Global Aerospace

# Green Aviation – A Primer

Primer

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## Green Aviation – pressure growing, so will investment

Aviation is under increased scrutiny for its environmental impact. It contributes c.2% of global $CO_2$ emissions and has committed to halving these by 2050 vs. 2005 levels. Airlines and OEMs will increase Investment materially over the next decade to drive decarbonisation via sustainable aviation fuels (SAFs), technology and offsetting. We see SAFs as gaining the most traction medium term given fungibility with existing infrastructure. Investment into zero carbon hydrogen technology will continue, but don't expect the investment cycle ramp this decade. We see electric architectures as a growing focus for eVTOL/small aircraft, but not realistic for large passenger aircraft.

## Tech: short term = evolution; long term = revolution

Replacement of today's fleet with modern 'neo' (New Engine Option) aircraft will help offset growth in emissions, but it is not enough to drive a decline, assuming we return to a sector growth rate of 4-5%. Significant technology advancements are required to drive meaningful change. We see these in two categories: evolutionary and revolutionary. Evolutions encompass new engine architectures, advanced aerodynamics, materials technology and SAF. Revolutions included hydrogen, all-electric and blended wing body.

## Sustainable Aviation Fuels – 'net' zero, not zero carbon

SAFs are a substitute for fossil jet fuels that are produced from sustainable feedstock. They are often referred to as 'drop-in' fuels as their chemical characteristics are almost identical to fossil fuels and they can be safely blended with existing fuels. These are considered net zero, not zero carbon, but they offer major life-cycle carbon reduction. Capacity remains the issue, with production today <1% of annual fuel consumption.

## Hydrogen – a zero carbon molecule gaining traction

Green hydrogen could support decarbonisation and its adoption has started gaining momentum. There are two paths: aircraft powered by hydrogen fuel or fuel cells. Fuel cells + distributed electric propulsion is feasible for short-range light aircraft, but the challenge remains for medium/large aircraft in the long term. Hydrogen is promising as a fuel, requiring manageable engine modifications, but with added complexity of storage and significantly increased volume relative to kerosene, driving a weight penalty. We see this as the path of least resistance for medium/large aircraft in the long term, but wider infrastructure challenges such as hydrogen production shouldn't be underestimated.

## Electric aircraft – growing focus for eVTOL industry

Electrical propulsion may significantly reduce emissions long term, but batteries are an order of magnitude away from the required performance for mid/large-sized aircraft. There are six key architectures under development, but all have weight challenges. Short term, we see development accelerating in the eVTOL sector, where smaller vehicles and specific missions are suitable for current technology.

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# Green Aviation

## The environmental impact of aviation

The UN 2020 Emissions Gap Report recently highlighted that, despite a brief dip in carbon dioxide emissions caused by the COVID-19 pandemic, the world is still heading for a temperature risk in excess of 3ºC this century. This goes far beyond the Paris Agreement goals of limiting global warming to well below 2ºC and pursuing 1.5ºC. In 2018, the UN Intergovernmental Panel on Climate Change (IPCC) reported that to remain below 1.5°C, global emissions must:

- reduce 55% from 2018 to 2030 (vs by 2050 for a 2°C (target))
- be "net zero" globally by 2050

**In order to help achieve this goal, the aviation industry, which contributes around 2% of global $C0_2$ emissions, has committed to halving emissions by 2050 compared to 2005 levels.**

Carbon offsets are currently the industry's primary tool to meet International Civil Aviation Organisation (ICAO) goals. These do not represent absolute reductions in emissions, but will allow aviation to manage its environmental impact whilst it transitions to new sustainable fuels and advanced zero carbon technologies.

According to IEA data, aviation industry emissions have increased by c.27% over the past 5 years, or 4.6% annually, while passenger numbers have grown by about 38%, according to IATA.

Pre-COVID aviation was one of the fastest-growing sectors for emissions globally and the industry is coming under increased scrutiny for its environmental impact. We believe this will accelerate investment into the green aviation sector as the COVID-19 pandemic recedes and recovery takes hold.

Management teams across the value chain are well aware of the growing expectation of sector participation in the global effort to decarbonise the economy. In 2019, several airlines announced their objectives to be carbon neutral by 2050. In 2020, Airbus announced its ZEROe programme, to drive decarbonisation of aircraft through the use of hydrogen. In early 2021, Boeing announced plans to begin producing commercial aircraft capable of flying on 100% sustainable aviation fuel (SAF) by the end of the decade. Investments have grown in the electric aircraft sector with the public listing through a SPAC of both Archer Aviation and Joby Aviation, leaders in the eVTOL (electric Vertical Take-off and Landing) urban mobility space.

We examine the key drivers of decarbonisation of the aviation industry over the next 30 years and split our primer into 6 sections:

1. Sustainable Aviation Fuels
2. Hydrogen (fuel or fuel cell)
3. Electric aircraft
4. The environmental airline
5. Other advanced technologies
6. What are companies current plans for Green Aviation

## What are the key technology trends?

In the past 5 years, the focus of R&T at airframe OEMs to materially reduce emissions has shifted away from electricity and electric aircraft, towards hydrogen and sustainable aviation fuels. In our view, this is recognition that battery technology is an order of magnitude away from the required specific energy to power 100+ seat aircraft for a reasonable range.

Airlines are increasingly focusing on Sustainable Aviation Fuels that are carbon-based, but developed from a sustainable feedstock. Several large global airlines have announced investments and partnerships to help develop SAFs. Engine OEMs are also investing in this area, carrying out test programmes with engines running on 100% SAF to better understand performance and safety, with a view to increasing the certified blend of SAF to above the c.50% allowed today. While SAFs are net zero, not zero carbon, we believe investment will only increase to raise production in the medium term. We see this area as the key focus of industry efforts to decarbonise aviation in the coming years, given the technology is available today, and it is fungible with existing infrastructure and technology.

## Everybody's talking about hydrogen

The focus is growing on hydrogen, both as a fuel and as fuel cells. Fuel cells have a much higher energy density by weight than batteries, but still come with the weight penalty of an electric propulsion system, fuel tanks required to store hydrogen, and a battery system to manage load levelling. The focus of these technologies will likely remain in the smaller/regional aircraft segment in our view at least in the medium term

### Hydrogen fuel is technically less complex than fuel cells

Hydrogen/other non-drop-in SAFs such as ammonia have the potential to reduce the carbon footprint of the sector as zero carbon fuels. The technology requires modifications to engines and technically challenging storage on the aircraft, but it is technically less complex than hydrogen fuel cell. Bloomberg has reported that Airbus is increasingly favouring the hydrogen turboprop design to meet its objective of developing a hydrogen aircraft by 2035. However, hydrogen-powered aircraft, if achievable in this timeframe, are targeting c.1000-2000nm in range (more likely the lower end), meaning medium term, drop in SAFs (carbon based) will be the key focus of decarbonisation efforts in the industry medium term.

eVTOL (electric Vertical Take-off and Landing) is an emerging segment, largely focused on electric. Airlines are increasingly paying attention to this market to provide travel from congested urban areas to hub airports. As the technology matures, we could see urban air-mobility platforms increase in size and scale to carry more passengers over longer distances.

## Taxes & emission schemes driving change in airlines

Environmental taxes for airlines are increasing at pace and management teams have already started to act, with many large airlines outlining medium-term plans to cap emissions in the 2020s and drive towards net zero emissions by 2050. Alongside this, global emissions regulations are expanding, with the already well-established European Emissions Trading System and the upcoming rollout of CORSIA, likely to push 'the environmentally friendly' airline narrative in the 2020s, in our view, supporting aircraft replacement (younger fleet age) and growing investment in SAFs.

## A growing area of focus for governments

Government support for green aviation has been mixed. The European Union has set a target to cut greenhouse gas emissions to net zero by 2050, but to date specific legislation supporting the transition to aviation is largely focused on the EU ETS carbon-offsetting scheme. We think there is a broad recognition that some sectors of the economy will still be net emitters for the medium term. However, by reducing emissions significantly, combined with growth in negative carbon sectors, the region can achieve its net zero targets. As part of the recovery fund, Horizon Europe will receive an incremental €5.4bn. This brings the total budget for Horizon Europe to €95.5bn. This will support the aviation sector through R&D, as it has been doing through the SESAR (air traffic management) and the Clean Sky programmes.

On 23 February 2021, the European Commission announced its proposal a European Partnership for Clean Aviation. Overall, the EU will invest €10 billion in the partnerships, which will then be matched by industry. The European Partnership for Clean Aviation will build on the work done to date by the Clean Sky and Clean Sky 2 Joint Undertakings, pursuing innovative and impactful research to ensure climate neutrality by 2050. The goal is to minimise the aviation sector's environmental impact, as part of the European Green Recovery priority of the European Union.

The partnership will accelerate the development of disruptive technologies through simulations & integrated demonstrations of novel aircraft and propulsion configurations and systems at the aircraft platform level. It will be a core European programme, leveraged by further activities funded at national, regional and private levels.

Also important will be the ReFuelEU Aviation initiative. Sustainable aviation fuels have the potential to significantly reduce aircraft emissions, particularly liquid advanced biofuels and electro-fuels, which are fully compatible with current technology and already certified by EASA for up to 50% of the fuel used during a flight. However, production is the issue, with annual production of SAFs below 1% of annual kerosene consumption globally. This initiative is expected to deliver by the end of 2021 and to support the scaling up of SAF production in the EU. The initiative is likely to include a blending mandate, increased multipliers to help countries hit renewable energy targets, and better monitoring. The blending mandate would likely increase over time.

The UK government has been providing support through the Renewable Transport Fuel Obligation (RTFO), whose objective is to reduce greenhouse gas emissions by gradually increasing the mix of Sustainable Aviation Fuels (SAFs). The aviation sector was brought into the scheme in 2020, with the aim of increasing the biofuel volume target from 4.75% currently to 12.4% in 2032. The UK also announced the Jet Zero Council in June 2020, a partnership between industry and government to support the delivery of technologies to reduce emissions.

Spain and Germany are working on initiatives to support sustainable aviation fuel uptake of 2% and 10%, respectively, by 2025. France targets the increase of SAFs to be 2% of volume in 2025, 5% in 2030 and 50% in 2050. The US is yet to make significant announcements on policy for decarbonisation of aviation. However, the Environmental Protection Agency has proposed an emissions standard for aircraft that would align with the international $CO_2$ emission standards set by International Civil Aviation Organisation. In the US, we could see the set-up of a federal Sustainable Aviation Fuel mandate by the Biden administration.

The EU green deal is the largest proposed plan for broad economic decarbonisation, with c.€550bn earmarked for climate goals as of October 2020. The specific investment into aviation is yet to be announced.

The UK government has committed c.£750m as of July 2020; £350m to fund carbon capture and storage + hydrogen and £400m for projects developing sustainable aviation fuels, energy-efficient electric aircraft components, high-performance engines and wing designs to minimise fuel consumption. A sum of £2bn would also be spent by the UK government on Research and Technology through the Aerospace Technology Institute Programme in order to develop a green aviation sector.

Germany identified green hydrogen as a major alternative energy and about €9bn has already been committed to develop the project. Between 2020 and 2024, Germany's Aviation Research Programme will spend €25m on hydrogen technology. France previously proposed an aviation tax that would generate €180m annually in 2019 to support investment in transport with a lower environment impact, including rail.

## What are airlines saying?

Major airlines have set ambitious goals, ranging from carbon offsetting, fleet replacement and SAF substitution for kerosene. Major investments, targets and strategy include:

**British Airways** has a goal of net zero in 2050. It will invest $400m in sustainable fuel over the next 20 years from 2019 via a commercial plant that converts waste into a sustainable jet fuel, reducing net greenhouse gas by 70%. Its Boeing 747 fleet will also be retired in 2024 for new 747s, 787 variants, A350 and 777-9s.

**British Airways** is partnering with LanzaJet for sustainable aviation fuel as part of the carrier's plans to decarbonise by 2050. The US start-up will supply ethanol-derived fuel from its Freedom Pines Fuels facility in Georgia, and British Airways will use it to power some flights from late 2022. As part of the collaboration, British Airways will invest in LanzaJet and the start-up will conduct early-stage planning to establish a larger biofuel facility in the UK. BA is also developing a sustainable fuel plant in the UK with Velocys that could begin producing jet fuel from 2025.

**Air France-KLM** operated a passenger flight from Amsterdam to Madrid – the first in the world to use sustainably derived synthetic aviation fuel, according to the carrier. The Boeing 737-800 narrow-body plane carried 500 litres of the fuel produced by Royal Dutch Shell Plc, equating to more than 5% of the total requirement for the trip. The flight took place on 22 January 2021 and was ground-breaking in that it combined carbon capture with solar and wind power to produce a fully sustainable kerosene substitute.

**Ryanair** has committed $20bn to purchase 210 new Boeing 737 in its 2020 environmental policy, targeting an improvement in fuel consumption of 16% and noise emissions of 40%. The airline also aims to reduce emissions to <60 grams of $CO_2$/pssg km by 2030, 10% less than the current rate.

**OneWorld,** a group of 13 airlines, committed to net zero carbon emissions by 2050 in September 2020. The initiative to achieve this includes the use of more sustainable materials, investment in more fuel-efficient aircraft and the development of SAFs.

**Finnair** targets carbon neutrality by 2045. The carrier is aiming for a 50% reduction of $CO_2$ from the 2019 baseline by 2025. The key strategy includes investments of €3.5-€4bn in fleets, €60m in sustainability and the use of SAFs through partnership with energy companies like Neste.

**EasyJet** is set to invest £25m/year in forestry, renewable and community-based projects, corresponding to 25p per passenger. The airline is also partnering with Wright Electric to introduce a commercial all-electric jet by 2027. easyJet is committed to net zero carbon emissions by 2050.

**Lufthansa**. Lufthansa aims to cut its net carbon emissions in half by 2030 compared with 2019 and supports the objective of making aviation carbon neutral by 2050.

**Qantas** aims to be a net zero emission carrier by 2050. Starting from 2019, it will double the number of flights being offset (10% of Qantas passengers currently offset vs a 1% industry average), cap net emissions from 2020 and invest $50m to develop SAFs over 10 years until 2029-30. The carrier retired its 747s in 2020 and started replacing them with the more fuel efficient 787.

**Delta Airlines** is committing $1bn over 10 years from 2020 to achieve carbon emission neutrality. Its outlined efforts include the reduction of jet fuel usage and investments in carbon removal programmes in forestry, wetland restoration, grassland conservation etc.

**American Airlines** signed the joint commitment to reach net zero emissions by 2050 under the OneWorld Alliance. The carrier is undertaking an extensive fleet replacement initiative, resulting in >500 new more fuel-efficient aircrafts joining its fleet.

**United Airlines** expects to invest $40m to decarbonise air travel. The focus of the fund is on accelerating SAF developments of and other decarbonisation technologies. The airline had earlier adopted split scimitar winglets on its aircrafts as part of a $30m investment. In 2020, United pledged to become 100% green by reducing greenhouse gas emissions by 100% by 2050. United also announced an agreement to partner with Archer Aviation to acquire a fleet of up to 200 of the eVTOL aircraft to offer customers a quick and low carbon way of getting to United's hub airports from dense urban environments within the next 5 years.

**Etihad** has also pledged to attain zero net carbon emissions by 2050. By 2035, it expects to be down 50% on net carbon emissions produced in 2019.

**IAG** has made a net zero pledge by 2050. IAG is involved in CORSIA which will enable aviation to cut its $CO_2$ emissions by 2.5bn tonnes in 2020-35 through $40bn of investment in regulated, carbon reduction projects in other sectors.

**JAL** aims to reach zero $CO_2$ emissions by 2050. JAL has implemented measures to reduce fuel consumption during daily flights and renew its fleet with fuel efficient aircraft types like Airbus A350 and Boeing 787s. In the long term, JAL intends to invest in sustainable aviation fuels and engage in emissions trading.

**ANA** plans to reduce $CO_2$ emissions from aircraft flight operations by 50% in 2050 compared to 2005 levels. ANA also plans to introduce sustainable aviation fuels (SAF) such as vegetable oil, sugar, animal fat and waste biomass. In addition, it aims to reduce $CO_2$ emissions globally by purchasing $CO_2$ emission allowances.

**SIA** has joined the IATA commitment to reduce emissions in three stages: 1) a 1.5% improvement in fuel efficiency each year from 2009 to 2020; 2) carbon neutral growth from 2020; and 3) a 50% absolute reduction in carbon emissions by 2050.

# Sustainable Aviation Fuels

## What are Sustainable Aviation Fuels (SAFs)?

SAFs are a substitute for fossil jet fuels (kerosene), produced from sustainable feedstock. They are often referred to as 'drop-in' fuels as their chemical characteristics are almost identical to fossil fuels and can be safely blended with existing fuels.

With fuel produced from sustainable feedstocks (used cooking oils, animal fats, crop residues), renewable fuels can deliver up to 90% lower $CO_2$ emissions than fossil fuels over the lifecycle of the fuel, due to the sustainability of the feedstock. SAF is subject to additional upgrading vs. other sustainable fuels such as diesel, so that it meets the more stringent specifications of aviation fuel. The fuel has already been proven, with many airlines using blends of sustainable aviation in commercial flights, but uptake has so far been limited since it is several times more expensive than fossil jet fuel.

Widespread adoption will likely require regulation (tax incentives) or price competitiveness, and we see encouraging signs on both: Norway (2021) and France (2022) have become the first countries to introduce renewable jet mandates, and the EU is reportedly considering introducing a SAF mandate in the coming years. Currently, the limit is 50% drop-in fuels by volume used in an aircraft to ensure the appropriate level of safety and compatibility with the aircraft fuelling systems. It is, however, likely that higher blend limits will be approved and some engine manufacturers have been testing engines with 100% sustainable aviation fuels.

SAFs represent an essential 'bridge' to zero carbon technologies like hybrid-electric aircraft and hydrogen-powered aircraft. They offer significant life-cycle carbon reduction gains and are cleaner burning, with up to 90% reduction in particulates. Alongside the introduction of a fleet of new engine option aircraft, reducing fuel burn of the fleet, SAFs represent a significant part of the aviation industry's plan to decarbonise in the coming decades.

There is still an issue of scalability, and the International Air Transport Association estimates 40 million litres of SAF was produced in 2020, representing 0.015% of total jet fuel consumed. This issue on scale is primarily caused by the limited capacity (biofuel refinery plants) that is deployed to produce SAFs and the higher cost of production, which is driven by the cost of feedstock and logistics.

## What are the types of SAF available?

In 2019, CORSIA identified 16 feedstock types that can be converted into aviation fuels through a fuel conversion process. These feedstock types can be broadly classified under waste, oil and plants.

**Exhibit 1: CORSIA identified feedstock**
CORSIA identified feedstock can be based on waste products, oil or plants

| Feedstock types | | |
|---|---|---|
| **Waste** | **Oil** | **Plants** |
| Agricultural residues | Corn oil | Sugarcane |
| Forestry residues | Soybean oil | Sugar beet |
| Municipal solid waste (MSW) | Rapeseed oil | Corn grain |
| Used cooking oil | Palm oil | Poplar |
| Tallow | | Miscanthus |
| | | Switchgrass |
| | | Palm fatty acid distillate |

**Source:** ICAO

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As of June 2020, 8 conversion processes have been approved for SAFs by the ICAO and these relate to the specifications of the fuel to ensure the products are safe for use in an aircraft. Exhibit 1 shows the conversion processes certified by the ICAO. These certifications have been issued when the SAF has been confirmed to comply with the standards developed by ASTM, an international fuel specification body.

**Exhibit 2: ICAO approved conversion process as of June 2020**

There are 8 approved processes for manufacturing Sustainable Aviation Fuel

| ASTM reference | Conversion process | Abbreviation | Possible Feedstocks | Blending ratio by volume | Commercialization proposals / Projects |
|---|---|---|---|---|---|
| ASTM D7566 Annex 1 | Fischer-Tropsch hydroprocessed synthesised paraffinic kerosene | FT | Coal, natural gas, biomass | 50% | Fulcrum Bioenergy, Red Rock Biofuels, SG Preston, Kaidi, Sasol, Shell, Syntroleum |
| ASTM D7566 Annex 2 | Synthesised paraffinic kerosene from hydroprocessed esters and fatty acids | HEFA | Bio-oils, animal fat, recycled oils | 50% | World Energy, Honeywell UOP, Neste Oil, Dynamic Fuels, EERC |
| ASTM D7566 Annex 3 | Synthesised iso-paraffins from hydroprocessed fermented sugars | SIP | Biomass used for sugar production | 10% | Amyris, Total |
| ASTM D7566 Annex 4 | Synthesised kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources | FT-SKA | Coal, natural gas, biomass | 50% | Sasol |
| ASTM D7566 Annex 5 | Alcohol to jet synthetic paraffinic kerosene | ATJ-SPK | Biomass from ethanol or isobutanol production | 50% | Gevo, Cobalt, Honeywell UOP, Lanzatech, Swedish Biofuels, Byogy |
| ASTM D7566 Annex 6 | Catalytic hydrothermolysis jet fuel | CHJ | Triglycerides such as soybean oil, jatropha oil, camelina oil, carinata oil, and tung oil | 50% | Applied Research Associates (ARA) |
| ASTM D7566 Annex 7 | Synthesised paraffinic kerosene from hydrocarbon-hydroprocessed esters and fatty acids | HC-HEFA-SPK | Algae | 10% | IHI Corporation |
| ASTM D1655 | Co-processing | | Fats, oils, and greases (FOG) from petroleum refining | 5% | |

**Source:** ICAO

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## Current limitations on SAFs

While Sustainable Aviation Fuels are technically feasible and are being used today, there are some limitations on use.

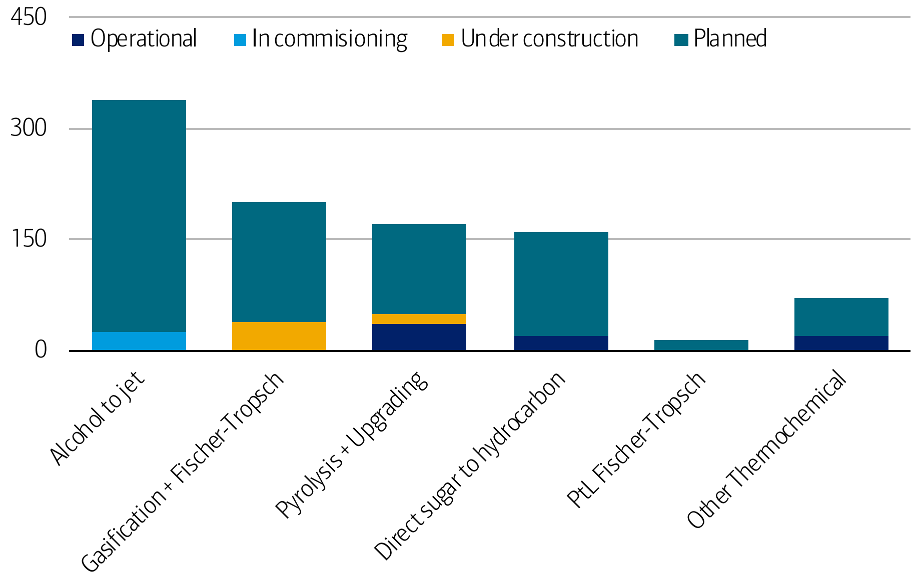
### Production volumes remain low

The production volume of SAFs is currently significantly below levels of the global fuel consumption of the aviation industry. The global aviation industry consumes 278 billion litres of jet fuel annually (pre-COVID level), and as we highlighted above, current SAF volumes are <1% of total jet fuel demand as estimated by IATA. Significant investments are needed to build capacity production (IEA estimates it would require about $10bn to meet 2% of annual jet demand with SAF). As a result of limited production capacity, the premiums for SAFs relative to kerosene remain substantial.

Another key challenge relates to the production conversion types that have been certified for SAFs. As we highlighted above, the ICAO has certified 8 biofuel production pathways, but only HEFA-SPK was technically mature and commercialised as of 2019. It is anticipated that it will be the principal aviation biofuel used over the short to medium term. Agricultural residues and municipal solid wastes are more abundant and generally cost less than the waste oils and animal fats commonly used by HEFA-SPK, and commercialising production conversion pathways that use those feedstocks could bring down the cost of SAFs medium term.

Global sustainable aviation fuel production capacity is dominated by plants using hydrogenated vegetable oil (HVO) as their feedstock. This can produce Hydrogenated Esters and Fatty Acids (HEFA), which can then be refined into aviation fuel. About 6,500kt/yr of HEFA can now be produced as of 2020 but other technologies are still building capacity.

**Exhibit 3: Plant capacities from current database (WIP) (ex. shut and decommissioned) – Kt./year**
Plant capacities excludes Hydrogenated Esters and Fatty Acids (HEFA) which is already commercial and producing c.6,500kt/yr




**Source:** Sustainable Aviation

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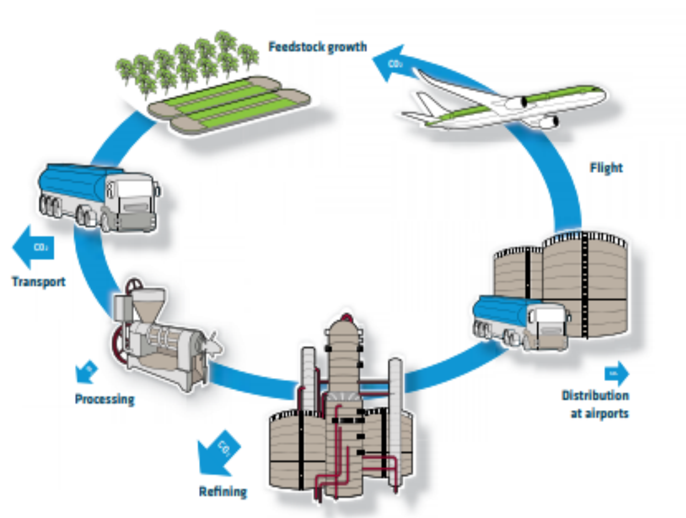
## A simple production lifecycle

SAF production typically starts from getting the available feedstock types to where the components needed would be extracted by a processing plant. Refining the fuel to blend with kerosene is then done using various processes that depend on the type of feedstock used. The SAFs would then be made available to the airports. The available storage plants at the airports are well suited to keep SAFs and no major investment is needed to put extra infrastructure in place.

**Exhibit 4: Carbon lifecycle diagram: Sustainable aviation fuel**
The feedstock types determines the blended ratio and can vary under the refining process




**Source:** aviationbenefits

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**Infrastructure needed to scale**

Since SAFs are chemically indistinguishable from conventional jet fuels, the existing infrastructure for kerosene storage and distribution could be used. We are starting to see partnerships between SAF producers and airports aiming to facilitate increased adoption of these fuels. Some airports including Dehradun in India and Shanghai and Beijing in China have adopted such measures.

EU Oil analyst Mehdi Ennebati hosted Neste in February, and, according to management, Global Renewable Diesel/Sustainable Aviation Fuel demand will increase from 6 million tons (2020) to at least 30 million tons by 2030 (excl. renewable plastics) and probably more. This will be on the back of favourable legislation changes. In Europe, discussions are ongoing to increase the Renewable Energy Directive II target from a 14% share for biofuels in road transport by 2030 to 20-24%. The law proposal could be presented before the end of this year. The European Commission is also working on a Sustainable Aviation Fuel (SAF) mandate for Member States. A 10% mandate by 2030 could mean a 5.5mt/yr demand for SAF. Neste SAF production could reach 2.5mt/yr by 2025. Management expects the SAF margin to be at least in line with that for Renewable Diesel. Regarding the US, the Biden administration wants to move fast with its climate agenda, which might include a federal Sustainable Aviation Fuel mandate.

**Other forms of SAF – Power to Liquid**

Significant interest also exists for non-bio-based feedstock, in particular the so-called drop-in Power-to-Liquids 'electrofuels'. This pathway allows the production of SAFs through the use of renewable electricity to produce hydrogen from water by electrolysis and a combination with carbon from $CO_2$ (ideally captured from the air) to create a synthetic kerosene. Electrofuels are a technically viable solution to help decarbonise the aviation sector. However, few demonstrator projects are being brought forward because electrofuels significantly more expensive than kerosene, and according to one study, using electrofuels to meet the expected remaining fuel demand for aviation in 2050 would require 95% of the electricity currently generated using renewables in Europe (**Source:** EASA – Sustainable Aviation Fuels).

An industrial consortium is planning Europe's first power-to-liquid plant that will produce hydrogen-based renewable aviation fuel in Norway. The Norsk e-Fuel consortium is initially looking to build a demonstration plant near Oslo, capable of producing 10 million litres of fuel a year before scaling up the facility to commercially produce 100 million litres by 2026. The output of the full-scale plant would save an estimated 250,000 tonnes of $CO_2$ emissions annually and fuel the 5 most frequently serviced domestic routes in Norway with a 50% blend.

**Rolls Royce investing heavily in the development of SAFs**

Rolls Royce has evaluated and approved 7 SAFs for unrestricted use in all engines including various synthetic paraffinic kerosenes (SPKs) in neat (100%) or blend form, Fischer-Tropsch (FT)-SPK, hydroprocessed esters and fatty acids (HEFA), catalytic hydrothermolysis jet (CHJ) and alcohol-to-jet (ATJ) fuel types; performed both civil and military flight evaluations and have developed new test methods specifically to understand fuel-related effects under engine conditions. Testing and evaluating SAFs allow the group to understand potential environmental benefits as well as any impact upon the performance, operability, durability, and safety of their engines.

Currently, under the Rolls-Royce CLEEN Sustainable Aviation Fuel Programme (2010-present), which contributes to the attainment of FAA NextGen Air Transportation System goals, the company has characterised a number of SAFs' performances under representative engine condition, including a novel fully-synthetic "Alcohol-to-Jet Synthetic Kerosene Aromatic" (ATJ-SKA). These goals have been accomplished through a series of "back-to-back" rig tests with conventional Jet A fuel. The tests provide an understanding of the ATJ-SKA fuel's impact upon elastomeric seal performance, combustion behaviour, operability and emissions with respect to: ignition, lean blowout, performance across the operating envelope, gaseous emissions, combustion efficiency and exhaust gas temperature profile. Test results indicate acceptable fuel performance with only minor differences noted, lending to the fuel being considered a promising candidate as a fully synthetic drop-in replacement for petroleum.

These SAF evaluation programs provide the aviation Industry valuable information to modify jet fuel specifications to increase flexibility and challenge the current performance versus the overall environmental impact equation. The data generated has been shared with the Aviation Fuels Community to support the International approval of increased SAF blends leading to a fully synthetic jet fuel. In addition, these programmes complement SAF work being carried out by the Commercial Aviation Alternative Fuels Initiative (CAAFI), National Jet Fuels Combustion Programme (NJFCP) and the American Society of Testing and Materials (ASTM) fuel committees for the evaluation and qualification of viable sustainable fuels.

On the 18th March, Airbus, DLR, Rolls Royce and Neste launched the world's first in-flight emissions study using 100% sustainable aviation fuel (SAF) on a wide-body commercial passenger aircraft. Fuel-clearance engine tests, including a first flight to check operational compatibility with the aircraft's systems, started at Airbus' facilities in Toulouse, France, in the middle of March 2021. These will be followed by the flight-emissions tests due in April and resuming in Q4 2021, using DLR's Falcon 20-E 'chase plane' to carry out measurements to investigate the impact of sustainable-fuel emissions. Meanwhile, further ground tests measuring particulate-matter emissions are set to indicate the environmental impact of SAF-use on airport operations.

Both the flight and the ground tests will compare emissions from 100% SAF made from HEFA (hydroprocessed esters and fatty acids) against those produced by fossil kerosene and low-sulphur fossil kerosene.

# Hydrogen – fuel or fuel cell

Hydrogen is a molecule that could support the decarbonisation of the aviation industry, and its adoption has started gaining momentum. In September 2020, ZeroAvia completed a test flight on a hydrogen-fuel-cell-powered aircraft and Airbus subsequently introduced 3 hydrogen-powered aircraft designs that it believes could enter into service by 2035. Engine manufacturers have also increasingly taken on the hydrogen challenge, with Safran, MTU, Rolls Royce, GE and P&W all announcing development projects on hydrogen propulsion in the past year.

Green hydrogen is attractive because it is a zero carbon emission energy source rather than a net zero emission source, as is the case with sustainable aviation fuels. Hydrogen also makes up roughly 90% of the universe. Despite such abundance, hydrogen remains unavailable unless it is produced through electrolysis, which is the process of using electricity to split water into hydrogen and oxygen.

### Initial disruption to short-range travel, next up: mid-range

The initial addressable market for hydrogen fuelled aircraft is small short-range (think commuter, regional) aircraft and eventually mid-range aircraft. The majority of the commercial aviation market is mid-size aircraft (i.e., Airbus A320, Boeing 737) flying 300-2,000nm. According to ZeroAvia, a start-up company with the goal of flying regional hydrogen-cell powered aircraft with 10-20 seats on routes of 575mi or less, the initial disruption could be seen in a $100bn+ market for faster, safer, cleaner more convenient local travel. According to the company, a hydrogen-based system will pack up to 4 times more energy than the best batteries.

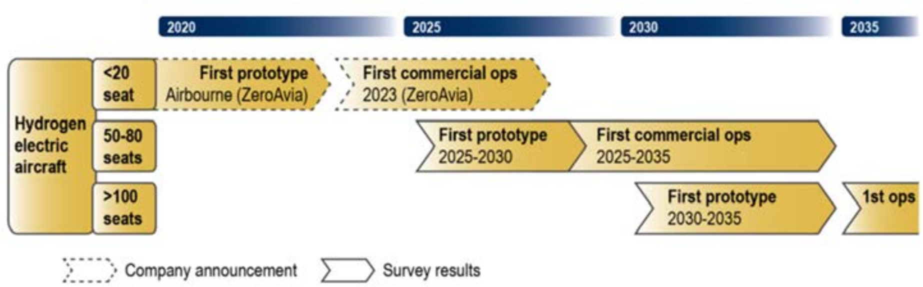
### Military interest: ISR potential

Hydrogen-powered aircraft may be of interest for military aviation as well, but not for emissions-related purposes. Military users are attracted by the quiet flight, low-heat signatures, and ability to potentially replenish fuel in the field. These advantages are particularly attractive for intelligence, surveillance and reconnaissance (ISR) missions.

### Roadmap: 50-80 passenger flights by 2035

The first cross-Atlantic flight powered by hydrogen is estimated to be 3-4 years away, with more regular commercial flight operations of 50-80 passengers potentially by 2035. Prototypes for larger commercial aircraft with 100-200 passengers for distances up to 600mi could be seen in the next 7-8 years.

**Exhibit 5: First commercial operations for 50-80 passenger turboprops by 2035**
Survey result shows that respondents expect hydrogen electric aircrafts from 2035




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

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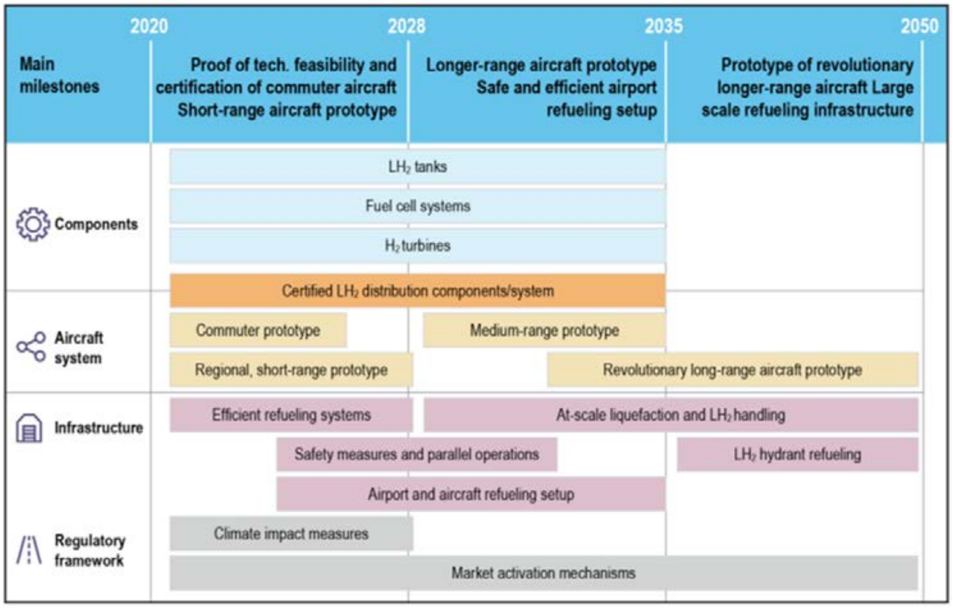
### Timeline feasibility: regulatory hurdles

The decarbonisation of aviation by 2050 in practical terms is a short-term goal, considering that developing and certifying a new aircraft can take up to 10 years or more, not including the time it would take to implement a new fleet. Even if retrofitting existing commercial fleets becomes an option, establishing the infrastructure for refuelling that fleet and its safety measures, procedures etc. could prove to be a challenge to the existing 2050 timeline.

**Exhibit 6: Hydrogen research and innovation roadmap**

Prototype for short range is expected before 2030, with longer range having a timeline for 2050




**Source:** McKinsey & Company, Hydrogen-powered aviation: A fact-based study of hydrogen technology, economics and climate impact by 2050

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### Timeline and COVID-19: hindrance or catalyst?

COVID-19 may not only have slowed aviation's greenhouse gas (GHG) growth over the next 2-5 years, but also impacted research for some bigger projects led by larger companies. Airbus and Rolls Royce's E-Fan X project was recently cancelled and Raytheon Technologies' Project 804 development, a hybrid electric regional-sized aircraft demonstrator, has been slowed as a means to conserve cash amid the COVID-19 pandemic. Both programmes were competing technology focused on electric or hybrid electric power for air travel. In this case, the pandemic may offer smaller hydrogen-focused companies (that don't depend on ongoing revenues) a chance to continue to move forward in their research while other technologies are held up.

### Infrastructure: financially sustainable on a small scale

Using the existing hydrogen supply chain and airport refuelling infrastructure may be financially sustainable in the early stages. However, scaling up to accommodate larger aircraft could be met with regulatory challenges as safe and reliable fuel distribution systems certified for commercial aviation are not available at this stage. A suggestion to tax Jet A fuel as a means of financing the transition has been offered. Additionally, some estimates forecast that green hydrogen infrastructure at small to medium-sized airports could achieve breakeven with jet fuel for small aircraft operators in 3 years.

Today, the majority of hydrogen production is known as grey hydrogen, produced using fossil fuels and, over time, this production will increasingly use renewable energy, creating green hydrogen.

Under ambient conditions, hydrogen exists in gas form. For many industrial processes, it is stored as a liquid at -252 degree Celsius. This requires hydrogen to be stored in a specially insulated cryogenic tank at high pressure. Aviation liquid hydrogen ($LH_2$) is the more feasible state for use in aviation vs. Gaseous hydrogen ($GH_2$):

a. $LH_2$ would requires 1/2 of $GH_2$ volume

b. $LH_2$ requires a smaller tank reducing weight

c. $LH_2$ will potentially have faster refuelling times

The debate on the technical and economic feasibility of using hydrogen to power aircraft will continue – below we highlight some key pros and cons:

a. Burning hydrogen results in water vapour being emitted into the environment vs. carbon emission when fossil fuels are used.

b. Renewable energy capacity will continue to expand, which will support growth in the production of green hydrogen.

c. Ease of redeploying existing asset/infrastructure (pipelines).

d. Availability of technology to produce green hydrogen (electrolysers).

However, the current limitations associated with using hydrogen include:

a. Hydrogen storage requires large tanks that will likely need to be housed in the aircraft fuselage, adding a weight penalty.

b. Public perception on the safety of flying a hydrogen-powered aircraft might be an issue as hydrogen is highly flammable.

c. Production costs for green hydrogen vs. grey hydrogen are high due to the cost of electrolysers and renewable equipment like wind turbines used in production.

d. The need to upgrade infrastructure across airport infrastructure will be required.

Nomenclature:

- Energy density = amount of energy stored in a given system per unit volume ($J/m^3$).
- Specific Energy = amount of energy per unit mass (J/kg).
- Flame speed = velocity at which the unburned gases propagate into the flame.

## Hydrogen-powered aircraft – fuel cells vs. fuel

Hydrogen is a clean burning fuel that does not produce any carbon emissions as it does not include any carbon. In a completed reaction, the combustion of hydrogen with oxygen would only produce water.

$$2H_2 + O_2 \rightarrow 2H_2O$$

However, within air hydrogen, combustion can produce oxides of nitrogen, known as NOx. Hydrogen can be used to power an aircraft either as a fuel for combustion in a turbine, as part of a fuel cell, generating electricity to power a distributed electric propulsion system, or a combination of both. The two main methods of using hydrogen on aircraft are as follows:

- **Hydrogen as a fuel:** This technology works in the same way as conventional internal combustion, which generates thrust by burning gas, kerosene or other fuel. In this case, hydrogen (liquid or gas) simply replaces its fossil-fuel counterpart.

- **Hydrogen fuel cells:** This technology converts energy stored in molecules into electrical energy. During oxidation, hydrogen atoms react with oxygen atoms to form water, a process during which electrons are released to power an electric or hybrid-electric propulsion system.

We believe industry consensus is increasingly shifting to the view that it is more practical to burn hydrogen as a fuel through an engine rather than using fuel cells for the operation of mid/large aircraft. Fuel cells, whilst having a higher energy density than batteries today, come with the weight of an electric propulsion/battery system, as well as the complexities of hydrogen storage on the aircraft. For large aircraft, these weight penalties significantly inhibit range with technology available today.

The Aerospace industry also has significant experience with liquid hydrogen, with it used as a coolant in a number of industrial processes, and as a fuel in rockets for space applications for decades.

## Using hydrogen as a fuel ($LH_2$) to power a plane

Kerosene has historically been used for flight because it has a very high energy density. Hydrogen has a specific energy (*energy/mass*) that is 3x higher than kerosene, but a lower energy density (*energy/volume*). As a result, liquid hydrogen has roughly 4x the volume for the same amount of energy of kerosene. As a result, burning 100% hydrogen would require modifications to the engine configured for the increased flow rates.

Hydrogen burns differently from kerosene/natural gas. It reacts much quicker, with a flame speed that is 10x faster than methane. The flame speed is the velocity at which the unburned gases propagate into the flame. This is important for a gas turbine as it could lead to issues with the flame propagating upstream from the combustion zone, and will require modifications to the combustor of the engine.

Hydrogen also has a very low molecular weight, which means it could diffuse through seals that might be considered impermeable to other gases, requiring modifications.

In addition to the engine modifications, if aviation were to use hydrogen as a fuel, the problem of storage would need to be solved. To be stored on the aircraft, the hydrogen would be kept as a liquid as $LH_2$. Given the complexities of storing liquid hydrogen, it is unlikely the wings would be used as storage (as they are today with kerosene), but would likely need to be stored in the fuselage. Higher volumes needed would require large tanks that would pose weight and space constraints that would influence the range of the aircraft.

Drop-in fuels are synthetic fuels similar to kerosene, which could be SAFs or from combining hydrogen with $CO_2$ captured in the atmosphere, which is called power-to-liquid. With these fuels the $CO_2$ is recycled, which means a net $CO_2$ reduction. On its own, hydrogen as a fuel is considered a non-drop-in fuel, as it can't be mixed with kerosene.

Hydrogen as a fuel appears the most likely path in the next decade for hydrogen-fuelled aircraft. The aircraft design would utilise engine architectures available today, reducing the development risk in this area. The technology leap in a demonstrator would come from the storage of the $LH_2$, the certification of $LH_2$ tanks on aircraft, and in sizing an aircraft with a payload range capability that would be commercially viable. Bloomberg has reported that Airbus is increasingly favouring the hydrogen turboprop design to meet its objective of developing a hydrogen aircraft by 2035.

## Hydrogen fuel cells – another way to power aircraft

Another way of using hydrogen to power aircraft is through a fuel cell. The fuel cell creates electricity through combining hydrogen and oxygen, and the fuel cell powers a distributed electric propulsion system on the aircraft.

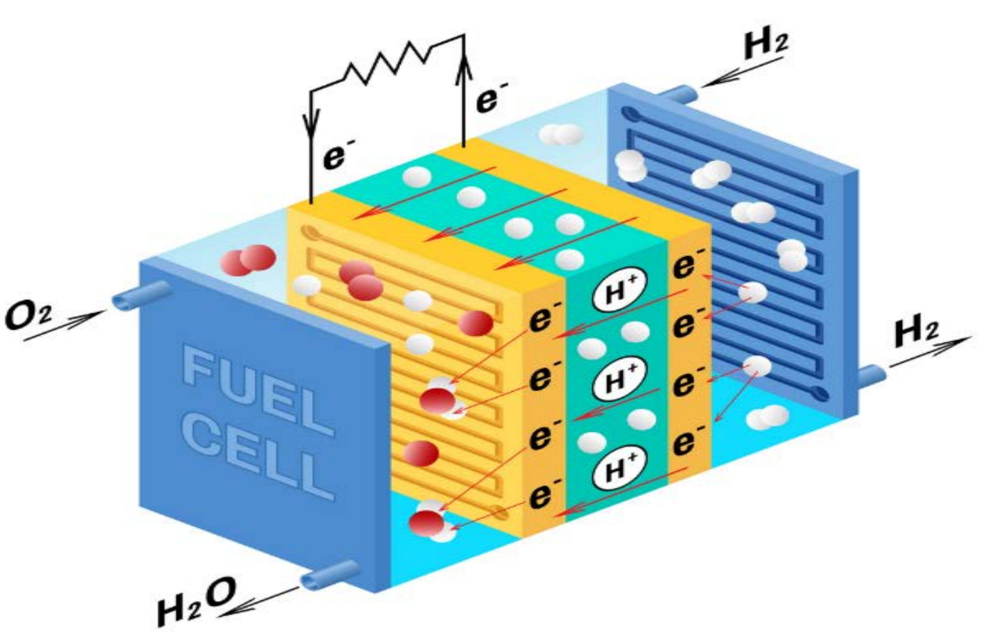
As fuel cells generate electricity through an electrochemical reaction, they are a clean source of power and unlike batteries that need to be recharged, they can continue to generate electricity as long as a fuel source is provided. Fuel cells can be stacked to form larger systems capable of providing more power allowing scalability.

Fuel cells in theory would be a more efficient form of propulsion than hydrogen combustion, driven by high levels of fuel cell efficiency (>50%) and the high efficiency of electric propulsion (>90%). In comparison, burning hydrogen as a fuel has energy efficiency in the c.40%s. Also, given the fuel cell would be powering a distributed propulsion system, this would be more efficient than two turbines under the wings, meaning the aircraft could utilise advanced aerodynamics to reduce drag alongside a more efficient chemical energy efficiency.

One issue with fuel cells is weight, as the propulsion system requires hydrogen fuel, the fuel cell, and the electric propulsion system to provide thrust, and could require a form of battery storage as well to manage requirements for fast load and power peak shaving.

For long range and larger aircraft, we believe turbines would be needed, based on today's technology, because fuel cells with their correlated cooling requirements would be too heavy. In our view, this likely limits fuel cells in the medium term to urban mobility and short-range regional aircraft.

**Exhibit 7: Structure of a hydrogen fuel cell**
Current technology is still suitable for smaller aircraft due to weight issues




**Source:** Airbus

## Airbus – increasing investment in hydrogen aircraft

Airbus has highlighted hydrogen as the carbon-neutral emission technology with the potential to power future aircraft and reduce aviation's climate impact. The airframer has an ambition to bring hydrogen-powered commercial aircraft into service by 2035. Airbus highlights 2 primary uses of hydrogen for commercial aircraft:

- **Hydrogen Propulsion:** Airbus highlights that hydrogen can be combusted through modified gas-turbine engines or converted into electrical power that complements the gas turbine via fuel cells. The two options can also be combined to create a hybrid-electric propulsion chain powered entirely by hydrogen.

- **Synthetic Fuels:** Hydrogen can also be used to create e-fuels, which are exclusively generated through renewable energy. The process of production is done by using renewable electricity that is combined with $C0_2$ to form a carbon fuel with net zero greenhouse gas emissions.

A decision on which combination of technology will be used to power its future commercial aircraft is expected to be determined by 2025. Bloomberg has reported that Airbus is favouring the hydrogen turboprop design to meet its objective of developing a hydrogen aircraft by 2035.

### Adoption requirements for hydrogen in aviation

Airbus expects the cost of hydrogen to decrease significantly over the next decade as production ramps up at a large scale, allowing it to become cost-competitive with existing jet fuel. Costs are also expected to fall as renewable electricity used to produce green hydrogen becomes cheaper.

Airbus has indicated that it targets wide-scale adoption and that starts with putting in place hydrogen infrastructure. Airports are expected to start using hydrogen to decarbonise their ground transportation ecosystem, enabling hydrogen to scale up at airports in preparation for future hydrogen aircraft by the mid-2030. Airbus has also highlighted that hydrogen can complement existing refuelling options at most major airports, facilitating wide-scale adoption.

In February, Groupe ADP, Air France-KLM and Airbus launched a call for expressions of interest to explore the opportunities generated by hydrogen in Paris airports with the aim to decarbonise air transport activities. The partners want to anticipate and support developments that should help transform the Paris airports into true "hydrogen hubs". The call for expressions of interest focuses on 3 main themes:

- Storage, transport and distribution of hydrogen (gaseous and liquid) in an airport environment (storage systems, micro-liquefaction, aircraft fuelling, etc.).

- Diversification of hydrogen use cases in airports and in aeronautics (ground handling vehicles and equipment, rail transport at airports, energy supply for buildings or aircraft during ground operations, etc.).

- Circular economy around hydrogen (recovery of hydrogen dissipated during liquid hydrogen fuelling, recovery of a by-product from a reaction to produce decarbonated hydrogen, etc.).

Safety concerns about hydrogen are high on the agenda, but regulations are already strict, given that kerosene is also extremely flammable.

## Airbus hydrogen-powered concepts – ZEROe

Airbus believes that in the narrow-body segment, hydrogen technology could be the solution for zero carbon flights in the 2030s. Roughly two-thirds of today's fuel consumption comes from flights operated with aircraft with 165-250 PAX or less (70% of the global fleet). This size of aircraft would benefit from higher power density than batteries can offer. Additionally, hydrogen is potentially lower cost due to the extended life of hydrogen systems vs batteries (which are limited to a number of cycles before requiring replacement).

Airbus has introduced 3 concepts that are designed as a hybrid-hydrogen aircraft, using liquid hydrogen as fuel in a modified gas turbine, with additional fuel cells that would create electric power to complement the gas turbine.

### 1) Turboprop

The Turboprop design (exhibit 9) is an aircraft with hydrogen turboprop engines, a range of c.1000nm and capable of carrying <100 people. The liquid hydrogen storage and distribution system is located behind the rear pressure bulkhead. This design is the most likely starting point for future development, we think.

Airbus also released a fuel cell turboprop design (exhibit 8). It features 6 removable fuel cell propeller propulsion systems, with each pod consisting of a propeller, e-motors, fuel cells, LH2 tanks, a cooling system, power electronics and a set of auxiliary equipment. When considering fuel cell technology, Airbus highlights that smaller experimental hydrogen aircraft, of up to 20 seats, can rely on a traditional fixed-wing configuration with two propellers. But more passenger capacity and longer range require another solution.

**Exhibit 8: The Pod Configuration Aircraft**
The aircraft will have 6 removable fuel cell propellers


**Source:** Airbus

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**Exhibit 9: The Turboprop Concept**
The aircraft will have 2 hybrid hydrogen turboprop engines.


**Source:** Airbus

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### 2) Turbofan

This concept features 2 hybrid-hydrogen turbofan engines. Storage of the liquid hydrogen is similar to that of the turboprop, i.e., behind the rear pressure bulkhead. The seat capacity is between 120 and 200 passengers with a range of 2000+ nautical miles, making it capable of operating transcontinental. Exhibit 10 shows a visual representation of the Turbofan Concept.

**Exhibit 10: The Turbofan Concept**
Design would have two hybrid turbofan engine with storage at the rear pressure bulkhead


**Source:** Airbus

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### 3) Blended Wing Body

This concept features a wide interior to enable multiple options for hydrogen storage and distribution. The liquid hydrogen is stored under the wings and the aircraft is designed with 2 turbofan engines that would produce thrust. The seat capacity will be up to 200 passengers. Exhibit 11 shows a visual representation of the Blended Wing Body Concept.

**Exhibit 11: The Blended Wing Body Concept**
The Blended Wing Body has a design that makes it more suitable as a large aircraft


**Source:** Airbus

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## Where is the technology today?

Currently, most of the hydrogen aircraft platforms in development are focused on light/regional proof-of-concept aircraft ranging from 1-20 seats. Development of the technology aims to scale up hydrogen's capabilities to power a larger regional aircraft (e.g., ZeroAvia) or even large commercial aircraft (e.g., NASA CHEETA). Roland Berger, a global consulting firm, highlights the main aircraft developments underway today in the table below. These include short-range light/regional prototypes using liquefied hydrogen such as HES Element One and the NASA CHEETA programme, and gas-stored hydrogen such as the HY4 and ZeroAvia.

**Exhibit 12: Current hydrogen aircraft developments**
Most of the technology prefers the hydrogen fuel cells as it is considered as the true zero carbon emission

| Programme | Year Announced | Power | Description | Storage System | Range (km) | Status |
|---|---|---|---|---|---|---|
| **HY4** | 2015 | Hydrogen fuel cells and electric batteries | Four seat fixed wing aircraft, single propeller, twin fuselage | Gas | 1,000 | Flown |
| **HES Element One** | 2018 | Hydrogen fuel cells | Four seat, fixed wing aircraft, 14 propellers | Gas/liquid | 500-5,000 | Under development |
| **Alaka'i Skai** | 2019 | Hydrogen fuel cells | Five seat futuristic "air-taxi" rotorcraft, six rotors | Liquid | 640 | Under development |
| **Apus i-2** | 2019 | Hydrogen fuel cells | Four seat fixed wing aircraft, two propellers | Gas | 1,000 | Under development |
| **NASA CHEETA** | 2019 | Hydrogen fuel cells | Blended wing-body large commercial aircraft | Liquid | n/a | Under development |
| **Pipistrel E-STOL** | 2019 | Hydrogen fuel cells | 19 seat, fixed wing aircraft | n/a | n/a | Under development |
| **ZeroAvia** | 2019 | Hydrogen fuel cells | 10-20 seat fixed wing aircraft, two propellers | Gas | 800 | Under development |
| **Airbus Cryoplane** | 2003 | Hydrogen combustion | Large commercial aircraft | Liquid | n/a | Feasibility study |
| **NASA Concept B** | 2004 | Hydrogen fuel cells | Blended wing-body large commercial aircraft | Liquid | 6,500 | Feasibility study |

**Source:** Roland Berger

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## ZeroAvia – fixed-wing turboprop hydrogen project

In 2020, ZeroAvia completed its first test flights of a modified Piper Malibu Mirage turboprop using a 300-kW battery electric power system using battery power. ZeroAvia aims to have a certifiable zero emissions hydrogen-electric turboprop by 2023. ZeroAvia's end goal is to use a hydrogen-electric powertrain for its final aircraft, with a hydrogen fuel cell system replacing the battery units on the initial test flights, significantly reducing weight.

In the final system, electrical motors will still drive the aircraft's propeller. One cost saving of using hydrogen fuel cells over battery power over the long term is the limited lifespan of batteries compared to the life of the aircraft. A typical high-energy battery based on existing technology will last 1,000-2,000 cycles, vs hydrogen fuel tanks, which can last as long as the aircraft. In addition, according to ZeroAvia, the energy density of the hydrogen electric system is 5 times greater than battery power due to the weight differential.

ZeroAvia completed its first test flights using the hydrogen electric system in 2020. Beyond the initial concept stage, ZeroAvia is targeting a 19-passenger twin engine turboprop regional aircraft capable of 500-mile flights. The ultimate goal of the concept is to target larger regional turboprops, such as the Bombardier Dash-8 or ATR500 by the end of the 2020s. ZeroAvia estimates that it can cut operating costs to half of what is required for jet fuel for a twin-engine, Twin-Otter-style aircraft.

## NASA CHEETA hydrogen system for all-electric aircraft

In 2019, NASA announced it would fund $6mn over the next three years to the University of Illinois for an electric aircraft research project. The Center for Cryogenic High-Efficiency Electrical Technologies for Aircraft (CHEETA) will investigate the technology needed to produce a practical zero-carbon aircraft. The programme is focused on developing a fully electric platform using cryogenic liquid hydrogen as an energy storage method. The hydrogen chemical energy is converted to electrical energy through a series of fuel cells, which drive an electrical propulsion system. Cryogenic electrical systems have significantly higher power density and efficiency than existing non-cryogenic systems and drives that are being used on current development prototypes for regional aircraft.

## Policy support – EU launches hydrogen strategy in 2020

The growth in support for hydrogen aircraft is relatively young and, as such, real policy support is only just beginning. In July 2020, the European Union launched a hydrogen strategy for Europe to help tackle emissions and support the EU's commitments to reach carbon neutrality by 2050.

As part of the European Union's roadmap to 2050, hydrogen-derived synthetic fuels are expected to grow for the aviation industry – like synthetic kerosene. In the report, the EU argues that hydrogen can become an option in the longer term to decarbonise the aviation and maritime sectors, through the production of liquid synthetic kerosene or other synthetic fuels.

In the longer term, hydrogen-powered fuel cells, requiring adapted aircraft design, or hydrogen-based jet engines may also constitute an option for aviation. The Clean Sky 2 group, which is a public private partnership with the EU, published a report alongside the EU's wider hydrogen strategy outlining that a hydrogen-powered, short-range commercial passenger aircraft could be flying within Europe by 2035. The report highlights that considerable long-term research will be required. The European Commission will address the use of hydrogen in the transport sector in the upcoming Sustainable and Smart Mobility Strategy.

Outside of the EU's emerging hydrogen strategy, other government support has been small, such as the UK government providing a grant of £2.7mn for ZeroAvia.

## Hypoint – fuel cell tech start up making strong progress

We recently hosted the 2021 STAARS – Future of Transportation & Mobility Summit, where we hosted Alex Ivanenko, the founder and CEO of Hypoint. Hypoint are targeting 2023 for its high power hydrogen fuel cell system to enter commercial service on a fixed wind aircraft. The company recently unveiled its first operable prototype if its turbo air-cooled hydrogen fuelcell system, which testing has shown is capable of achieving up to 2,000 watts per kg of specific power.

At the STAARs summit, it was noted that safety is critical. The FAA has started evaluating electric propulsion and Hypoint has started to establish relationships with the FAA. While the OEMs had hobby projects in electrification pre-Covid they have abandoned these undertakings post-Covid and are now back to focusing on internal combustion. However, it's important to focus on the "New World" and not the old ways of doing business and enabling flight. The biggest hurdle today is the fuel cell weight and the amount of room required to house the hydrogen. Increasing efficiency is key to offsetting these barriers.

# Electric aircraft

## Electric propulsion technologies under consideration

Electrical propulsion in commercial aircraft may be able to significantly reduce carbon emissions, but only if new technologies attain the specific power, weight, and reliability required for a successful commercial fleet. Six key architectures are under development today:

- **All-electric:** These systems use batteries as the only source of propulsion power on the aircraft.

- **Hybrid Electric Propulsion Systems:** These systems use gas turbine engines for propulsion and to charge batteries; the batteries can also provide energy for propulsion during one or more phases of flight.

    - **A series** configuration means that the power supplied to the fan is supplied by electric motors only, which in turn are driven by electric power produced by the turbo generators. Only the electric motors are mechanically connected to the fans; the gas turbine is used to drive an electrical generator, the output of which drives the motors and/or charges the batteries.

    - **A parallel** configuration power is supplied by both the electric motor, which is powered by a battery, and the combustion engine. A battery-powered motor and a turbine engine are both mounted on a shaft that drives a fan, so that either or both can provide propulsion at any given time.

    - **A Series/parallel hybrid** configuration has one or more fans that can be driven directly by a gas turbine as well as other fans that are driven exclusively by electrical motors; these motors can be powered by a battery or by a turbine-driven generator.

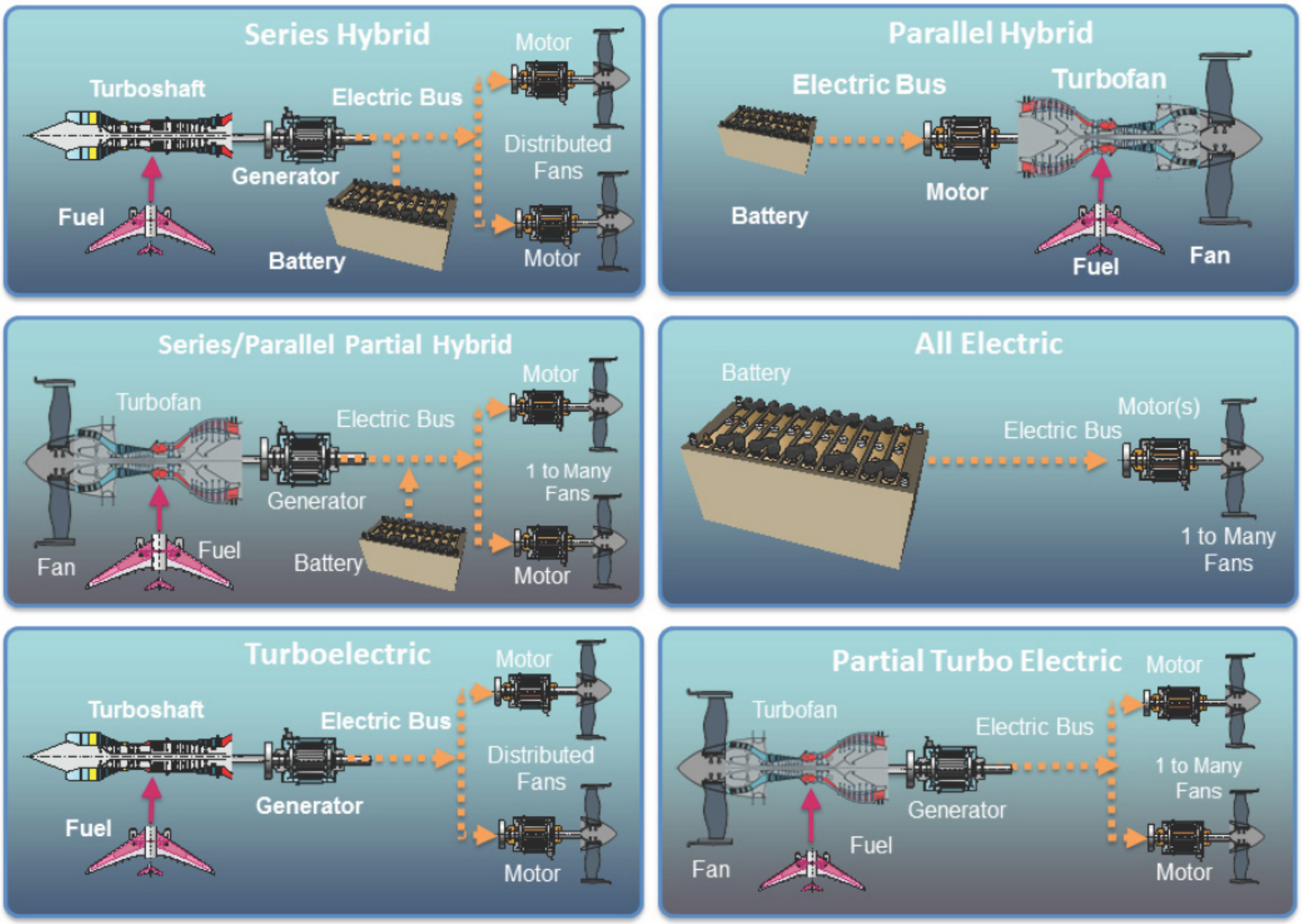
- **Turboelectric:** Full and partial configurations do not rely on batteries for propulsion energy during any phase of flight. Rather, they use gas turbines to drive electric generators, which power inverters and eventually individual direct current (DC) motors that drive the individual distributed electric fans.

    - **Full turboelectric** system uses electric propulsion to provide all of the propulsive power.

    - **Partial turboelectric** system is a variant of the full turboelectric system that uses electric propulsion to provide part of the propulsive power; the rest is provided by a turbofan driven by a gas turbine.

**Exhibit 13: Electric propulsion architectures**

Electric propulsion designs can be fit with both Turboshaft and Turbofan engine to create a hybrid propulsion




**Source:** Modified from James L. Felder, NASA Glenn Research Center, "NASA Hybrid Electric Propulsion Systems Structures," presentation to the committee on September 1, 2015.

## Hybrid Electric Aircraft Propulsion

One of the most prominently researched architectures is the Hybrid Electric Aircraft Propulsion System (HEPS) architecture, which considers combining a combustion engine with an electric motor. An HEPS has the potential to meet the future environmental goals of the industry as it uses the benefits an electric motor, but also a gas turbine.

The combination of both allows the gas turbine to be sized more specifically for one phase of the mission, such as cruise, resulting in a more efficient engine design for that part of flight, but would also mean less overall power coming from the combustion engine for the overall mission, which would reduce emissions. Also, electric motors have very high power-to-weight ratios (5Kw/kg), and offer rapid and precise control, which through this system can be combined with a combustion engine running at peak efficiency. There are 3 typical architectures within the HEPS family (see exhibit 13).

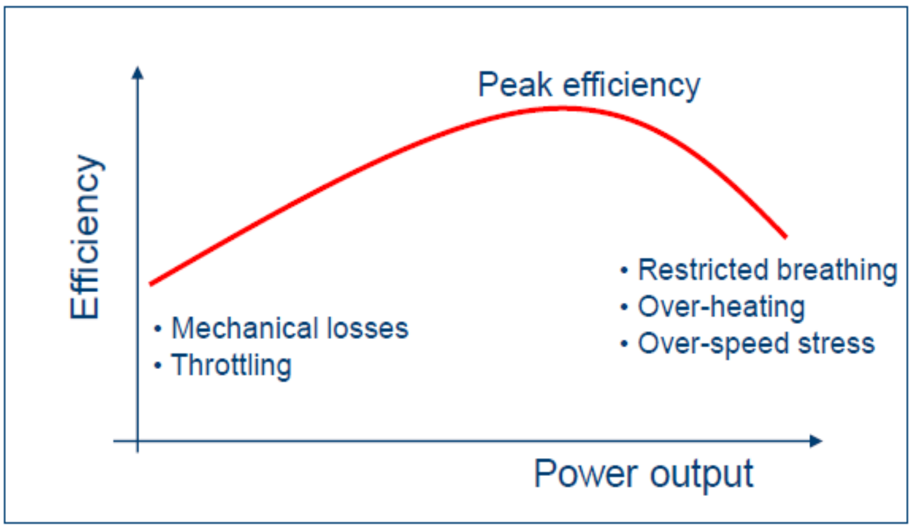
### Series Hybrid Electric Propulsion System

In a series HEPS, the gas turbine is connected to a generator that converts the mechanical power output of the turbine into electrical power. This electric power is then supplied to an electric motor, which is mechanically connected to a fan.

An advantage of the series HEPS architecture is that the engine is decoupled from the fan, meaning that it can run at an RPM rate independent from the fan, improving efficiency of the overall system. This also means the size of the turbine can be reduced (because it isn't directly driving the fan) and where the engine goes on the aircraft, is not dictated by the best position of the fan. The engine could even be positioned such that it brings aerodynamic benefits to the aircraft, i.e., Boundary Layer Ingestion which can help reduce aircraft drag. The primary disadvantage of the system is that the generator, converting the mechanical energy from the gas turbine into electrical energy, adds weight to the aircraft.

One real life example that implements a series HEPS is the E-Thrust concept, based on a project developed by the Airbus Group and Rolls Royce. The system is comparable to the TeDP on NASA's N3-X concept, but differs in the aircraft configuration on which it is applied and the use of an energy storage system. The E-Thrust features numerous electric fans arranged in clusters along the length of each wing. These electric fans are powered by a battery which, in its turn, is powered by one turbogenerator embedded in the fuselage. The E-thrust concept is also based on the assumption that the required level of energy density for the storage of energy can be achieved within the 25-year timeframe envisioned for the concept to mature.

**Exhibit 14: Thermodynamic efficiency of internal combustion engines**
Engines sized for peak power are less efficient at low power settings




**Source:** University of Cambridge

### Parallel Hybrid Electric Propulsion System

In the parallel HEPS, the electrical power component is used to convert electrical power into mechanical power. This mechanical power is added to the mechanical power provided by the gas turbine.

The advantage of the parallel HEPS is that the electrical system and engine system operate independently. This allows temporary operation with either the engine or an electric motor. Having a parallel configuration also enables independent design of the power share between both subsystems.

A disadvantage is that since the engine is mechanically linked to the fan, it cannot operate at its optimal RPM during the complete flight envelope.

### Series-parallel Hybrid Electric Propulsion System

In the series-parallel HEPS, the architectures of the series and parallel HEPS are combined. The combustion engine, like in a series architecture, is connected to an electric generator that is linked to the electric motor that will subsequently drive the fan. The difference with the series architecture is that the combustion engine is also directly connected to the fan. Moreover, the electric motor is able to drive the fan independently as well.

The series-parallel architecture combines both advantages of the series and the parallel architecture. The electric motor is driven from either the electrical storage or by the generator which receives its energy from the combustion engine. It can drive the fan on its own, but can also add power to the power from the combustion engine. The engine can run at its optimal RPM while it can also run independent from the electrical part.

A disadvantage is that it is inherently heavier than the series and parallel architecture due to the extra mechanical coupling. Moreover, being able to run the engine either independent or through the generator requires an additional mechanical link. Another disadvantage is that the increased freedom in energy transfer, results in an even more complicated control strategy for the propulsion system.

## Companies' progress with Hybrid Electric Propulsion Systems

### Safran – making progress with the EcoPulse

In July 2018, Safran passed a major milestone in its hybrid electric propulsion roadmap with the first ground test of a distributed propulsion system. In a distributed hybrid electric propulsion system for aircraft, a turbo-generator (a gas turbine driving an electrical generator) is coupled to a bank of batteries. This system powers multiple electric motors turning propellers to provide propulsion. The power is efficiently distributed by a new-generation power management system, and the motors are controlled by a fully-integrated smart power electronics assembly.

Several operating modes were tested and validated during this first series of tests, with the electric motors powered only by batteries or by a combination of batteries and turbo-generator. The system generated 100 kW of electrical power.

The demonstration was conducted by Safran Helicopter Engines, Safran Electrical & Power and Safran Power Units, in conjunction with Safran Tech, the Group's research & technology center. It was carried out according to Safran's roadmap for the development of hybrid propulsion solutions.

At the Paris Airshow in 2019, Safran, Airbus and Daher announced the EcoPulse project, which was backed by the French government. In December 2020, the project passed its Preliminary Design Review as a first key step toward validating the project's feasibility and firming up the architecture for a first flight scheduled in 2022. The project is based on a light aircraft platform supplied by Daher. The project is now entering the assembly and integration phase at Daher, with systems supplied by Safran and Airbus. The start of final assembly is planned for late 2021, with the first flight scheduled to take place in 2022.

Safran is responsible for EcoPulse's distributed hybrid-electric propulsion system. The Safran ENGINeUS™ motor will be submitted for EASA certification – the same type as granted for a turboshaft engine.

### Airbus/Rolls Royce – E-Fan X project scrapped last year

At the 2018 Farnborough Airshow, the UK government announced financial support for the pioneering Airbus E-Fan X hybrid-electric flight demonstrator. This project, in partnership with Siemens and Rolls-Royce, aimed to develop a flight demonstrator testing a 2MW hybrid-electric propulsion system

Starting in 2010 with the CriCri – the world's first fully electric aircraft – Airbus also produced the all-electric E-Fan 1.0 and hybrid E-Fan 1.2, which combined a 60 kW motor with a combustion engine. While these represented major achievements, the steps between each project were incremental. The E-Fan X represented a comparatively huge step forward. Key to this major jump is the rapid pace of development in battery and fuel cell technology. Airbus, Rolls-Royce and Siemens each focused on developing certain parts for the E-Fan X, with Airbus responsible for the overall integration of the electric motor into the test aircraft, a British Aerospace RJ100.

With the E-Fan X, Airbus was looking to investigate the challenges of such a high-power propulsion system, such as thermal effects, electric thrust management, altitude and dynamic effects on electric systems, and electromagnetic compatibility issues. It was also working with authorities to establish certification requirements for electrically powered aircraft. Parts manufacturing for the E-Fan X began in 2019, followed by ground testing.

In 2020, Rolls Royce and Airbus scrapped the programme, with it being reported that they were not satisfied with the incremental change that the E-Fan demonstrator would deliver, but also as a result of the COVID-19 pandemic and pressure on cash flows.

**Boeing – SUGAR Volt combines advanced aerodynamics & hybrid electric**
The Subsonic Ultra Green Aircraft Research (SUGAR) Volt concept has been developed by a team led by Boeing Research & Technology. The SUGAR Volt implements a parallel HEPS on an aircraft with a large span and high-aspect-ratio wing. This improves the fuel efficiency as it increases the lift and decreases the drag. This would reduce take-off distance and generate less noise. To enable operation at an airport, the wings are hinged so that they can be folded, similar to what has recently been approved on the 777X.

The SUGAR Volt has both a gas turbine and an electric motor attached to the Low Pressure (LP) spool. This allows the use of both jet fuel and battery power. The flexibility in the power extraction from the gas turbine or battery means that the electrical system does not have to supply all the power.

This yields a reduced required motor size and power output from the battery. The percentage reduction in fuel will depend on the development of battery, electric motor and gas turbine technologies over the coming decades.

**magniX**
magniX is a company that has developed propulsion systems for electric aircraft, including motors, inverters and motor controllers. The CEO recently presented at the 2021 BofA STAARS submit, where he highlighted electric aviation will enable the right technology for the right mission. This will start with small aircraft using batteries and will allow more point-to-point travel at a lower price point; Electric flight costs are 40-80% lower than traditional power. Niche airlines have already shown interest (Harbor Air, Cape Air, etc) as have cargo operators with the uptick in on-demand delivery and aircraft lessors looking to maintain residual value via evolving battery technology.

magniX in Dec 2020 was picked to provide the electric motors for a proposed fleet of 300 aircraft to be built in the United Kingdom by 2030 manufactured by UK startup Faradair. magniX has also recently announced deals with Sydney Seaplanes in Australia to retrofit a nine-passenger Cessna 208 Caravans with battery-powered electric motors, and has joined an effort to retrofit a 40-passenger de Havilland Dash 8 Q-300 with two electric motors powered by hydrogen fuel cells.

magniX is also working to certify its first battery-powered aircraft which first flew 12 months ago so that it can begin carrying paying passengers.

## Turbo-electric propulsion system
NASA introduced the concept of a Turbo-electric propulsion system on a blended wing-body airframe, replacing the turbofans with a small number of motor-driven fans, but with a turbo shaft engine producing the power to the motors.

The N3-X features turbo generators that generate mechanical energy and convert this into electrical energy. This electrical energy is distributed by superconducting cables over a number of high-power electric motors that drive a continuous array of propelling fans, this is also known as Turbo-electric Distributed propulsion (TeDP).

The turbogenerator's primary function is to generate electricity and, as a result, most of the energy of the gas stream is extracted by the power turbine that is connected to the generator, which results in a low exhaust velocity and hence a low jet noise.

Conventional technologies used for the transfer of power would typically result in low efficiency factors, thereby leading to poor performance and hence higher fuel consumption. As a result, the N3-X targets the use of super-conducting materials to improve efficiency of the energy transfer.

## All-electric aircraft

All-electric aircraft consist of just a battery and a motor providing thrust. However, flying requires an incredible amount of energy and batteries are currently too heavy and too expensive. Energy density is the key metric, and today's batteries don't contain enough energy to get most planes off the ground.

### Electric motors vs. combustion engines

Electric motors don't give up much efficiency or specific power as they're scaled down, which compares to combustion engines, where the power-to-weight ratio falls as size is reduced. Electric motors are also extremely simple, having just one moving part, so they require very little maintenance. As a result, there is little disadvantage to using a large number of small electric motors, which can be placed at locations on the aircraft where a combustion engine would be impractically bulky or heavy, such as near the wingtips.

Although most of the architectures highlighted above include combustion engines as a driver of power, the benefits are even greater if the aircraft is battery-powered. Battery-electric propulsion is about 3 times as efficient as a typical combustion-engine power train, and is materially quieter.

## Battery technology

As shown by the integration of batteries within the majority of the next generation power systems considered above, batteries are expected to play a decisive role in advanced electric propulsion systems to provide electric energy at high efficiency. The evolution of specific energy and power will determine the feasibility of a battery-based electric propulsion system for commercial aircraft.

Battery technology has been improving for many decades and specific energy continues to improve, but it is important to note that efficiencies of electric motors vs. gas turbines are materially different. The peak energy efficiency of an alternate current (AC) 3-phase electric motor can be as high as 93%, much more than the internal combustion engine's 35%. The battery system's weight, volume, power output, and energy capacity can influence the electric aircraft's manoeuvrability, stability, range, and endurance. For a fuel-driven aircraft, due to the weight reduction during flight, the relation between the range and sizing of the fuel system is non-linear.

For an electric-driven aircraft, the weight of the battery system will remain unchanged throughout the entire mission profile. However, the power of a battery system is the product of the discharging current and the battery voltage. The voltage of the battery will decrease during discharge. Therefore, if assuming constant power is required for the cruise flight, the current draw from a battery system will increase throughout cruise flight. This behaviour makes the battery pack sizing also a non-linear relationship with the cruise endurance requirement.

To achieve higher power, one must increase the battery system's voltage or current. The voltage of a battery is constrained by the operating voltage range of the chosen battery chemistry type. The current output from any battery cell is also limited by the maximum C rating of the battery. Therefore, a power output rating will require a certain sizing of a battery system's capacity.

## Safety will improve with more electric aircraft

9% of all general aviation accidents in 2010 were caused by power plant or related systems failures. An additional 5% of all 2010 general aviation accidents were caused by pilot mismanagement of power plant systems. The switch to electric propulsion could significantly reduce the frequency of these power plant-related accidents.

Compared to the single rotating part in an electric motor, the internal combustion engine has several reciprocating parts, of which failure of any single component would lead to a complete power loss. The electric propulsion system can be designed such that failure of a single component causes only a partial power loss, enabling the aircraft to limp home under at a reduced power setting.

# eVTOL gaining traction and investment

Interest in the urban mobility space has increased sharply in the past 5 years, and advancements in battery technology have supported the development of eVTOL aircraft with operating ranges of 100-200 miles, c.6 passengers.

There are several different designs of eVTOL systems (hovercraft, fixed wing), but all use a distributed electric propulsion system, which allows those with fixed-wing configurations to take advantage of advanced aerodynamics to improve efficiency.

One area of the market that has seen a significant increase in investment over the past few years is eVTOL (electric vertical takeoff and landing). This has been seen recently with the announced merger of Archer Aviation and a SPAC to take the eVTOL company public, and agreement between Archer Aviation and United Airlines to work together as part of the airlines' efforts to decarbonise travel.

Under the terms of the agreement, United will contribute its expertise in airspace management to assist Archer with the development of battery-powered, short-haul aircraft. Once the aircraft are in operation and have met United's operating and business requirements, United, together with Mesa Airlines, will acquire a fleet of up to 200. They will be operated by a partner and are expected to give customers a quick, economical and low-carbon way to get to United's hub airports and to commute in dense urban environments within the next five years.

With today's technology, Archer's aircraft are designed to travel distances of up to 60 miles at speeds of up to 150 miles per hour. Future models will be designed to travel faster and further. Not only will Archer's aircraft save commuters time, United estimates that the eVTOL aircraft could reduce $CO_2$ emissions by 47% per passenger on a trip between Hollywood and Los Angeles International Airport (LAX), which is one of the initial cities where Archer plans to launch its fleet. Archer plans to unveil its full scale eVTOL aircraft in 2021, begin production in 2023 and launch consumer flights in 2024.

Joby Aviation, an eVTOL company also announced in Feb 2021 it would merge with Reinvent Technology Partners in a deal that would value the company at $6.6bn. Joby has built a prototype that has flown more than 600 flights, according to the company, which says it is targeting Federal Aviation Administration certification in 2023 and hopes to start commercial operations a year later.

In 2020, at the BofA Space, Transportation, Aviation, Autos Research Summit, we hosted a number of companies in the eVTOL space, including Textron and Joby Aviation. See feedback here, 9th March 2020.

# The environmental airline

## How can airlines achieve net zero emissions?

The move to net zero emissions for airlines will come in stages, and focuses around three primary pillars: 1) Fleet and Operations; 2) Sustainable Aviation Fuels: and 3) Carbon Offsets. Below we show a possible timeline of the three pillars and potential advancements within each one.

**Exhibit 15: The environmentally friendly airline – three key pillars of reducing net emissions for an airline: 1) Fleet and operations; 2) sustainable aviation fuels; 3) carbon offsets.**

The three pillars have a target to achieve Net Zero by 2050

| | Fleet & Operations | Sustainable Aviation Fuels | Carbon offsets |
|---|---|---|---|
| | ↓ | ↓ | ↓ |
| 2020 | - Peak aircraft age? | ↓ | - EU ETS (In operation today) |
| ↓ | ↓ | ↓ | ↓ |
| ↓ | - Incorporating carbon prices into fleet Planning | - Increasing investment into SAF capacity | - CORSIA Implementation (2021-26) |
| ↓ | ↓ | ↓ | ↓ |
| ↓ | - Accelerate Investments into fleet replacement | - Government tax incentives for Sustainable Aviation Fuels grow | - Customer voluntary offset schemes |
| ↓ | ↓ | ↓ | ↓ |
| ↓ | - Airbus consolidate design for hydrogen regional jet | - 'neo' aircraft certified for high SAF fuel blends | ↓ |
| ↓ | ↓ | ↓ | ↓ |
| ↓ | - Digital Aircraft / Operations / Flight Planning (Airbus Skywise) | - Continued SAF expansion, including Power-to-Liquid | - Carbon Capture investments (IAG investment into Mosaic Materials) |
| ↓ | ↓ | ↓ | |
| 2030 | - More Electric Aircraft - Next Gen Single Aisle | ↓ | |
| ↓ | ↓ | ↓ | |
| ↓ | - Acceleration in Hydrogen Propulsion certification | ↓ | |
| ↓ | ↓ | ↓ | |
| ↓ | ↓ | ↓ | |
| ↓ | - Launch of all hydrogen regional jet aircraft | ↓ | |
| ↓ | ↓ | ↓ | |
| 2040 | - Launch of hydrogen narrow body jet aircraft | ↓ | |
| ↓ | ↓ | ↓ | |
| ↓ | ↓ | ↓ | |
| ↓ | ↓ | ↓ | |
| 2050 (Target Net Zero) | - Launch of all electric regional jet aircraft | - Sustainable Aviation Fuels the majority of Aviation fuel | |

**Source:** BofA Global Research estimates

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## Fleet replacement – highest yielding environmental investment available to airlines today

At its 2019 CMD, IAG highlighted that its 2020 targets are to be met partly by investing in fleet modernisation, with their targeted fleet age dropping from 11.4 to 10.2 years by 2022, on top of over 50 initiatives across the group to improve efficiency. The group also announced a targeted 20% drop in net emissions by 2030, from 27MT to 22MT, to be achieved by fleet and operations (c.40%), market-based schemes (60%), and sustainable aviation fuels (c.5%). The market-based schemes will likely be a mix of the EU ETS Scheme and the successful implementation of CORSIA.

COVID-19 has clearly shifted priorities to cash generation protecting balance sheets in the near term. However, as the market recovers, we believe the themes above will become a growing focus for airlines globally.

### Emissions trading schemes increase the value of fuel efficiency

Carbon dioxide emissions related to the aviation industry have been included in the "EU emissions trading system" (EU ETS) since 2012. This requires all airlines that operate in Europe (European and non-European alike) to monitor, report and verify their emissions, as well as surrender allowances covering a certain annual level of emissions derived from their flights.

The EU ETS is based on a "cap and trade" principle. A cap is established on the overall amount of given greenhouse gases that can be emitted, which is then reduced over time so that the overall emissions decline. Within this cap, companies are allowed to buy or receive emission allowances, which they can trade among each other. Under the EU ETS rules, airlines were granted initial $CO_2$ allowances on the basis of historical RTKs (revenue ton kilometres) and a $CO_2$ efficiency benchmark. In summary, the cost of growth for European airlines will increase.

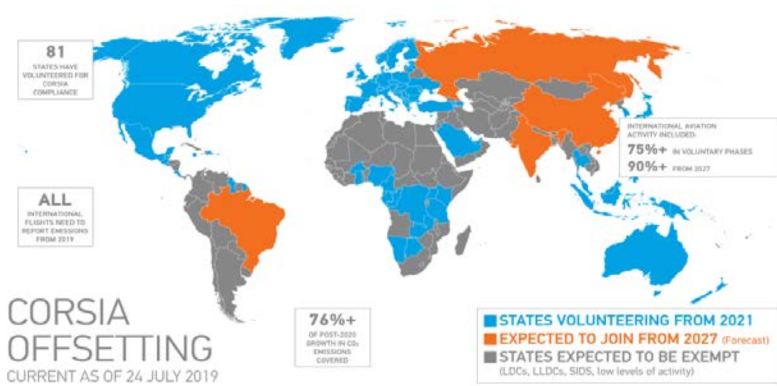
### Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

CORSIA is the only example of a global industry mechanism to reduce $CO_2$, which requires airlines to purchase carbon offsets for flights between CORSIA-eligible countries, above a 2020 baseline. This is the mechanism to deliver the industry goal of carbon-neutral growth from 2020 and a 50% net reduction by 2050.

In 2016, the member states of ICAO (191) agreed to implement CORSIA, and baseline emissions monitoring started in 2019. Between 2021 and 2026, 75%+ of global international aviation emissions will be covered through a voluntary phase. From 2027, 90%+ of emissions will be covered when participation of the scheme becomes mandatory for all countries.

**Exhibit 16: CORSIA countries and roll out timing**

There are about 191 member states represented in the ICAO as of 2019




**Source:** IAG 2019 Capital Markets Day.

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### Understanding CORSIA vs. EU ETS

During the implementation period of CORSIA, the calculation of carbon offsets will be based on a sector-wide growth factor, which is common for all operators and does not take into consideration varying sizes of operators. This growth factor will be multiplied by the operator's emissions to give the offsetting requirement.

From 2030 through 2032, the offset calculation will also include an operator's emissions growth factor (20%), along with the sectoral growth factor (80%). From 2033 through 2035, these percentages will transition to 70% and 30%, respectively.

The European Union Emissions Trading System (EU-ETS) is a cap-and-trade system, which means that even if gross emissions from aviation rise, there is no net increase in $CO_2$ emissions across the scheme as a whole. But CORSIA is an "offset" scheme, which means carriers must buy offsets from internationally accredited programmes.

While EU-ETS applies to all emissions within the relevant geographical area, CORSIA applies only to growth in emissions over the 2021 baseline, and it applies only to international flights. Under EU-ETS, airlines are required to surrender allowances equivalent to their own relevant $CO_2$ emissions, but in phase 1 of CORSIA they will have to acquire offsets, based on their share of total industry growth in emissions. This share is computed according to the individual airline's proportion of total emissions, not its contribution to the growth in those emissions.

### How do the schemes incentivise airlines?

We consider the impact of these schemes through the way they impact the marginal cost for airlines. Just taking the cost under ETS of buying carbon credits and dividing by total passengers underestimates the impact on marginal cost. In 2012-17, the impact on margin cost was relatively low, but this was primarily because the cost of carbon was low. Given airlines are required to buy offsets for every incremental ton of carbon over a base line, the impact on marginal cost is actually the cost of 1 ton of carbon divided by the number of passengers that ton of carbon flies.

### Cost of carbon will accelerate aircraft replacement

When considering the impact of the EU ETS scheme and CORSIA post the initial introduction phase, we believe these two schemes will become important drivers of demand in the 2020s.

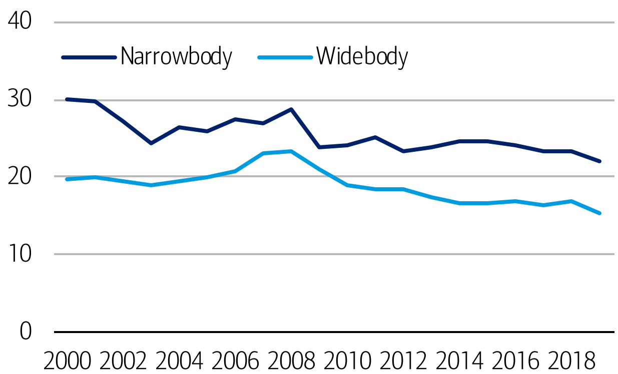
We have seen how the economics of aircraft replacement change with adjustments in fuel costs (the oil price fall in 2014-15 drove the drop in 'neo' lease rates as airlines pushed out replacement), and we believe carbon taxes through emissions schemes should be considered as increasing the marginal cost for growth. As airlines grow, this requirement will also grow, and could be substantial over time. **This drives a strong incentive to improve fuel efficiency and accelerate the replacement of the fleet.**

As an example, Ryanair paid €115mn for EU Emissions Allowances in FY19, which at an average price per ton of $CO_2$ of c.€19 equates to c.6mn tons, vs. total $CO_2$ emissions of c.11.7mn tons in Calendar Year 2018. This is based on a fleet of c.471 aircraft (455 737NG and 16 A320). Improving the fuel efficiency of the fleet by 15%, could reduce $CO_2$ emissions by c.2m tons, and the cost of Ryanair's ETS credit cost by €40mn.

At €25, this saving would rise to c.€50mn, or c.€100k incremental value per aircraft, a saving which has an NPV of €1mn over the life of the aircraft. This increases the NPV benefit to airlines of the more fuel-efficient, next generation aircraft by 19% based on our analysis, vs. a NPV benefit of c.$6.7mn for a next generation aircraft alone when considering aircraft replacement. As of February 2021, the cost of carbon is €38/ton. Higher NPV savings to the airlines support accelerated replacement assumptions. We expect a younger average age of the fleet in the 2020s.

A by-product of increased retirements and a younger fleet on average could be lower aftermarket growth. This could become a risk for the engine OEMs. For narrow-body engines, typically the majority of the value is in the first two shop visits (typical years seven and 14), and we assume only c.50% will actually go through a full third shop visit, as airlines typically start using increased amounts of used serviceable material in later life engines.

**Exhibit 17: Average retirement age of both Airbus and Boeing narrow-body and wide-body aircraft**
Wide-body aircrafts have lower retirement age over the years vs narrow-body




**Source:** BofA Global Research estimates, Cirium

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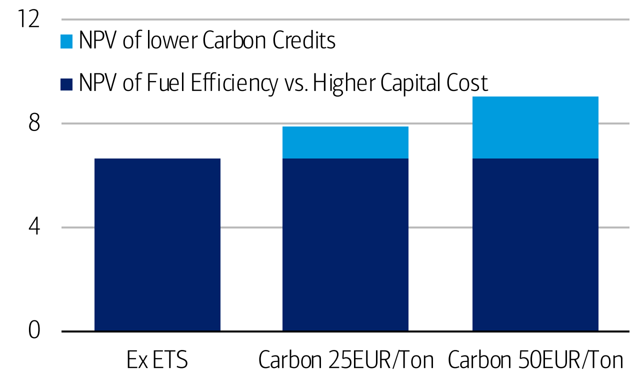
**Exhibit 18: NPV of MAX vs. NG for aircraft replacement inc the benefit from lower carbon purchases from credits at different carbon prices.**
NPV of fuel efficiency remain higher than that from lower carbon credits




**Source:** BofA Global Research estimates, Airline Monitor

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# Other advanced technologies

As the sector focuses on reducing emissions with the use of hydrogen, sustainable aviation fuels (SAFs) and hybrid electric propulsion systems, future aircraft design will also have a meaningful impact on aviation emissions. A number of advanced technologies are under development. Some can be retrofitted to current aircraft in service and some cant, which will require new aircraft designs to be introduced into the fleet. Exhibit 20 highlights some of the technologies under consideration, the expected impact on fuel economy, and whether they can be retrofitted.

**Exhibit 19: List of retrofits and upgrades potentially available for aircraft before 2030**
Fuel reduction benefit from retrofit and upgrade can be as high as 10%

| Group | Concept | Type of Technology | Fuel Reduction Benefits |
|---|---|---|---|
| Aerodynamics | Variable Camber | Retrofit | 1 to 2% |
| | Riblets | Retrofit | 1% |
| | Raked Wingtip | Retrofit | 3 to 6% |
| | Winglets | Retrofit | 3 to 6% |
| Cabin | Lightweight Cabin Interior | Retrofit | 1 to 5% |
| Material & Structure | Advanced Materials | Production Upgrade | 1 to 3% |
| | Active Load Alleviation | Production Upgrade | 1 to 5% |
| | Composite Primary Structures | Production Upgrade | 1 to 3% |
| | Composite Secondary Structures | Production Upgrade | <1% |
| System | Adjustable Landing Gear | Production Upgrade | 1 to 3% |
| | Taxi Bot | Retrofit | 1 to 4% |
| | Advanced Fly-by-Wire | Production Upgrade | 1 to 3% |
| | Structural Health Monitoring | Retrofit | 1 to 4% |
| Advanced Engine Components | Fan Component Improvement | Production Upgrade | 2 to 6% |
| | Very High BPR Fan | Production Upgrade | 2 to 6% |
| | Advanced Combustor | Production Upgrade | 5 to 10% |

**Source:** IATA

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Exhibit 21 shows some new concepts that either have, or could be introduced into aircraft design and their impact on fuel efficiency.

**Exhibit 20: List of new technology concepts (2020 to 2035)**
New engine architecture is expected to have the most fuel efficiency benefits

| Group | Concept | EIS | Fuel Efficiency Benefits |
|---|---|---|---|
| New Engine Architecture (Ultra-High Bypass Ratio: UHBR) | Ultrafan | 2025 | 25% (Trent 700) |
| | GE9X | 2023 | 10% (GE90-115B) |
| | Counter Rotating Fan | 2030 | 15 to 20% |
| | Ultra-High Bypass Ratio Engine | 2025 | 20 to 25% (5 to 10% re LEAP) |
| Engine Cycle | Adaptive/Active Flow Control | 2025 | 10 to 20% |
| | Ubiquitous Composites (2nd Gen) | 2025 | 10 to 15% |
| Aerodynamics | Natural Laminar Flow | 2030 | 5 to 10% |
| | Hybrid Laminar Flow | 2030 | 10 to 15% |
| | Variable Camber with New Control Surfaces | 2030 | 5 to 10% |
| | Spiroid Wingtip | 2025 | 2 to 6% |

**Source:** BofA Global Research estimates, IATA

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## Aerodynamics – laminar flow

Aerodynamics is a key focus of future aircraft designs as airframers look at ways to reduce drag and improve fuel efficiency. One of these areas seeing increased development activity is laminar flow control.

Laminar flow can be described as the smooth, uninterrupted flow of air over an aircraft's wing. As highlighted in Exhibit 21, this solution could potentially drive an improvement in fuel burn of between 5% and 10%.

The principle of laminar flow is that the air follows a smooth and regular path around an aircraft's wing, resulting in minimum drag. The issue is that so far, natural laminar flow has not been achieved across the complete airfoil, as this would require perfecting the shape. Recent projects like the Breakthrough Laminar Aircraft Demonstrator in Europe (BLADE) have conducted flight tests using Airbus A340 by replacing the outer-wing section of about a 10-meter width with laminar profile. The result shows a potential 4.6% fuel saving for a flight with a distance of 800nm, with a reduction in wing friction of up to 50%.

## Ultra High Bypass Ratio Engines

There are two key elements in a gas turbine to try to maximise: thermal efficiency and propulsive efficiency. Thermal efficiency comes from running turbines hot and fast, whereas propulsive efficiency comes primarily from a very large front fan running at slow speed. Hence modern engines have large bypass ratios, as much of the thrust is derived from the front fan itself. New engine aircraft delivered from 2015 typically already have a high bypass ratio (BPR) of >10:1. As a result, Ultra-High-Bypass Ratio engines are currently under consideration.

Rolls-Royce is developing the UltraFan Engine that targets a 25% reduction in fuel burn and $CO_2$ emissions vs. the Trent 700, with a bypass ratio of 15:1. Safran is also developing an Ultra-High-Bypass Ratio (UHBR) turbofan engines with a bypass ratio of at least 15, and the new engine would have achieve a fuel efficiency about 5-10% vs LEAP, or 20-25% vs older engines used in the narrow-body category.

## Open rotor

Open rotor engine technologies have the potential to lower fuel burn and $CO_2$ emissions substantially relative to turbofan engines with the same amount of thrust. An open rotor engine is like a turbofan in that it uses a central gas-turbine core to drive a larger fan diameter, which pushes air through the outer engine. But like a turboprop, it has no surrounding nacelle. Open rotor engines also have two counter-rotating rows of propeller blades, which remove the spin from the column of air, creating more direct thrust. The counter-rotating fans also allow a high pressure ratio and a high bypass ratio to be achieved with short rotors.

As we highlighted above, to achieve higher propulsive efficiencies with a turbofan engine, the bypass ratio must be increased with a larger fan diameter, but this increases the weight (nacelle) and drag of the aircraft. On the other hand, the lack of a nacelle increases the area of air on which the blades can work, but makes the open rotor engine much noisier.

**Exhibit 21: NASA and GE open rotor prototype**
The open rotor with rows of propeller and no surrounding nacelle


**Source:** NASA, GE

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Technological challenges for open rotor engines include noise, blade pitch control through the counter-rotating power transmission systems, appearance concerns by customers, and installation of the engine on the airframe to minimise interaction of the propeller airflow with that of the airframe.

In order to keep the tips of the blades subsonic at cruise (reducing shock wave losses and noise), the rotational speed of the rotor must be reduced. This leads to a rotational flow or swirl in the propeller wake. The use of a second propeller to capture this swirl flow allows the overall efficiency to be significantly improved, whilst maintaining a propeller diameter that can be integrated with the airframe

## E-Taxi

The E-Taxi is a development in the aircraft system that could be retrofitted to the current fleet to help reduce fuel burn. The goal is to substitute small on-board electric motors with the main engine for taxiing on airport taxiways, and this has the potential to cut fuel burn by as much as 4%. The primary limitation of E-Taxi systems, is the additional weight of c.400kg, but this would still be offset by fuel savings. Safran has developed the Electric Green Taxiing System, which features electric motors that are mounted in the main landing gear wheels, and this allows taxiing without using the main engine or a towing tractor.

## Blended Wing Body

Conventional aircraft are designed with a tube-and-wing configuration, but achieving significant fuel savings through aerodynamics and reduced drag could be driven by new airframe configurations. The Blended Wing Body (BWB) is among the designs that are seen as more promising. Also called the Hybrid Wing Body (HWB), the blended wing body is primarily designed as a large flying wing, with the passengers or cargo area at the centre section. The outer wing is blended with this centre section.

Current aircraft that utilise this design include the Northrop Grumman B-2 bomber and Airbus recently announced this design as part of its ZEROe concept, which will be considered for development as the company investigates hydrogen-powered aircraft. Blended wing-body aircraft are seen as attractive for long-range flights as the aerodynamic benefits are highest in cruise flight. Smaller blended wing-body aircraft with about 100-passenger capacity on short-haul routes are also under consideration, and DZYNE Technologies has worked with NASA to design such a concept with 120 seats. Exhibit 23 and 24 show the small BWB design and Airbus large BWB concept.

**Exhibit 22: NASA X-Plane: BWB designed by DZYNE**
The plane has the capacity to take up to 120 seats

**Source:** NASA

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**Exhibit 23: The Blended Wing Body Concept**
The concept would be powered by a hydrogen propulsion system

**Source:** Airbus

Fuel reduction with the BWB configuration is expected to be about 25-50% for the large designs vs existing aircraft of similar size, and 30% for smaller aircraft. A key challenge with this aircraft is that commonality is difficult to achieve, compared to tube-and-wing aircraft that allow for modification to fuselage, cabin size etc. Another issue would be current aircraft operations, and their ability to refuel and disembark BWB aircraft.

# What are companies' current plans?

Climate goals are now well-established within aviation as different industry-partnership groups and regulatory authorities have announced defined timelines to achieve zero carbon emissions.

With sustainability becoming a growing focus for the industry, major Aerospace companies have started outlining their action plans:

### Airbus – leading the journey towards clean aerospace

Air transport currently makes up c.2% of global emissions, and 12% of transport sector emissions, and the industry is coming under increased scrutiny for its environmental impact. Airbus have published their annual report, where they outline emissions reporting and policies. Airbus highlight their *'foremost ambition as an aircraft manufacturer is to bring the first zero emission (also referred to as "ZEROe") commercial aircraft to the market by the mid of the next decade and to play a leading role in the decarbonisation of the aviation sector.'*

The group's environmental policy has 4 key ambitions:

- Lead the decarbonisation of the aerospace sector aiming to bring the first zero emission commercial aircraft to market by 2035;
- Reduce our industrial environmental footprint at sites worldwide and throughout our supply chain;
- Develop a more circular model, leveraging ecodesign and digitalisation to optimise material utilisation and reduce use of critical resources;
- Enhance our current product and services portfolio contributing positively to climate change mitigation and adaptation.

## Green targets becoming part of exec/manager pay

The Executive Committee agreed in 2019 to include a reduction target for 2020 (compared to 2019) of -2.7% for $CO_2$ and -5% for purchased water as part of the Company's top objectives. In 2020, the Executive Committee agreed to include reduction targets of -3% for $CO_2$ and -5% for water for 2021 (compared to 2020) as part of the Company's top objectives. These annual targets form part of the CEO's and other Executive Committee members' remuneration. In 2021, the $CO_2$ target will also be included as a non-financial KPI in the variable remuneration of executives and success sharing for all eligible employees.

### Emissions reporting of products

Airbus has extended its reporting to include the in-use emissions of commercial aircraft delivered in 2019 and 2020, and can be found in the report of the board of directors.

In 2019, the Company delivered a record 863 commercial aircraft. Based on an average lifetime in service of around 22 years (average lifetimes specific to each aircraft type were used in the calculation), the total $CO_2$ emissions for these products over their anticipated lifetime is estimated at around 740Mt$CO_2$e (of which around 130Mt are linked to upstream fuel production), which translates to an average efficiency of 66.6g$CO_2$e per passenger-kilometre.

In 2020, the Company delivered 566 aircraft with resulting estimated lifetime emissions of around 440Mt$CO_2$e (of which 80Mt are linked to upstream fuel production) and average efficiency of 63.5g$CO_2$e per passenger-kilometre.

Airbus highlight that for the purpose of this calculation, the operating conditions of the aircraft were considered to be static over the whole service life. Therefore, it has to be taken into account that these numbers do not reflect the anticipated gradual introduction of decarbonisation measures such as SAF and probably constitute a "worst case scenario" in terms of carbon intensity.

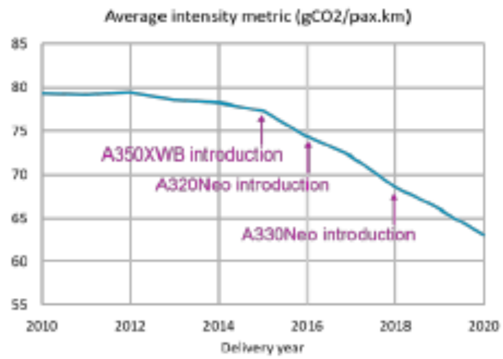
# Airbus' roadmap to reducing emissions

## Fleet replacement

The Company's commercial aircraft products have reached a rolling average of 2.1% fuel efficiency improvement annually over the past 10 years,

**Exhibit 24: Average carbon intensity of aircraft deliveries**

The carbon intensity of Airbus products has been reducing medium term with the introduction of new products.




**Source:** Airbus Board of Directors Report.

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## Technology

### Zero-emission commercial aircraft ambition

Airbus is increasing investment into a zero-emission commercial aircraft known as ZEROe, where they are exploring a variety of hybrid-electric and hydrogen technology options.

### Zero-emission Urban Air Mobility

In May 2018, Airbus created the Urban Mobility entity to take its exploration into cutting-edge commercial urban air mobility solutions and services to the next level.

The idea for a compact "flying taxi" first came from Airbus desire to take city commuting into the air in a sustainable way. Airbus has been investing in a multirotor design based on electric motors. To date, the CityAirbus sub-scale model has flown more than 100 test flights, which has proven the aerodynamic configuration of the full-scale prototype.

## Investing in smart ATM solutions and optimised operations

Airbus is developing digital solutions (through its subsidiary Navblue and its digital platform Skywise), and will continue to support its customers to minimise fuel consumption with best operational practices, innovative services and training.

Airbus believe that improving operations and infrastructure could contribute to emission reductions by around 10%: The Company supports initiatives aimed at reducing ATM inefficiencies (such as the Single European Sky Air Traffic Management Research program - SESAR), while working on disruptive practices, such as formation flying.

In November 2019, Airbus launched the fello'fly project which aims to demonstrate the technical, operational and commercial viability of two aircraft flying together for long-haul flights. Through fello'fly, a follower aircraft will retrieve the energy lost by the wake of a leader aircraft, by flying in the smooth updraft of air it creates. This provides lift to the follower aircraft allowing it to decrease engine thrust and therefore reduce fuel consumption in the range of 5-10% per trip. By end 2020, Airbus fello'fly had signed agreements with two airline customers; Frenchbee and SAS Scandinavian Airlines, as well as three Air Navigation Service Providers (ANSP) to demonstrate its operational feasibility; France's DSNA (Direction des Services de la Navigation Aérienne), the UK's NATS (National Air Traffic Services) and European Eurocontrol.

In December 2020, after two years of experimental entry-into-service programmes and more than 20,000 flights carried out by about 90 A320 aircraft from six airlines (Air France, British Airways, easyJet, Iberia, Novair and Wizzair), the "4D-Trajectory Based Operations" project led by Airbus alongside more than 15 partners in the frame of the SESAR programme came to an end. The project focused on analysing the real-time transmission of four-dimensional trajectory data (latitude, longitude, altitude, time) as a solution to better inform ATM operations, and significantly improve aircraft emissions.

**Developing and deploying SAF**

The main driver of Airbus commercial aircraft products emissions and $CO_2$ intensity is the energy source. Although they only represented a small share of aviation's current fuel use in 2020, SAF (biomass-based or synthetic) are key in the air transport sector decarbonisation strategy.

Since 2008, Airbus has acted as an important catalyst in the certification process, demonstration flights, partnerships and policy advocacy of sustainable jet fuel. Since 2011, over 250,000 commercial flights have used SAF.

All Airbus commercial aircraft are already certified to fly with a fuel blend including up to 50% of SAF, and Airbus has an ambition to reach a certified 100% blending capacity. SAF produced using the most advanced pathways can provide $CO_2$ emission reduction of up to 80%. This means that today, the emissions from aircraft currently offered by Airbus could be reduced by 40% if their potential was fully used.

Airbus estimates that products delivered in 2020 could see their lifetime emissions reduced by around 10% thanks to the gradual introduction of SAF during their operational life. However, today the price and global production capacity remain the main constraints preventing operators from massively incorporating these types of fuels.

**Encouraging temporary $CO_2$ emission compensation schemes**

Temporary $CO_2$ emission compensation will be instrumental to stabilising aviation's emissions in the medium term until disruptive solutions reach maturity. For that reason, Airbus supports ICAO's CORSIA as the only global market-based measure for international aviation

## Safran

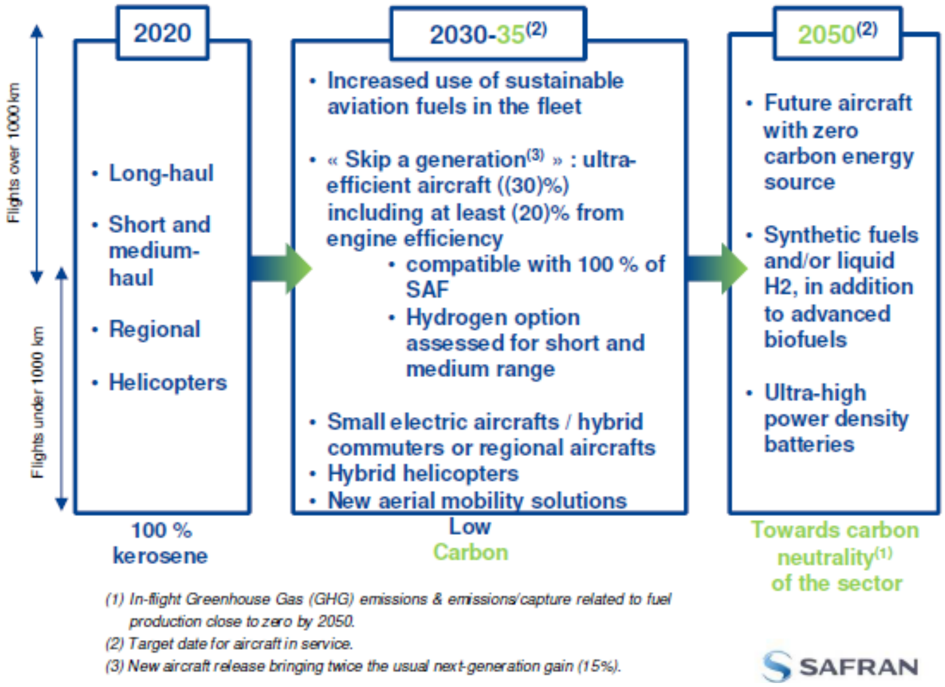
Safran has a plan to tackle the environmental impact of aviation, and has highlighted that the cost cutting plan through 2020, Safran maintained the environmental priorities of R&T and its innovation roadmap. Safran has outlined three key priorities:

1. Safran is working on the next generation of small-medium range (SMR) aircraft and, together with its partner GE, on the successor to the LEAP engine, which is expected to offer fuel savings of at least 20 % over the LEAP.

2. The future generation of engines will be compatible with 100 % “drop-in” sustainable aviation fuels, and Safran explores the potential of liquid hydrogen solutions.

3. For the lower end of the market, Safran unlocks the potential of electrical/hybrid propulsion.

**Exhibit 25: Safran vision air transport decarbonisation**
The timeline is a mix of new fuel adoption and fuel efficiency




**Source:** Safran

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## MTU

The Aero-engine company regularly reports its ESG performance in line with the internationally recognised Global Reporting Initiative (GRI) standard. In its last 2019 report, MTU highlighted its commitment towards reducing carbon emissions.

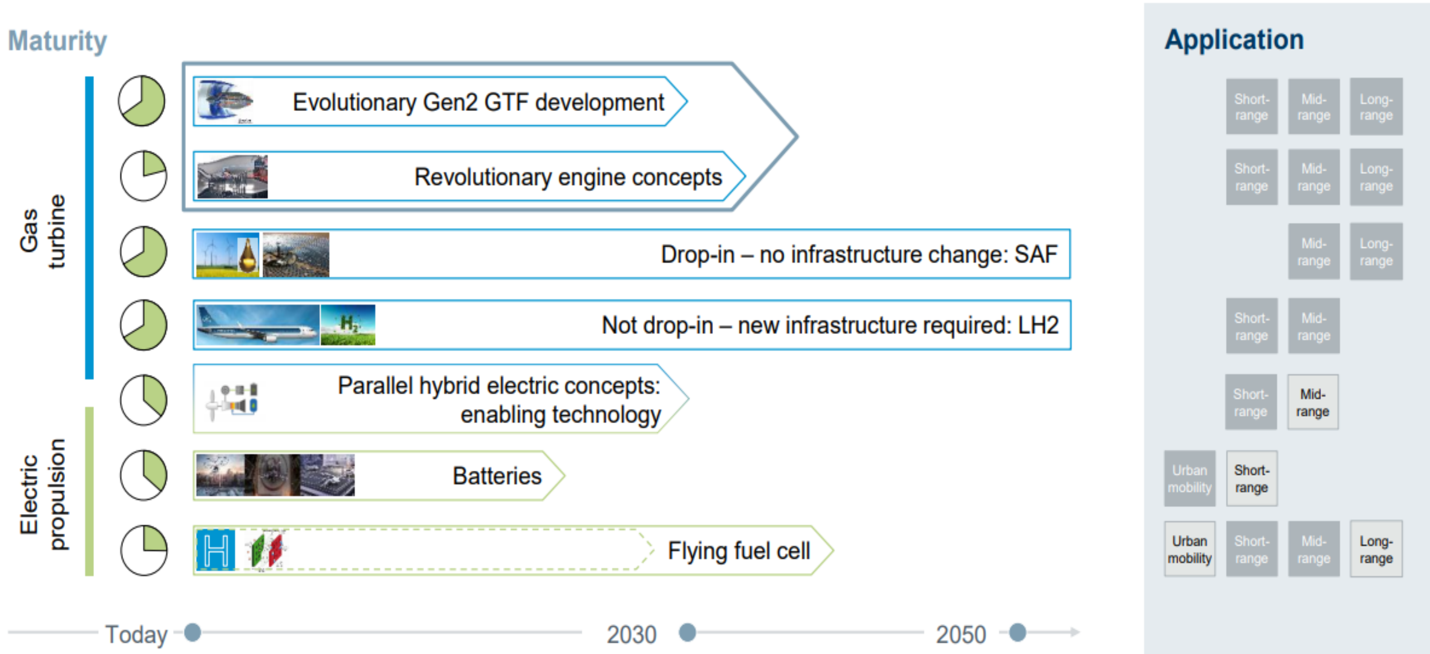
- Achieving a 15% reduction in $CO_2$ emissions with the 1st Generation Geared Turbofan.
- Supporting the rollout of sustainable fuels with MTU engine expertise and the status on this already tagged as 'ongoing'.

The Clean AirEngine (Claire) technology agenda is MTUs roadmap for green aviation. The next step (after GTF introduction), includes further development of the geared turbofan in order to exploit its full potential. For instance, there is scope to obtain even lower fan pressure ratios, which would achieve an even higher bypass ratio. Moreover, the core engine's thermal efficiency could be further improved by increasing the pressure ratios, designing the compressor and turbine components as an integrated unit, and using new materials.

MTU is developing two propulsion concepts based on the GTF engine, for which it combines the gas turbine with brand new technologies: in the composite cycle approach, the conventional high-pressure compressor system is to be complemented by a piston compressor and motor; the steam-injected and water-recovering gas turbine integrates a steam power process into the gas turbine cycle.

Another revolutionary concept that MTU is pursuing is electric propulsion. Compared to battery- and hybrid-electric engines, the hydrogen-powered fuel cell has particular potential to enable emissions-free aviation down the line, without transport capacity and range restrictions. The technology roadmap for MTU is shown in the exhibit below.

**Exhibit 26: MTU's technology roadmap**
Technology is a combination of electric propulsion and gas turbine




**Source:** MTU

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## Rolls Royce

Rolls Royce at their FY20 results highlighted the company was going to increase investment to improve gas turbine efficiency and Sustainable Aviation fuel. The group is targeting approximately 20% of its annual R&D spend on low carbon solutions including hybrid, hydrogen and electric power technologies by 2023.

Rolls has highlighted its commitments to enabling the vital sectors in which they operate to achieve net zero by 2050, as well as becoming a carbon neutral business by 2050: net zero greenhouse gas emissions from operations and facilities by 2030 (ex-product development/safety testing) and fully compatible by 2050.

A key focus of this will be the group's investment into the UltraFan, which will be 100% sustainable aviation fuel compatible, which is progressing to final assembly in 2021, as well as extensive work in sustainable aviation fuels across their portfolio. Rolls has successfully tested 100% blends in widebody, business jet and defence aircraft.

Rolls is also working in the electric aircraft domain, as part of the CityAirbus eVTOL demonstrator flight test programme, and with a commercial contract for electric propulsion units to power an eVTOL manufactured by Vertical Aerospace.

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|---|---|---|
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| Neutral | ≥ 0% | ≤ 30% |
| Underperform | N/A | ≥ 20% |

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