engineering – a Canadian company that has managed to get the cost of capturing a tonne of CO_2 down from $600 in 2011 down to as low as $94.[45] This is significantly higher than CO_2 prices in the market today, for example the ETS, which slows the application of this technology significantly.

Therein lies the major challenge from a sustainability perspective. The promise of direct air capture does offer carbon reduction through the production of ultra-low carbon fuels, thanks to low emissions and the removal from the atmosphere of some CO_2. However, it depends upon the use of clean electricity for both the extraction of CO_2 and the generation of hydrogen through electrolysis.

Status quo

Today's production capacity is non-existent in terms of commercial scale. Pilot operations are underway at numerous companies, including Carbon Engineering in Canada as described above, and also at Swiss firm Climeworks and US firm Global Thermostat.

While the leaders of larger aviation players, for example Lufthansa's CEO Carsten Spohr,[46] have lauded power-based fuels as a key decarbonisation solution, the timeline for realistic production at scale is unclear. Debate is also raging about the cost decrease that synthetic fuels can realistically achieve, for example, with opinion diverging significantly between analysts in the UK and Germany.

[40] S. Searle and C.J. Malins, Waste and residue availability for advanced biofuel production in EU Memebr States (2016).
[41] ICCT.
[42] ICAO, First ICAO Stocktaking Seminar toward the 2050 Vision for Sustainable Aviation Fuels (2019).
[43] T. Takeshita, Important roles of Fischer-Tropsh synfuels in the global energy future (2008).
[44] Carbon Engineering quote, provider of power-based fuel production facilities.
[45] Vox, Sucking carbon out of the air won't solve climate change (2018).
[46] At IATA Wings of Change Conference in Berlin (2019).

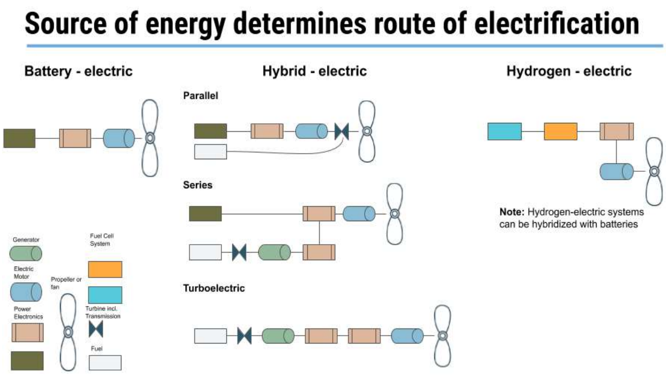
6.2 Electrification

Until recently, SAFs and efficiency improvements were the only supply-side emission reduction levers viewed as realistic by the industry.

The situation has evolved rapidly. The electric transport revolution that is burgeoning in road vehicles has swept over to aviation. Improved power density of components, as well as improved energy density of energy storage mechanisms, have turned electrified aircraft from a utopian vision into a reality – with electric-powered planes taking to the skies.

Just as there are diverging technological approaches to the development of more sustainable jet fuel, there are different solutions to electrify the air. Figure 10 shows the architecture of these solutions that will be analysed in this study for their potential applications in regional air travel:[47] Hybrid-electric, battery-electric, and hydrogen-electric.

Figure 10. Powertrain architectures for battery-electric, hybrid-electric and hydrogen-electric



Source: Source: ONERA presentation at CleanSky Info event, MAHEPA Consortium.

Hybrid-electric

For passengers and the public, the concept of hybrid-electric powertrains is most familiar from cars, where gasoline or diesel-burning engines are combined with a battery. Typically, short distances can be driven solely on battery-electric power, whereas the combustion engine kicks in for longer distances or higher speeds.

The idea to increasingly use electric systems on aircraft is not new either and has been discussed at length within the aviation industry over the course of the last decades, with new aircraft like Boeing's 787 Dreamliner spearheading more electric aircraft. The difference in today's hybrid-electric movement is that these electric systems are now used for propulsion as well.

By combining a conventional fuel-powered system and an electrically-powered system in one of the three configurations shown in Figure 10, manufacturers hope to improve efficiency, reduce fuel consumption and enable new airframe designs. Increased complexity and high-power and voltage electric systems will need to be managed.

Benefits

The technology's main benefit is its enabling of more distributed propulsion and new concepts for whole aircraft designs – allowing better aerodynamic efficiency, higher fuel efficiency in cruise, and less energy consumption during take off and landing. This new degree of design freedom is enabled by the use of electric motors, which are smaller and more light weight than conventional engine units. This means that motor and propeller can be positioned more freely along the wing.[48] Hybrid-electric systems also allow the aircraft to independently optimise the gas turbine system and the electric motor/battery system so that both run at peak efficiency most of the time. However, the technology faces a slight 'catch-22' situation: while more likely (than battery-only, see next section) to be scalable to larger aircraft, the emissions and cost savings potential is more and more limited the larger the aircraft gets.[49] For small aircraft, efficiency improvements using hybrid-electric are therefore highest at up to 12 per cent,[50] combining benefits from new aerodynamic design concepts as well as higher efficiency use of both systems.

Crucially, given the continued dependence on jet kerosene as the major driver of propulsion, the range capable with hybrid-electric aircraft currently exceeds that of purely battery-electric options by considerable margins, just as in hybrid automobiles when compared to battery-electric only.[51]

Compared to conventional propulsion systems, hybrid-electric can also generate noise benefits, given that noisier components can be placed in better insulated areas, for example, the gas turbine.

Barriers to implementation

There are a number of hurdles that hybrid-electric aircraft will need to overcome; some which are shared with other forms of electrified aviation. Firstly, equipment manufacturers must work together closely with regulators to write the rules under which an electrified propulsion system can be certified. Both the Federal Aviation Administration Innovation Center (FAA) and European Union Aviation Safety Agency (EASA) have set up dedicated teams to work with industry in bringing safe and electrified propulsion to the market.

Secondly, the scalability of hybrid-electric remains uncertain. As stated, the benefits are greatest for smaller aircraft and several studies have shown the diminishing returns in terms of reducing emissions and costs as the aircraft grows in size. In a CleanSky 2 project, only one new aircraft configuration enabled by hybrid-electric propulsion was deemed to bring considerable savings, at seven per cent.[52] One of the key drivers for this is the additional weight of carrying two propulsion systems and through inefficiencies by the additional energy conversions taking place.

A hybrid-electric powertrain is also more complicated to integrate into existing airframes as the system architecture is more complex than gas turbine only or battery only. Furthermore, the high-power electric motors and electric components are not yet widely available, especially for 50-seat-plus aircraft, and the supply chain needs to mature, but it will require confidence in the demand. There are also fears about the safety of high voltage power systems in aviation.

Status quo

Despite growing interest, there are no commercially available hybrid-electric aircraft on the market in any size. That said, the industry has seen significant milestones in terms of the first hybrid-electric demonstrations. In June 2019, Ampaire successfully completed a test flight using a Cessna 337 six-seater aircraft on hybrid-electric propulsion.[53] Their retrofit approach and focus on the powertrain is contrasted by former

[47] Urban Air Mobility and electric air taxis are not covered in this study.
[48] DLR.
[49] Viswanathan and Knapp, Potential for electric aircraft (2019).
[50] Atanasov, E2Flight conference contribution (2019).
[51] DLR, Electric flight from Mannheim to Berlin in a 19-seater aircraft (2020).
[52] Iwanitzki, E2Flight conference contribution (2019).
[53] Avionics International, Hybrid-Electric Cessna 337 Takes Maiden Flight (2019).

companies like Zunum, who intended to fully draw on hybrid-electric benefits by designing an entirely new airframe.

In addition, many major original equipment manufacturers (OEMs) have kicked off projects on hybrid-electric regional aircraft, often together with airlines, including Project 804 by Pratt and Whitney, E-Fan X by Rolls-Royce and Airbus, collaborations between Airbus and SAS as well as Rolls-Royce and Widerøe, typically looking at entry into service at the end of the decade. Section 6.4 will provide further background.

Future developments

In spite of the challenges, there are a number of developments to watch in the hybrid-electric space. E-Fan X is projected to be conducting hybrid-electric demonstrations by replacing one of four engines on a BAE Avro RJ100, an aircraft capable of 75–100 passenger payload, with an electrically-driven fan in 2022.[54]

Ampaire has announced plans for the first hybrid-electric aircraft to be commercially available and in operation by 2021.[55] Zunum Aero had promised delivery of hybrid-electric aircraft by 2022, before running into development trouble.[56] Project Fresson aims to develop hybrid-electric propulsion systems for a Britten-Norman Islander in the nine-seat aircraft category to culminate in demonstration flights by 2022.

The roadmap could well be bolstered by R&D in other areas, given that improving power electronics, electric motors, motor controllers, and so on, is done not only by aviation but also by the maritime and automotive sectors. However, the challenges in improving the energy densities of batteries may prove a limiting factor.

Battery electric

Similar to the automotive sector, the next step from hybrid-electric propulsion systems is to move to fully battery-electric propulsion systems. This is also the logical culmination of the electric aircraft mentioned above. Significant improvements in battery energy density and power density of electric motors, for example, from motorsport, over the past years have started to enable these developments.

Battery-electric aircraft promise highly-efficient powertrains and the opportunity for a complete redesign of airframes. The potentially zero-emission technology could provide drastically reduced fuel costs but has infrastructure challenges and provides limited scalability due to the energy-to-weight ratio of current battery technologies.

Benefits

First, battery-electric powertrains represent truly zero-emission solutions in flight, if renewable electricity is used. Neither CO_2 emissions nor non-CO_2 emissions occur in the air. For a full life-cycle assessment of battery-electric aircraft, the emissions from producing and recycling batteries would have to be considered. However, no such studies exist yet for battery-electric aircraft.

Second, battery-electric propulsion systems can be more efficient than conventional ones, especially in regional aircraft. This is due to both the very high tank-to-wake efficiency of the powertrain itself and the better aerodynamic efficiency of the airframe it enables (see hybrid-electric for distributed propulsion discussion). The relatively low number of components also makes the system a relatively simple one, which is beneficial in discussions with regulatory bodies.

Another benefit of the simplicity and the electric components is their longevity. Electric propulsion is inherently more reliable with a very small number of moving parts and much lower requirements in terms of frequency of servicing, especially given that there are no high-temperature parts in the powertrain.

Finally, reducing noise is a major goal of battery-electric developments. Unlike conventional propulsion systems, where noise is driven by engine, noise and aerodynamic/propulsion noise alike, the battery system's noise for a battery-electric aircraft is negligible, so engine noise is eliminated.[57] However, there may be an increase in airframe noise due to the increased weight caused by the batteries.

Barriers to implementation

Battery-electric aircraft are already certified for training purposes by EASA, notably Pipistrel's two-seater aircraft the Alpha Electro. However, the certification pathway for non-trainer aircraft needs to be clarified further as aircraft reach the size of CS-23 and CS-25 regulation, similar to hybrid-electric systems. First, special conditions have now been released by EASA, which start to pave a way for these types of powertrains.

While certification of very small aircraft will be possible given time, the physical challenges facing battery electric aircraft R&D may be less easily overcome. The current trajectory of improvements in energy-to-weight ratio of upcoming generations of battery sit at around 3–4 per cent year-over-year. This does not offer a realistic pathway over the next 10 years to suppose that battery electric can practically be used within the regional aviation industry. As an example, the DLR stated recently that "under current technology, powering an A320-size jet for just one hour would require a battery roughly the same size as the aircraft".[58]

Looking into the future, battery energy-to-weight ratio will continue to limit scalability in terms of both range and aircraft size. According to research led by Professor Andreas W. Shafer of University College London, batteries in aviation would need a specific energy of 800 watt-hours per kilogram on a system level to compete on air routes up to 600 nautical miles in a Boeing 737- or Airbus A320-size airliner. The best batteries are capable of around 250 watt-hours per kilogram on a cell level today, and maybe 150–200 watt-hours per kilogram on a system level.[59] According to Argonne National Laboratory, improving the energy density fivefold – to 1,000

[54] Flight Global, UK project to install hybrid-electric power in BN-2 Islander (2019).
[55] Ampaire, Flight (nd).
[56] https://www.prweb.com/releases/2017/10/prweb14750814.htm.
[57] UK CAA, Emerging aircraft technologies and their potential noise impacts (2019).

[58] DLR's Andreas Kloeckner at IATA Wings of Change Conference in Berlin (2019).
[59] Nature Energy, Technological, economic and environmental prospects of all-electric aircraft (2018).

watt-hours per kilogram on a cell level – would be necessary to power small-scale commercial aviation.[60]

Furthermore, even supposing a much-accelerated timeline for the improvement in energy-to-weight, the cycle life of batteries would add cost pressures for regional airlines. Battery lifetimes typically range from 500 to 1,200 cycles.[61] The increased operating expenditure related to periodic battery replacement in electric aircraft creates another headache for moving in this direction, even without considering the environmental impact of the ramped-up production.

Adding to the cost of batteries and electricity is the high-power charging infrastructure that will be required at airports to provide low turnaround times. Some research concepts therefore started to investigate the possibility of battery swapping, which would reduce turnaround times significantly, but also increase capital expenditure at an airport before first flights can occur.[62]

There are new safety concerns for battery-electric flight. The electrical power created by aircraft engines or transported on board have typically been at low voltage levels. Once scaled to large aircraft, battery-powered airplanes would by necessity represent high-voltage systems with increased risk of an electrical breakdown.[63]

As previously stated in reference to hybrid-electric aircraft, the supply chain for high-power electric motors and electric components required for battery electric flight is limited – a challenge for all forms of electrification in aviation.

Status quo

There are currently no battery-electric aircraft certified to fly commercial routes, with just the two-seat Pipistrel Alpha Electro certified and in use for pilot training.

However, 2019 represented a momentous year for battery-electric demonstrations with genuine commercial potential. In the first half of the year, ZeroAvia conducted several test flights in California of a Piper Malibu six-seat aircraft on battery power. Harbour Air and magniX closed out the year with a successful test flight of a six-passenger DHC-2 de Havilland Beaver on the Fraser River in British Columbia, Canada.[64] High-speed electric aircraft, for example Rolls-Royce's ACCEL, have been unveiled and are ready for demonstration flights in the early 2020s.

Israeli startup, Eviation, is in the vanguard here and has stated publicly that they are aiming for FAA certification of its nine-passenger Alice plane by late 2021 or early 2022.[65] Other companies are targeting larger aircraft more aggressively, with Wright Electric announcing a project to develop a 186-seat electric aircraft with a plan to enter service slated for 2030.[66] Swedish Heart Aerospace targets the 19-seat segment with plans to be on the market in 2025 with a range of 400km.[67]
Some larger programmes for electric propulsion systems have been kicked off as well, for example, Wright Electric's co-operation with EasyJet to develop an A320-size aircraft, or Siemens/Rolls-Royce collaborating with Oswald Elektromotoren on superconducting motor technology for multi-Megawatt motors.

Future developments

As outlined, large question marks remain about the practicalities of developing battery-electric technologies for commercial flights. The scalability of battery-electric technology is limited by a number of factors in terms of aircraft size and range.

Firstly, whereas gas turbines typically improve in power density the larger they get, electric motors do not enjoy improvements at close to the same ratio currently. In theory, newer electric motor technologies such as superconducting motors could outperform gas turbines, but these are not commercially available within the next five years.[68]

Secondly, battery energy-to-weight ratio drastically limits scalability in terms of both range and aircraft size – as previously discussed in reference to the research paper led by Professor Andreas W. Schäfer. According to his study, it might be another 30 years before batteries can reach the 800 watt-hours per kilogram milestone he outlines.

However, there are many ambitious companies seeking to develop battery-electric options with an eye to commercial operations and 2020 will see yet more demonstrations and development.

Beyond the major schemes, there are some important external factors at play that will shape the development of the technology. Given the net zero push of many countries, particularly in Europe, much relevant research and development is happening in other transport sectors, including maritime and automotive. It is expected this cross-sectoral push will accelerate improvements in power electronics, electric motors and motor controllers – to name but a few crucial components for battery-electric flight.

There is also hope of a breakthrough that would change the paradigm around battery energy density. This may come in the form of a move away from Lithium-ion batteries. Lithium-sulphur batteries are thought to offer the prospect of reduced weight with a theoretical energy density more than five times that of Lithium-ion batteries.[69] However, commercially viable options for Lithium-sulphur batteries in aviation remain a long way off, with current solutions offering a highly-limited cycle life that would require several battery exchanges per year.

[60] Wired, The age of electric aviation is just 30 years away (2017).
[61] Electropaedia, Battery Life (and death).
[62] DLR, Electric flight from Mannheim to Berlin in a 19-seater aircraft (2020).
[63] I. Cotton, High voltage aircraft power systems (2008).
[64] Harbour Air, Harbour Air and magniX announce successful flight of world's first commercial electric airplane (2019)..
[65] GeekWire, Eviation unveils electric airplane and plans light tests in central Washington state (2019).
[66] Green Car Congress, Wright Electric begins motor development program for 186-seat electric aircraft; 1.5MW motor, 3kV inverter (2020).
[67] Heart Aerospace.
[68] Oswald Elektromotoren presenting ASUMED project.
[69] Science Daily, Graphene sponge helps lithium sulphur batteries reach new potential (2019).

Batteries are not immune to sustainability challenges of their own, with mining of production-grade lithium often requiring large amounts of water and creating the risk of toxic chemical leaks.[70] A circular economy approach for the use of batteries therefore needs to be developed in conjunction with other battery users.

Those developing battery-electric aircraft will hope for the emergence of a dynamic second-hand market for aircraft batteries to help offset the battery cycling costs. This will certainly take time to come to fruition and airline operators will consider battery cycling costs cautiously.

Hydrogen electric

Hydrogen-electric aircraft concepts share the electric drivetrain with battery-electric aircraft (electric motor, motor control, power electronics) but use a hydrogen fuel cell system instead of a battery for the storage of energy. Whereas the hydrogen-electric systems used in the automotive sector are always fuel cell–battery hybrids, the need for hybridisation in aircraft propulsion systems is not a given, and therefore propulsion architecture innovation can take place.

This potentially zero-emission technology could provide reduced fuel and maintenance costs. Moreover, its scalability is promising because of the energy-to-weight ratio of hydrogen storage systems, which is four times that of batteries even for gaseous systems and can even get close to jet fuel where liquid hydrogen is the fuel used, as opposed to gaseous hydrogen.[71]

The concept is not new, and the first hydrogen-powered aircraft was flown back in the 1980s by Russian manufacturer Tupolev. The first hydrogen-electric aircraft – Boeing's Fuel Cell Demonstrator, developed as part of the EU's ENFICA-FC programme – was flown in 2008. However, it was not until recently, when significant improvements in the commercial availability and performance of hydrogen components (compressed gas storage tanks, fuel cell systems, liquid hydrogen tanks) and in the performance of electric components (motors, motor controllers) enabled the use of those components for aircraft propulsion.

Benefits

Similar to battery-electric systems, hydrogen-electric's primary benefit lies in the complete absence of CO_2 and non-CO_2 emissions except for water, provided renewable electricity is used to produce hydrogen. Fortunately, the best economic case for hydrogen is achieved with on-site generation from renewable electricity sources, meaning that the zero-emission solution does not run counter to cost drivers.

Water emissions from the fuel cell system can either be stored on the aircraft, used on the aircraft, or discharged when effects on contrail formation and atmospheric GHG effects are least likely.

Due to hydrogen's energy-to-weight ratio, the technology could scale up very well to larger aircraft, switching from using compressed hydrogen for smaller aircraft to liquid hydrogen in larger airframes. This means that technological advancements made today in small aircraft can be carried over and scaled up as needed, with a potential to look drive larger and larger aircraft development towards the end of this decade.

The potential benefits are not all about weight or energy density, however. Hydrogen fuel cell power also enables more distributed propulsion, leading to better aerodynamic efficiency and less energy consumption during flight. Also, a hydrogen fuel cell driving a motor controller and electric motor represents a high efficiency system, with tank-to-prop efficiency of in excess of 40 per cent compared to 30 per cent in conventional turboprops.

Another advantage of hydrogen as a fuel is that dispensing hydrogen gas or liquid into the on-board storage tanks can be achieved within regular turnaround times of aircraft, enabling integration into existing airline routines.

Given the importance of managing noise in and around regional airports as the industry looks to expand, the noise reduction benefits of hydrogen-electric aircraft are also worth considering and are similar to those of battery-electric aircraft discussed above. Fuel cell-powered aircraft offer a seven-dB reduction in noise due to the ability of electric motor to produce rated power at lower RPM.[72]

Hydrogen-electric power also potentially offers safer air travel, building on the benefits detailed within the section on battery electric. Again, electric flight systems have a lower probability of failure, as electric propulsion is inherently more reliable thanks to the smaller number of moving parts and the reduced servicing requirements. In addition, hydrogen tank integrity is superior to any liquid fuel tank in use today. They are highly crash resistant and tested by firing high-calibre firearms at short range. This means a lower chance of a combustion event in the case of a crash.

As a fuel too, contrary to popular myth caused by the Hindenburg disaster nearly a century ago, hydrogen is substantially safer than jet fuel for three key reasons. Firstly, hydrogen is the lightest molecule and dissipates very quickly if leaked, so it is hard to maintain a combustible mix in open air. Secondly, hydrogen is harder to ignite than most fuels, with an auto-ignition temperature of 500°C – more than double that of jet fuel. Finally, if ignited, the H_2 flame emits much less radiative heat than jet fuel, meaning a reduced possibility of secondary fires.

Barriers to implementation

Several barriers to implementation overlap with hybrid or battery-electric powertrains: firstly, certification pathways are in the process of being shaped at the moment; secondly, high-voltage systems on aircraft are technologically challenging; thirdly, the emerging supply chain for high-power electric components; and finally, scaling electric components to higher power levels underlies different logics than gas turbines. Some unique challenges occur because of hydrogen's unique physical properties.

[70] Wired, The spiralling environmental cost of our lithium battery addiction (2018).
[71] Air Liquide at E2Flight 2020, ATR at E2Flight 2020.
[72] NASA, Low-Noise Operating Mode for Propeller-Driven Electric Airplanes (2018).

Additionally, although hydrogen has a high energy-to-weight ratio, its energy-to-volume ratio is inferior to jet fuel. The integration of hydrogen storage systems into existing airframes is therefore challenging. An airframe redesign might well be necessary for larger planes.

Lastly, perhaps the most significant challenge facing hydrogen-electric will be the infrastructure requirements and associated costs for enabling filling H_2 tanks at airports. As part of its HyFlyer project, ZeroAvia is collaborating with the UK Government and the European Marine Energy Centre to investigate appropriate infrastructure for green hydrogen production and refuelling. The mitigation of risks at airports has been looked at previously, with airports such as Memphis International, Hamburg, Toulouse and Liège, either already having hydrogen fuelling infrastructure in place or looking into their feasibility. The hydrogen is typically used for ground handling equipment, for example, forklifts, luggage tugs or local buses.

Status quo

There are currently no commercially available hydrogen-electric aircraft in any size categories, despite prototypes of up to four seats having been flown from 2009–2016. The first hydrogen-electric demonstrator flying in a six-seat aircraft is expected in 2020. This project is led by ZeroAvia and backed by the UK Government. In parallel, the Modular Approach to Hybrid Electric Propulsion Architecture MAHEPA consortium intends to demonstrate hydrogen-battery hybrid electric flight in 2020 on a four-seat aircraft.

Several studies are underway to explore the feasibility of hydrogen's use in larger aircraft, either through fuel cells or hydrogen-combustion in turbines, for example, EnableH2 – a NASA study – or the new FUTPRINT50 project.

Future developments

Both DLR and ZeroAvia expect commercial availability of hydrogen-powered aircraft by 2030. However, there are many developments that need to be considered in the interim between the shortly expected commercial aircraft, and the promise of greater scale on the horizon.

The next stage for ZeroAvia will be the development of a 19-seat aircraft powered by a hydrogen fuel cell, with test flights expected in 2021. The company has stated publicly its intention to deliver a 19-seat passenger aircraft for commercial operations with a range of around 500 nautical miles by 2023.

Scaling the technology to larger aircraft requires storing more energy on board and delivering higher power to the propeller/fan.

The development of liquid hydrogen as a fuel storage source will be key to development beyond smaller, regional aircraft given that it has nearly a three times better energy-to-weight ratio than that of compressed gas storage. Liquid hydrogen promises power for larger aircraft on longer routes.

To deliver higher power, similar challenges as in battery-electric aircraft will evolve, especially on power density of electric components when reaching higher power levels. In addition to that, fuel cells will need to deliver on promised scaling factors as well.

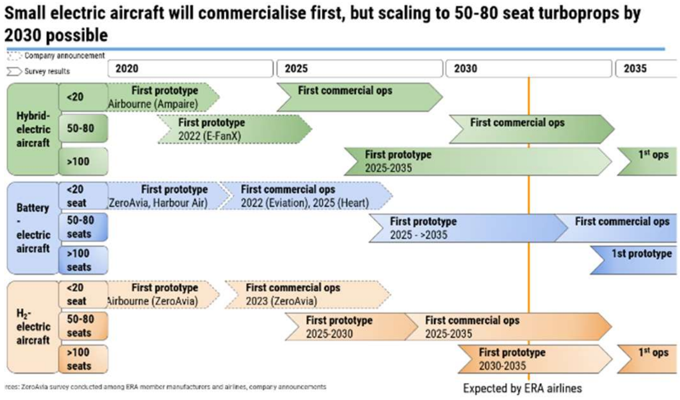
As with battery-electric, a host of external factors will influence the development of hydrogen fuel cells, including the efforts being made in other transport sectors to develop and harness components like power electronics, electric motors and motor controllers.

Another helpful aspect will be the development of the hydrogen economy as a whole, with the price of green hydrogen likely falling. The UK's Committee on Climate Change, for example, has made several key recommendations to the UK Government relating to developing hydrogen as a heating source in the UK.[73] Aviation can play the lead in providing scale for transport applications.

6.3 A timeline to electric aviation

As part of this study, ZeroAvia and ERA have conducted a survey amongst its member airlines and member manufacturers to find out expectations on when electrified aircraft will be available. Figure 11 outlines the results:

Figure 11. 2020–2035 timeline for electric aircraft



Source: ZeroAvia survey conducted among ERA member manufacturers and airlines, company announcements.

These survey results lead to the following conclusions for the remainder of the study:

- Aircraft providing more than 100 seats in the small narrow-body or regional jet segment are not expected to be commercially available before 2035 (or ever be feasible in the case of battery-electric). The only way to reduce emissions from the propulsion system within that timeframe is therefore the use of SAF. This aircraft size is therefore not considered in the full cost comparison following in section 7.
- Electrified turboprop aircraft with 50–80 seats – the bread and butter of today's regional fleet – are generally expected to enter into service in the late 2020s or the early 2030s. Hydrogen-electric aircraft in that size are expected to be available commercially slightly earlier than hybrid-electric, with battery-electric only in the mid-2030s. The cost implications for aircraft of this size are difficult to predict given that no prototypes have been up in the air yet and timelines are further out. This study will show predictions by member manufacturers in section 7, but these should be watched carefully.
- Turboprop aircraft with less than 20 seats are clearly the first ones expected to be electrified, with several prototypes already in the air. Generally, first introductions into fleets are expected by 2025.

[73] The Committee on Climate Change, Hydrogen in a low-carbon economy (2018).

6.4 Key stakeholders

A myriad of projects promoting electric aviation has emerged over the past five years and interest in sustainable aviation fuels has skyrocketed as well. The following figures show a non-comprehensive selection of projects and stakeholders in the respective technology's ecosystem.

Within the SAF ecosystem, shown in Figure 12, most traction is currently gained by building consortia where airlines, airport operators, and fuel suppliers come together to build new fuel production facilities. The airlines' role is to provide offtake agreements and the airports' is to provide the right infrastructure on site where the fuelling will take place. AVINOR at its Bergen and Oslo airports and Swedavia have pioneered these efforts as well as only a handful of other airports worldwide.

The companies developing new fuel production technologies are also important stakeholders and exemplified by three companies developing power-based fuel production technology in Figure 12.

Several initiatives try to foster the roll out of SAFs, for example, the Clean Skies for Tomorrow initiative, Fossil Free Aviation 2045 in Sweden, or the FlyGreen Fund.

Figure 12. The SAF ecosystem map

Figure 13 shows the electric flight ecosystem. It is worth highlighting the widespread influence this new third era of aviation has had. Virtually every major incumbent, be it an airframer or an engine manufacturer, has started projects and young companies are flocking to the race with technology developments from within aerospace, as well as from neighbouring industries. Some companies intend to certify whole new airframe designs (Eviation, HES, Faradair), whereas others focus on the powertrain as the key innovation area (ZeroAvia, Ampaire, H55).

Figure 13. The electric flight ecosystem map

7. Emissions and costs performance of propulsion decarbonisation

ZeroAvia and ERA have conducted a survey among member manufacturers to provide a balanced view of the expectations in terms of emissions and costs performance of electrification. This data was then combined with in-depth research on the cost and emission implications of SAF. The study looks at a 300 nautical mile flight to standardise responses and analyses. First, the emissions reduction potential of the various decarbonisation options is highlighted and compared to other, non-propulsion emission reduction measures.

Second, the standard flight is used to determine the cost associated with switching such a flight to low-emission alternatives more generally.

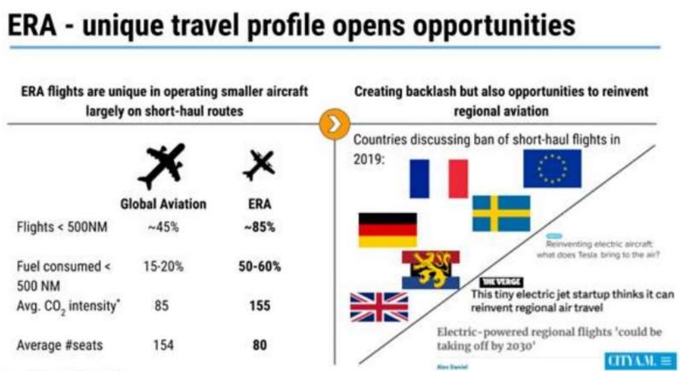
As discussed in Section 6.3, the small narrow-body segment (and the 50–80 seat turboprop segment) is omitted from this summary report for brevity, but the analysis behind it can be requested from the study's authors.

7.1 Potential emissions reduction

To compare emissions from various aircraft sizes and the respective decarbonisation options, CO_2 emissions per passenger on a standard flight are used as a metric.

First, one can look at the emissions between the different aircraft categories and conclude that in today's world, the 50–80 seat turboprop segment is the most CO_2-efficient means of transportation for these short-haul missions.[74] Similar to the economics discussed in the next section, the emissions per passenger decrease by nearly half, as the aircraft size increases from turboprop with less than 20 seats to the 50–80 seat category. Compared to the wider aviation industry, as shown in Figure 14 however, the regional segments still have almost double the CO_2 intensity of longer flights because of the higher share of take-off phases (high fuel burn) compared to cruise phases (moderate fuel burn).

Figure 14. ERA unique travel profiles



** In g CO2 per Revenue Passenger Kilometer*
Sources: ICCT (2019), ERA statistics, Schafer (2018); Icons from surang and Freepik

Second, the emissions reduction potential of the analysed decarbonisation options is highest for battery-electric and hydrogen-electric aircraft as shown in Figure 15 for a 19-seat aircraft, with no significant changes when scaling to larger aircraft. If the electricity or the hydrogen is produced from renewable energy sources, a zero-emission flight is possible. For SAFs, the emission reduction potential is up to 80 per cent as discussed in section 6.1. Survey results for hybrid-electric

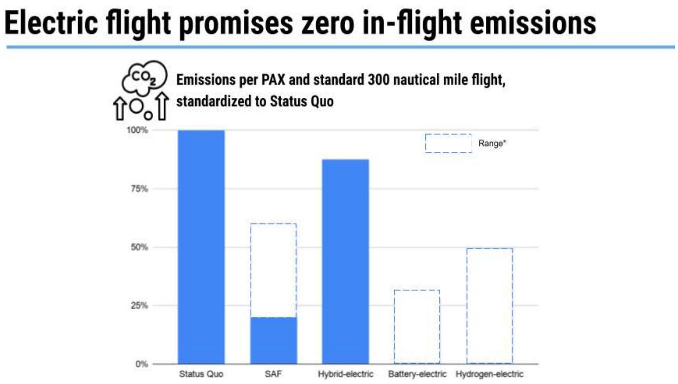
[74] ICCT (2014).

aircraft indicate an estimated average emissions reduction of 12.5 per cent.

The source of the fuel matters when moving to electrified powertrains. However, even with fuel coming from grey electricity or hydrogen sources, an emissions reduction is possible. Similarly, the emissions reduction for SAF is significantly higher if they can be blended up to 100 per cent instead of today's 50 per cent, although limited by availability today.

- Whereas the emissions reductions of SAF are based on their full lifecycle emissions, this is not the case for electricity and hydrogen. No full lifecycle assessment of battery-electric (including battery production and second life) and hydrogen-electric propulsion was conducted in this study; instead, only fuel reduction and use was considered.
- This analysis only takes into account CO_2 emissions, excluding non-CO_2 emissions such as NOx and particulate matter, as well as water vapour or contrail formation.

Figure 15. Emissions comparison for propulsion decarbonisation



**For SAFs, indicates the difference between a 50 per cent blend and 100 per cent blend; For battery-electric, zero-emission electricity production and 208's EU 28 average; for hydrogen-electric, zero-emission and 'grey' hydrogen from natural gas.*
Source: Icons by surang, survey results conducted by ZeroAvia among ERA member manufacturers.

Last, these emissions reduction numbers can be compared to other, non-propulsion related emission reduction measures in aviation. The Energy Transitions Commission[75] has pointed out the following measures and their potential:

- modal shift (or demand side measures) – 15 per cent;
- aircraft efficiency improvements:
  - thermodynamic efficiency of new engines – 30/45 per cent;
  - aircraft design – 30/45 per cent;
- load factor improvement –15 per cent; and
- better air traffic management – 15 per cent.

It becomes clear that reducing emissions in the near term will require all these measures to work together, but deep decarbonisation will require the aviation industry to tackle propulsion, where even a 50 per cent SAF blend can already provide 40 per cent emissions reduction per flight.

The remaining carbon emissions of those propulsion decarbonisation options might also have an economic impact with the growth of carbon pricing or ETS. This might become an important input in the following section in the future but was omitted for the time being because of the uncertainty surrounding carbon price levels going forward.

[75] Energy Transitions Commission (ETC), Mission Possible (2018).

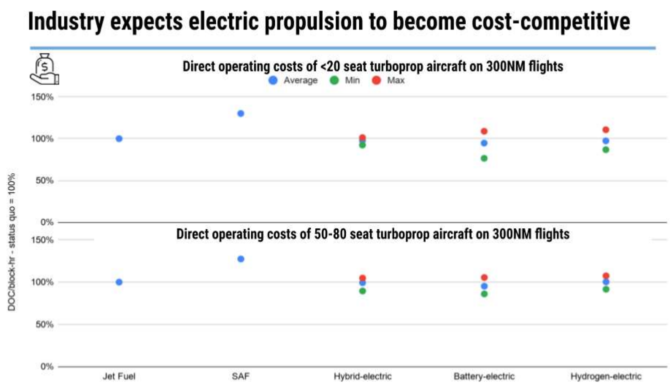
7.2 Direct operating cost effects

ZeroAvia and ERA have surveyed the member airlines to provide a status quo for the operating costs of existing aircraft in their fleet. These results were averaged and form the basis of our analysis, providing the direct operating costs per block hour for sub-20-seat turboprops, 50–80 seat turboprops, and for small regional narrow bodies. Then, ERA member manufacturers were surveyed to provide data on how their electrification programmes would impact certain cost categories.

First, it is of course not news to the industry that the direct operating costs per passenger or cost per available seat kilometre decrease as the aircraft increases in size. This trend has encouraged airlines to fly larger and larger aircraft wherever travel volume and airport infrastructure allow them to do so.

Second, electric aircraft will be cost competitive with traditional propulsion systems, even without a carbon price (Figure 16). However, uncertainties remain, shown by the spread in survey results, where some respondents expected electric aircraft to be more expensive and others expected cost to decrease for the sub-20-seat aircraft. Interestingly, the spread in survey results decreases when moving to larger aircraft (Figure 15), likely because respondents were more conservative in their expected benefits, so results stayed closer to the status quo.

Figure 16. Less than 20 seat and 50–80 seat turboprop aircraft cost comparison



Source: Icons by monkik Survey results conducted by ZeroAvia among ERA member manufacturers.

Third, electric aircraft tackle the major cost elements of airlines' direct operating costs head-on: fuel and maintenance. Those are expected to decrease according to almost all survey respondents, whereas capital expenditures (CAPEX) and associated depreciation costs are expected to stay the same or increase slightly. The other near-term decarbonisation option, SAF, increases fuel costs significantly due to the cost per gallon of it expected to be at least three times the price of jet fuel in the 2020s. The latter might change with a growing carbon price.

These insights into the economics of propulsion decarbonisation are enabled by technological advancement, a growing share of renewable energy sources in electricity grids, and any policy measures that would make flying more expensive, given that electric flight would likely be exempt from such policies. However, a few barriers remain:

- The range of battery-electric aircraft:
  As described in the timeline in section 6.3, experts expect battery-electric aircraft in the sub-20-seat

turboprop market to enter into service in the 2020s. However, no such alignment exists on the expected range. The most optimistic voices assume a 400km range in 2025. For hydrogen-electric aircraft, there is less concern on range, with experts assuming ranges up to 1000km in a similar timeframe.

- The infrastructure requirements for battery- and hydrogen-electric aircraft:
  Airports will need to be fitted one-by-one with respective charging or hydrogen-dispensing infrastructure. Several airports already use hydrogen on the airside today (Hamburg, Memphis for example), but widespread adoption of electric aircraft requires an infrastructure rollout at a similar pace to current technology development.
- These two barriers lead to a third, operators' flexibility:
  Operators might have to accept a limit in flexibility on which routes the first electric aircraft can be used, because of lack of infrastructure availability or new routing necessary because of limited battery-electric range. The longer range of hydrogen-electric aircraft could serve as a double benefit here. Operators need change their existing route network less and might not require infrastructure at every target airport because there-and-back missions can be fulfilled on one fuelling load. The need for airline network studies is highlighted by this barrier.

These considerations mean that, even with competitive economics, the use of electric aircraft for regional airlines needs to be discussed on a case-by-case basis. To bring these findings to life, the following section investigates two case studies of how decarbonisation might impact key regional routes in Europe.

8. Case studies for selected regional airlines

Section 7 has shown that electric aircraft have the potential to compete with traditional propulsion systems on a direct operating cost basis and do not rely on external market factors such as a carbon price. This section now answers the question where the first electric aircraft might fly in a commercial setting, what hurdles they will need to overcome, and what the economic and emissions implications could be for the first operators on specific routes

This section presents two case studies from ERA members:

1. A typical example in the media of potential for electric aircraft is inter-island transport, where the range constraints of electric propulsion technology have a lower impact. Operator Binter, based in the Canary Islands, looks at the decarbonisation of one of its routes.
2. Several countries in Europe have indicated strong political will to reach net-zero emissions sometime between 2040 and 2050, Scotland being one of them. Scottish operator Loganair provides insight into how parts of its route network could be operated with zero emission aircraft, given that they already operate sub-20-seat aircraft today.

8.1 Island regions and their thin-haul inter-island transport – Binter

Binter's route network is unique with most of its route network located on the Canary Islands with relatively short-haul flights, but high traffic volumes. Given that the islands' renewable power generation capacity is slowly growing, electrifying some of these routes might prove to be an interesting option.
For this analysis, the thinnest route is analysed, from La Gomera to Tenerife North, used by roughly 60,000 passengers every year.

For the analysis, Binter has provided operational data for the aircraft currently in use, an ATR 72. The analysis then provides a view on how this could be decarbonised, either by switching to SAF (a 100 per cent blend is assumed to be realistic by mid-decade) or by switching to sub-20-seat electrified aircraft (larger electric aircraft are not commercially available by mid-decade). Figure 17 shows the results of this analysis.

Figure 17. Case study results for Binter

Source: Icons by surang, monkik; analysis conducted by ZeroAvia based on own data and survey results from ERA member manufacturers.

First, the analysis shows that using hydrogen-electric 19-seat aircraft could be the cheapest way to reduce emissions for this inter-island route. Although increasing Cost per Available Seat-Kilometre (CASK) slightly compared to today's operations (14 per cent), it is significantly cheaper than using SAF (33 per cent compared to status quo) or switching to battery-electric (24 per cent compared to status quo). Moreover, it shows that hybrid-electric aircraft technology is stuck in the middle, with emissions reductions (not taking into account the use of SAF for hybrid-electric) not sufficient for deep decarbonisation.

Second, the infrastructure requirements for the route can be analysed. Transporting the same number of passengers between these two airports requires fuel production in the scale of 200 tonnes of hydrogen per year, equivalent to just under 800kg per day and airport, which in turn requires roughly seven megawatts of solar power capacity. This should easily be obtainable in the Canary Islands given that as of spring 2019 this would only represent less than four per cent of the islands' existing solar power.[76]

[76] PV Magazine, Tenerife plans 350 MW of solar alongside 1 GWh storage (2019).

Third, a limit to scaling the use of 19-seat aircraft in the Canary Islands is the very high passenger volumes for virtually all legs. If routes with higher passenger volumes are analysed, moving from existing ATR 72 aircraft to 19-seat aircraft becomes impossible because of the increase in the number of movements and the number of pilots required. For these routes, SAF is the only near-term option, until larger electric aircraft come online towards the end of the decade (see Section 6.3).

8.2 Net-zero ambitions and existing small aircraft fleet – Loganair

Loganair's route network lies entirely in countries where governments have made a strong push towards decarbonising their economies, including aviation. Scotland has a target of achieving net-zero (all GHGs) by 2045, Norway's airport operator Avinor is looking to fly fully electric by 2040, the UK's airlines have recently presented their plans for net-zero emissions by 2050, and all other destinations have similar plans in place. For Loganair, this presents an incredible opportunity, because all of these markets also show some of the highest growth rates in renewable power generation and interest in the production of green hydrogen. Moreover, in its home market, Scotland, regional connectivity is of utmost importance to the government, so that experimentation with lower emitting solutions to current aircraft should be viewed favourably.

For this analysis, the longest route currently operated by a 19-seat aircraft is analysed, from Glasgow to Barra. Loganair has provided operational data for the aircraft currently in use, a Viking Twin Otter (DHC 6 - 300/400). The analysis then provides a view on how this could be decarbonised, either by switching to SAFs (a 100 per cent blend is assumed to be realistic by mid-decade) or by switching to electrified aircraft.

Figure 18 shows the analysis' results.

Figure 18. Case study results for Loganair

Source: Icons by surang, monkik; analysis conducted by ZeroAvia based on own data and survey results from ERA member manufacturers.

Just like in the previous case study, the analysis shows that using hydrogen-electric 19-seat aircraft could be the cheapest way to reduce emissions from this route. CASK is reduced drastically compared to today's operations, enabling lower ticket prices which directly relates to better regional connectivity. The use of SAF on this route is 37 per cent more expensive than the status quo. Battery-electric aircraft, while cheaper than the status quo, are less economical than hydrogen-electric ones and require infrastructure at both airports on the route.

There is already excellent overall hydrogen economics in Scotland and an enormous push for it in the region because of its very good wind resource, with Barra leading the deployment. Transporting the same number of passengers between these two airports requires fuel production in the scale of 30 tonnes of hydrogen per year or roughly 100kg per day. This requires less than one megawatt of dedicated offshore wind capacity. Using battery-electric aircraft, the need for renewable power generation decreases by almost 80 per cent, as the conversion chain is more efficient. However, the range limits require charging infrastructure to be built in Barra as well as in Glasgow, potentially being a challenge in Barra. Hydrogen-electric aircraft could provide there-and-back journeys to Barra including reserves, easing the infrastructure requirements at an airport as remote as Barra.

Given the limited availability of SAF up to 2025, it is most likely that routes like this one will leapfrog SAF deployment and move directly to being electrified.

9. Conclusion of the technology review

It is essential for airlines to learn about how operations might change with the upcoming introduction of electric aircraft into fleets. Selecting demonstration routes where electric propulsion companies can come in and demonstrate their technology helps the airline and airport operator to build a knowledge base for the future. Otherwise, new operators who fully bet on the disruption potential of electric aircraft could see their time has come.

Airlines should also look at the revenue potential that zero-emission aircraft bring. Customers are likely willing to pay a premium for actual zero-emission flights as opposed to carbon offsetting. Similar experiences were made in road transport or the consumer goods industry (paper straw versus single-use straws).

Governments should be made aware of this opportunity so that the solution space for aviation decarbonisation is opened up beyond increasing taxes and limiting demand or forcing the implementation of expensive SAF mandates. Providing benefits to cheaper decarbonisation solutions, for example, through PSO routes.

Whereas this study has shown the potential of electric flight for thin-haul regional segments, bio-based fuels will form the most near-term opportunity and the only option for larger aircraft and cross-Atlantic flights. Continued support for their deployment will remain essential for regional airlines on a case-by-case basis.

10. ERA member survey results

In September 2019, ERA circulated a survey among its airline members in order to better understand their environmental footprint and their commitments to a cleaner sector. The results helped us inform the report in the various sections.
Out of the 43 per cent of members that have responded:

- 27 per cent already offer carbon-offsetting programmes to their passengers.
- 9 per cent operate on SAF, with one respondent using 0.8 per cent of SAF in the blend.
- 90 per cent of the respondents acknowledged that their biggest environmental impact is the emission of CO_2 emissions, in addition to NOx, noise pollution and impacts from maintenance facilities.
- 81 per cent of the airlines have improved their fleet's fuel efficiency, with the majority of the airlines having improved it by 3–5 per cent from 2015.

ERA airline members have been taking various actions to improve their environmental performance. These include:

- aircraft weight reduction;
- fleet modernisation;
- turboprop use;
- sustainable on-board products;
- waste management, separation of waste from source, reducing plastic on board;
- introduction of biofuel;
- flight operations improvements;
- EFB operations, making flight decks paperless;
- background process optimisation, for example, office printing;
- eco flight procedures;
- implementation of fuel management software;
- improved tankering;
- shortening routes;
- optimisation of flights Continuous Climb Operations (CCO) and Continuous. Descent Operations (CDO); and
- planning introduction of electric engines.

These actions have contributed to CO_2 and NOx emission reductions and noise reduction, reputational benefits and cost efficiency for the majority of the respondents.

Many ERA airline members are already thinking of future actions to take such as fleet renewal by moving towards electric, introduction of SAF and recycling on board. The most common response is moving ground handling towards carbon neutrality and introducing offsetting. When it comes to the next five years, most airlines are looking to renew their fleet with more efficient aircraft. From those who responded, 45.54 per cent have an environmental strategy for the long term, beyond the next five years. In addition, 81 per cent are facing challenges to reduce emissions due to a lack of government support, investments in better technology, high costs of SAF and their availability, poor airspace design or, finally, public scepticism.

Only 40 per cent of the airlines have a dedicated page on their website regarding their environmental commitments and when asked about the flight shaming movement, 18 per cent have been affected, either by experiencing a reduction in demand – Sweden has seen a 10 per cent reduction in 2019 – or by receiving questions regarding their operational effects.

11. ERA members' initiatives

ERA members are concerned about their current impact on the environment and, as such, are undertaking different initiatives and projects to address the challenge. These initiatives are outlined in the upcoming pages and will be updated on a yearly basis as ERA members launch new initiatives and projects. The list in non-exhaustive as it outlines only a few examples.

ERA airline members:

- Air Iceland Connect;
- Binter;
- Braathens Regional Airlines;
- Croatia Airlines;
- Euroairlines;
- HOP!;
- Jet Time;
- KLM Cityhopper; and
- Luxair.

Other ERA members

- Airbus;
- ATR;
- Collins Aerospace;
- Embraer;
- Textron Aviation; and
- Zeroavia.

The focus is on keeping Air Iceland Connect green by means of sustainable practices and optimal use of resources at its disposal. EMS will be fully integrated into their management system and will be a normal part of the airline's operations.

Air Iceland Connect recognises that its activities have an impact on the environment in terms of the use of raw materials, emissions to air and water, and waste generation, and seek to minimise this as far as is reasonably practicable.

The airline is committed to operating in a sustainable and environmentally sound manner, complying with all applicable legislation, environmental standards and other relevant requirements or commitments. This policy shall apply to all activities carried out by or on behalf of Air Iceland Connect and to locations in which it operates. In fact, Air Iceland Connect has been found to conform to the Environmental Management Standard ISO14001 (EMS).

Air Iceland Connect is committed to:

- continual improvement in environmental performance;
- preventing pollution where possible;
- compliance with applicable environmental legislation, regulations and codes of practice relevant to the tourism and the aviation industry;
- implement programmes to reduce our environmental impact;
- educating, training and motivating employees to carry out tasks in an environmentally responsible manner;
- working toward industry-specific goals;
- cap on CO_2 emissions from 2020;
- average improvement of fuel efficiency of 1.5 per cent from 2009–2020;
- reduction in CO_2 emissions of 50 per cent by 2050, relative to 2005 level; and
- offering customers the opportunity to participate in offsetting the carbon footprint of their flight as part of the booking process (since autumn 2019) and around four per cent of customers are already taking part.

It is the policy of Air Iceland Connect to:

- promote responsible use of natural resources;
- reduce waste by recycling and minimising their carbon footprint and raising awareness;
- work with existing contractors/subcontractors and suppliers to reduce its environmental impact; and
- consider environmentally-friendly products and service when considering new subcontractors and suppliers.

Air Iceland Connect will review this policy and performance on annual basis, taking account of any changes within legislation and the organisation, and other factors.

The airline will communicate this policy to all its employees and ensure that they are given appropriate training to raise awareness of environmental issues and ensure communication between management and staff regarding our environmental performance.

Binter

Binter has a strategic commitment towards the decarbonisation of the sector. Its four cornerstones of sustainability ensure that the airline enhances its commitment to sustainability and society, improving its engagement and involving all of its stakeholders in the quest for protecting the environment.

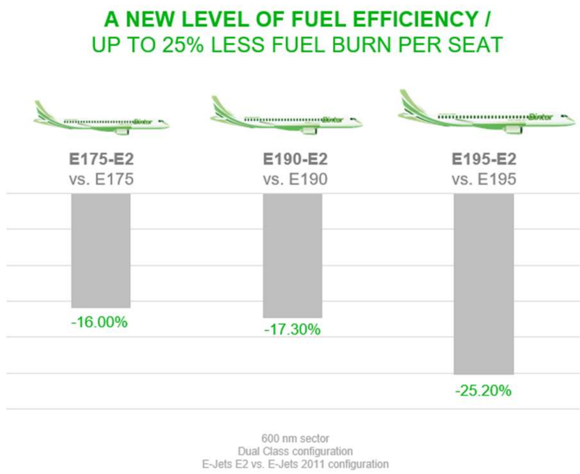
The cornerstones involve:

- commitment to society;
- outreach to suppliers and other stakeholders;
- care for people and human rights; and
- environmental protection.

Binter's actions with its fleet

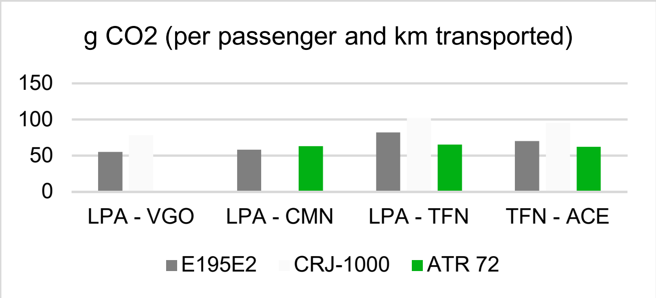
Turboprops:

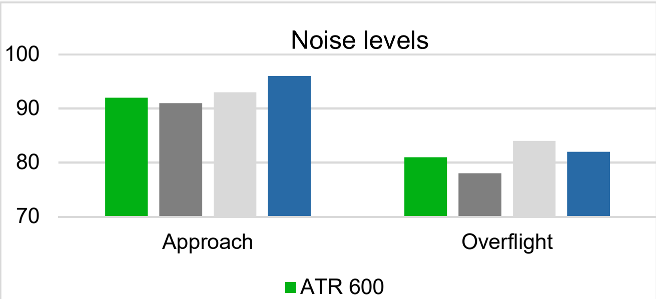
- In energy terms, turboprops are advantageous because they use less fuel than jet planes, with savings of up to 50 per cent on short-distance flights. Furthermore, they fly at an altitude of some 6,000m, therefore their pollution levels are lower



Embraer E195 E2

- Designed and built with innovative materials and forms incorporating the latest advances in aerodynamics, producing important weight savings.
- They use the latest advances in thermodynamics and materials which, combined with the aircraft's design, achieve fuel savings of approaching 25 per cent compared to older models.
- They reduce noise footprint by up to 75 per cent, nitrogen oxide emissions by up to 50 per cent and CO_2 emissions by around 25 per cent.
- CO_2 emissions per passenger and kilometres transported are significantly lower for the E195 E2 fleet than for the CRJ1000.
- Even on very short routes, Binter's turboprop fleet emits less CO_2 than the E195.





Noise pollution and weight reductions

- Binter's fleet has lower effective perceived noise levels (EPNL) than other aircraft. A comparison of aircraft types shows a considerable reduction in the noise levels.
- The introduction of the electronic flight bag (EFB) has enabled the airline to eliminate some 20kg in weight compared to hard copy documentation, which leads to lower fuel consumption. Redesign of flight sheets and improved descents to reduce flight duration.
- Periodic meetings with ENAIRE/AENA and flight planning systems to fine tune routes, gaining in efficiency and cutting duration.
- Choice of continuous descent as the priority approach method. The crew calculates descents from cruise level using the continuous descent criterion.

Binter's electrical equipment on the ground


flota ecológica

- The introduction of a green tractor fleet, power units and gardeners has led to notable cuts in consumption per operation and to a saving of 120,000 litres of fuel with the corresponding reduction in CO_2 emissions stemming from combustion of said fuel.
- All tractors at Canary Island airports have been replaced. Using prediction techniques, the working lives of their batteries have been extended and every 10 years the planet is saved from receiving 150 tonnes of lead waste.
- The thermal ground power units (GPUs) are being replaced by electrical versions as are baggage conveyor belts and fuel-powered gardeners.

Binter's fuel and waste management

- Elimination of plastic items on board, ceasing to use three million cups per year and introducing recyclable items. These actions cut consumption of plastics by nine tonnes per year.
- Classification of on-board waste, separating it by type and replacing plastic bottles with metal ones.
- Online check-in option, providing very important savings in the use of paper.

Binter's sustainability in the workplace



- Thermal solar panels to generate hot water.
- Automated system with motion, light and temperature sensors to control lighting and heating/cooling systems.
- Waste separation in the office with different bins and destruction using waste managers.
- Plugs for charging electrical vehicles.

Binter's agreement with forests

- Binter collaborates with Foresta in assessing the environmental and landscape restoration work in various areas of the Canary Islands affected by fires in summer 2019. Work will be undertaken in various areas of Valleseco since this is one of the most affected areas and because it is a valuable part of the island's natural heritage.
- The project intends to set up a local business structure that can respond to the future needs of the municipality, reducing unemployment rates and improving the quality of life of the inhabitants.
- This local activity will generate wealth not only through the employment of people in the municipality but also by the stimulation of small businesses that generate local jobs that will have an impact on the municipal economy.
- Regarding the social aspects, it will also have an impact, encouraging participation in the project not only from groups at risk of exclusion but also for students and/or other groups, allowing us to carry out at least two inclusive environmental restoration actions.

Sustainability at Braathens Regional Airlines (BRA)

Sustainability is based on a have a financially profitable business, be relevant to customers and employees and, at the same time, accept responsibility for the environmental impact of the business. Braathens' sustainability efforts are integrated into the whole organisation and employees receive regular online training in the basics of sustainability.

Climate

Braathens has an environmental management system which is environmentally certified to ISO 14001:2015, an international standard to ensure systematic, controlled environmental improvements. The airline has established environmental objectives, and its environmental management system is reviewed annually.

Aviation is included in the EU ETS, and the Group pays for its carbon dioxide emissions under EU ETS.

Braathens' objective is to halve carbon dioxide emissions from fossil fuels per passenger between 2015 and 2025 through investments in technology, by upgrading its fleet to the most climate-effective ATR 72-600 aircraft, and access to sustainably-produced biofuels.

Fossil free 2030

Braathens is a member of the government initiative Fossil Free Sweden, initiated in 2015. A new environmental goal is for domestic services to be operated on a fossil-free basis by 2030. This requires policy being formulated in such a way that the transport sector gains access to biofuels at a reasonable price and in sufficient quantity. Braathens has committed to the same goal as an airline – to be fossil free by 2030.

Biofuels

With the airline's work on biofuels, Braathens wishes to show realistic possible ways forward for the aviation industry and thus help influence decision makers and encourage the market for large-scale Swedish production of biofuels. In 2017, 2018 and 2019, all of Braathens' own business travel was carried out with a five per cent biofuel blend with access to biofuels having been ensured in a local project together with Halmstad City Airport. Braathens has a co-operation with Kalmar Oland Airport where they help, blending in five per cent biofuel in all departing flights by financing the extra cost. The airline also offers members of its loyalty programme, BRA Vänner, the option of swapping bonus points for biofuel. To ensure the quality of the offered biofuel products, Braathens takes responsibility for the biofuel purchased and used for refuelling in Sweden.

In 2018, Braathens introduced an option for customers to buy biofuel directly at the time of booking on its website. Although only a small proportion of travellers (less than one per cent) choose to purchase biofuel for SEK 300 (approximately €29), this has contributed to raising awareness among consumers and reinforcing BRA's position as the greener alternative in the sky. The two products Green Annual Ticket and Green Multi-Trip Ticket, pre-paid corporate products for frequent flyers launched at the end of 2018, provide further opportunities for different customer groups to purchase biofuel for their journeys.

Offsetting

From 1 April 2019, an offsetting programme was launched, including complete compensation for all emissions of GHG from Braathens' activity. The calculation is based on the figures reported to EU ETS with an extra 10 per cent (190,000T of CO_2-equivalent). The projects involved are large-scale wind projects that contribute to accelerate the change to renewable energy in countries where the demand for electricity is growing fast, like India.

Environment Class

In 2019, a new booking class was created: Environment Class. The aim is to encourage and facilitate the customer to add biofuel when buying a ticket. The goal for 2020 is to reach five per cent of total ticket sales. Braathens has a challenge in front of them as the number of passengers paying extra for biofuel was one per cent in 2019.

The Perfect Flight

Braathens Regional Airlines has collaborated with Air BP, ATR and Neste to achieve 'The Perfect Flight' from Halmstad City Airport to Stockholm Bromma Airport in Sweden – a country aiming to be carbon neutral by 2045. SAF, produced by Neste and supplied by Air BP, was used to power the ATR 72-600 – the regional aircraft with the best environmental credentials. Every element of the flight management process has been optimised to keep carbon emissions to a minimum.

On 16 May 2019, a number of companies from across the aviation sector rose to the challenge of turning a typical weekday service from Halmstad City Airport to Stockholm Bromma Airport (BMA/ESSB) into the 'Perfect Flight'.

This is the first time that every element in the flight management process on a regional flight has been optimised to keep carbon emissions to a minimum and achieve The Perfect Flight – in Sweden, a country that is aiming to be carbon neutral by 2045. A full flight of 72 passengers, including international media, were on board the Braathens Regional Airlines ATR 72-600 turboprop, the regional aircraft with the best environmental credentials, which took one hour to reach its destination.

According to ATR, the ATR 72-600 has an environmental advantage, in that it produces 40 per cent less carbon emissions per trip compared with regional jets, saving 4,000 tonnes of carbon emissions per aircraft per year. ATR aircraft can also take off and land where other aircraft cannot, ensuring accessibility to all airfields, including those that are the most challenging. This helps connect more communities and provides more opportunities for people, wherever they live.

With the electrification of commercial aircraft thought to be decades away, advances in aircraft efficiency and the use of SAF is likely to play a significant role in supporting the aviation industry to meet its ambitious target of reducing carbon emissions to half 2005 levels by 2050.

The Perfect Flight was powered by SAF supplied by Air BP and produced by Neste. The fuel supplied will produce up to 80 per cent fewer emissions over its life cycle compared with conventional jet fuel and is produced from non-palm renewable and sustainable raw materials. In addition, Air BP's operations at Halmstad City Airport is one of its more than 250 locations that have been certified as carbon neutral since 2016.

Following the flight, a responsible aviation seminar was held at Stockholm Bromma Airport where the crew shared the results of how The Perfect Flight had been achieved. A host of experts shared their views, including Peter Larsson, CEO, Sweden's Regional Airports; Jonas Bergman, Mayor of Halmstad; Tom Anderson, Senior Vice President, Programmes and Customer Services, ATR; Anna Soltorp, Head of Sustainability, Braathens Regional Airlines (BRA); Tom Parsons, Commercial Development Manager, Low Carbon, Air BP; and Andreas Teir, Vice President Renewable Transportation, Nordics, Neste.

From his seat on The Perfect Flight, Parsons said: "At Air BP we are committed to working across the industry to meet our collective carbon reduction goals. Today has highlighted what is possible when we all work together, and we are proud to have been the supplier of sustainable aviation fuel for this perfect flight. We will continue to look for ways to reduce emissions in our own operations and for our customers."

Meanwhile, Soltorp commented: "We want to continue to fly 'perfectly' in the future. To achieve this, it is important that we can access sustainable aviation fuel in sufficient quantities and at the right price. For that we need political initiatives. We intend to continue the development of sustainable flying to make every flight as close to perfect as we possibly can. As a society we need to take action to combat climate change and drastically reduce emissions, aviation must play its part in this. Today, we have demonstrated what can be achieved through more efficient flying without compromising connectivity. It is another positive step forward."

Anderson added: "Today, using existing technology and available solutions, we have pushed the boundaries even further. This great achievement wouldn't have been possible without using an ATR aircraft, as our ATR 72-600 version uses 40 percent less fuel and emits 40 per cent less CO_2 than a regional jet. We are delighted to have taken up this challenge and demonstrate what is possible, which will hopefully set an example for other communities around the world."

Teir commented: "Aviation stakeholders in Sweden have adopted a proactive approach to show their commitment to reducing emissions from their operations by promoting the use of renewable jet fuel. Decarbonising aviation calls for close co-operation between aviation stakeholders combined with a strong willingness to work collaboratively. We are proud of our partnership with Air BP in bringing sustainable jet fuel to Sweden, which sends a strong signal to the international aviation community also."

Corporate social responsibility

BRA has a code of conduct for employees and business partners that is based on ethical business principles, their values and internationally agreed rules, primarily the 10 principles of the UN Global Compact. The code of conduct is regularly communicated to BRA's suppliers. Braathens has a whistleblower function which allows any infringement and any misconduct to be reported anonymously. The airline continuously develops local partnerships to ensure that the whole of Sweden will thrive by supplying efficient flights and is also sensitive to the need for regional transport.

CROATIA AIRLINES

A STAR ALLIANCE MEMBER

Croatia Airlines, the national air carrier of the Republic of Croatia, began its development in the year 1991 with very limited funds. The company has changed its organisational structure a couple of times; the aircraft fleet with old technology was replaced by new, state-of-the-art aircraft; new staff have received training, work procedures have been established; and the company has strengthened its market position.

The process of joining the EU, the company's membership of international airline associations and alliances have encouraged its growth and the programme for the implementation of sustainable development.

Environmental protection

One of the most important challenges of airline sustainable development is a dynamic growth of the airline industry and its influence on global climate change by the emission of CO_2. For that reason, the EU has set up the EU ETS in which, beside other industries, it has included all airlines that operate to and from the EU, thus including Croatia Airlines. The company has set up a regular update and report system of monitoring of CO_2 emissions.

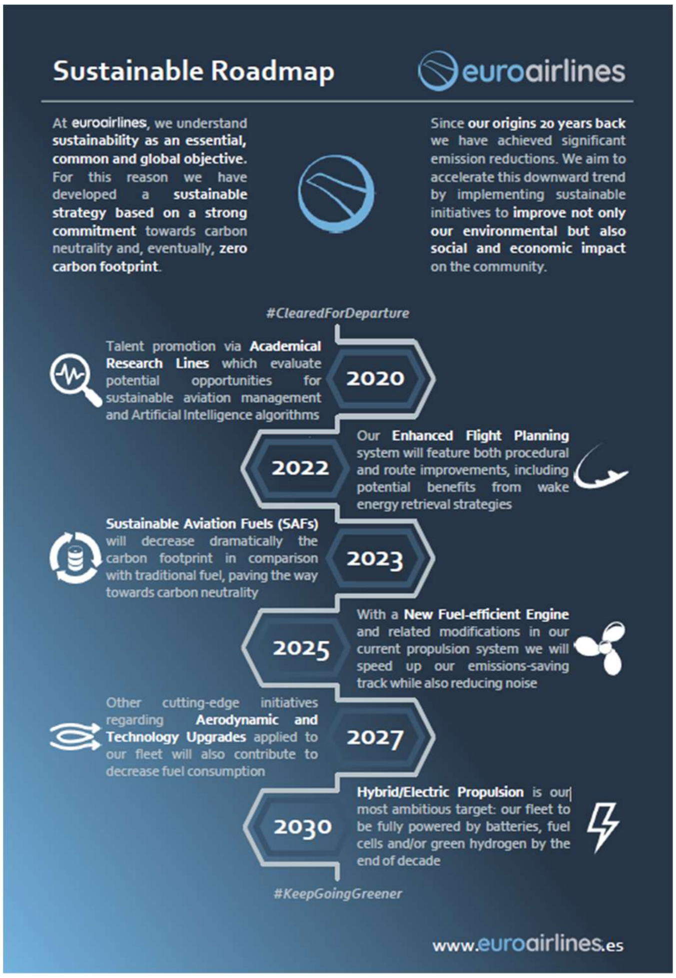
In its growth, Croatia Airlines has been following the principles of sustainable development in the main areas – the choice of its fleet and the application of certain procedures that diminish spend of fuel and CO_2 emissions and noise.

In 2019, the airline:

- modified its Airbus aircraft with wake vortex generators to reduce the noise pitch;
- eliminated plastic cups from its catering from June 2019, thus removing up to about 30 tonnes of plastic waste per year;
- equipped its aircraft with EGNOS/ADS-B equipment which improves spatial guidance, leading to less emissions. This project was co-financed by the European Commission under the Connecting Europe Facility (CEF) programme.

Croatia Airlines has also been recently re-certified for ISO14001/50001 and have few project proposals through local environmental funds.

euroairlines

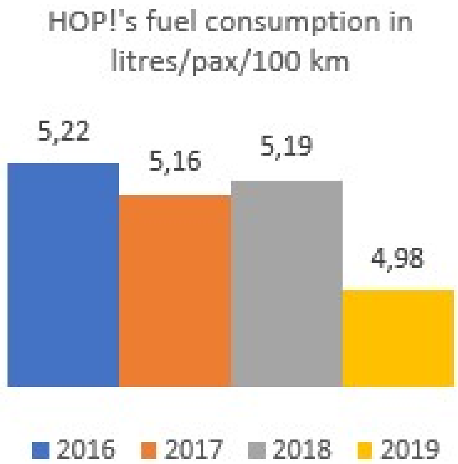


Sustainable commitments and initiatives

HOP! is taking actions and setting objectives to achieve environmental improvements through a programme focussing on three themes.

KéroZen fuel management plan

This is part of HOP!'s strategy to reduce its carbon footprint and the associated expenses. Five areas for progress have been identified, from flight paths planned directly with air traffic control to flight procedures which enable fuel reduction without compromising safety. As a result, HOP!'s fuel consumption has already been reduced from 5.22 litres per pax per 100km in 2016 to 4.98 litres in 2019.



Waste sorting on board

HOP!'s cabin crew have shown great interest in getting involved in environmental actions and since October 2019 they are committed to waste sorting on board: plastic bottles, carton Tetra Pack packaging and aluminium cans. All these materials are handled by the service provider Servair at Paris-Orly and Paris-Charles de Gaulle and recycled in France or Europe. Other caterers will progressively be invited to join in the practice. HOP!'s initiative is part of an Air France commitment to increasing waste recycling, reflecting on professional practices and identifying more sustainable and eco-friendly ones.

Wage war on plastic

Air France has replaced on board all its flights plastic cups with paper cups and plastic sticks with wooden stirrers, HOP!'s flights being included in this process.

Offsetting on domestic flights

Through Air France offsetting commitments, HOP! contributes to neutralising the impact of CO_2 emissions on the planet. As of 1 January 2020, Air France began proactively offsetting 100 per cent of CO_2 emissions on all its domestic flights. In concrete terms, as far as HOP! operating for Air France is concerned, this represents an average of 220 flights and over 20,000 customers concerned per day.

Jet Time has commenced the journey towards sustainability. Danish airline Jet Time, has started its journey towards sustainable aviation. Air travel gives us the chance to see the world and experience new places and cultures. But when we travel by air, we also impact the climate with CO_2 emissions and by generating travel-related waste.

We acknowledge the environmental challenges of the airline industry, and as an airline, we take our environmental impact and responsibility seriously.

As a charter carrier, Jet Time has one of the highest load factors in the industry with approximately 95 per cent of its seats filled on our charter flights from Denmark, Sweden and Finland – and we can do more to make flying with Jet Time more sustainable. That is why we have started on our journey towards sustainability, with focus on social responsibility and our impact on climate and environment, without compromising the profitability of Jet Time as a private company.

Our goals and ambitions

We have the ambition to reduce our environmental impact through a sustainability strategy with three focus areas, namely planet, people and profit, with a number of targets set out to be reached by 2025.

By focussing on people, planet and profit, we strive to reduce our environmental impact, take care of our passengers, employees and everyone else involved in Jet Time's production and value chain, and subsequently generate sustainable profit for the long term.

As part of our ambitions, we will in Jet Time strive to:

- reduce CO_2 emissions on Jet Time's flights by a minimum of 15 per cent from 2015–2025 (per passenger seat kilometre);
- reduce single-use plastic consumption on board Jet Time's flights by a minimum of 50 per cent from 2020–2025;
- utilise biofuel as alternative to fossil fuel to the extent feasible;

- work actively to minimise and mitigate non-biodegradable waste;
- source-separate waste to the extent feasible;
- ensure health and safety for people throughout our value chain; and
- be ambassadors of positive change towards sustainable aviation.

A sound framework and strategic co-operation

Environmental management framework

To strengthen our work towards sustainability, we have since 2014 worked with environmental process and management under the ISO 14001:2015/50001 certification.

The ISO 14001 framework contributes with process demands and tools that secure a systematic effort to reduce fuel consumption and the emission of GHGs. A dedicated, internal ISO group ensures a structured approach to the overall work with sustainability and the ISO 14001 framework is actively integrated into Jet Time's overall sustainability strategy.

Sustainable development goals

Jet Time supports the UN's Sustainable Development Goals (SDG) that serve as a blueprint to achieve a better and more sustainable future for all. The UN SDG framework is a good guideline for Jet Time, as these goals address the global challenges we face, including those related to sustainable production, health, climate and environment.

We have chosen to actively work with goal 12: consumption and production patterns; goal 8: decent work and economic growth; and goal 3: healthy lives and promote well-being, as these relate to Jet Time's core business and as we believe this is where we have the biggest impact.

Internal commitment and partner co-operation

The road towards more sustainable aviation is ongoing and long – but by joining forces in the industry, it becomes possible to share ideas and co-create on a joint sustainability effort. Since September 2019, Jet Time has co-operated with relevant sustainability stakeholders in TUI Nordic to make our flights greener, working together to mitigate the environmental impact of our shared flights.

Likewise, all employees at Jet Time are invited to share their ideas and knowledge about how we can work towards our 2025 goals and ambitions to make our business and production more sustainable.

The internal work towards sustainability in Jet Time is organised in three working groups each with a specific focus area – one for making the on-board service greener, one for reducing CO_2 and one with a people-specific focus. By placing the actual work towards sustainability within the organisation in the different departments, it is ensured that those who know the most about our improvement potential address the different projects in the most direct manner with focus on the selected UN SDG goals.

Accelerated focus with fast results

Jet Time has for many years been working on minimising the environmental impact of the airline's production, for example, through the ISO 14001 environmental management framework and the UN Global Compact. This focus was accelerated in 2019 where Jet Time's revised sustainability strategy was officially implemented in the organisation with its clear 2025 goals and ambitions.

This has resulted in the development and implementation of a large number of sustainability priorities that each contribute to Jet Time's journey towards sustainability.

Reducing CO_2

As a primary sustainability focus, it is Jet Time's ambition to reduce CO_2 emissions on own flights by 15 per cent over a ten-year period from 2015–2025. To achieve this goal, aircraft weight reduction is of outmost importance – and every kilo counts, both when it comes to weight and performance of the actual aircraft, but certainly also when it comes to the things we bring on board each flight.

Less paper on board

One focus of weight reduction has been to reduce paper consumption in our production through more digitalisation, where more electronically based communication both creates a more agile way of working but also reduces the amount of paper used on board our aircraft.

An example is the introduction of an EFB as replacement for paper manuals where two digital tablets holding the same information have replaced approximately 20kg of paper in each cockpit of Jet Time's aircraft. This saves a significant amount of production-related paper waste, just as it has lowered the weight of the aircraft, reducing the annual CO_2 emission by approximately 48 tonnes of CO_2 per year.

Another and very tangible effort to minimise paper on board has been to reduce the number of in-flight magazines on board each Jet Time charter flight. As not all magazines are read at the same time, it was decided to reduce the number of magazines on board our aircraft by only placing the in-flight magazine in the aisle and window pockets, thus leaving the middle pocket empty. The reduction is equivalent to one third of all in-flight magazines on all flights, which on average reduces 10.5kg paper on each flight. This has resulted in an annual reduction of 13 tonnes of fuel, equalling 40 tonnes CO_2 emissions.

LED tubes

Another example of aircraft weight reduction is the change of the cabin lights on all our B737-700 aircraft, where fluorescent light tubes have been changed to a modernised LED light system, reducing each aircraft by 30kg. In addition, the LED light has a longer duration than fluorescent light tubes and have in that way less impact on the environment. This weight reduction is equivalent to an annual CO_2 reduction of approximately 72 tonnes.

Split-scimitar winglets

Reducing CO_2 emissions is of course not only a question of weight reduction but also a question of the performance of the aircraft. In 2019, Jet Time introduced its first two B737-800 aircraft with split-scimitar winglets.

Jet Time has for many years had regular winglets on all aircraft that reduced 2–3 per cent of fuel consumption compared to aircraft without winglets. With the split-scimitar winglets, fuel consumption is reduced by an additional 1.5 per cent meaning that Jet Time's two new aircraft will save approximately 154 tonnes of jet fuel each year, thus reducing Jet Time's CO_2 emissions by 480 tonnes CO_2.

Green power in the hangar

Although our primary sustainability focus at Jet Time is to reduce CO_2 emissions of our aircraft, sustainability in all other parts of our organisation is also welcomed. When it comes to energy consumption, Jet Time's technical division is the second-most energy intensive part of our production. It requires quite a lot of energy to keep Jet Time's hangar lit and heated, and although we have successfully reduced our energy consumption in the hangar, for example, by changing to LED light and installing a new hangar door, Jet Time's technical department still has an annual energy consumption equivalent to that of 89 Danish families.

In an effort to make that consumption greener, we have changed our energy supply from fossil fuels to offshore wind turbines in accordance with the European Energy Certificate System (EECS). This means that we now compensate for our CO_2 emissions of our technical division, equivalent to 153 tonnes of CO_2 a year.

A greener on-board service

Sustainability and environmental impact is also a focus when it comes to catering for Jet Time's passengers. Here, one focus area is to make the Jet Time on-board service greener, for example, by reducing single-use plastic and unnecessary waste. We have the ambition of reducing our on-board plastic waste by 50 per cent from 2020–2025. This goal, will among other initiatives, be achieved by looking at how we can change some of our plastic wrapping to biodegradable alternatives. However, we are also looking at how we can remove unnecessary plastic on board like straws and stirrers, just as the products we serve on board in some cases will be substituted with more sustainable alternatives.

No red meat policy

In 2019, Jet Time implemented a no red meat policy, meaning that no beef, pork or lamb is to be served on board our flights. To live up to this policy, 24 tonnes of beef was in 2019 substituted with chicken in Jet Time's hot meal menus. This change in protein has resulted in a CO_2 reduction of approximately 4,000 tonnes of CO_2 as a spill-over effect in Jet Time's supply chain.

Source separation of waste

In 2019, an internal investigation showed that we generate approximately 60kg waste on an average round-trip flight. To make our flights more sustainable, we are looking at how we can reduce the amount of waste, but we are also looking at how we can make our waste and our handling of it more sustainable – sending our used cans from our on-board passenger service for recycling is the first step in this process. Jet Time's cabin crew has therefore, since late 2019, been collecting all used cans on board our flights as separate waste for recycling. This will potentially send approximately seven tonnes of aluminium cans for recycling each year.

Reduced dry store load

Another example of the work towards a greener on-board service is a reduction of waste by only bringing on board the items that we need. In spring 2020, Jet Time's crew has participated in counting all unused dry-store items left on our flights, for example, milk, sugar, cups and napkins. That has given us data to adjust the items we bring on board and thus reducing waste significantly. By only bringing on board the sugar we actually need, we will, for example, reduce the annual sugar consumption from Jet Time's charter production by approximately two tonnes.

The future looks greener

With the development and implementation of these, and many other sustainability projects with a clear strategy and internal process, we have in Jet Time made a big leap in our continuous journey towards more sustainable aviation.

One parameter for a successful journey and an accelerated sustainability focus is active industry networks, employee commitment and strong partnerships where knowledge is shared and ideas are generated. Another parameter is innovative technology for more sustainable flights and an increased availability of SAFs, which are an important focus area for Jet Time going forward.

The journey towards sustainability has just begun, and we expect the future to look green, and also for the airline industry.

Jet Time is a Danish-owned airline founded in 2006. The company operates purely business-to-business, delivering charter transport and ACMI solutions to tour operators and airlines with need for air transport capacity.

Jet Time has grown from being a small company, with two aircraft and a handful of employees, to a major player in the Nordic aviation industry and a large company in Denmark with more than 500 employees. We currently operate a unified fleet of 12 B737-700 and -800 NG aircraft.

Jet Time had in the financial year 2018/19 a production of 33,771 block hours, a turnover of DKK 1.444bn (€190m) and a profit before tax of DKK 31.9m (€4.2m).

KLM Cityhopper

KLM Cityhopper's sustainability targets and results must be seen in the broader context of AF–KL strategy and targets.

Carbon offsetting programme

KLM Cityhopper (KLC) is aligned with KLM's CO_2 compensation service, CO2ZERO, which enables KLC's passengers to compensate for their share of the CO_2 emitted during their flight. CO2ZERO was launched in 2008 and at the time KLM was one of the few airlines with its own carbon footprint compensation service. Over the past 12 years, more than 420,000 tonnes of CO_2 emissions have been compensated via KLM's CO2ZERO. In 2019, over 175,000 passengers travelled CO_2 neutral with KLM's CO2ZERO service.

KLM's CO2ZERO enables passengers to engage in CO_2 neutral travel by compensating for CO_2 emissions from their flight(s). This can be done when booking or via MyTrip on the KLM website before they make their flight. KLM invests these compensation funds in CO_2 reduction projects certified with the Gold Standard for Global Goals. These projects do not only reduce CO_2 emissions, but also promote local sustainable development. KLM only invests the compensation funding in projects that are certified within the Gold Standard of the Global Goals, such as the 'CO2OL Tropical Mix', a project which transforms former pastures into new forests consisting of a mix of tree species and a variety of ecosystems.

Carbon footprint reduction

KLM works with a carbon reduction roadmap to reduce its carbon footprint. This plan means we can focus on the solutions that are available today, while keeping abreast of developments in the sustainable aviation fuels of the future.

In 2007, KLM drew up a policy to reduce the environmental impact of its own operations. The current goal is to reduce absolute CO_2 emissions by 15 per cent in 2030 (compared to 2005). By the end of 2019, we had reduced our total carbon emissions by four per cent. In relative terms, KLM lowered its CO_2 emissions per passenger with 31 per cent compared to 2005.

KLM's carbon reduction roadmap contributes to one of the United Nations' Sustainable Development Goals (SGDs); namely, SDG 13: climate action. KLM has identified three ways to reduce the carbon footprint of its flight operation: reduce fuel consumption, replace fossil fuel, substitute and compensate for CO_2 emissions. Each entails a different approach. Increasing the sustainability of the ground operation is also part of KLM's roadmap to reduce its carbon footprint. KLM aims for zero emissions of ground operations by 2030.

Smart and sustainable

KLC is also part of the smart and sustainable action plan. It contains a comprehensive set of topics and actions to make the aviation industry in the Netherlands more sustainable.

This action plan revolves around the idea that a combination of Dutch ingenuity, innovation and close co-operation between all stakeholders will boost sustainability in the short, medium and long term. In this regard, it is important to bear in mind that the air transport sector is complex and diverse, and that increased sustainability can only be achieved through co-operation throughout the international chain. This presents a bright future for air transport through 2030, with onward projections to 2050, offering an appealing and collective route to achieving these objectives.

The Dow Jones Sustainability index (DJSI), the main international index evaluating companies on their performance in terms of sustainable development, has put Air France-KLM for the 15th consecutive year as one of the frontrunners of the DJSI's Europe and World Index and in the year 2019, Air France–KLM has secured the top spot.

All companies in the Air France–KLM Group are deeply committed to reducing their carbon footprint; it has entered our DNA. With all our partners, we are working on plans to be even more ambitious, with large investments in new fleet (effectively reducing CO_2 emissions more than 25 per cent compared to the aircraft they replace), lighter equipment, smarter operational procedures, but also on SAFs.

Luxair

Luxair is committed to pursuing its efforts in decarbonising the aviation industry, after decades of progress that have halved aviation emissions per passenger worldwide since 1950, whilst maintaining connectivity between individuals and businesses.

Newer and cleaner aircraft

Operating cleaner planes is the first way an airline can reduce its environmental impact. This is why Luxair chose the De Havilland Q400 as the mainstay of its fleet. This aircraft is considered to be the most environmentally-friendly model on the market with a 30–40 per cent reduction in fuel consumption on certain types of journeys. This is obviously interesting for Luxair from an economic point of view, but it also allows the airline to significantly reduce CO_2 emissions.

A closer look at the aircraft's engine explains why the Q400 is so efficient. The Q400 uses turboprop engines that use the hot air produced more effectively to provide greater fuel efficiency. That said, this aircraft is slightly slower than a jet. The Q400 must be used for shorter journeys to have a real impact on CO_2 emissions; it is therefore the most logical choice for operating Luxair's European destinations. On average, the 19 aircraft in its fleet are 6.5 years old. Aircraft are generally designed for 40 years of service. Advances in technology means that older aircraft generally consume more fuel and emit more CO_2. Furthermore, Luxair's maintenance teams replace aircraft engines when necessary. The airline replaced one Boeing 737-700 engine in 2019 and three more are due to be changed in 2020. This is an expensive enterprise as an engine costs $10m (€8.85m) on average, but fuel consumption is then reduced by two per cent.

Hunting weight everywhere

Luxair's teams also constantly review ways of optimising aircraft fuel efficiency through operational adjustments, in addition to its aircraft selection and renewal strategy. "It's first and foremost a matter of reducing the weight of the aircraft," reveals Daniel Colling, Vice-President of Luxair Flight Operations. "Over the past few years, for example, we have removed the integrated boarding stairs from our Boeing 737; optimised the amount of drinking water on board; developed our own electronic flight bag with a tablet containing all the information crew need throughout the flight (limiting paper documentation and extra weight). We are currently looking into a digital alternative to on-board paper magazines and newspapers. All these combined measures have allowed us make a small percentage of fuel savings."

Each procedure is carefully considered before its implementation. "For example, we analysed the average amount of water consumed on flights over a sufficiently long period before reducing the amount of water carried on board by 70kg without affecting our passengers' comfort." Pilots also have their part to play in the quest to further reduce aircraft weight. Luxair planes carry more fuel than is legally required, which already includes an extra safety reserve on top of the amount needed for the journey. "However, pilots have the final say on the amount of fuel carried and often tend to overestimate this reserve," Colling continues. "I will soon be launching an in-house awareness raising campaign again about this issue, which should reduce the weight of our aircraft further still."

New trajectories and new procedures

However, when it comes to making aircraft lighter, there are some physical limitations that cannot be overcome. Luxair's aircraft are carefully cleaned to reduce their weight, as well as lower their air resistance. Specific components have also been fitted to make the aircraft more aerodynamic and reduce consumption. "Both standard and split-scimitar winglets have been installed on our 737s for example," explains Christoph Blaha. "They have been placed at the end of the wings. This improves efficiency by reducing the drag caused by lift without increasing the wingspan.

Lastly, various procedures on the ground and in the air have been implemented over the years to reduce fuel consumption. "The Q400s only use one engine whilst taxiing on the ground. Many procedures can also be optimised in the air, such as retracting the flaps and reducing power a little earlier after take-off or maintaining a continuous descent for landing, and so on," Colling states. "An algorithm is also used during flights to adjust speeds and flight trajectories to weather conditions to optimise fuel consumption. Manufacturers install this algorithm on large aircraft but not on small ones, so we developed one specifically for our Q400s." Airlines must pursue their efforts for a more responsible aviation industry. Luxair will continue to implement the procedures that keep it one step ahead until alternative energy sources, such as biofuel or even electricity, become a reality.

Developing environmental projects

Luxair ensures that it offsets its environmental impact and is currently considering various projects, such as agroforestry. "It's all about regenerating wasteland by planting trees and vegetables, and so on," explains Paul Nilles, Environment Co-ordinator at LuxairGroup. "This regenerated land would be managed by protected workshops and its produce could be served on our planes." The LuxairGroup head office building was sustainably designed, whilst the grounds were developed according to the Syndicat Intercommunal à Vocation Multiple (SIAS) association's advice. LuxairGroup also keeps black bees on its roof and uses electric vehicles in-house, to mention just a few of the company's many other green initiatives.

EMBRAER

Embraer, as the leading manufacturer of commercial jets up to 150 seats, has continuously advanced technologies and design in its aircraft in order to reduce their environmental impact, in terms of both emissions and noise levels. The company is working hard not only to make its products more efficient and sustainable, but it is developing local initiatives in its plants to reduce energy consumption and to increase the recycling of waste and water.

Embraer's most advanced commercial aircraft family, the E-Jets E2, brings minimum impact for the environment through its systems, airframe and engine. Compared to the first-generation E-Jets, the E-Jets E2 offers up to 25 per cent reduction in fuel burn per seat and CO_2 emissions, which amounts to around 3,600 tonnes per aircraft per year.

In order to reduce emissions of nitrogen oxides (NOx), unburned hydrocarbons (UHC) and carbon monoxide (CO), the PW1000G engine family uses the TALON X combustors (Technology for Advanced Low Nitrogen Oxide), developed by Pratt & Whitney in partnership with NASA, which delivers over 35 per cent margin to CAEP/8 emissions standard. The E2 also presents large margins to CAEP/8 standards when it comes to parameters such as hydrocarbons, carbon monoxide (CO) and smoke, being more than enough to cover for future CAEP updates.

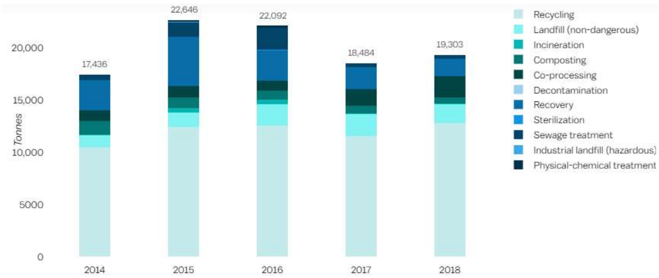
Table 1. Margins to CAEP/8 Limit.

EMISSIONS PARAMETER	MARGIN TO CAEP/8 LIMIT		
	E175-E2	E190-E2	E195-E2
HC	99%	98%	98%
CO	75%	72%	76%
NOX	37%	39%	40%
SMOKE	74%	89%	86%

When it comes to noise levels, the E-Jets E2 count with 20 EPNdB margins to Stage 4 standards, the quietest aircraft in its class. Also, the significant reduction in noise contours in airports – such as Charles de Gaulle in Paris (65 per cent), Congonhas in São Paulo (65 per cent), and Changi in Singapore (70 per cent) – provides an opportunity for additional 2–3 per cent reduction in aircraft cash operating cost via lower noise fees, direct flight tracks and curfew extensions.

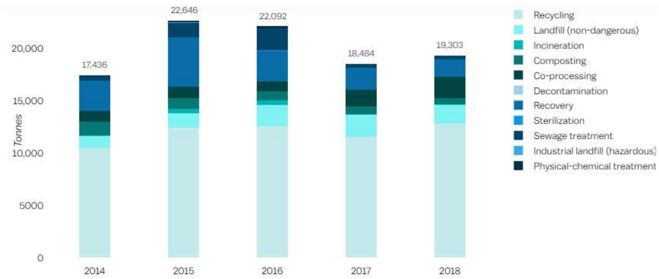
Regarding its facilities in Brazil, Embraer has been investing in solutions to reduce water consumption, seeking to optimise and reuse water in its processes. Recycled and reused water is used mainly in gas scrubbers and cooling towers, processes that consume large amounts of water as well as in the washing of manufacturing and administrative areas. Other initiatives, such as the installation of double action flush, ecological urinals and tap aerators in the toilets, have been carried out in order to reduce water consumption. With these initiatives, Embraer has been able to increase its total amount of recycled water year after year (see Figure 1).

Figure 1. Total amount of water recycled and reused per year.



The company has also been successful in increasing the total amount of recycled waste. In 2018, more than 75 per cent of its total waste was recycled.

Figure 2. Total weight of waste, separated by disposal method.



In addition, ongoing energy saving projects, through improvements in lighting, installation of photovoltaic panels and the replacement of air conditioning machines in our plants, have delivered strong results in 2018.

Table 2. Reduction of energy consumption (2018).

Project	Unit	Annual savings [*MWh*]
Improvements in lighting	GPX	1,220
Photovoltaic panels	SJK	200
Replacement of air conditioning machines	SJK	1,807
	Total	**3,227**

AIRBUS

Shaping the future of flight

Aviation has the power to connect people and cultures. Airbus, as a pioneering, worldwide leader in commercial aviation, is committed to ensuring the next generations can fly with respect for the planet and is proactively contributing to the development of sustainable air travel through innovation and continuous improvement.

The A220 family: purpose-built for efficiency

The A220 family combines state-of-the-art aerodynamics, advanced materials and latest-generation technologies and engines, together translating into a lighter and more efficient aircraft.

The A220's avant-garde design features a low drag nose and tail cone, the smallest fuselage wetted area, optimised wing aerodynamics, and is powered by the latest generation geared turbofan engines. As the only aircraft purpose-built specifically for the 100–150-seat market segment, the A220 is simply the most efficient and environmentally-friendly aircraft in its category, featuring 20 per cent lower fuel burn and CO_2 emissions per seat compared to previous generation aircraft, NO_x emissions up to 50 per cent below CAEP/6 limit, as well as noise reduction of up to 50 per cent compared with previous generations of aircraft.

Airbus' latest addition to its single-aisle family will significantly contribute to further reduction of both emissions and noise.

Hybrid electric flight: a giant leap towards zero-emission flight

The aviation industry has committed to carbon-neutral growth starting from 2020, for which electric and hybrid-electric propulsion are very promising solutions.

With the E-Fan X, Airbus will be the first to flight test a hybrid-electric propelled demonstrator in 2021: using a BAe146-RJ100 as a platform, the teams will flight test a serial hybrid-electric propulsion architecture composed of a 2MW electrical power unit, a gas turbine with an integrated 2MW generator and a 2MW battery pack controlled by a unit called the e-supervisor

Electric flight for the urban skies

Airbus has a long history of designing, certifying, and manufacturing airborne vehicles. The company has been a successful architect in commercial aviation for 50 years, putting millions of parts together and integrating thousands of vendors to take commercial aircraft to the skies.

The concept of a 'flying taxi' first came from the idea of taking city commuting into the air in a sustainable way. Airbus teams began by rethinking traditional aircraft architecture, creating a multi-rotor design based on electric motors. And so, CityAirbus was born.

CityAirbus is a fully-electric, four-seat, multi-copter vehicle demonstrator, and one of the urban air vehicles solutions proposed for congested urban areas.

ATR

Part of our identity

Ever since ATR's creation 35 years ago, protection of the environment has been part of our identity. ATR turboprops not only have the world's lowest energy consumption per passenger per kilometre of all regional aircraft in their category but are also good neighbours in terms of noise levels, at nine decibels below ICAO regulations.

Indeed, the ATR 72-600 aircraft has a significant environmental advantage over regional jets and other turboprops, emitting 40 per cent less CO_2. Turboprops are more efficient than jets on short sectors as they accelerate air using less power, so use less fuel.

The spirit of ATR is therefore to combine connectivity to sustainability by propelling sustainable aviation.

Fuel efficiency and low CO_2 emissions

Like the jet, the turboprop engine uses a thermodynamic turbine. With its large propeller and a gearbox, the turboprop engine moves a greater quantity of air for less thermal power. A turboprop burns 40 per cent less fuel than a jet on short distances. It represents 4,000 tonnes of CO_2 emissions saved per aircraft per year and less than 2.6L/100km fuel consumption for a 550km trip on a per-seat basis.

Biofuel and new technologies

ATR's determination to reduce operator's environmental impact is also a driving factor in our development of technologies and our commitment to biofuel.

Some sustainable alternative fuels can reduce an aircraft's carbon footprint by up to 80 per cent over its entire lifecycle. However, they are also three to four times more expensive than ordinary fuel. ATR sees as its duty to support local development of sustainable alternative fuels by investing in them and supporting their use, especially in important markets for ATR that have strong biofuel production potential such as Indonesia or Brazil.

ATR is involved in the Toulouse Biohub bringing together local authorities, the aviation industry and oil companies to support local production.

With regard to new technologies, ATR engineers are working hard to yet further improve both the environmental and the economic efficiency of our aircraft via engine, propeller and aerodynamic adjustments. These include studies for a new engine version that will use 3–5 per cent less fuel; and a process of 'aerodynamic cleaning' to reduce overall drag by 2–3 per cent. All these improvements could enter into service by 2021 and would yet further reduce our turboprops' fuel consumption, CO_2, NOx and micro particle emissions and noise level.

All of which goes to prove that measures to protect the environment can boost economic savings too, making this a win–win situation for the planet and the operators alike.

Green financing

ATR delivered the very first aircraft acquired with 'green' financing.

The aircraft was leased under an environmental initiative known as the 'green loan' principle.

Green loans are defined by the Loan Market Association as instruments made available exclusively to finance eligible green projects, which need to meet certain core criteria, including utilisation of the loan proceeds to meet environmental sustainability objectives. Green loans require the borrower to use proceedings on eco-friendly projects.

This first ever green financing of an aircraft confirms the high sustainable value of the modern ATR turboprop aircraft. ATR is one of the best assets in terms of residual value retention in the business.

Accessing the most remote airports and connect the most remote communities

Not only do turboprops offer the right capacity and technology, they also reach places where no other aircraft can go: more than one third of the world's commercial airports rely exclusively on turboprops. By using aircraft well over 2,000 new routes have been opened.

To increase the possibility of reaching even more remote areas and giving the opportunity of sustainable economic growth and connection, ATR has developed a variant of its ATR 42-600 that allows to take off and land from much shorter runways. The ATR 42-600S, can take off from 800m paved runways with 40 passengers in standard meteorological conditions for 200 nautical miles (nm) missions, as opposed to the 1,050m lower limit for the non-STOL variant.

The 42-600S will have a larger rudder for increased control at lower speeds and will be able to symmetrically deploy its spoilers to improve braking efficiency on landing. It will come with an autobrake system, to ensure full braking power occurs immediately upon landing.

The aircraft will be powered by the Pratt & Whitney Canada PW127M engine, like the standard ATR 42-600 and ATR 72-600. But pilots will be able to select between engine ratings for the ATR 42 and ATR 72 in order to increase power for STOL operation or operate more efficiently with less power on longer runways.

The STOL version will give about 500 more airports, with runways from 800–1,000m in length (2,625–3,280ft), the possibility to expand regular air traffic. The STOL version could help airlines widen their horizons. For example, Tahiti is a territory as big as Western Europe, but with just 283,000 inhabitants spread over 118 islands. Only 47 of these islands have airfields enabling regular air service to Tahiti, the main island with the French overseas territory's capital Papeete.

The two main islands Nuku Hiva and Hiva Oa get daily service from Air Tahiti and the remote Marquesas archipelago, the home of painter Paul Gauguin and Belgian chansonnier Jacques Brel, is a dream destination for many visitors. On these popular and profitable routes Air Tahiti has carried in total 826,000 passengers in 2018, one third being tourists, with 539,000 guests flown. Almost a quarter of all passengers, 199,702 to be precise, flew on the bread-and-butter run between Tahiti and Bora Bora, the biggest tourist destination.

But, on the other hand of the spectrum there are islands such as Reao or Vahitai with less than a hundred inhabitants, such destinations are serve once a week, though they generate less than 300 passengers a year for Air Tahiti, it's a community service not subsidised by the government. Moreover, the smaller neighbours Ua Pou and Ua Huka have to be reached by connecting flights in Twin Otter or Beechcraft aircraft because ATRs normally need about 1,200m of runway to operate, but Ua Pou and Ua Huka only offer 800 meters. These connecting flights makes operations expensive. ATR's new STOL version could enable Air Tahiti to reach these islands and lower the costs.

Beechcraft | Cessna | Hawker
TEXTRON AVIATION

Sustainability starts at home

Textron Aviation aircraft, consisting of Beechcraft, Cessna and Hawker models, accounts for more than half of all general aviation aircraft flying today. In 2019, the company delivered more jets than any other business aircraft manufacturer in its segment, according to the annual shipment and billings report published by the General Aviation Manufacturers Association (GAMA). In total, Textron Aviation has delivered more than 250,000 aircraft in over 170 countries.

Given the diversity of its product line and extent of its operations, Textron Aviation's sustainability strategy is still evolving as new technologies become available. Yet the clarity of its vision reflects the leading position this manufacturer holds in the industry.

"Sustainability starts at home," says Brad White, senior VP of operations at Textron Aviation. "As a manufacturer, we must find ways to make sure our product line has longevity, and that means understanding how to operate in a carbon neutral way."

Clean energy in Kansas

In October 2018, Textron Aviation signed up to a 20-year green energy programme with Evergy, an electric utilities business providing emission-free energy to Kansas and Missouri. The Renewables Direct programme should begin in 2020 following the construction of a wind farm in Nemaha County, Kansas, and will replace nearly all of Textron Aviation's electrical needs in Wichita and Independence, Kansas with renewable wind energy.

According to a 2019 report by the International Renewable Energy Agency (IRENA), wind energy will transform the global electricity sector. Combined, onshore and offshore wind could generate more than a third of the world's total electricity needs, becoming the prominent generation source by 2050.

"We're deeply committed to renewable energy and are thrilled to be able to utilise the naturally windy atmosphere of our home state of Kansas to power Textron Aviation's business. Evergy's Renewables Direct programme takes us closer to our long-term vision of zero adverse environmental impact, and net zero carbon emissions for our company," says Brad White.

Sustainable Aviation Fuel

Textron Aviation's commitment to renewables is further demonstrated through its actions on SAF. In an internal review process, the company has confirmed SAF as viable across its product line and is working with other industry leaders to explore how to improve access to the fuel.

"We've pledged to take part in the 2020 SAF summit in Washington, DC, hosted by the SAF coalition, and in 2019 we flew aircraft to the trade shows EBACE and NBAA-BACE using a SAF and petroleum-based jet fuel mixture," notes Rob Scholl, senior VP of sales at Textron Aviation. "Although the availability of SAF is currently limited worldwide, we are supporting organisations such as GAMA, NBAA and EBAA in their work to improve access to the fuel."

The next step

Textron Inc., Textron Aviation's parent company, has been named in the Newsweek Most Responsible Companies 2020 list, largely due to its Corporate Social Responsibility (CSR) programme, in which Textron Aviation plays its part.

"Our employees are passionate about our customers and their aircraft, a dedication reflected in the innovation, quality and market leadership of our products and services," says Scholl. "Looking ahead, our industry's future will be shaped by a focus on sustainability as we continue to embrace new technologies while retaining the confidence and trust of our customers."

Collins Aerospace

Hybrid-electric propulsion – a great start to reducing aviation's carbon footprint

The aviation industry connects people safely, transports goods efficiently, and is a powerful engine for global commerce. It has always been at the forefront of technological innovation and leadership. The world is now looking to the industry to develop enduring solutions that will address carbon emissions and environmental impact.

The aviation industry knows it has a growing challenge – the need to reduce its carbon footprint faster. Over the years, aerospace has made great strides in aircraft efficiency, operations and the production environment, but significantly more needs to be done. The data is incontrovertible. If you consider the world's human-generated carbon dioxide emissions, as well as CO_2 emissions from all transportation sources, 2–3 per cent of the former and 12 per cent of the latter are generated by the aviation industry. As the most recent example of just how seriously the industry is taking this issue, in February, Delta Airlines announced it would commit $1bn to become the first carbon-neutral airline globally.

Source: leonard_c/E+ via Getty Images

So, here are a few important questions that get to the crux of the challenge. How does our industry reduce its carbon footprint while ensuring the technological advance and economic viability of one of the world's great industries? How can aviation be a force for sustainability and continue to be a source of economic vitality? The challenges posed by these questions are worthy of thoughtful consideration.

Many within the aviation industry are convinced that the answer lies in electric propulsion. The difficulty – and it is huge – is that energy storage (battery technology) needs to advance. Today, we have two serious challenges to electric propulsion.

1. Energy and power density

Weight is not an aircraft's friend. If we installed today's electric batteries that could power a commercial air transport aircraft, the aircraft would be so heavy, that it would be aerodynamically, operationally and economically unfeasible. Even smaller, regional electric aircraft would have a range of less than 500 nautical miles. And, again, it would be economically unsustainable.

The reason is a function of the ability to store energy (expressed as energy density in kilowatt–hours per kilogram), and the ability to convert that energy into power (expressed as power density in kilowatts per kilogram). The task ahead of us

is evident when you consider that jet fuel has 50 times the energy density of today's batteries, and a typical jet engine has three times the power density of today's electric engines. Further, as a traditional aircraft burns fuel, the aircraft gets lighter. It should be noted – at least parenthetically – that jet fuel is much cleaner and more efficient than in previous generations, and innovation should ensure that it's even less polluting in the future. But fuel still pollutes.

Bottom line, an all-electric transcontinental aircraft will need orders of magnitude improvement in energy and power density and isn't expected to be viable anytime soon.

2. Power management

In addition to generating more power, we also need to be able to control, protect and manage the power and thermal environment. Managing significant amounts of electrical power at high altitudes is not easy to do and real expertise is needed. Highly-efficient power distribution and conversion is required to maximise the use of available power and minimise the thermal management system. High voltage systems will be required for commercial aircraft. However, isolating high voltage at high altitudes is challenging. Additional spacing and insulation systems are required, and that impacts weight. Also, the safe use and management of electricity on an aircraft – the system design – is critically important and another crucial challenge.

Because of the significant technological challenges to delivering a commercial air transport aircraft with electric propulsion, we believe that the best way to lower the aviation industry's carbon footprint is to begin with hybrid-electric propulsion. This is technologically feasible, and, if smartly planned, will ensure corporate viability and growing job opportunities. Hybrid-electric propulsion for smaller aircraft is the place to start.

- We believe that to power a regional, hybrid-electric aircraft with usable range and less than 50 passengers, the energy and power density of current batteries will need to double. We believe there is a path to achieve this in the next few years, and that a hybrid-electric passenger aircraft with 50 passengers or fewer and a range of less than 500 miles will be certified within the next 10 to 15 years.
- Looking further ahead, to make a single-aisle, 100-seat hybrid-electric aircraft viable will require that densities double yet again. This capability is probably at least an additional 10 years beyond the regional case. This is a four-times density improvement over 15 years.

The challenge is obvious when you consider that it took us 30 years to improve the power density from a 1980s-era, large commercial air transport aircraft by 50 per cent.

The aviation industry is ahead of the technology curve with regard to commercial hybrid-electric propulsion, and this is a big reason why Boeing, Airbus, Collins Aerospace and others are investing now in the research and development (R&D) necessary to make commercial aircraft hybrid-electric and electric propulsion a reality. If you're behind the curve in a high-tech industry like aerospace and defence, it's difficult to catch up. If you try to time the curve – if you try to stay on the curve – that's not leadership and it won't deliver innovation. As an industry, it's crucial that we stay ahead of the curve.

The challenges presented above should not be seen as arguments for delaying work on both commercial hybrid-electric and electric propulsion. In fact, the strongest argument for proceeding rapidly is this: The results for OEMs, airlines, passengers and our environment will be worth it.

Internal United Technologies Corporation studies indicate that commercial hybrid-electric and electric propulsion could:

- reduce aircraft noise up to 85 per cent;[77]
- improve fuel consumption up to 40 per cent;[78]
- reduce carbon dioxide emissions by more than 20 per cent;[79] and
- reduce airline operating and maintenance costs up to 20 per cent.[80]

In April 2019, Collins Aerospace confirmed its commitment to hybrid-electric and electric propulsion technology by introducing The Grid: a 25,000ft^2, next-generation, electric systems integration facility in Rockford, Illinois. The Grid will be the aviation industry's most advanced electric power systems lab and will be the test platform for the development of new products and systems for electric aircraft.

At The Grid, Collins will test high-powered generators, distribution systems, and motors, as well as install and test connected systems, such as actuation, air management and turbo machinery. The Grid will bring aircraft architecture integration testing to another level.

The $50m investment in The Grid is part of a larger $150m total investment that Collins Aerospace expects to make in electric systems over the next three years and builds on the $3bn the company has invested over the past decade.

As Collins Aerospace builds out The Grid, a key focus is on sustainable building practices. So far, we have used:

- 4 million pounds of recycled concrete;
- 500,000 pounds of recycled steel; and
- all-electric tractors to excavate and move soil.

The Grid will also serve as the research and development home for key pieces of United Technologies' Project 804, a regional-size, hybrid-electric demonstrator aircraft that we are supporting along with Pratt & Whitney. The demonstrator will consist of an engine optimised for cruise efficiency and augmented by a battery-powered electric motor. Project 804's hybrid-electric propulsion system is expected to yield an average fuel saving of 30 per cent.

In addition to its key focus on hybrid-electric propulsion, Project 804 is expected to advance other technologies as well, such as more power-dense electronics, lightly hybridised larger engines, and hybrid supplemental power units.

[77] Electric propulsion.
[78] Hybrid propulsion.

As we think about the broader aviation industry, we have a unique opportunity to continue connecting the world and enabling global commerce while reducing emissions and our overall environmental footprint. Strategic investments in next-generation hybrid-electric and electric platforms are well worth it. It's an exciting time for our industry.

ZeroAvia is a leader in zero-emission aviation, flying a hydrogen-fuelled zero-emission aircraft without any fossil fuel support since the spring of 2019. Its focus is the design and commercialisation of hydrogen-electric powertrains for aviation to address a variety of markets, initially targeting short-haul 19-passenger commercial flights up to 500 miles. Based in Cranfield in the UK and Hollister, California, ZeroAvia's current programmes include a six-seat and a 19-seat programme.

By the end of summer 2020, ZeroAvia will demonstrate the readiness of its technology through a zero-emission UK-based 250–300 nautical mile flight from the Orkney Isles in Scotland on a Piper M-class six-seater aircraft, enabled by ZeroAvia's hydrogen powertrain. Its applicability to actually operated commercial routes will showcase ZeroAvia's potential to transform regional travel.

Next, ZeroAvia intends to take its technology development up to 19-seat aircraft, commercially targeting 500-mile flights to serve the short-haul and commuter air travel markets. Powered by ZeroAvia powertrains, smaller zero-emission aircraft can achieve similar per-seat economics as today's large regional jets, allowing economical use of smaller local airports for point-to-point travel with virtually no security lines or delays. In addition to passenger transport, the ZeroAvia powertrain will have applications across other use cases including cargo, air taxis and agriculture.

Starting in 2023, the ZeroAvia powertrain will offer operators a sustainable option for new aircraft made by established manufacturers where customers already purchase their aircraft. ZeroAvia will lease the drivetrain to customers and provide fuel and maintenance as part of its power-by-the-hour model, in which customers pay only for the hours that they use. This model emulates engine leasing options already popular in the aviation market.

Technology

ZeroAvia is focussed on hydrogen because it has four times more energy density than the best electric batteries available today and provides the lowest operating costs. By leveraging hydrogen and fuel cell technology, ZeroAvia aims to enable zero-emission commercial aviation by as early as 2023. In fact, after 10 years of ZeroAvia's commercialisation path (2023–2033), the company's powertrains alone could remove 115 million tonnes of CO_2 from air transport emissions, or 13 per cent of the global industry contributions.

The ZeroAvia hydrogen-electric powertrain is a combination of best-in-class hardware components from several partners and its proprietary software that replaces conventional propulsion systems. ZeroAvia also works with its partners to jointly

[79] Hybrid propulsion.
[80] Electric and hybrid-electric propulsion.

improve the powertrain components for aviation use. Fuel cells use hydrogen to create a chemical reaction that produces electricity, but unlike burning hydrogen, which generates energy at high heat, the fuel cell converts hydrogen into electricity at a low temperature. In its fully redundant system architecture, the fuel cell system provides power to the electric motors, which propel the aircraft.

ZeroAvia can use any hydrogen as its fuel and is starting with compressed hydrogen. The components it uses, such as hydrogen fuel cells, motors, and inverters, are aviation-certified third-party components. With more than 20 patents pending, ZeroAvia brings it all together with a proprietary integration software and hardware to create a complete powertrain system. The system provides full redundancy across the powertrain, which results in much higher safety and reliability than conventional liquid fuel powertrains. ZeroAvia installs the powertrain in existing certified airframes, starting with the Piper M Class for its current demonstrator and test platform, producing 250kW of peak power.

Business model

ZeroAvia's business model is focussed on producing hydrogen-electric powertrains as a drop-in replacement for conventional turboprop engines, in existing airframes, and using the existing leasing model already prevalent in the industry. In this H2 Engine-as-a-Service model, customers will pay by the flight hour, as they already do with their jet engines.

Unlike other electric aviation companies, ZeroAvia will not force airline companies to change how they do business or abandon existing contracts with their current airframe suppliers. Additionally, pilots and maintenance crews of ZeroAvia-powered aircraft will already be familiar with the vast majority of functionality and repair needs for ZeroAvia airplanes, because they are the same as the ICE or turboprop versions. Only the propulsion is different. In this respect, ZeroAvia is heralding a new era of aviation, which has a rich history of adopting new propulsion systems.

Stage

In 2019, the company's six-seat Piper M class prototype was the largest zero-emission airplane to fly. Since its inception, ZeroAvia has completed multiple test flights. ZeroAvia currently holds an Experimental R&D Certificate for its Piper M-Class R&D platform from the FAA.

ZeroAvia was also recently awarded a grant from the UK government that will support the development of the principal technology to enable practical, zero-emission aviation in commercial aircraft. By the summer of 2020, this project will culminate in a UK-based 250–300 nautical mile flight on a Piper M-class six-seater aircraft, a zero-emission combination of range and payload uniquely enabled by ZeroAvia's hydrogen-electric powertrain.

ZeroAvia and its project partners, EMEC and Intelligent Energy, have already engaged with several airports in the UK and beyond for promising discussions of on-site hydrogen production and refuelling.

Beyond its six-seater programme, ZeroAvia is working on a 600kW powertrain for a 19-seat aircraft in 2020 under a schedule similar to its successful six-seat testing programme. The testing starts with battery-electric flights, progressing to multiple hydrogen-powered flight tests in various powertrain configurations, culminating in a demonstration of a 300-mile trip in 2021 as the powertrain gets submitted to the FAA for certification. The 19-seat programme will work with existing suppliers who are tech-tested and de-risked following the success of the six-seat programme.

About the HyFlyer programme

ZeroAvia's HyFlyer project recently received a £2.7m (€3.4m) grant from the UK Government. The UK Government grant is part of the ATI programme, supported by the Department for Business, Energy & Industrial Strategy, the Aerospace Technology Institute and Innovate UK, and will fund ZeroAvia's HyFlyer project to demonstrate principal technology readiness for a hydrogen fuel cell powertrain. The Government's grant is matched by Project HyFlyer participants, making the scope of the project in excess of £5m (€5.6m).

The project will culminate in a UK-based 250–300 nautical mile flight on a Piper M-class six-seater aircraft, which is a zero-emission combination of range and payload uniquely enabled by ZeroAvia's hydrogen powertrain. The HyFlyer project is a key step on ZeroAvia's journey towards supplying to commercial operators and aircraft manufacturers in 2022, initially targeting up to 500-mile regional flights in 10–20-seat fixed-wing aircraft. ZeroAvia's solution aims to deliver the same performance as a conventional aircraft engine, but with zero carbon emissions and at around half of the operating costs.

To date, ZeroAvia's R&D has already achieved the following:

- Flight testing of its powertrain prototype in a Piper M-Class airframe.
- The Federal Aviation Administration issued an Experimental R&D Certificate to ZeroAvia's Piper M-Class R&D platform earlier this year. At a two-tonne takeoff weight and six seats in a business class arrangement, it is currently the world's largest zero-emission aircraft flying without any fossil fuel support.
- The aircraft has completed a variety of test flights, which validated key components and their integration into a complete powertrain system. These tests confirm the company's 'fuel' economy and maximum power delivery targets.

ZeroAvia's HyFlyer is an exciting project because it aims to address one of the most pressing environmental issues of our time, ensuring a sustainable future for aviation. The project links closely to the five foundations of the UK Government's wider industrial strategy. Equally, it brings together a group of innovative UK organisations with the aim of enabling a potentially transformational shift to zero-emission aviation, whilst reducing road and rail congestion, cutting air pollution and noise, promises jobs and improved infrastructure, creating greater choice and convenience for consumers and potentially boosting regional economies across the UK.

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17 June 2020
Version 1