ICAO

ENVIRONMENT

# Cleaner Energies at Airports


ECO AIRPORT TOOLKIT
2025

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ICAO ENVIRONMENT

# Cleaner Energies at Airports

# ECO AIRPORT TOOLKIT 2025

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# 1. INTRODUCTION

In June 2021, ACI member airports committed at the global level to reach net zero carbon emissions by 2050, for their own operations. This was followed in October 2021 by a commitment from the entire aviation industry through the Air Transport Action Group (ATAG) and finally, by ICAO Member States through the Long-Term Aspirational Goal (LTAG) at the 41st ICAO Assembly.

In line with that, ICAO and its Member States have adopted the “ICAO Global Framework for Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other Aviation Cleaner Energies” during the Third Conference on Aviation and Alternative Fuels (CAAF/3) in November 2023. The ICAO Global Framework sets a collective global aspirational vision [1] to reduce $CO_2$ emissions in international aviation by 5 percent by 2030 through the use of SAF, LCAF, and other aviation cleaner energies, in contribution to the LTAG. The role of this global framework is to facilitate the global scale-up in the development and deployment of SAF, LCAF, and other aviation cleaner energies by providing greater clarity, consistency, and predictability to all stakeholders, including those beyond the aviation sector. It provides clarity on the policies, regulations, implementation support, and financing and investments required. The aim is to ensure that all States have equal opportunities to contribute to, and benefit from, the expected emissions reductions from such aviation cleaner energies.

As described in the ICAO Global Framework adopted by CAAF/3, the achievement of the collective aspirational Vision needs a collaborative effort with action required from different stakeholders, and States are to encourage relevant stakeholders (i.e., aircraft operators, airports, aircraft and engine manufacturers, fuel producers and suppliers, ICAO’s approved Sustainability Certification Schemes, and fuel standards bodies) to plan, develop and implement their own actions to help achieve the Vision.

Transition to cleaner energy use at airports involves a fundamental shift from conventional, fossil fuel-based energy sources to more sustainable alternatives. This transition is imperative for mitigating the environmental impact of the aviation ecosystem. It encompasses a comprehensive approach that integrates various initiatives aimed at reducing the amount of energy used by means of efficiency improvements, changing the energy to renewable alternatives, and promoting overall environmental responsibility in airport and airline operations. Various examples of action, under Section 6 (Appendix 1) of this document, describe initiatives taken by airports to integrate renewable alternatives. In addition, airports should plan and deliver changes in airport infrastructure necessary to ensure efficient supply and access to drop-in fuels and, in collaboration with aircraft operators, fuel producers, and other stakeholders, explore innovative ways to share the cost of such infrastructure changes across the value chain.

*[1] ICAO Newsroom, 2023, ICAO Conference delivers strong global framework to implement a clean energy transition for international aviation, 24 November 2023*

The document focuses on three key elements:

1. Actions that airports are taking to facilitate the reduction of aircraft emissions, particularly those associated with aircraft propulsion. The tailpipe emissions of aircraft operations represented approximately 98% of the combined aircraft-airport emissions in 2019.

2. Actions that airports are taking to reduce the climate impact of their own operations, including zero-emission ground support equipment, electrification of boilers and heaters, and electrification of airport fleets. These emissions represented 12% of ACI member airports scope 1 and 2 emissions in 2019 [2].

3. Actions that airports are taking to reduce the carbon footprint of the energy they purchase including the use of market-based instruments such as renewable Power Purchase Agreements (PPAs), Renewable Energy Certificates (RECs), Renewable Energy Guarantee of Origin (REGOs), etc., or the generation of renewable energy on-site. On average, these represented 88% of ACI member airports' scope 1 and 2 emissions in 2019, according to ACI's Long-Term Carbon Goal. For this third pillar, most of the actions on on-site renewable energy generation are covered under the "Scope 2 initiatives" Section of this e-publication. PPAs, RECs, or REGOs are not covered in this document, as they don't impact airport operations or infrastructure.

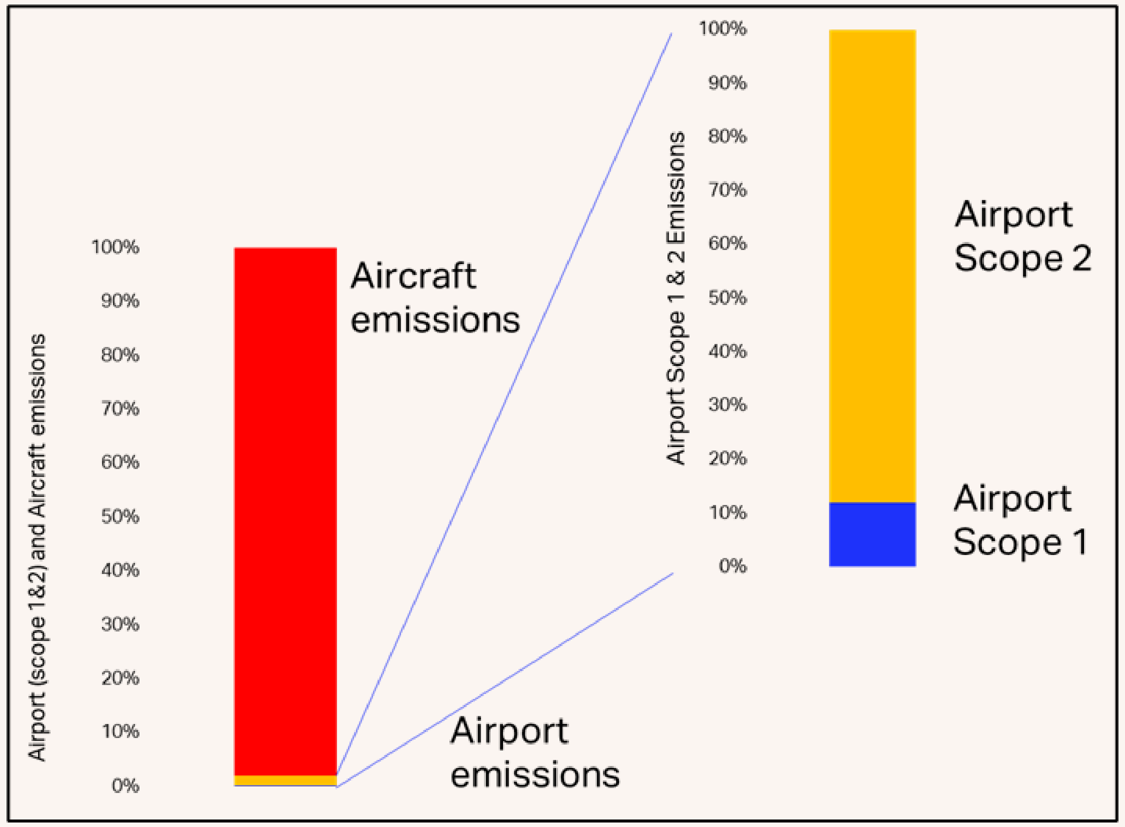


**Figure 1.** Airport (Scope 1 and 2) and aircraft- borne CO2 emissions. Based on ACI's Long Term Carbon Goal Study and IATA's Net Zero Roadmaps, emissions representative of 2019

[2] ACI (2021). *Long-Term Carbon Goal Study for Airports (Report 2021)*



Finally, the document also tackles broad considerations for the energy transition required to enable reductions in aviation emissions (both for aircraft and airports), as well as future challenges and opportunities on the road to Net Zero CO2 emissions by 2050.

## 2. AIRPORT ACTIONS TO SUPPORT AIRCRAFT EMISSIONS REDUCTION

Airports are the beginning and the end of each aircraft journey, and the middle point between the aircraft and the energy source. As such, they play a key role in enabling the energy transition of aviation. For almost a decade some airports have taken a leadership role in facilitating Sustainable Aviation Fuels (SAF) to aircraft. This started with on-site trials of the logistics, coordinating working groups with airlines, fuel providers, fuel farm managers, government authorities, and onto-wing refuelers. Many airports and airlines started their SAF journey with individual SAF trucks that would deliver the fuel directly into the aircraft. These learnings have now led to constant batch supplies of SAF directly into the fuel farm.

Airports are also beginning to understand and plan how to support aircraft powered by non-drop-in fuels, like hydrogen, electricity, or indeed 100% paraffinic SAF. Figure 2 shows different alternative fuels for aviation and the fundamental link between them: SAF, once blended and certified can be used as a drop-in fuel in existing aircraft and be made from Biomass (BtL), Waste (WtL), or captured CO2 (PtL). For nearly all pathways of SAF, hydrogen is required for refining the feedstocks into jet fuel, but hydrogen can also be used on its own for powering hydrogen-powered aircraft. As energy is required both to make hydrogen and to make SAF, energy needs are common to all alternative aviation fuels. For short haul (100-200 km) and small aircraft (approximately 1-30 seating capacity), electricity can be used directly on batteries for electric or hybrid-electric aircraft. More details on this can be found in "Sustainable Energy Sources for Aviation: An Airport Perspective (ACI)".

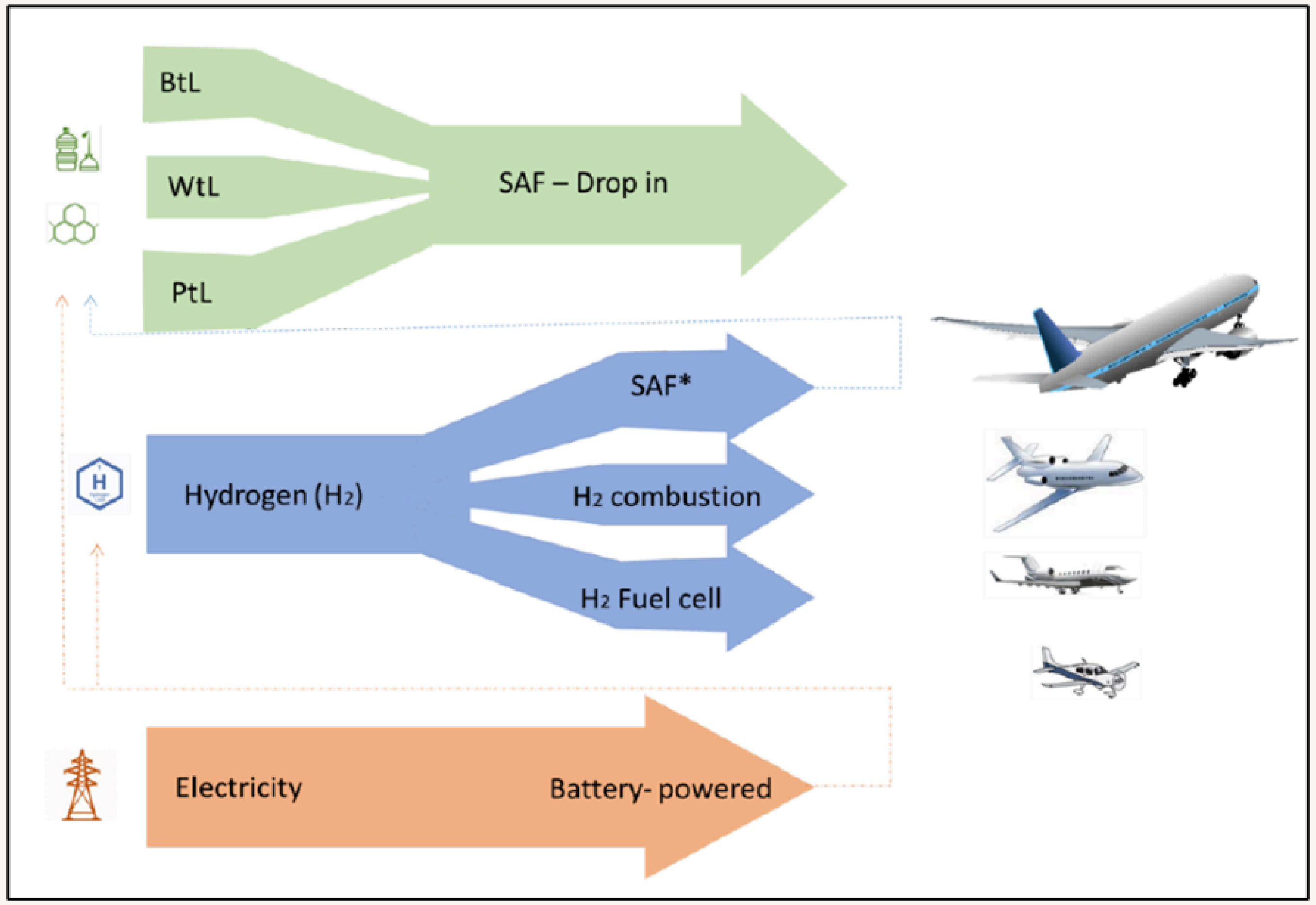


Figure 2. Alternative Aviation Fuels and the link between them
Source: ACI World [3]

## Facilitating Sustainable Aviation Fuels (SAF)

Aircraft movements represent close to 98% of airports' scope 1, 2, and 3 emissions combined, and all aviation stakeholders can contribute towards tackling this. Once SAF is blended and certified to ASTM D1655 jet fuel, it can be mixed in the existing fuel infrastructure and used with existing aircraft. The ACI-ATI publication on the integration of SAF into the air transport system summarizes SAF technical requirements as well as the different supply chains of SAF into airports and recommended blending locations (all off-airport) [4]. Furthermore, the document highlights actions that airports can take to implement and scale up SAF, based on the experience of airports that have gone through this process.

The document highlights three phases of SAF supply chain development:

- **Initial facilitation**
- **Early ramp-up**
- **Scale-up**

*[3] ACI (2021). Sustainable Energy Sources for Aviation: An Airport Perspective*
*[4] ACI-ATI. Integration of Sustainable Aviation Fuels into the Air Transport System*



### Initial Facilitation Phase

In the initial SAF facilitation phase, the airport operator is encouraged to create consortiums or working groups with airlines, ground handling, and airfield operators, refueling operators, fuel farm operators, SAF suppliers, government authorities, regulatory bodies, and logistics companies. This is to provide all parties involved with all the information needed to introduce SAF into the airport.

In this initial facilitation phase airports should:

1. Familiarize themselves with SAF literature (scientific research, standards, publications, current news), attending industry-relevant events, and organizing informational workshops, including capitalizing on ICAO activities (i.e. ACT-SAF); and,
2. Identify current SAF suppliers, some of which can be found on ICAO's Global Framework for Aviation Alternative Fuels (GFAAF) website; and,
3. Create working groups with all the parties mentioned above; and,
4. Test the process from the SAF supplier to the aircraft wing of a flight demonstrator.

### Early Ramp-up Phase

The early ramp-up phase is when SAF begins to be supplied to the airport in small but constant quantities. At this stage, the airport is encouraged to work together with airlines and maximize existing policy frameworks to help the airlines bridge the cost gap between conventional fuels and SAF, as well as socialize the SAF benefits to customers and other stakeholders.

### Scale-up Phase

The scale-up phase is when a robust SAF supply chain is established, and the airport has little or no influence on how the SAF is delivered because this is perfectly integrated into the fuel supply chain.

The IATA SAF Handbook [5] and the Energy Institute EI 1533 [6] publication provides recommendations with regard to quality assurance requirements and recommendations for the blending of SAF, their transportation, delivery, and distribution at airports. While SAF blending at airports is technically possible and being explored by some facilities, it may not be practical due to airport permits, fuel quality controls, test and certification, and supply chain simplification.

*[5] IATA (2024). SAF Handbook*
*[6] Energy Institute (2022). EI 1533 Quality assurance requirements for semi-synthetic jet fuel and synthetic blending components (SBC)*

## Preparing for hydrogen and electric aircraft

Similar to the SAF approach, the joint ATI-ACI's publication on the integration of hydrogen aircraft [7] and ACI's document on Sustainable Energy Sources for Aviation: An Airport Perspective [8] provide high-level recommendations on actions airports can take to prepare for a zero-carbon aircraft. The documents have been validated by scientific studies, which take a similar approach, where the supply chains of hydrogen to airports are analyzed. This lays the foundation for the infrastructure requirements at airports.

Figure 3 shows the three most common approaches to delivering hydrogen to an airport:

- generating hydrogen (or electricity) on-site;
- importing the hydrogen via a gaseous pipeline (or the electricity with a cable); or,
- importing the hydrogen in its liquid form via road transport (trucks or trains).

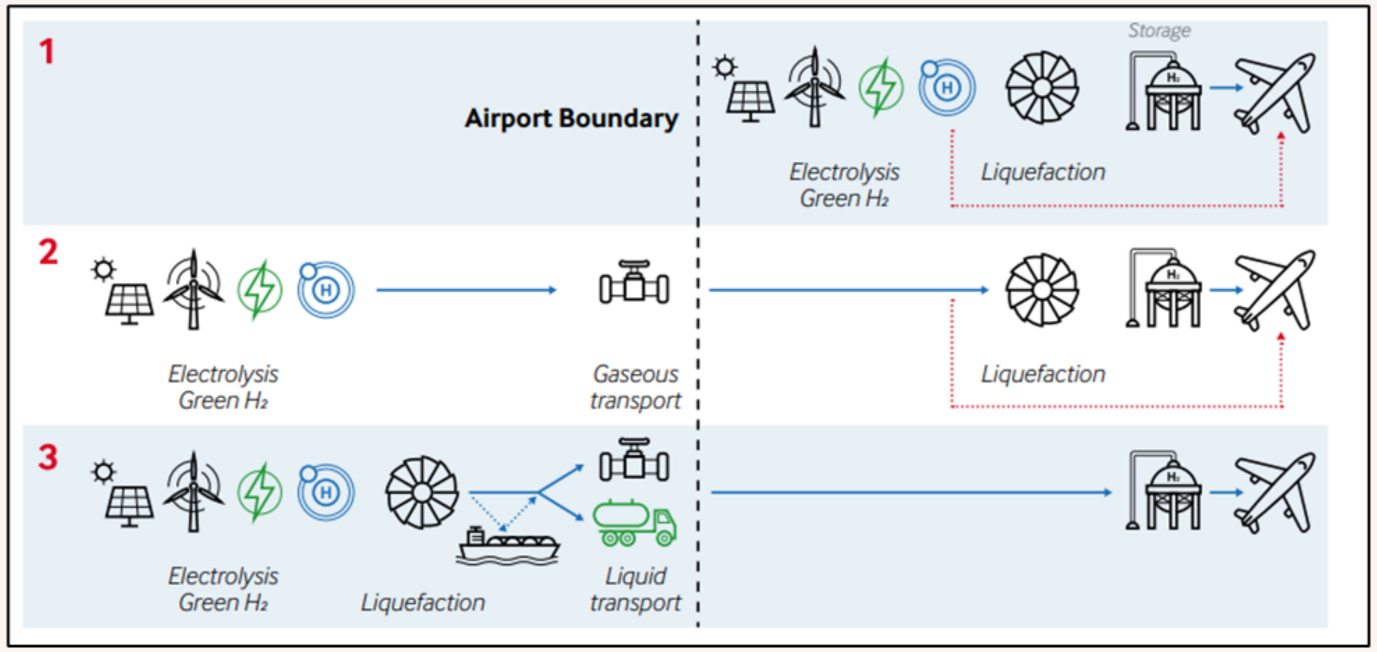


Figure 3. Hydrogen supply chain options into airports.
Source: Aerospace Technology Institute and ACI World [7]

This might be a time-variable approach where the first phase involves airports producing very small quantities of hydrogen on-site for scope 2 emissions reductions (see Appendix A "Examples of Action"). The following phase could involve importing hydrogen with trucks to facilitate the first hydrogen-powered flights. A third long-term approach would be to introduce hydrogen to the airport via pipeline delivery (possibly gaseous with on-site liquefaction) as traffic grows. In this case, airports should first know their constraints and limitations.

For example, some airports like Christchurch in New Zealand have a considerable amount of land at their disposal for green energy projects, as showcased in future sections of this document. Some other airports, like London City and a few others, are more restricted by land availability and have limited space for accommodating on-site energy generation.

[7] ACI. *Integration of Hydrogen Aircraft into the Air Transport System: An Airports Operations and Infrastructure Review*
[8] ACI. *Sustainable Energy Sources for Aviation: An Airport Perspective*





Airports are also encouraged at this stage to create a consortium and working groups with OEMs, airlines, energy providers, hydrogen providers, and government authorities to understand the infrastructure and operational requirements to enable alternative propulsion flights. Numerous examples of these initiatives are mentioned in the Examples of Action section. In the case of hydrogen, at the time of writing, 44 airports have been identified as being involved in supplying hydrogen. Figure 5 shows the location of those airports, and the projects include the supply of H2-GSE, feasibility studies for the adoption of hydrogen-powered aircraft, and partnerships with OEMs, hydrogen providers, and airports.

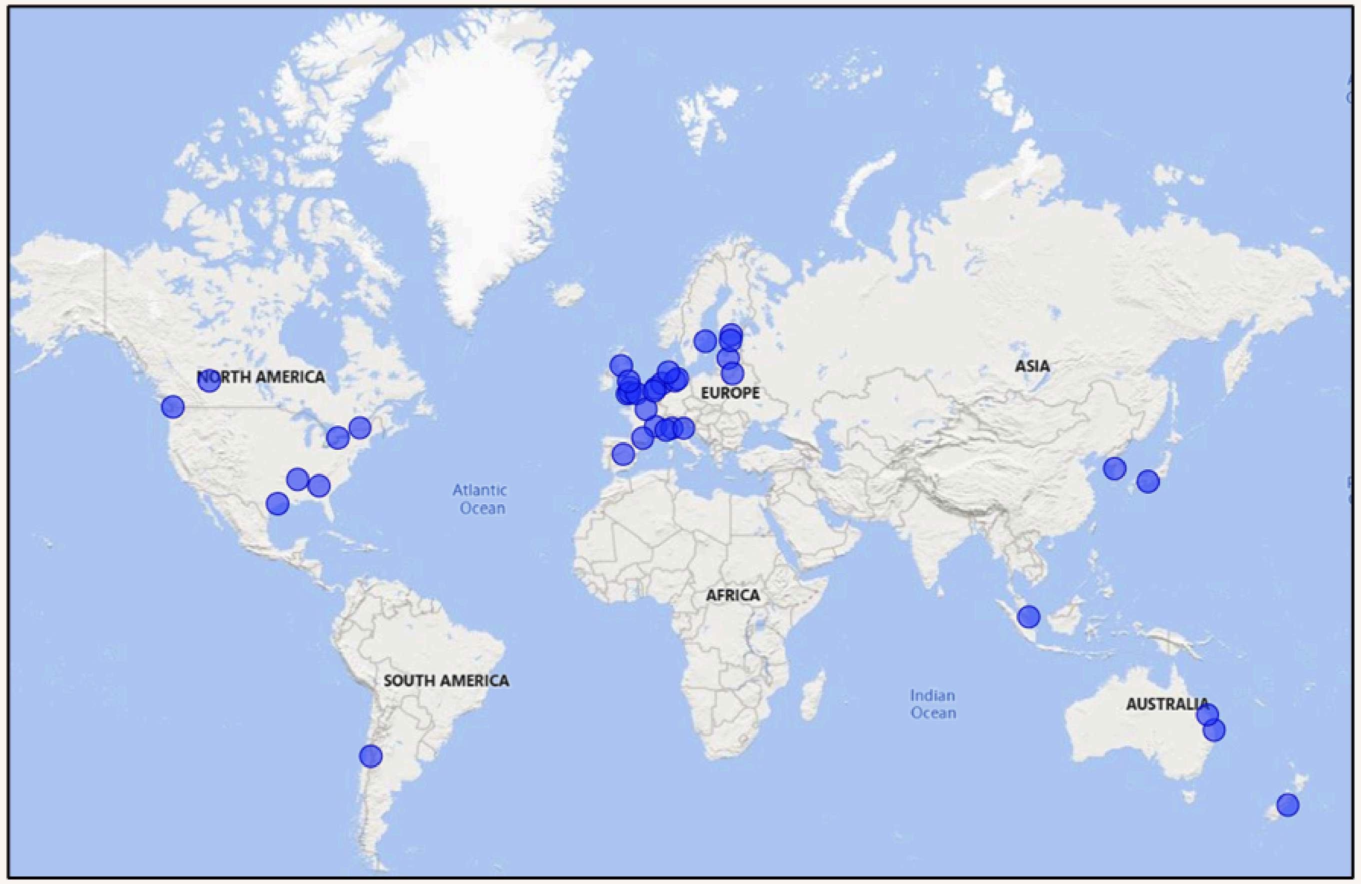


Figure 4. Examples of airports involved in hydrogen projects (September 2024).
Source: IATA Sustainability and Economics

The ACI-ATI document already provides a high-level view of some basic considerations to be taken right now, as well as a future early implementation period and a ramp-up period of hydrogen aircraft operations. The document highlights space, energy, and cost implications for specific airport examples.

An example of the footprint needed for different hydrogen quantities, compared to existing airport infrastructure is shown in Figure 6. The ATI-ACI report assumes that a regional aircraft would require around 1 tonne (t) of hydrogen for full refueling, and a narrow body around 4 tonnes. In this context, an electrolyzer producing 15 t/day of hydrogen, would require around 1,800 m2of surface area, and one for 50 t/day (equivalent to refueling 50 regional aircraft per day) would require around 8,000 m2, a footprint comparable to a long-haul aircraft stand.

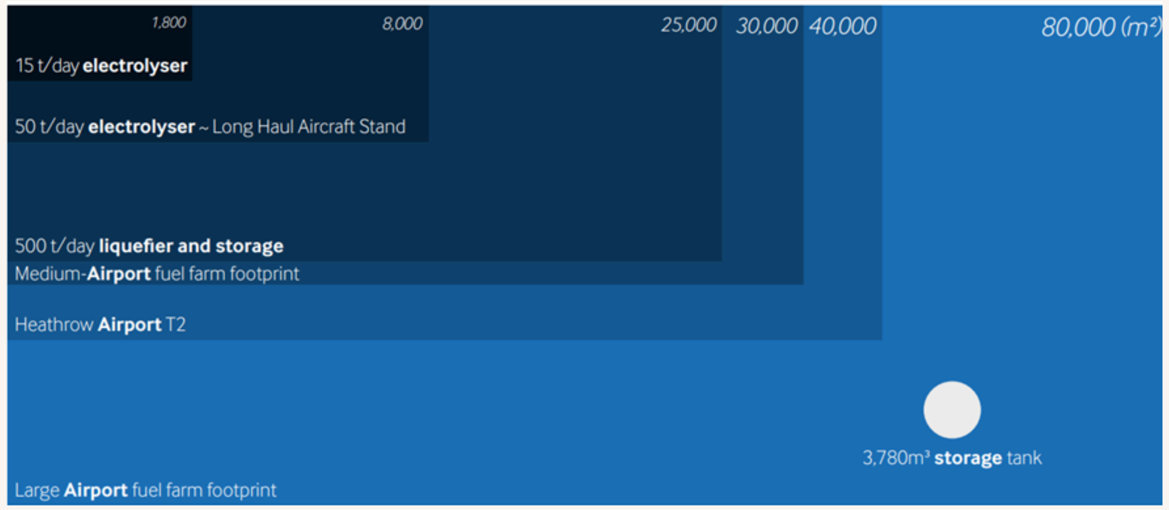


Figure 5. Hydrogen infrastructure footprint compared to commonly found infrastructure at airports.
Source: Aerospace Technology Institute and ACI World

The UK's FlyZero project further analysed hydrogen infrastructure needs for three airports, considering also storage, and liquefaction[9]. The report highlights results for small, medium, and large airports both by 2035 and 2050 under specific assumptions for the adoption of hydrogen aircraft, and under the three scenarios highlighted in Figure 4 (production on-site, liquefaction only on-site, and storage only on-site).

## 3. AIRPORT ACTIONS TO REDUCE THE CLIMATE IMPACT OF THEIR OWN OPERATIONS

Airports, as infrastructure providers and enablers of progress, play a key role in decarbonization and are crucial actors when discussing the emissions reduction strategies of the aviation industry. The two most common ways to reduce emissions from airports scope 1 and 2 include the implementation of energy efficiency measures and the use of cleaner energies.

Several existing publications provide a general description of, or more in-depth, mitigation measures that airports can implement to reduce their emissions across all scopes. These can be found in the section "Useful publications on the decarbonization" of this e-publication.

For the purpose of this publication, only the use of cleaner energies is considered. Figure 6 shows an example of a holistic approach for airport emissions reductions, which includes on-site generation and storage of renewable energy, considering the impact on airport and flight operations and potential safety considerations, which reduces reliance on purchased electricity and possibly enhances the power supply reliability. In addition, the Kowhai Park Ecosystem of Christchurch Airport shows how these energies can be used to power the airport's electrical needs (terminal electricity, data centers), as well as providing green energy for electrified ground transportation and even providing electricity for hydrogen electrolyzers or charging electric aircraft.

[9] FlyZero - Aerospace Technology Institute (2022). Hydrogen Infrastructure and Operations (Airports, Airlines and Airspace)





Further analysis and examples are given for Scope 1 and Scope 2 initiatives, as highlighted in the introduction.

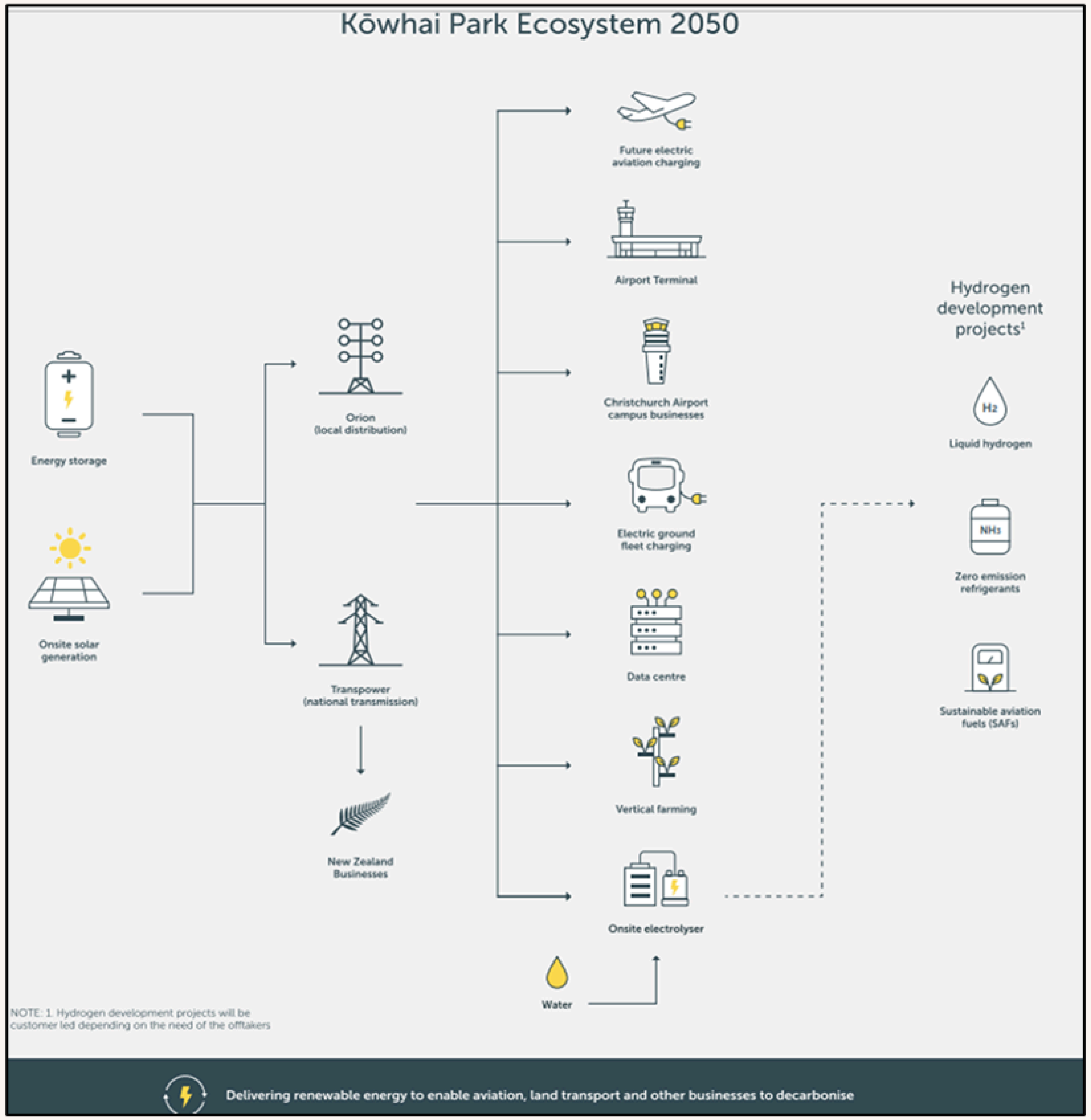


Figure 6. Kōwhai Park—A new concept in renewable energy
Source: Christchurch Airport [10]

[10] Christchurch Airport (2023). Sustainably powering the next generation

## Scope 1 Initiatives

Scope 1 activities encompass the conversion of resources owned or regulated by airports to sustainable or zero-emission energy sources. This involves actions such as electrifying the airport's vehicle fleet, implementing on-site renewable power generation infrastructure, and transitioning airport-owned ground support equipment (GSE) to electric or hydrogen power. It must be highlighted that introducing cleaner energies for GSE, like hydrogen, can also be an important enabling step towards implementing hydrogen aircraft. Deploying hydrogen infrastructure at airports will allow airports to train personnel and get familiar with the procedures and infrastructure needed ahead of deploying hydrogen to power aircraft.

Figure 7. Brussels Airport Cargo: A new installation of 65.000m² of solar panels (7.3 MW) covering the roof of our newest building at Brucargo.

## Scope 2 Initiatives

Activities for Scope 2 emissions reductions focus on minimizing indirect emissions resulting from the airport's purchased energy consumption and can be tackled through strategies like optimizing electricity purchases and refining heating and cooling systems. Other actions could involve transitioning to solar power generation (Figure 8), supporting sustainable construction endeavors, and striving for environmentally friendly heating and cooling solutions. An illustration of how Christchurch Airport in New Zealand is integrating renewable energies for Scope 1 and 2 reductions is offered in Figure 6, and details of the project can be found in the section “Examples of action”.





Since the beginning of April 2024, a Taxibot has been tested at Brussels Airport (Figure 9) for sustainable aircraft towing, in cooperation with TUI Fly. Brussels Airport is the first Belgian airport to test the Taxibot. This biodiesel-powered semi-robotic truck allows aircraft to be taxied without using their engines

Figure 8. Brussels Airport Cargo: Taxibot.

### Information Box: Airports as energy hubs?

The energy transition and the journey towards net-zero present airports with an opportunity to position themselves at the center of the industry transformation to sustainable aviation by becoming a renewable energy production and distribution hub for local communities; this could also lead to new revenue streams and economic growth for the airport and the communities around.

This opportunity, however, comes with certain challenges:

Every airport is different, and each must evaluate how alternative fuels and energy demand will impact its operations. Several considerations come into play, such as the location of the airport, including its value chain, and the imbalances of demand between the local communities and the airport. The energy hub concept is an energy system approach, where the need for resilience and for balancing the energy supply and demand must happen across a wider system. Certain jurisdictions and markets today place restrictions on airports that prevent them from being energy providers – hopefully as we move through the energy transition, this will change. They might also look for partners in the energy ecosystem to support them and gain necessary support or with whom common interests are shared.

**Information Box: Airports as energy hubs?**

One example of an airport already becoming a local energy hub is Copenhagen Airport (CPH), which partly electrified its vehicle fleet as part of its strategic plan. In 2022, the company entered into an agreement with an energy provider to roll out up to 1,350 electric vehicle (EV) charging points over a 10-year period. These charging points will include a mix of AC and DC charge units. Although electrifying large, infrequently used vehicles involves considerable expense, the company, in collaboration with partners from the EU project ALIGHT, conducted an analysis of the future potential of an electrified fleet, particularly focusing on its battery storage capacity.

With the expected future capability for bidirectional energy flow, the fleet has the potential to act as a catalyst for scaling up battery storage solutions, reducing both $CO_2$ emissions and the payback periods associated with these significant investments. Additionally, the aggregated battery capacity of the fleet could generate extra revenue by participating in energy markets, offering ancillary services to the transmission system operator.

# 4. BROAD CONSIDERATIONS FOR THE ENERGY TRANSITION OF AVIATION

Transitioning the aviation sector towards net zero carbon emissions by 2050 and ensuring the industry's long-term sustainability will require the deployment of significant volumes of cleaner energies for aviation.

The commitment to transition away from fossil fuels established during the ICAO Third Conference on Aviation Alternative Fuels (CAAF/3) by the adoption of an ICAO Vision and a Global Framework for Cleaner Energies, signals the commitment from the ICAO member states and the need for collaboration and participation from the entire ecosystem, in the transformation of the sector. ICAO's Vision to reduce the carbon intensity from international aviation fuel by 5% by the year 2030 through the use of Sustainable Aviation Fuel (SAF) and Lower Carbon Aviation Fuel (LCAF) should provide further certainty and release capital to accelerate the production and deployment of SAF across all regions. Three main considerations are highlighted in this document: energy demand, infrastructure, and operational needs, and the development of human factors and capacity building.





## Energy Demand

Airports are at the forefront of providing solutions for decarbonization and the deployment of alternative fuels and energy sources for aircraft. They have been—or will be—facing increasing demands for energy. In addition to the electrification of their operations and growth in traffic, airport tenants and stakeholders are setting their own decarbonization goals. Some of those measures rely on the electrification of stationary, mobile, and transportation equipment that currently operates using fossil fuels. This electrification direction will continue to put pressure on the capacity of the electric grid installations of airports.

For many airports, the issue is not only to plan for future energy use but also to understand and track current energy demand and how to cope with their limited grid capacity. Airports must conduct thorough assessments to determine this, considering not only existing capacity but also potential efficiency gains. Without such understanding, energy management becomes an even bigger challenge. The adoption of cleaner energy sources also entails difficulties such as power reliability and quality, availability, maintenance, new skills, and costs. Without proper planning, addressing these challenges can be complex.

The IATA New Fuels Infrastructure Net Zero Roadmap projects that global demand for alternative aviation fuels (SAF, batteries, and hydrogen) could require 10,000 TWh of clean energy by 2050 [11]. The World Economic Forum, in turn, estimates that to support new propulsion systems, large airports could consume five to ten times more electricity by 2050 than they currently do [12].

### Actions to address ever-growing energy demand

Airports will need to actively engage in proactive dialogues with utility companies and stakeholders to ensure alignment with decarbonization and electrification goals and consider potential delays in feeder station upgrades.

Some airports can invest in renewable energy sources, such as solar panels (Figure 9) onsite or near-site. Safety considerations may play a role when installing solar panels on site, such as the effects of glare from reflection on the solar panels, thermal disturbances from heat radiation, the effect on wildlife, the accessibility of (remote) areas by emergency services, and possible interference of communications and navigation systems. Airports can furthermore work with local governments and energy providers to create solutions that address the increasing demand for green energy. Planning for future growth and technological advancements is vital for maintaining efficient and reliable electrical services at airports.

For larger aircraft, it will be more efficient to produce the hydrogen off-site and transport it to the airport, as opposed to transporting electricity to make the hydrogen on-site. This will not remove the overall need for electrical energy but will shift this need away from the airport.

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[11] IATA. Energy and New Fuels Infrastructure - Net Zero Roadmap
[12] World Economic Forum (in collaboration with McKinsey & Company (2023). Target True Zero: Delivering the Infrastructure for Battery and Hydrogen-Powered Flight, White Paper

Figure 9. Borg El Arab International Airport - Solar farm on the terminal phase 2 with capacity 1.4 Mw

## Infrastructure and operational needs

The challenge is not only to generate electricity but also to transport it to and distribute it within the airport (via cables, hydrogen atoms, or hydrocarbon fuels) as well as store it. For example, infrastructure might be needed for storage of batteries and hydrogen, charging electric vehicles (Figure 10), including aircraft, and perhaps even considerations on the type of materials the stands are built on.

The International Industry Working Group (IIWG) has a task force co-chaired by ACI, IATA, and ICCAIA/Airbus (Airport Compatibility of Alternative Aviation Fuels Task Force), which looks at analyzing some of these operational and infrastructure changes from an Aerodrome Design & Operations standpoint in view of feeding the ICAO Aerodrome Design & Operation Panel (ADOP) and the Air Navigation Committee (ANC). The Alliance for Zero-Emission Aviation (AZEA) in Europe has also developed a CONOPS with insights into future infrastructure and operational needs. [13a,13b]

These new energy sources require additional safety considerations. Specific risks are introduced when fueling hydrogen-powered aircraft or charging electric-powered aircraft, along with other ground handling activities. The aerodrome emergency plan and rescue and firefighting procedures need to be reviewed with the introduction of these new energy types.

The storage and transportation of hydrogen at or near aircraft operational areas introduce additional risks into the aerodrome environment due to the specific properties of hydrogen, as it is highly combustible and volatile and is stored under cold or high-pressure conditions.

[13a] AZEA (2024). *AZEA Concept of Operations for the Introduction of Electric Hybrid-electric and Hydrogen Zero Emission Aircraft 2024 | Cluster 5 | Horizon Europe NCP Portal*
[13b] Airport Compatibility of Alternative Aviation Fuels Task Force, International Industry Working Group (2025). *Concept of Operations of Battery and Hydrogen-Powered Aircraft at Aerodromes*





Electric charging of aircraft has other specific safety challenges. The storage, transportation, and charging of batteries at or near aircraft operational areas may introduce additional risks into the aerodrome environment as well, requiring additional aerodrome infrastructure, operational measures, and safety precautions. These risks encompass high voltage levels, battery thermal runaways, and electromagnetic interference (EMI).

Figure 10. Sharm-El Sheikh International Airport - Electric buses

### Actions to address future infrastructure needs: Airport Master planning

Good planning ensures new airport development is integrated seamlessly, efficiently, and safely. The airport master planning process offers a great opportunity to include clean energy goals and align them with other airport needs[14]. An airport master plan is a comprehensive study of an airport and usually describes the near, medium, long-term development plans to meet future aviation demand [15]. ICAO recommends that all airports have a master plan [16].

[14] ICAO doc 9184 Airport Planning Manual (2023). *Airport Planning Manual - Part I - Master Planning (Doc 9184 - Part 1) | ICAO Store*
[15] FAA Advisory Circular 150 5070-6b Airport Master Plans (2005). *AC 150/5070-6B - Airport Master Plans (faa.gov).*
[16] IATA. *Airport Master Planning.*

### Actions to address future infrastructure needs: Airport Master planning

The master planning process starts with a look at existing conditions and what is needed to meet forecasted demand for aviation services. The assessments of supply and demand are then considered against a set of goals and objectives, and formulated into airport development initiatives that will meet the desired future state. The elements of a master planning process will vary in complexity and level of detail, depending on the size, function, and issues of the airport, and may focus on airside runway facilities and passenger accommodations. Energy goals are often included in such a process, along with other sustainability goals.

Including clean energy goals in a master planning process ensures that energy systems are considered and coordinated in proportion and scale with other airport developments. The master plan process has proven to be a successful method for setting goals, tracking progress, and communicating performance. However, airports can undertake energy management planning separate from the master plan process. This would start with an energy assessment that provides an understanding of where and how energy is used at an airport. With that information, the airport can develop a plan to manage and track energy efficiency and undertake projects toward cleaner energy. Each airport will have its own site, infrastructure, organizational, financial, and legal considerations that affect the proper path forward.

Integrating adaptation and resilience into airport master plans is also crucial to effectively manage and mitigate risks from future disruptions, especially given the increasing frequency of extreme weather events, combined with predicted growth in aircraft movements. Developing energy contingency plans and backup systems to ensure uninterrupted operations during unexpected disruptions or to adapt to changing circumstances, such as socioeconomic issues and environmental concerns, is another imperative.

## Human Factors

When handling electric ground service equipment or alternative aviation fuels, it is important to consider the human factor component. Errors and omissions, which can lead to an accident, incident, or interruption of operations, can be the result of miscommunication, fatigue, complacency, distraction, pressure, lack of training, disregarding warning signs appearing on a vehicle, or other causes. They can occur at any time when operating and handling eGSE or transporting aviation fuels. It is important for operators to be aware of these factors and take steps to mitigate any potential risks.



### Actions to address future human factors needs

Certain mitigating steps can include (but are not limited to) ensuring staff follow internal procedures by getting familiarised with technical manuals, raising awareness, providing in-house training/recurrent training programs that include consequences of disregarding warning signs, the proper charging procedures, and the management of emergencies such as battery or hydrogen fires. These steps can help reduce the likelihood of accidents, errors, or omissions.

Additionally, creating a culture of safety and accountability within the workplace can also contribute to overall risk reduction. Operators should also prioritize regular equipment maintenance and inspections to ensure optimal performance and safety. By consistently monitoring and addressing potential issues, operators can further minimize the risk of accidents or errors while using eGSE (Figure 11).


Figure 11 ACI APAC & MID-Green Airports Recognition 2017 - Sydney Airport - Electric GSE

## 5. CONCLUSION

The energy transition of the aviation ecosystem from traditional fossil-fuel-based energy sources to renewable energies has begun. Close to 98% of the combined airport-aircraft emissions around the world come from the operation of aircraft, followed by the electricity purchased by airports. Airports initiatives all around the world are focused on helping aircraft operators reduce the 98% share of emissions, while also reducing the emissions of their own operations, with the goal to reach net-zero by 2050.

The transition to alternative energies faces many challenges, including limited availability of electric light-duty vehicles, environmental management of batteries, lack of regulatory frameworks, high financial costs, lack of awareness and training, the cost of infrastructure and vehicle replacement, user-owned chargers, the standardization of chargers, and charging booking systems. The transition is also stressed by factors within and outside of the airport like the availability of renewable energy, SAF, or low carbon hydrogen. Aviation could require an amount of clean electricity equivalent to half of today's world-wide electricity use, to produce zero-carbon and net-zero fuels by 2050 which could displace 90% of the 2050 fuel usage in accordance with the projections published in IATA and ICAO Long Term Aspirational Goal (LTAG). The decarbonization of the electrical grid and the progress of the whole economy towards net-zero is and will be an important enabler for aviation as well.

To navigate in a resource-limited environment, the aviation sector must collaborate with diverse industries to ensure an ample supply of green electricity and hydrogen, all while participating in shaping the deployment of SAF and the trajectory of the hydrogen ecosystem.

The progress in the last few years, however, is impressive: Hydrogen aircraft prototypes are taking the skies and have flown by at least four companies in recent dates (ZeroAvia, Boeing, Universal Hydrogen, H2Fly), with many others planning to do so soon (Airbus, Stralis, Cranfield Aerospace).

The uptake of SAF in 2024 will be 0.5 Mt, a record-high number (although still only representing less than 1% of fuel use) and ICAO has set the collective vision to reach a 5% reduction in the carbon intensity of fuels by 2030. Airports around the world have built or are planning to build Mega-Watt scale renewable energy production facilities on-site. Some others are already storing hydrogen on-site for passenger cars, buses, and Ground Support Equipment. The boundaries are being pushed, and progress is happening in every aspect analysed in this report, but we must still accelerate our efforts, with only five years until 2030 to reduce the carbon intensity of fuels by 5%, and twenty-five years remaining to achieve the main target of net-zero by 2050.

The current state of global temperatures and emissions is unprecedented; there is no time to lose. By uniting all aviation industry efforts, the transition to cleaner energies and the achievement of LTAG of net zero carbon emissions is possible.

# 6. APPENDICES

## Appendix A: Examples of action
## Initiatives focused at enabling the energy transition of aircraft and reducing Airport's Scope 1 and 2 emissions


Figure 12 Examples of action of initiatives focused at reducing aircraft and airport emissions. The blue dots are government-led initiatives, and the red dots are industry-led initiatives

**Airports of Tomorrow (AoT) [17]:** The World Economic Forum, in partnership with Airports Council International (ACI), launched in 2023 the Airports of Tomorrow (AoT), an initiative that aims to address shared challenges for accelerating the net zero journey at the CEO level, driving strategic dialogues between airport executives, and leveraging the Forum's neutral platform, through public-private consensus. It provides a cross-sectoral, coordinated, global vision to avoid fragmented approaches. It is centered around several pillars, tackling the infrastructure challenge (airports as energy hubs, resilience, smart airports and circularity) and the SAF challenge (supply scaling and financing).

**International Industry Working Group (IIWG):** The IIWG is an industry work of experts which has a task force on Airport's Compatibility of Alternative Aviation Fuels (ACAAF), which is led by ACI, ICCAIA/Airbus, and IATA, providing ICAO with recommendations on documentation that needs to be revised and adapted to facilitate the introduction of zero-carbon aircraft (hydrogen and electric). The task force is in its final stages of drafting a Concept of Operations (CONOPS) and has a strong membership of airlines, airports, legacy OEMs, and start-ups, as well as regulators.

*[17] World Economic Forum, Airport of Tomorrow*



**Asia and Pacific (APAC)**

**1- Hydrogen grid at Kansai Airport, Japan [18]:** Kansai International Airport (KIX) is collaborating with airport businesses to promote hydrogen energy use in airport facilities and vehicles. The Hydrogen Grid Project was launched in May 2014 and actively engaged in testing fuel-cell forklifts for practical applications, establishing a model case involving the use of hydrogen at airports, and other activities. Hydrogen is the ultimate clean energy source, generating water after combustion and being able to be stored and shipped, making it a vector for energy to be transported. KIX has installed hydrogen stations for fuel-cell vehicles and buses and a hydrogen-charging facility for fuel-cell industrial vehicles. The Kansai Airports Group currently uses 3 fuel-cell vehicles and 21 fuel-cell forklifts. In March 2022, KIX introduced a fuel-cell bus as the airport shuttle bus, marking a first for Osaka Prefecture.

**2- Public-Private Committee on New Technologies toward Decarbonization of Aircraft, Japan [19]:** with the purpose of discussing challenges to formulate globally harmonized safety standards related to new technologies such as electrification and hydrogen-powered aircraft, promoting the practical application of these new technologies, and contributing to decarbonization in the global aviation sector.

**3- Hydrogen Aviation Consortium, New Zealand [20]:** In New Zealand the hydrogen consortium launched by Christchurch Airport is one of the leading projects in the region, where Christchurch Airport partnered with an OEM (Airbus), an airline (Air New Zealand), and energy companies (Fortescue Future Industries, Hiringa Energy, and Fabrum) to prepare the airport for the entry into service of a hydrogen aircraft. The hydrogen consortium was strategically launched at Christchurch, where the airport is developing a 400-hectare renewable energy precinct (Kowhai Park). This solar farm will provide energy to the airport as well as being capable of producing hydrogen on-site.

**4- Hydrogen Flight Alliance (HFA), Australia [21]:** The HFA is bringing together a start-up company looking into retrofitting existing aircraft with hydrogen with Aviation Australia, Brisbane Airport, SkyTRans, and BOC, as well as leading universities (Griffith, Queensland University of Technology) and a few others to bring stakeholders together to work towards the first commercial hydrogen electric flight from Brisbane to Gladstone.

**5- Airport Carbon Evaluation Scheme, China (People's Republic of) [22]:** The initiative is executed by the China Civil Airports Association (CCAA) to boost airport energy transition and carbon emission reduction, as mandated by the Civil Aviation Administration of China (CAAC). It features an indicator-based evaluation system that scores airport applicants from the basic one-star airport to the highest five-star airport. All applicants will be assessed by the scheme in three aspects: 1) management system, 2) emission reduction actions, and 3) green performance, while they must meet more stringent requirements as shown by more and higher indicators under each aspect of assessment if applying for a higher star-level airport. The promotion and facilitation of SAF adoption and the usage of renewables such as wind, solar, and ground-source heat pumps are also highlighted indicators, which encourage airports to leverage resources and to mobilize stakeholders to advance their renewable transition.

*[18] Kansai Airports (2023). Environmental Report 2023*
*[19] Ministry of Economy, Trade and Industry (2022). Commencement of the First Meeting of Public-Private Committee on New Technologies toward Decarbonization of Aircraft*
*[20] Christchurch Airport. The New Zealand Hydrogen Aviation Consortium*
*[21] Hydrogen Flight Alliance (2023). Accelerating Australian aviation towards an emission-free future*
*[22] China Civil Airports Association (2024). The on-site audit of the "double carbon airport" evaluation of Kunming Changshu International Airport was carried out smoothly (Chinese translation)*

The evaluation will be undertaken by authorized third-party on-site evaluation entities, with its evaluation report reviewed by a technical expert panel to support the final decision made by the CCAA Committee for the scheme. Not only will the evaluation report be delivered for each airport applicant, but also recommendations will be made to inform their continued low-carbon actions to improve. Since its inauguration in 2022, a total of 32 airports were evaluated, and 11 were identified as three-star airports by the scheme. There's no airport achieving four-star or five-star yet. Currently, the 2024 evaluation cycle is underway.

**North America, Central America and Caribbean (NACC)**

**6- Airport City Solar Project, Canada [23], [24]:** Edmonton Airport, in Canada, is constructing a 627-acre, 120-megawatt solar farm on the west side of the airport to produce renewable energy for its own use. The project (Airport City Solar) will be the world's largest solar farm built at an airport. Edmonton has also partnered with startup company ZeroAvia to bring hydrogen-electric flights to Canada. The airport and the start-up will work together to bring gaseous hydrogen to the airport, with plans to expand to liquid hydrogen.

**7- Hydrogen feasibility study at Hartsfield-Jackson Atlanta International Airport (ATL) [25]:** Hartsfield-Jackson Atlanta International Airport (ATL), Airbus, Delta Air Lines, and Plug Power have joined forces to assess the feasibility of hydrogen fueling at the world's busiest airport in support of advancing a more sustainable future for travel. The study will help define the infrastructure, operational viability, and safety and security requirements needed to implement hydrogen as a potential fuel source for future aircraft operations at ATL. It will also contribute to the understanding of supply and infrastructure requirements for hydrogen hubs at airports worldwide.

**South America (SAM)**

**8- Santiago's Airport hydrogen ambitions, Chile [26]:** Santiago's Arturo Merino Benitez Airport, in Chile aims to be the first airport in Latin America to operate on green hydrogen. Chile is one of the States with the largest potential for low-cost green hydrogen production, according to IRENA, and so there are ample opportunities here for aviation in the South American nation. The project in Chile brings together airport operators with hydrogen providers (Air Liquide) and the local government ministries (transport and telecommunications, science and technology, public works, and energy).

**9- Aeropuertos Argentina 2000, Argentina:** In 2022, Aeropuertos Argentina 2000, the airport operator, entered into a long-term agreement with renewable energy provider GENNEIA as part of the Renewable Energy Term Market (MATER). In 2023, 65% of Ezeiza Airport's energy consumption was provided under this agreement.

*[23] ZeroAvia (2022). ZeroAvia & Edmonton International Airport Tie Up to Bring Hydrogen-Electric Flights to Canada*
*[24] Edmonton International Airport. Airport City Solar*
*[25] Delta News Hub (2024). Delta joins ATL, Airbus, Plug Power in hydrogen fuel study*
*[26] Vinci Concessions (2022). Santiago airport launches plan to become the first in Latin America to operate with green hydrogen*



**European and North Atlantic (EUR/NAT)**

**10- Alliance for Zero Emission Aviation (AZEA), European Union [27]:** The alliance is a European Union (EU) commission-led initiative that brings together a very wide range of stakeholders to prepare Europe for the entry into service of zero-emission aircraft (hydrogen and electric). The alliance has an important membership made of airports, airlines, trade organizations, government representatives, OEMs and start-ups, and research centers. The work is divided into six work packages, which include scenario development, airport infrastructure, ecosystem view (to provide the $H_2$ and energy), certification requirements, policy, and risk assessment.

**11- Jet Zero Council (JCZ) – United Kingdom [28]:** A partnership between JZC and various high-level stakeholders from the industry (including UK airports), academia, and the government. It aims to deliver at least 10% of SAF in the UK by 2030. Additionally, it is also targeting zero emissions in transatlantic flights within a generation, delivering new technologies and implementing creative approaches to reduce aviation emissions.

**12- Hydrogen Airport Joint Venture, France [29]: In** France, Groupe ADP and Air Liquide have taken a unique approach to create a joint venture to prepare the airport ecosystem for hydrogen. The Hydrogen Airport JV will initially be focused on feasibility studies to facilitate the introduction of $H_2$ aircraft to airports around the world.

**13-Connected Places Catapult (CPC), United Kingdom [30]:** The CPC in the UK launched the Zero Emission Flight Infrastructure initiative to prepare UK airports for hydrogen aircraft. The initiative looked at infrastructure requirements at the airport and procedural operation modifications. The potential that airports have as energy hubs has also been highlighted, and a thorough review of hydrogen standards, for example for storing large quantities of hydrogen on-site, has been done.

**14-Project TULIPS, The Netherlands [31]:** TULIPS is a consortium that will develop innovations that facilitate the transition to low-carbon mobility and enhance sustainability at airports for the next four years, supported by the EU with €25 million in funding. The TULIPS project started in January 2022 and lasts until December 2025. The consortium aims to speed up the roll-out of sustainable technologies in aviation and significantly contribute towards zero-emission and zero-waste airports by 2030 and net-zero aviation by 2050. Amsterdam Airport Schiphol will be the proving ground for 17 demonstrator projects that result from the collaboration. Collaborating at different airports in 4 countries (Cyprus, Norway, Italy, and the Netherlands) with the input from the broad coalition of partners will allow the impact of the solutions on the European climate targets to become apparent.

A hydrogen-powered GPU is already being trialed at Schiphol airport, which supplies stationary aircraft with electricity. Other demonstrators include liquid hydrogen storage at airports, iron flow battery, and zero-emission (electric and H2) road vehicles testing.

*[27] European Commission. Alliance for Zero-Emission Aviation*
*[28] UK Government. Jet Zero Council*
*[29] Air Liquide (2023). Air Liquide and Groupe ADP announce the creation of "Hydrogen Airport," the first joint venture to support the development of hydrogen infrastructure in airports*
*[30] Catapult Connected Places (2023). Preparing UK Airports for Zero-Emission Aircraft*
*[31] TULIPS. Innovative & sustainable airports*

**15-Project OLGA, France [32]:** OLGA (Holistic & Green Airports) has been selected by the European Commission as part of the H2020 call for projects under the European Green Deal, focusing on environmental innovation. This new strategic project, coordinated by Aeroports de Paris SA (ADP), with Paris-Charles de Gaulle Airport in France as the lighthouse airport and with Zagreb Airport in Croatia, Milano-Malpensa Airport in Italy, and Cluj Airport in Romania as partners, started on October 1, 2021. The project aims to improve the aviation sector's environmental impact in an innovative and sustainable way. Paris-Charles de Gaulle Airport is therefore positioned as the consortium leader carrying out major environmental innovations deployed and disseminated until 2026.

OLGA has a total budget of €34 million, with €25 million in funding from the European Commission over a period of 60 months. The consortium is formed of 41 partners and 17 third parties, involving large and small airports, airlines and the aviation industry, public authorities, researchers, and innovative start-ups.

One of the project's focuses is to decarbonize ground operations and explore the idea of hydrogen hubs for ground operations and aircraft. A recent milestone was the first hydrogen-powered bus fully integrated into the public transport fleet of Cluj-Napoca.

**16-Groupe ADP and GRTgaz joined forces to study the transport of hydrogen by pipeline to Paris-CDG and Paris-Orly, France [33]:** Continuation of pre-feasibility studies on the structuring of a hydrogen logistics chain serving Paris airports. In 2021, Groupe ADP, Airbus, and Air Liquide jointly conducted studies aimed at characterizing the volumes of hydrogen required and the challenges of integrating hydrogen infrastructure at the airports in the Paris region. In 2023, Groupe ADP undertook studies on the operation and infrastructure of the upstream value chain, outside the airport, in order to qualify the possibility of transporting electricity for hydrogen production at airports or hydrogen directly in gaseous form

**17-EU – Hydrogen project at several airports [34]:** Led by Airbus and supported by academic partners, airport operators and hydrogen industry leaders, an innovative aviation liquid hydrogen handling and refueling project has been launched to conduct ground operations on liquid hydrogen-powered aircraft - on a smaller scale - at three European airports. The GOLIAT (Ground Operations of LIquid hydrogen AircrafT)* project is funded over four years with €10.8 million from the EU's Horizon Europe framework program, and its aim is to demonstrate how high flow liquid hydrogen (LH2) handling and refueling technologies can be developed and safely and reliably deployed in airport operations.

[32] OLGA | hOListic & Green Airports. OLGA Project
[33] Groupe ADP (2023). Groupe ADP and GRTgaz join forces to study the supply of hydrogen by pipeline from Paris-CDG and Paris-Orly
[34] Airbus (2024). Innovative aviation liquid hydrogen project launched





**18-Airports as Alternative Fuel Infrastructure Facilities [35],[36],[37]:** The European Commission launched the Alternative Fuels Infrastructure Facility (AFIF), with the objective of supporting the deployment of alternative fuel supply infrastructure, contributing to decarbonizing transport across the Trans-European Transport Network (TEN-T). VINCI Airports, committed to decarbonizing the mobility industry as a whole by helping its clients and partners to reduce their own emissions (scope 3), applied to the call for proposals launched in 2023 for its airports in Portugal and France. Eleven (11) VINCI Airports were for the installation of systems that limit the use of Auxiliary Power Units (APU) of aircraft, resulting in emissions reductions during the turnaround time. In Portugal only, this initiative with a total cost of more than €100 million is part of VINCI Airports sustainability programme, which aims to achieve carbon neutrality in its scope 1 and 2 emissions by 2030 and support the transition of its partners. This includes the implementation of energy supply and air conditioning systems for parked aircraft, which by switching off their engines, will reduce fuel consumption and emissions. Including the installation of electric charging points for ground vehicles, the project will revolutionize the operational environment at Portuguese airports. The project covers around 135 aeroplane parking spots and 600 charging points.

**Middle East (MID)**

**19-Masdar partnering with Total Energies, United Arab Emirates [38] [39]:** Masdar is a global green hydrogen economy leader based in the United Arab Emirates (UAE), whose aim is to become the hub for green hydrogen production and export. It united with three companies, Mubadala, ADNOC, and TAQA, and their expertise will be utilized to promote innovative solutions in renewables and green energy. Masdar also partnered with TotalEnergies to develop commercial green hydrogen in Abu Dhabi with the potential of converting methanol to SAF. The UAE's General Policy for Sustainable Aviation Fuel aims to achieve a voluntary target of supplying 1% of fuel to national airlines at UAE airports using locally produced SAF by 2031.

**20-Sustainable Retrofit and Solar Integration, United Arab Emirates [40]:** Collaboration between Etihad Energy Services and Dubai Airports on energy-efficient projects that aim to address energy efficiency through retrofit measures and clean energy with solar integration. It focuses on both energy efficiency and environmental safekeeping.

**21-Energy Efficiency Project, Saudi Arabia/Riyadh [41]:** Riyadh Airports Company (RAC), which manages and operates King Khalid International Airport (KKIA) in Riyadh, and the global leader in low-carbon energy and services, ENGIE, launched the Energy Efficiency project at KKIA to identify and develop cost-effective and smart energy conservation measures, identifying the optimal mix of clean energy sources. The project will provide the best solutions to reduce energy demand and costs and ensure reliable supply through clean and renewable energy sources.

[35] European Commission (2024). CEF Transport Alternative Fuels Infrastructure Facility (AFIF) call for proposal
[36] European Investment Bank (2024). Portugal: EIB and ANA announce €50 million finance contract for low-carbon airport infrastructure
[37] ACI Europe – Airport Carbon Accreditation (ACA) (2024). Interview with Nicolas Notebaert
[38] Masdar (2024). Masdar and TotalEnergies to Develop a Commercial Green Hydrogen to Methanol to SAF project in Abu Dhabi
[39] World Economic Forum (2023). Beyond oil and gas: how to unlock MENA's low-carbon hydrogen potential
[40] Solarquater (2023). Etihad Energy Services and Dubai Airports Unite for Sustainable Retrofit And Solar Integration At COP28
[41] Engie (2024). Riyadh Airports Company launches KKIA Energy Efficiency Project with ENGIE

## Appendix B: Useful publications on decarbonization

**Aerospace Technology Institute (ATI)**
- FlyZero: Hydrogen Infrastructure and Operations: Airports, Airlines and Airspace (2022)

**Airports Council International (ACI)**
- ACI World, Guidance on Airport Decarbonization (2024)
- ACI World High-level Guidance for Developing and Costing an Airport Net Zero Roadmap (2023)
- ACI EUROPE, Guidance on Developing an Airport Net Zero Carbon Roadmap
- ACI and ATI, Integration of Sustainable Aviation Fuels into the air transport system (2022)
- ACI and ATI, Integration of hydrogen aircraft into the air transport system (2021)
- ACI Sustainable Energy Sources for Aviation - An Airport Perspective (2021)
- ACI Sustainability Strategy for Airports Worldwide (2021)
- ACI Long-Term Carbon Goal Study for Airports (2021)
- ACI Guidance Manual: Airport Greenhouse Gas Emissions Management (2009)

**ASTM**
- Future Directions in Petroleum and Natural Gas Refining
- ASTM D7566, Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons

**Energy Institute (EI)**
- EI 1533 Quality assurance requirements for semi-synthetic jet fuel and synthetic blending components (SBC)
- Energy Essentials: A guide to hydrogen,
- Electrical installation of facilities for the storage and dispensing of LPG and CNG automotive fuels at vehicle refueling stations
- Guidance on green and low carbon hydrogen production: plant design, construction, operation and maintenance, co-location and other considerations
- Federal Aviation Administration (FAA)
- Report on the Sustainable Master Plan Pilot Program and Lessons Learned
- Zero Emissions Vehicle Pilot Program Technical Guidance

**International Civil Aviation Organization (ICAO)**
- ICAO Eco-Airport Toolkit: Greenhouse Gas Management and Mitigation at Airports

**International Air Transport Association (IATA)**
- Direct Air Capture (DAC) and Storage (DAC+S) Essential Components to Achieve Net Zero Carbon in Aviation
- Brief on Access to fuel infrastructure to enable aviation's decarbonization
- IATA Net Zero Roadmaps: Infrastructure Roadmap
- IATA SAF Handbook

**Jacobs**
- Airports as Catalysts for Decarbonization

**World Economic Forum (WEF)**
- World Economic Forum Financing Airports of Tomorrow: A Green Transition Toolkit.



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