Flying on **electricity and hydrogen** in Europe

How Europe can reduce aviation's climate impact and create the aircraft of the future

Alliance for **Zero-Emission Aviation**

PREPARING EUROPE
FOR HYDROGEN
& ELECTRIC FLIGHT

JUNE 2024

> The Alliance for Zero-Emission Aviation is a voluntary initiative that **prepares the European aviation ecosystem for the transition to electric and hydrogen propulsion,** in line with the objectives of the European Green Deal.

Novel propulsion technologies will enable aircraft to **operate with in-flight zero carbon emissions** and have the potential to significantly reduce aviation's non-carbon effects. These aircraft could abate up to 43 megatonnes (Mt) of CO_2 annually on intra-European routes by 2050, reducing intra-European aviation emissions by a third by 2050, and could reduce aviation's total warming impact by much more.

Electric and hydrogen propulsion are a unique opportunity **to keep Europe at the forefront of aviation's technology.** By winning the global race to develop zero-carbon flight, Europe will strengthen its role as innovation incubator and global manufacturer. It will also open up new possibilities for sustainable regional air mobility in Europe.

Achieving this outcome is only **possible if coordination starts today** between elements of the aviation ecosystem and EU/national policymakers, to ensure that targeted investments are made, and the right policies are laid out to remove obstacles and incentivise the industry to adapt.

Purpose of the document

In this document, the Alliance for Zero-Emission Aviation outlines its member's views on the benefits and challenges of deploying electric and hydrogen-powered flights in Europe, with the aim of rallying the aviation ecosystem around a common vision and informing policymakers and the general public.

Foreword by

Timo Pesonen

Director-General, European Commission DG DEFIS

The European aviation sector stands on the brink of a transformative revolution, poised to not only achieve the Green Deal's ambitious goal of net-zero emissions by 2050, but to use this challenge as a catalyst for shaping a climate-neutral future for air travel. Commissioner Breton is determined to lead the charge towards a new era, where renewable and low-carbon energies power our aircraft and greenhouse gas emissions are drastically reduced.

The aeronautics industry is already investing heavily in groundbreaking aircraft and powertrains fuelled by electricity and hydrogen, unlocking exciting new market opportunities. However, integrating these innovative aircraft configurations into the operational landscape demands a radical transformation of the entire aviation ecosystem. This requires a collaborative effort, where all stakeholders in the ecosystem take concerted action to overcome the barriers to change.

To empower the aviation sector in this ambitious endeavour and align with the EU's overarching policy objectives, Commissioner Breton launched the Alliance for Zero-Emission Aviation in June 2022.

This Alliance brings together a diverse range of players from across the ecosystem, united by a voluntary commitment to work together to remove obstacles hindering the deployment of revolutionary electric and hydrogen-powered aircraft configurations. The Alliance's broad membership ensures comprehensive representation across the entire value chain, fostering a holistic approach that encompasses all technologies and configurations.

The Vision document you hold in your hands is a testament to the Alliance's groundbreaking work and the unwavering commitment of its members. It showcases a shared determination to make electric and hydrogen-powered flights a reality, even in the face of differing and sometimes competing ambitions. This Vision represents a collective ownership of the challenges ahead, a pledge to overcome them, and a rallying cry to unite around a common goal.

I invite you to delve into this inspiring Vision document, a blueprint for a zero-emission aviation future that promises to reshape the skies and contribute to a greener, more sustainable world."

Supporting Statements by the Alliance's Co-Chairs

Karine Guénan

VP ZEROe Hydrogen Ecosystem at Airbus

It is required to maintain mobility by plane; it is expected from society, and the aerospace sector has committed to net-zero carbon emissions by 2050. We see the development of disruptive propulsion technologies, like hydrogen- and electric-powered aircraft as essential to achieve this goal. This ambition cannot be achieved alone, it requires a huge effort from multiple sectors with new and decarbonised energy supply being pivotal for a successful transition.

The time to act is now and we're already building the future hydrogen ecosystem as deploying all infrastructure comes with long lead times. While aircraft manufacturers in Europe have been pioneers in connecting people around the world, the next frontier is to make zero-carbon emissions in flight happen.

David Morgan

Chief Operating Officer at easyJet

Around 4% of the EU's carbon emissions are from aviation and that's something we need to urgently address. At the same time, aviation brings huge economic and social benefits, and we must make sure these are retained to ensure flying does not revert to being something only the select few can afford.

Zero-carbon emission technologies have the potential to deliver on this ambition, but achieving it will require coordination from industry, governments and regulators. We should be motivated by the scale of the opportunity – a chance to reindustrialise European air travel in a way that will not only reduce our environmental footprint, but one that will open up a wealth of new opportunity for Europe's aeronautics sector for generations to come.

1. Introduction

Aviation is a European[1] success story: it is a leading global example of an integrated aviation market and one of the world's largest, accounting for over **20% of global traffic and over 900 million passengers a year.**

The sector is estimated to support nearly **5 million jobs and contribute €300 billion to European GDP.**

If the aviation industry is to continue to thrive in the future, it must eliminate its contributions to climate change. Developing the technologies supporting aviation energy shift towards electric and hydrogen propulsion represents at the same time a way to reduce aviation's warming impact and an opportunity to open new markets for Europe's aeronautics sector.

1.1 THE BENEFITS OF ELECTRIC AND HYDROGEN PROPULSION

The European aviation sector has committed to net zero emissions from all flights departing from European aerodromes by 2050[2], in line with the EU Green Deal. Achieving net zero aviation as outlined by industry will require the use of sustainable aviation fuels (SAF), operational and airspace efficiency, improvements in aircraft design, and propulsion systems with the ability to eliminate in-flight carbon dioxide (CO_2) emissions, which are particularly important over short-haul routes.

Three propulsion technologies are identified as having the potential to power conventional aircraft without generating in-flight CO_2: hydrogen combustion, hydrogen fuel cell, and battery-electric propulsion. Hybrid propulsion systems, with range extenders powered by hydrocarbons such as SAF, may significantly reduce in-flight CO_2 emissions of short-haul and regional aircraft compared to fossil alternatives. They represent an essential technological advance in the transition to fully zero in-flight carbon aviation and contribute to increased carbon efficiency and reduced SAF requirements.

Europe is home to an aircraft manufacturing industry that is ready to revolutionise traditional aviation propulsion systems with these technologies. Europe's aeronautics industry is also one of the world's largest, putting Europe in a unique position to win the global race to develop zero-carbon flight, which the UK, Japan, and US have joined. This includes established European manufacturers as well as emerging companies developing innovative air mobility products.

Electric and hydrogen propulsion can significantly increase aviation's CO_2 abatement by 2050, offering a cost-effective solution and creating better source-to-thrust energy efficiency relative to other decarbonization options. It opens new possibilities for reducing aviation's non-CO_2 warming impacts while improving local air and potentially noise pollution.

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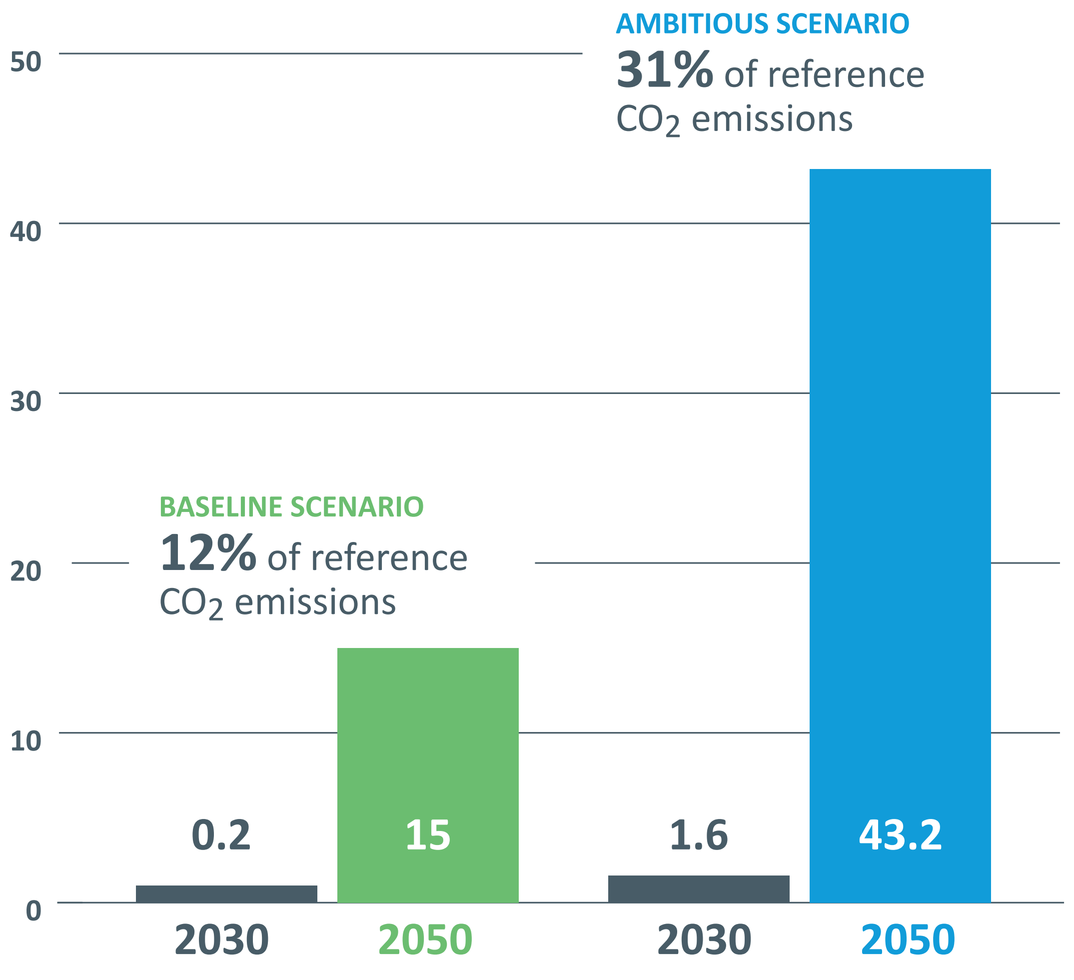
[1] Europe is defined throughout the document to be the EU-27 Member States.

[2] *Destination 2050 – A route to net zero European aviation* is a flagship sustainability initiative led by a wide cross-section of the European aviation industry, including Airlines for Europe, Airports Council International Europe, AeroSpace and Defence Industries Association of Europe, Civil Air Navigation Services Organization, and European Regions Airline Association.

1. Introduction

FIGURE 1

In-flight CO_2 emissions saving potential when introducing electric (incl. hybrid-electric) and hydrogen aviation in European short- and medium-haul fleets until 2050 (excluding widebody aircraft) – these figures only address carbon, but when considering the entire climate impact of aviation, the benefits are expected to be greater.



In-flight CO_2 emission savings, in Mt

As the market penetration of these technologies will depend on many factors within the ecosystem, AZEA has developed two scenarios to describe it. These scenarios consider short- and medium-haul routes flown by the future EU aircraft fleet. Long-haul flights are not expected before 2050. The ‘baseline’ scenario extrapolates from current planned aircraft deliveries and assumes no additional policy support beyond what exists and is planned as of today. It foresees around 20,000 aircraft delivered[3] between 2023 and 2050 in Europe - both conventional as well as hybrid-, electric and hydrogen aircraft. The ‘ambitious’ scenario is based on updated emissions and rollout forecasts, and is dependent on accelerated uptake through faster technological development driven by ecosystem and policy coordination and foresees stronger traffic growth in the regional and short-haul travel segments. In that case, total delivery figures increase to nearly 40,000 aircraft.

In the baseline scenario, the traffic projections established by the Alliance for Zero-Emission Aviation (AZEA) show that, if fuelled with fossil kerosene, aircraft registered in EU-27 would generate an estimated 125 Mt of CO_2 emissions across all aircraft on short- and medium-haul routes in 2050. This will be slightly less than half of all CO_2 emissions from all departures, short and long-haul, across Europe in 2050. In the ambitious scenario, these reference CO_2 emissions would increase to 142 Mt in 2050.

With the introduction of electric and hydrogen aircraft, AZEA’s baseline scenario estimates that our reference short- and medium-haul emissions will fall by 12% by 2050. However, under AZEA’s ambitious scenario the reference short- and medium-haul **emissions could fall by up to 31% by 2050.**

Beyond 2050, the potential for CO_2 savings is much greater, as lengthy aircraft development, deployment, and fleet renewal cycles mean benefits accumulate over time. Electric and hydrogen propulsion is also expected to create new options for limiting non-carbon warming effects due to their ability to fly without a carbon penalty.

While current research is directed at short- and medium-haul aircraft, long-haul/widebody aircraft represent over half of the current share of air transport emissions, and using the advances made on shorter range aircraft to extend hydrogen propulsion to this market segment would provide a route to transitioning the entire aviation fleet to zero operational carbon emissions.

[3] Including general & business aviation, new regional air mobility, regional turboprops and smaller single-aisle as well as larger single-aisle aircraft - widebody aircraft are not considered.

1. Introduction

Moving aviation like other transport modes towards electric and hydrogen propulsion is a climate opportunity, broadening aviation's decarbonisation options and mitigating the risks of overreliance on current options such as sustainable aviation fuels.

But equally, these technologies are **a huge industrial opportunity for Europe's aeronautics industry,** both the newer innovative companies as well as the large and established manufacturers. By promoting the development of electric and hydrogen propulsion, Europe has the potential to create a fresh industrial platform by becoming the first mover and **the world's supplier of zero-carbon aircraft, generating new jobs and economic growth.**

The emergence of innovative markets for air mobility, fuelled by electricity and hydrogen, also has the capacity to strengthen both the connectivity and accessibility across European regions. Deploying these technologies could make new routes more affordable, stimulating regional development and investment. A recent European Parliament resolution underlines how cleaner, faster, more convenient air transport can be a boon for remote areas, notably by improving access to public services, promoting job creation, and sustaining tourism[4].

This paper contains **initial guidance for the ecosystem and policymakers.** It should serve as a basic factsheet for policymakers and stakeholders who want to support the sector's transition to electric and hydrogen propulsion. AZEA is working to produce additional materials to identify in greater detail the ecosystem and policy requirements needed to fully realise the potential that electric and hydrogen offer, including guidance at individual Member State level.

1.2 THE FULL CLIMATE IMPACT: NON-CO2 EMISSION EFFECTS

Other than in the case of fully electric propulsion, hydrogen-based systems might still generate non-carbon emission effects during flight. These could hamper the climate benefits if not adequately addressed or mitigated.

Today, conventional combustion can have significant non-CO_2 emission effects in terms of contrail and cirrus cloud formation or through the emission of nitrogen oxide (NOx). Depending on the flight altitude and region, this non-CO_2 emission effect could be in the magnitude of several factors higher than the CO_2 emissions alone. There are still many research initiatives ongoing on these effects to reduce uncertainties around the climate impact with current combustion technologies as well as for future fuels and hydrogen propulsion systems.

Compared to conventional hydrocarbon combustion engines, hydrogen propulsion generates more water as a by-product of its reaction in a fuel cell, as well as through combustion in a hydrogen turbine.

However, in the fuel cell case, the resulting water emissions can be controlled and modified to mitigate the climate impact effects from contrail and cirrus cloud formation. Additionally, no NOx emissions are produced by fuel cells. Especially with hydrogen combustion, the contrail effects of the resulting water vapour and mitigation measures are still under research[5]. The quantity of NOx emissions from hydrogen combustion and their full climate impact also requires further investigation. In addition to the in-flight effects, leaks and vents of gaseous hydrogen from the tanks of parked aircraft need to be addressed.

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[4] European Parliament Resolution on electric aviation – a solution for short and mid-range flights (2023/2060(INI)).

[5] It should be noted however, that in the short to medium term, most aircraft that are expected to enter into service (e.g., eVTOL, low level operations and regional air mobility) will likely cruise below FL250. As these cruising levels are below the altitudes normally associated with the development of contrails and contrail cirrus, it is likely that there will be minimal non-CO_2 (contrail and contrail cirrus) impacts from these initial operations.

1. Introduction

However, unlike conventional engines, hydrogen propulsion creates **the potential for aircraft to reroute without incurring a direct carbon penalty,** meaning that weather regions that are prone to contrails persistence can be avoided without additional in-flight carbon emissions. This opens a route to an expected overall reduction in climate impact that is not available with today's technology without a negative impact on SAF requirements.

One of the key remaining challenges lies in the ability to clearly demonstrate that any recommendation on non-CO_2 policy measures results in the targeted environmental benefits and is a politically, technically, and administratively feasible option that does not create net increased adverse outcomes. Reducing the level of uncertainty around the climate impact of non-CO_2 aviation emissions is at the core of many research initiatives sponsored by Horizon Europe, SESAR 3 as well as the Clean Aviation Joint Undertakings.

Environmental certification standards already exist for aircraft engine non-CO_2 emissions, including NOx and non-volatile Particulate Matters (nvPM)[6]. Regulators and authorities are working together to establish further mitigation policy options and set adequate certification limits. The European Union is establishing a Monitoring, Reporting and Verification (MRV) Framework for non-CO_2 emissions under an implementing act of the Emissions Trading System (ETS) Directive by 31/08/24, which will provide the necessary methods and tools to monitor non-CO_2 emissions, enabling a CO_2 equivalent per flight to be produced. Moreover, under ReFuelEU Aviation Regulation, aviation fuel suppliers will report on their fuel quality (notably on sulphur, naphthalene and aromatics content), which creates non-CO_2 emission effects.

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[6] Particulate matter is a general term used to describe non-volatile (nvPM) or volatile particles (vPM) in various sizes and compositions. At the engine exhaust, particulate emissions mainly consist of nvPM containing soot, or black carbon.

2. The evolution of electric and hydrogen-powered flight in Europe

Air travel on electricity and hydrogen is **likely to be different to today's air travel.**

Short-to medium-haul journeys that are **entirely free from CO2 emissions during flight** will enable fast mobility over shorter journeys with lower contributions to climate change.

AZEA's baseline scenario forecasts that approximately **5,000** electric and hydrogen aircraft (excluding urban air mobility vehicles and helicopters) will be delivered to European operators between now and 2050. Under a more ambitious scenario, which includes appropriate ecosystem and policy coordination, this number could rise to **23,000** aircraft by 2050.

If AZEA's ambitious scenario is achieved, it could significantly change how people can fly in Europe.

From the late 2020s and early 2030s, people will have the option to fly regionally in Europe on smaller electric or hydrogen aircraft. The first zero in-flight carbon routes will be operated on regional aircraft.

From the 2030s, as larger regional and smaller single-aisle aircraft become available, short- and medium-haul routes will start. These aircraft will be similar in size to those used by the airlines' passengers today on mostly intra-EU routes and will be powered by liquid hydrogen.

By 2050, more than every third short- to medium-haul flight could potentially be powered by liquid hydrogen. Nearly all regional flights within Europe could be powered by hybrid-electric, electric or hydrogen propulsion.

As with today's networks, hydrogen-powered aircraft could feed passengers into larger aerodromes for connecting flights, or offer point-to-point journeys between major cities, maintaining the mass-transport routes that serve European tourist destinations today.

General aviation and light helicopters are likely to become adopters of hybrid-electric and electric propulsion. Hydrogen-powered business aircraft are expected to be available in the late 2030s.

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2. The evolution of electric and hydrogen-powered flight in Europe

FIGURE 2

Electric (incl. hybrid-electric) and hydrogen aircraft deliveries between 2023 and 2050 - this excludes ~24,000 (baseline) and ~31,000 (ambitious scenario) urban air mobility and helicopter deliveries.

Cumulative electric and hydrogen aircraft deliveries until 2050

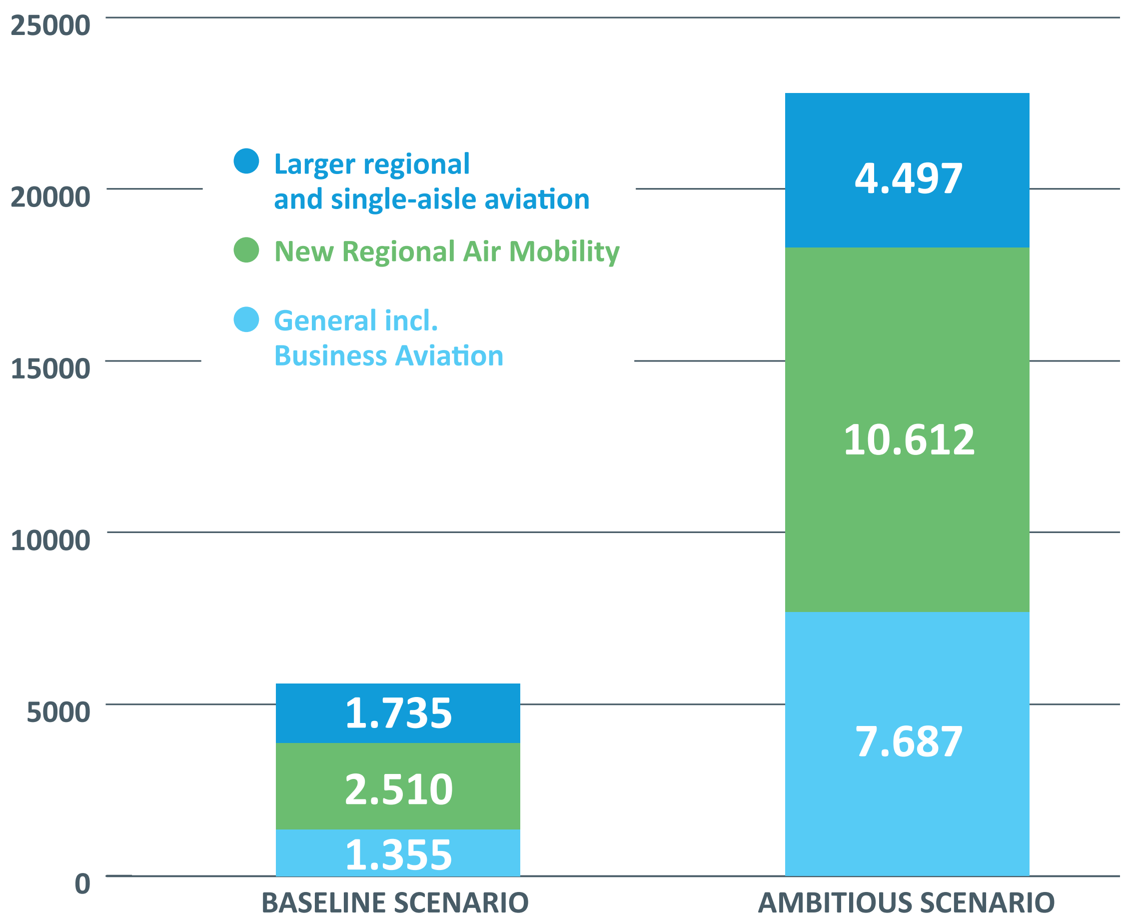
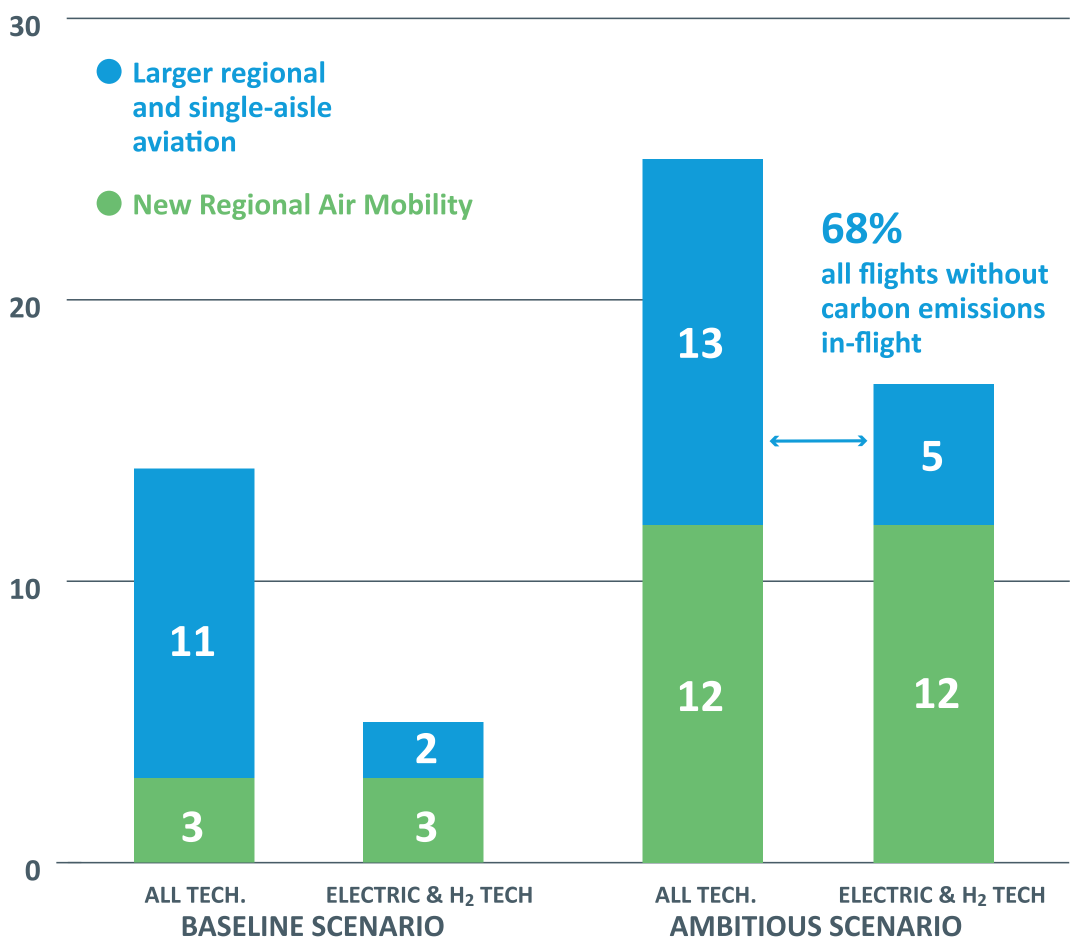


FIGURE 3

Selection of number of flights in Europe and share of flights operated by electric (incl. hybrid-electric) and hydrogen aircraft (without widebody aircraft, general aviation, business aviation, helicopters, and urban air mobility).

Flights in Europe in 2050, in Mn



AZEA foresees new opportunities for connectivity that could evolve with the development of electric and hydrogen aircraft. New regional air mobility (RAM) services could offer fast connections between currently underserved regions, making use of small, highly efficient aircraft. Urban access could be simplified by using eVTOL (electric vertical take-off and landing) aircraft that do not require large aerodrome and runway infrastructure.

Hydrogen represents a great opportunity for short- and medium-haul, offering a cost-replacement for today's travel and opening new travel possibilities. However, over the longer term there is the potential for hydrogen-powered flight to be extended to long-haul aircraft, creating another avenue for most aviation's in-flight CO_2 emissions to be abated.

AZEA members have set themselves the goal of deploying electric and hydrogen-powered aviation in Europe according to the objectives defined in Figures 2 and 3, considering the ambitious scenario to be the most appropriate for reaping the full benefits of these new technologies.

While the full advantages of electric and hydrogen aviation in Europe will take time to develop, they require action today. The ecosystem for these aircraft must be prepared, and the development of the aircraft, aerodrome and energy infrastructure, regulations, and other aspects can take years or even decades. These will represent a huge challenge to European aviation and overcoming them will require coordinated action between the aviation ecosystem and policymakers. Some (but not all) of these requirements are outlined in the next chapter.

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3. Ecosystem requirements

Electric and hydrogen operations will **require an ecosystem** of airlines, aerodromes, manufacturers, energy producers, air traffic managers, regulators, and policymakers who are **ready for change and accompanied by supportive policy.** The technology is moving ahead fast, and it is crucial that other actors keep up in order not to become a barrier.

Key elements of the ecosystem include:

THE AIRCRAFT

The development of electric and hydrogen-powered aircraft has jumped forward in the last years and it remains an area of constant change. Based on current projections, AZEA expects the following entry-into-service dates according to aircraft size and design approach:

- **By 2030:** general aviation, eVTOLs, and regional air mobility aircraft will enter the market.
- **By late 2030s:** larger regional and single-aisle hydrogen-powered aircraft developed for mass-transit short-haul markets will follow.
- **From 2040+:** potential hydrogen-powered longer-range aircraft.

Aircraft in the eVTOL segment will be designed from scratch to accommodate four to six passengers and the new propulsion system. For the other segments, both clean-sheet-aircraft-designs and retrofitting approaches are already being developed by aircraft manufacturers.

While retrofitting existing aircraft with new propulsion systems promises a faster development and potentially certification time, clean-sheet aircraft designs allow for greater energy efficiency when integrating the systems into the aircraft. New, Lighter-Than-Air vehicles with electric propulsion could open new markets such as unmanned surveillance, cargo, or luxury tourism.

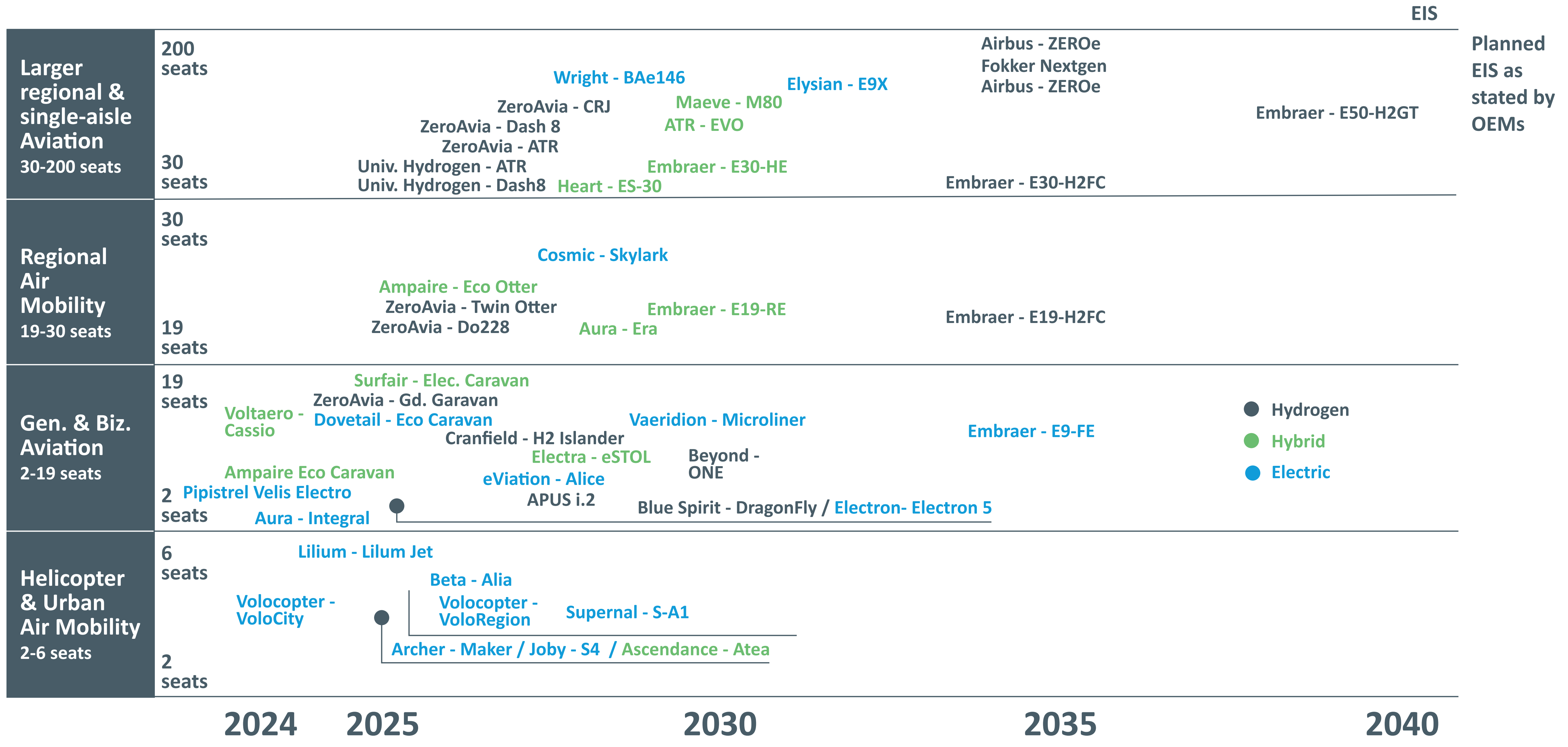

FIGURE 4

Overview of aircraft developments and their announced entry-into-service (EIS) dates. This shows the huge wealth of different initiatives and underlines how fast electric and hydrogen aviation is moving forward.

Note: Certification times are not always taken into consideration. These depend on several factors such as the maturity of applications received as well as the volume of applications to be handled at a specific time.

3. Ecosystem requirements

Major advancements in technology and aircraft system integration remain crucial for realising electric and hydrogen aircraft in the presented timeframe. These include further performance improvements in the technology around hydrogen fuel cell systems, hydrogen combustion engines, (cryogenic, liquid) hydrogen fuel systems, and jet turbines. Industry is actively resolving efficient thermal management solutions and other aircraft system integration issues to achieve high-performing aircraft.

Policy actions should focus on **a long-term strategy of supporting** these initiatives, creating a policy framework that gives comprehensive support to the development of electric and hydrogen aviation technologies. Signalling long-term support through policy will help provide certainty and enable more private investment into electric and hydrogen aviation.

While existing structures are good at funding initial research into the latest technology, there are fewer mechanisms available for **supporting commercialisation.** Zero-carbon flight is likely to be a strategic global technology. To ensure Europe benefits from it, we must ensure that **Europe becomes the place where these technologies are fully deployed.** This means supporting technologies at a high technological-readiness level.

Electric and hydrogen aviation is moving forward quickly.

To ensure Europe benefits from this technology it should commit to a policy of long-term support.

The EU should ensure that Europe becomes the place where these technologies are commercialised.

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3. Ecosystem requirements

ENERGY GENERATION AND TRANSMISSION

Vast amounts of renewable and low-carbon energy will be needed to power the aircraft. Based on AZEA's forecasts, **9-30 TWh/a** (Terawatt-hours per annum, baseline vs. ambitious scenarios) of electricity generation will be required for electric (incl. hybrid-electric) aircraft in 2050, while **69-168 TWh/a** will be required to produce renewable and low-carbon hydrogen. The variation depends on the speed of market uptake reflecting the different AZEA scenarios. The latter figure for hydrogen translates into a demand of **around 1.2 Mt to 2.9 Mt of hydrogen per annum**[7] used for direct propulsion in 2050[8]. This could be achieved by adding around 10-50 GW of water electrolysis capacity or by partially importing renewable or low-carbon hydrogen from outside Europe.

Furthermore, significant additional capacity of renewable energy generation will be needed to supply electric and hydrogen aircraft in the EU - especially between 2041-2050. In that time frame, their total electricity demand might grow by around 69-142 TWh/a . Within current renewable energy generation forecasts for the EU[9], this would represent roughly 3% to even 9% of the total new renewable electricity generation additions.

Bringing electricity and hydrogen to the aircraft will require infrastructure, whether it is from external low-carbon sources or generated on-site. Most of this infrastructure is yet to be developed. This means that aviation's needs for electricity and hydrogen must be **factored into national and European energy plans,** ensuring aerodromes are connected to the key junctions in the electric grids or hydrogen distribution networks.

AZEA sees the availability of required energy and the deployment of the related supply chains in the first five to 10 years as manageable. For the first five to 10 years, the energy demands will be significantly lower than in 2050, with a total of 9-56 TWh/a electricity (incl. 0.1-0.8 Mt/a hydrogen) demands by 2040, before significant ramp-up to 2050. To ensure minimal viable supply, fast-charging facilities, and reinforced electricity grid capacities at aerodromes, together with hydrogen trucks into and out of aerodromes, could be viable first steps to bring power to electric and hydrogen aircraft.

Hydrogen is light and can be **tankered over long distances** without a carbon penalty, potentially reducing the number of aerodromes at which new infrastructure is required, as hydrogen planes are expected to be able to fly out and back on several European destinations without refuelling. The ability to tanker hydrogen is a significant advantage, although it might come at an energy cost, and could represent a first step to support the rollout of hydrogen aviation.

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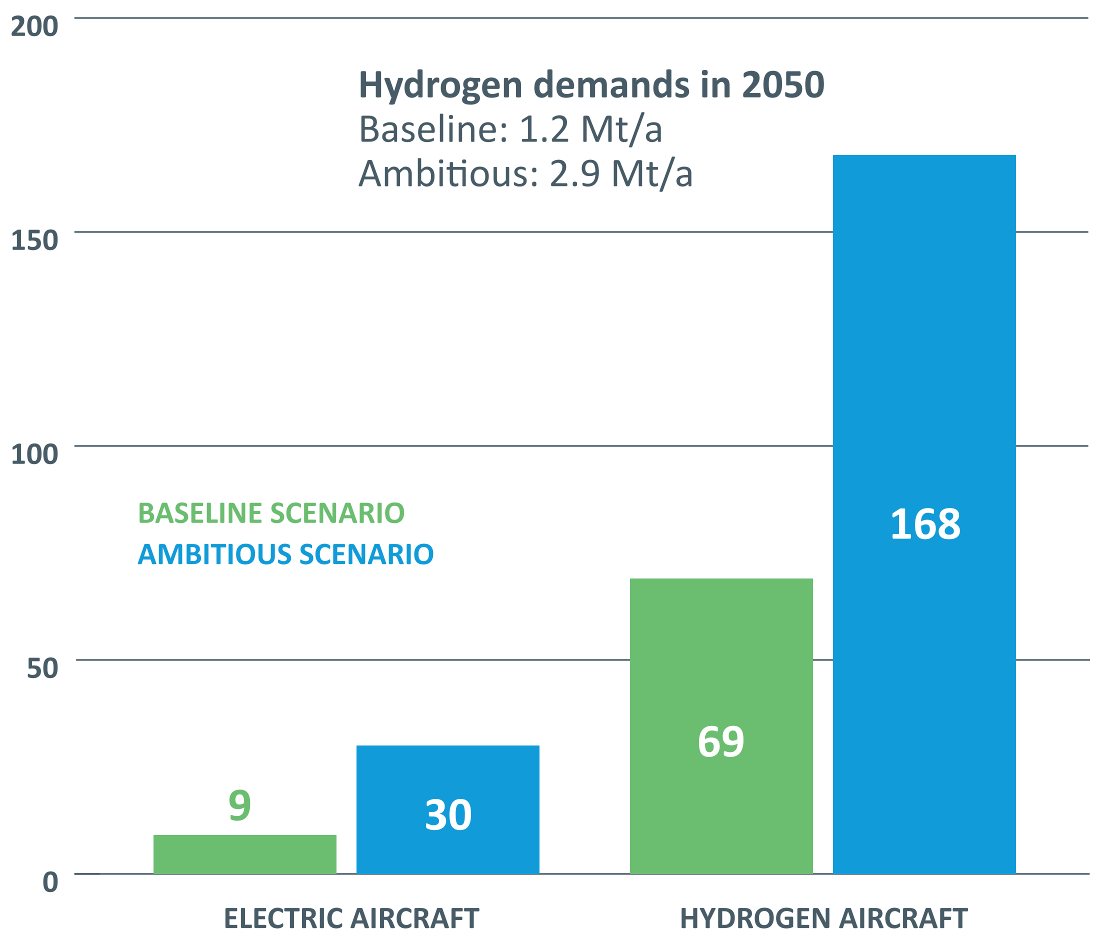
FIGURE 5

Electricity requirements for electric (incl. hybrid) and hydrogen aircraft in 2050[10].

Electricity requirements for powering European electric and hydrogen-powered fleet in 2050, in TWh/a



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[7] This is equivalent to 3.4 Mtoe - 8.3 Mtoe/a, slightly above the forecast considered in the Impact Assessment Report accompanying the Communication from the European Commission COM(2024)63 "Securing our future Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society", see Part 3 Fig. 75.

[8] The use of renewable/low-carbon hydrogen for sustainable aviation fuels is not included in this figure.

[9] Cfr. Impact Assessment Report accompanying the communication from the European Commission COM(2024)63, see Part 3 Fig. 28 - scenarios of renewable power generation in the EU between 2041-2050 ranging between ~1,500-2,500 TWh/a.

[10] The baseline hydrogen demand projections are in line with the Impact Assessment Report accompanying the communication from the European Commission COM(2024)63. The ambitious scenario demand adds an aspirational goal for having a stronger role of hydrogen in the decarbonisation pathway for the aviation sector.

3. Ecosystem requirements

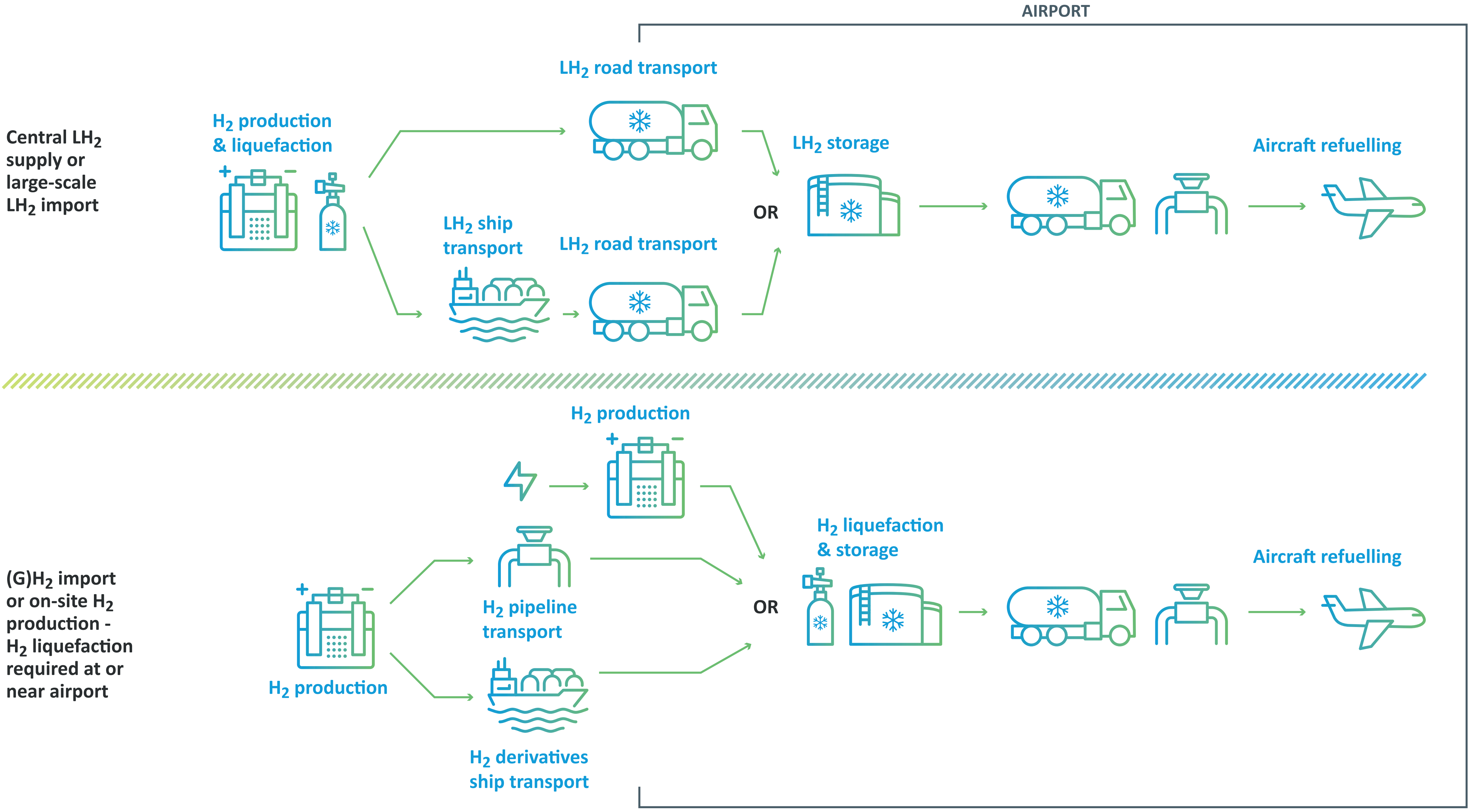
Selected aerodromes are expected to become hydrogen "hubs" where the refuelling of regional and eventually larger aircraft can take place. Destinations within tankering range and diversion aerodromes will only require access to hydrogen-filled trucks for occasional use such as in emergencies – until, over time, the growth in hydrogen demand requires these aerodromes to have hydrogen infrastructure such as pipelines. At this point, the inflection point at which trucking hydrogen will become uneconomical is not yet known.

Long-term however, there is a risk around the deployment of the aviation energy ecosystem if today's planning of general energy infrastructure and supply does not yet take into consideration the needs of electric and hydrogen aircraft. It is important that these are anticipated through planning, and where necessary, investments and action as soon as possible to compensate for long deployment and construction times.

Three pathways to supply the required energy to aerodromes might be deployed as follows:

- **For electric charging,** electricity grid capacities need to be expanded and fast chargers installed at aerodromes. Local renewable energy generation at airfields should be considered, where possible.
- **For hydrogen,** it can be:
  - Transported from central production sites as a liquid or gas via pipelines, or transported by truck, or transported using exchangeable centrally-refilled hydrogen tanks, or:
  - Fully or partially produced on-site at the aerodrome.
  - Several combinations of these options are shown in Figure 6.

The energy infrastructure for electric and hydrogen aviation relies on using energy networks that already exist and/or are planned independently of the use case in aviation. This means relying on electricity grids and hydrogen distribution networks using pipelines or other modes of transport, such as trucks.



Connecting aerodromes to economically viable hydrogen and electricity networks is essential for the uptake of hydrogen in aviation. The formation of **hydrogen hubs at and around key aerodromes** will be crucial to form larger demand centres and economies of scale. This underlines the importance of ensuring that demand from aerodromes is considered early on during the planning of future energy networks and the development of initiatives like the creation of Hydrogen Valleys.

FIGURE 6

Energy supply scenarios for hydrogen to the aerodrome. Central liquid hydrogen supply via truck transport might be the primary option for the first years of deployment. Trucks might also supply exchangeable, reusable, centrally-refilled hydrogen tanks.

3. Ecosystem requirements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The efforts of AZEA members in the energy supply sector are exemplified through initiatives such as the Hydrogen Valley Airport in Groningen and the Hamburg Airport Hydrogen Hub. Both projects are oriented towards researching, developing, and expanding the infrastructure for hydrogen use at aerodromes. Specifically, the Groningen project is designed to provide a scalable testing ground for hydrogen innovations in aviation. It includes a comprehensive hydrogen ecosystem encompassing the production of green hydrogen, its distribution, and the utilisation of both gaseous and liquid hydrogen at the aerodrome.

Factors which will be critical to energy generation and transmission include:

- Europe **must produce or import enough renewable and low-carbon** energy to meet aviation's future demand. This will require more renewable energy generation, electrolyser capacity, and the ability to import any electricity or hydrogen shortfalls.
- Key aerodromes must be connected to major energy grid infrastructure. For example, the EU Hydrogen Backbone should consider the location of future hydrogen airport hubs.

Aerodromes, aircraft manufacturers and airlines should begin engaging with energy suppliers, distributors and their governments and the EU to **ensure aviation's electric and hydrogen demand is visible for appropriate planning.** Economies of scale in hydrogen production to bring cost and efficiency advantages. Identifying hub locations to serve several aerodromes can reduce cost significantly.

Europe must ensure aviation's demands for renewable and low-carbon energy are matched by production or imports. Aerodromes must be included in major energy infrastructure decisions to ensure they are connected.

Some aerodromes are expected to become hydrogen 'hubs' requiring significant supply, while destination and diversion aerodromes will only require access to hydrogen trucks until demand increases beyond an inflection point.

3. Ecosystem requirements

AERODROMES

Energy supplied to the aerodrome, or generated on-site, needs to be complemented by charging capacity as well as liquid hydrogen storage and refuelling facilities.

For **electric aircraft,** charging or battery swapping stations should be gradually integrated into existing aircraft stands and hangars where possible. These can gradually be included in each ramp to ensure full compatibility between different types of aircraft propulsion. This would enable compatibility with operations and fast turnarounds. Alternatively, swapping battery packs with offsite charging may be feasible for certain aircraft and locations. General aviation and pilot training should also be considered, with aerodromes equipped with fast charging and equipped hangars for night-time recharges.

For **hydrogen aircraft,** both **gaseous** as well as **liquid hydrogen,** there are several refuelling options that could work. The simplest option in the initial stages is likely to involve hydrogen trucks refuelling the aircraft at existing stands.

As refuelling demands at aerodromes grow in response to increased use, a pipeline-and-hydrant refuelling system with dispenser trucks could meet increased needs. If the aircraft are fitted with exchangeable hydrogen tanks, it may be possible to use the existing cargo and logistical processes at aerodromes to swap the storage containers on the aircraft stand.

Specific skills will be required in the aviation sector, in particular when it comes to **handling hydrogen.** There is currently a shortage of staff in the aviation sector with these skills. Industry should develop **workforce plans to determine the numbers of staff** needed, and work with other stakeholders to build a strategy to ensure they are available. Governments and authorities should develop national or European plans to ensure **hydrogen skill programmes** are set up, and that aerodrome ground operations are included in their training. Regulators should develop a programme to certify requirements.

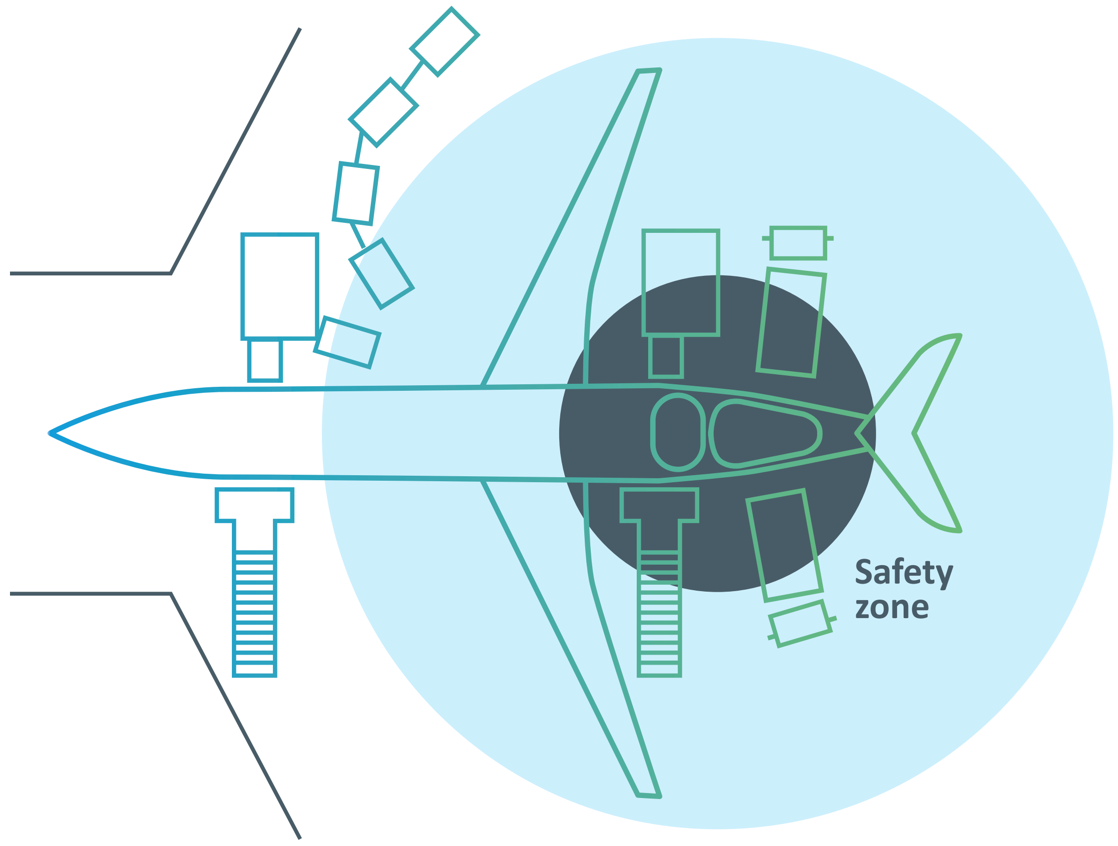
As we incorporate hydrogen, **additional space** may be needed at aerodromes. This will accommodate fuel farms for the storage of liquid hydrogen and potentially hydrogen liquefaction plants. Maintaining safety distances between these potentially hazardous zones and areas designated for passengers will be crucial.

Enabling electric and hydrogen aviation at aerodromes will involve more than just setting up charging and refuelling systems. The overall aerodrome system must be ready to operate aircraft with new propulsion systems, which may entail modifying existing procedures to ensure the compatibility of operations with safety standards.

Further work is needed to understand the **safety distance** from the on-board hydrogen tanks potentially placed in the rear of the aircraft. This could impact ground handling procedures and even distances between aircraft stands.

FIGURE 7

Schematic safety distance zones around the refuelling points of a hydrogen-powered aircraft. The exact distances and potential limitations on neighbouring aircraft stands or ground handling operations are still under investigation.



3. Ecosystem requirements

Aerodrome operations might be more restrictive during the initial testing and adaptation phase to account for additional operational safety requirements. This could temporarily prevent parallel refuelling procedures; isolating aircraft stands and hydrogen fuel farms during the first years of operation.

Reaching similar turnaround times to kerosene-powered aircraft will be crucial to minimise impacts on aerodromes and carrier business models and maximise the uptake of hydrogen aircraft. LCC (low-cost carriers) make use of short turnarounds to maximise aircraft utilisation. It may be necessary to adjust aerodrome designs and procedures in future to facilitate shorter turnaround times.

For the aerodromes to be ready to handle novel aircrafts, a minimum level of readiness needs to be ensured. While aircraft delivery numbers will not be initially relevant, their rapidly increasing energy and ground handling demands will mean changes at aerodromes will be needed 10-15 years from now at the latest. Changing aerodrome designs takes years, so the window of time for preparation is short. Aerodromes need to plan for reliable electricity and hydrogen fuel supplies, including backup systems.

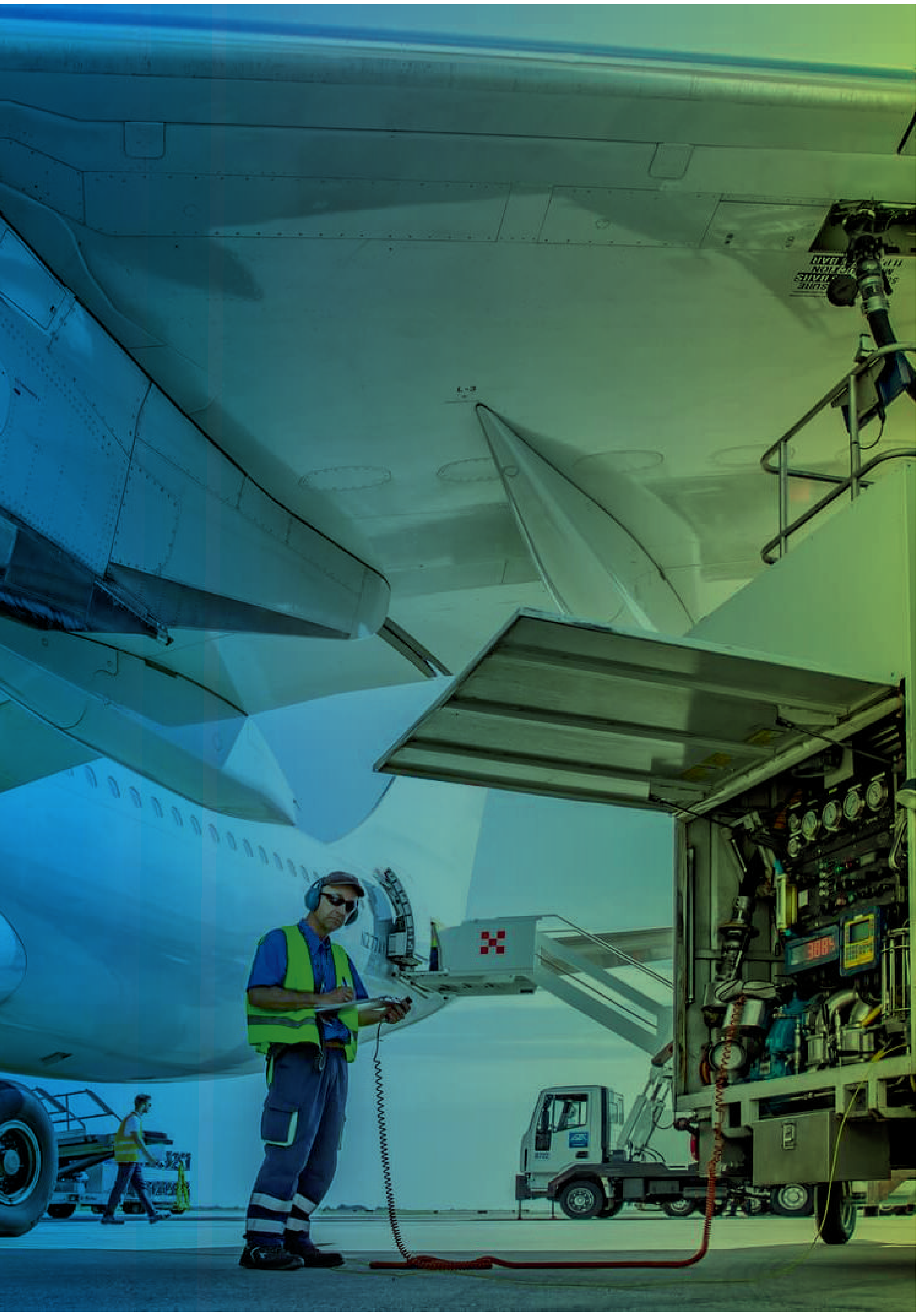
Aerodromes that provide regional connectivity are expected to adopt electric aviation first. Having a **secure supply chain and backup will be a challenge,** especially for offshore or remote aerodromes. Even without the need for large infrastructure, there must be alternative methods to transport hydrogen and connect to the power grid, to ensure business continuity. Small aerodromes, used either for general aviation or rescue flights, are expected to have similar needs.

The greatest demand for hydrogen will be at international and large point-to-point aerodromes. **If the demand for hydrogen increases significantly (to more than 50 tH_2/day)** at these aerodromes within the first 10 years of using hydrogen aircraft, then this means connections to main transport pipelines will need to be discussed and planned imminently. This will affect aerodrome master plans, which typically have a 15-year lifespan and involve long decision and approval processes, meaning the time for preparation is short. **Aerodromes should start engaging with governments and hydrogen producers and distributors** to plan future supply.

In the framework of the Airports Carbon Accreditation (ACA) initiative launched by ACI Europe to support aerodromes in their effort to reduce their CO_2 emissions, a number of aerodromes are already addressing the need to supply green energy for their own operations. Additionally, many aerodromes are also engaged in building and actively supporting the deployment of new infrastructures, equipment and handling processes required for aircraft powered by electricity and hydrogen. Achieving level 4 of ACA certification requires aerodromes to actively support reductions of emissions beyond their control, including aircraft emissions (Scope 3 of ACA). ACA level 5 (aerodromes that achieved the net-zero target) requires a commitment to reduction targets for Scope 3 emissions. Shareholders and sustainable finance are also pushing airport companies to set Scope 3 targets as KPIs for accessing better financing opportunities. Commitments to reducing scope 3 emissions is becoming a concrete incentive for airport companies to invest in supporting the introduction of H_2 and electric aircraft into operations.

Securing a supply of electricity and hydrogen will be a challenge for remote aerodromes.
As hydrogen demand increases, aerodromes will need space and energy for hydrogen refuelling systems. A workforce with specific skills will be needed to handle hydrogen, industry and governments must cooperate to develop it.
Aerodrome master plans must consider electric and hydrogen demands. Aerodromes should start engaging with governments and hydrogen producers and distributors to plan future needs.

3. Ecosystem requirements



CERTIFICATION, REGULATION, AND INDUSTRY STANDARDS

Certification and standardisation of new technologies is vital. The European Union Aviation Safety Agency (EASA) is already working to adapt the regulatory framework in aviation to the use of electric and hydrogen propulsion. Standardisation organisations (such as EUROCAE, CEN, SAE, and ASTM) are working on a range of technical standards and procedures in areas like aircraft components, charging/refuelling, hydrogen storage, distribution, and ground fuelling, ground support, and operating procedures.

To date, more progress has been made in the standardisation of electric and hybrid-electric technologies than in hydrogen technologies[11]. In fact, the first certified electric-powered aircraft is already operating. In hydrogen, both liquid and gaseous, the standardisation work is ongoing addressing areas like fire safety, airside use and refuelling, and purity and quality[12]. These should cover the skills that aviation staff will need for handling hydrogen, including curriculums and permits/licences.

It is essential that this work continues at pace. **EASA must continue to be adequately supported** in delivering a regulatory framework that is electric and hydrogen-ready and in ensuring the timely certification of the new aircraft. EASA and other bodies should continue to **interact with international counterparts** to ensure that electric and hydrogen aircraft can operate internationally.

To support innovation into new areas, EASA is engaging with future applicants through Pre-Application Service Contracts, which gives stakeholders access to technical advice services outside of an actual certification process. **Aircraft certification costs** remain a barrier to new entrants, since in Europe these costs are borne by the manufacturer, and this could be an area where policymakers could help.

Many standardisation initiatives are ongoing and should continue. EASA must continue to be supported and funded to deliver a regulatory framework that is electric and hydrogen-ready. International harmonisation in standards will be needed. Certification costs remain a barrier for new entrants in Europe.

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[11] AZEA Report - Aviation Regulatory landscape for hydrogen and electric aircraft.

[12] AZEA Report - Standardization Subgroup Current Standardization Landscape.

3. Ecosystem requirements

AIRSPACE READINESS

Unlocking the era of electric and hydrogen aviation requires a **European network that optimises flight profiles while ensuring the safety of all aircraft operations,** as some novel aircraft may exhibit performance characteristics different from conventionally powered planes.

Additionally, the integration of electric and hydrogen aircraft will occur within a European network facing numerous challenges in terms of capacity, demand fluctuations, adapted flight operations, and the need to provide solutions that reduce both CO_2 and non-CO_2 emissions. This requires operational coordination among various stakeholders such as the European network manager, air navigation service providers, aerodromes, airspace users, manufacturers, and flight planning service providers.

AZEA envisions a network that will adapt to best serve new routes, supporting regional hub feeder connections and new routes for point-to-point trips. This adaptability is crucial for delivering increased connectivity.

Operations of today will have to evolve to fully support these new aircraft types and propulsion methods. Main challenges to the integration of these aircraft operations into the network include:

- Airspace considerations involve increased movement numbers and aircraft interactions below FL300, changed departure & arrival procedures, changed airspace design, managing Traffic Complexity and ATC workload supported by appropriate tools such as Demand & Capacity Balancing Flow tools and conflict detection and resolution tools.
- Ground considerations include aircraft weight changes, new fuel storages, new aircraft refuelling or charging, as well as on-stand and engine start procedures, and adopted rescue and firefighting services.
- Other considerations include the measurement and reduction of non-CO_2 emissions and general climate change adaptation.

Electric and hydrogen aircraft may exhibit novel performance characteristics. Integrating them into the European network will require operational coordination between airspace stakeholders and political willpower to achieve an adaptable network.

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4. Conclusion and way forward

The members of the aviation ecosystem gathered within AZEA are **committed to pursuing their individual and common efforts to achieve the successful integration** of electric and hydrogen aircraft into European aviation and call on other actors to take an active part in this challenge.

AZEA will continue to deepen the industry's understanding of the requirements to bring electric and hydrogen aircraft into operational service, with working groups on aircraft development, energy generation and transmission requirements, aerodromes requirements, certification, regulation and standardisation, network requirements, and other incentives.

The initial economics of deploying electric and hydrogen aircraft must not become an obstacle to long-term success, and early adopters should be encouraged. Incentives and policies applying to the sector, from supply markets to end users, should look at ways to lower starting costs and bridge operating gaps relative to hydrocarbon-powered aircraft technologies. Public support should aim to encourage activity and provide market certainty for private sector investment. National funding tools such as grants and low-cost loans for infrastructure, capital incentives for aircraft purchases, and Public Service Obligations, could be used by national governments to support first movers.

The Alliance will continue to foster collaboration and coordination within the ecosystem. It will develop further actions and issue ecosystem and policy recommendations to fully realise the potential that electricity and hydrogen offer to aviation. Areas of public-private coordination already identified are summarised below.


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- **Aircraft –** The policy framework should continue to look to maximise support for electric and hydrogen aircraft technologies to help leverage private investment, including for technologies at high technological readiness levels.
- **Energy generation and transmission –** Aviation stakeholders and governments should begin a dialogue to coordinate the integration of aviation's energy demands into energy planning, including the connection of key aerodromes to electric and hydrogen grids, and the generation or import of renewable and low carbon energy.
- **Aerodromes –** Aerodromes should start early dialogues with governments as well as electricity and hydrogen suppliers to prepare the adaptation of their infrastructures (including for instance additional space for battery charging and hydrogen infrastructure) and the supply of the required energy; government-industry cooperation will also be needed to equip the aviation workforce with new skills.
- **Certification, regulation, and standardisation –** Regulators need to be supported in engaging with industry at an early stage, ensuring regulations and certification are electric- and hydrogen-ready, and certification costs should be considered.
- **Airspace –** Integrating new aircraft into the European network will require operational coordination between airspace stakeholders and continued political support.

The transition to electric and hydrogen aviation represents a considerable challenge, requiring the collaboration of all stakeholders to address the technological, infrastructural, and regulatory hurdles. However, beyond these hurdles is an opportunity that is even greater - to reshape the way we travel, to significantly reduce our environmental footprint, and to pioneer a sustainable future for global aviation with European technology.

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- Beyond Aero
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- CEN and CENELEC
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- CHESCO - Center for Hybrid Electric Systems Cottbus
- Clean Aviation Joint Undertaking
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- Compania Espanola de Sistemas Aeronauticos
- Conscious Aerospace
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- Dublin Airport Authority (daa)
- EasyJet
- EENUEE
- EH Group Engineering
- Electric Flying Connection (EFC)
- Electron Aerospace
- Elixir Aircraft
- ELSA Industry
- Elysian Aircraft
- Engie
- Estonian Aviation Academy
- Euroairport (Basel-Mulhouse Freiburg)
- EUROCAE
- Eurocontrol
- European Business Aviation Association (EBAA)
- European Cockpit Association
- European Federation for Transport and Environment
- European Flyers
- European Regional Aerodromes Community (ERAC)
- European Regions Airline Association Ltd. (ERA)
- European Union Aviation Safety Agency (EASA)
- EVIA AERO
- Federation of European Tank Storage Associations (FETSA)
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