European Commission

Alliance for **Zero-Emission Aviation**

PREPARING EUROPE FOR HYDROGEN & ELECTRIC FLIGHT

Zero Emission Aviation Alliance
WG 03 Aerodromes

March 2025

Helping Airports understand the challenge of zero-emission aviation:
AZEA Airports Infrastructure Factsheets Tool

High level picture

Electric, hybrid-electric and hydrogen-powered aircraft for short- and medium-haul flights within Europe offer a transformative solution to reducing the environmental impact of air travel. However, the transition to supporting **new energy aircraft will require significant infrastructure and operational upgrades at airports**.

For **electric aircraft, investments will focus on high-power charging capabilities at dedicated stands**, expanded underground electrical grids, and strengthened connections to renewable energy sources.

For hydrogen-powered aircraft, hydrogen infrastructure deployment will likely follow a phased approach, starting with gaseous and liquid hydrogen storage systems, truck-based refuelling solutions, and later evolving towards near-site or on-site liquefaction facilities, cryogenic LH2 storage, and potentially pipeline networks.

Multi-fuel refuelling stands capable of handling both liquid hydrogen and SAF/JET A1 will also become essential, requiring likely substantial redesigns and adherence to rigorous safety standards.

It is **crucial for airports to estimate the demand for electrical energy required** not only for hybrid-electric and fully electric aircraft but also for the complete electrification of airport operations, ensuring sufficient capacity and grid resilience to meet future energy needs.

Current initiatives focusing on feasibility studies, participation in European pilot projects, and hands-on testing of hydrogen in ground-handling operations are **critical steps for identifying operational challenges and regulatory gaps**. Airports should also invest in **workforce training for hydrogen and electric safety protocols**.

Help airports develop actionable plans

Given the **diversity of aircraft types**, **decarbonised electricity and hydrogen needs**, **supply methods**, and **business models**, **airports will** likely **face challenges** in identifying clear requirements and **planning for the future**. **This document aims to offer** practical **guidance to help airports develop actionable plans** and identify opportunities to support the integration of next-generation energy-powered aircraft

- **This guidance document is a catalogue where multiple factsheets regarding infrastructure, operation, and safety will be available for airports to help in their future planning.**
- **The factsheets are aimed at facilitating the airport's long-term development strategies.**
- **The main objective is to assist airports in planning and managing the new aircraft's impacts on the airport's operations and infrastructure requirements over different time horizons.**

1. Airports **assessment** of **impacts of new energy aircraft** on infrastructure and **operations-based business model/traffic mix**.
2. Number of **annual passengers** at an airport
3. **Traffic mix by range** (mix by share of connected destination distances)
4. Macro environment factors (**local infrastructure / H2 power demand**)
5. Microenvironment factors (**space availability** for new infrastructure, **local communities' attitudes**)

Issues addressed by the document

The transition to hydrogen and electric-powered aircraft presents significant **operational challenges for airports**, necessitating **adaptations in infrastructure**, **safety measures, and workflow processes**.

This document's operational **factsheets explore these challenges through open-ended questions**, emphasising the **need for additional research**, **regulatory advancements**, **and the establishment of standardised procedures**.

ISSUES ADDRESSED IN THIS DOCUMENT

Hydrogen aircraft

- Refuelling safety zone
- Stand configuration/design & allocation
- Dedicated areas/Remote stands
- Refuelling with pax on board
- Weight and balance limitations and different turnaround milestones (A-CDM)
- Firefighting, rescue and emergency

Hybrid-electric aircraft

- Stand configuration/design & allocation
- Battery charging and refuelling of SAF/JET A1 with passengers on board
- Thermal/ Climate condition
- Weight and balance limitations and different turnaround milestones (A-CDM)
- Firefighting and rescue and emergency
- Storage areas security risk

Recommendations for EU and National policies

A comprehensive policy framework and robust financial support are essential for airports to accommodate and advance new energy aircraft successfully.

More specifically, future European and National policies should:

Renewable Energy Demand & Production

- Integrate airport renewable energy access into EU and Member States' energy policies.
- Allocate funding for renewable projects (e.g., solar parks) at or near airports.
- Harmonize regulations for managing on-site renewable energy production.

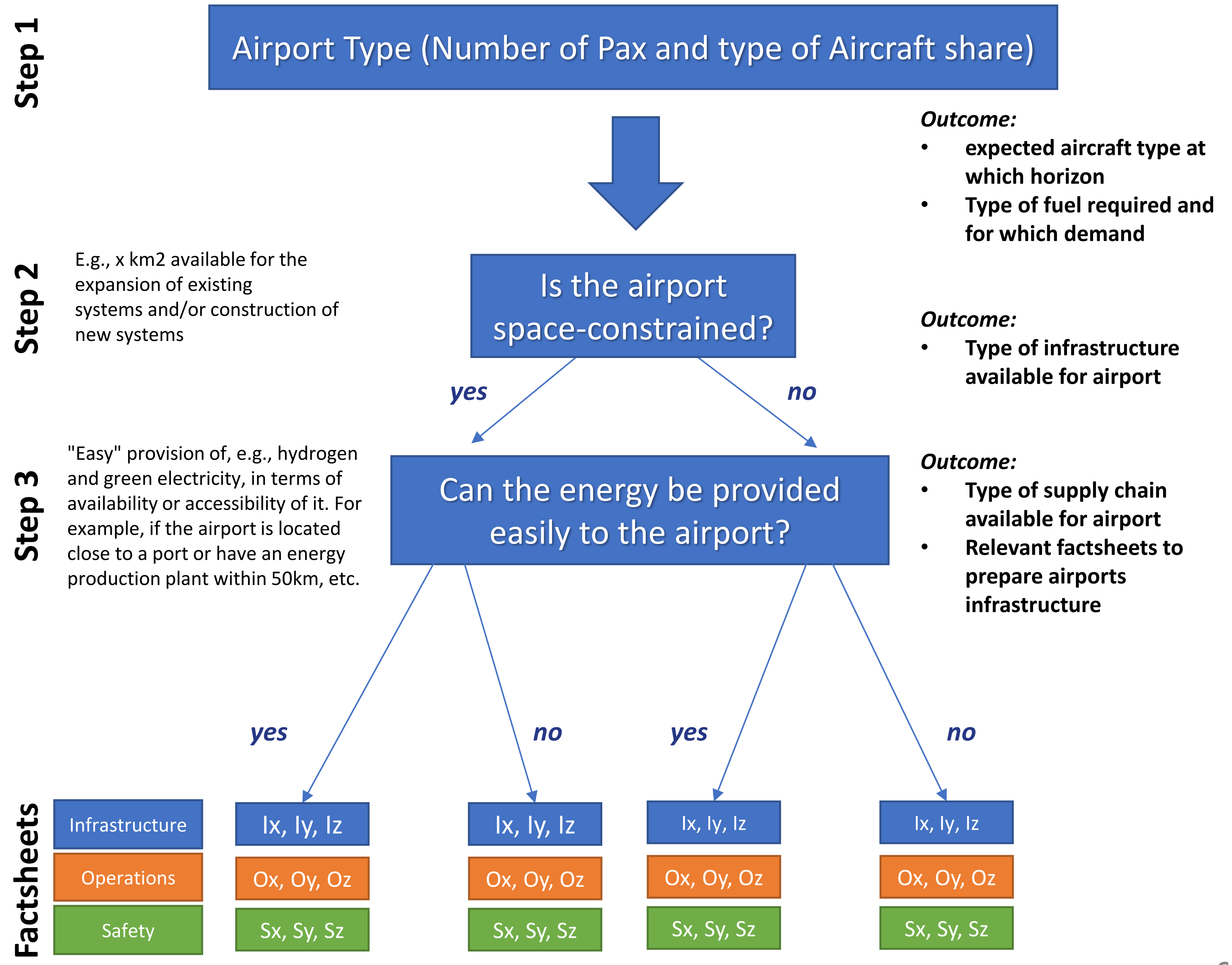
Regulatory Framework

- Standardize charging plugs and protocols for electric aircraft.
- Safety and operational standards for charging equipment and hydrogen refuelling (GH2/LH2).
- Regulatory measures to address hydrogen-related safety and infrastructure needs.
- Safety risk assessments to ensure compliance with operational standards

Infrastructure Development

- Fund upgrades for airport grids for airside operations.
- Support electric fast chargers and GH2/LH2 refuelling infrastructure, including pipelines and storage.
- Incentivise investment in electric charging stations and hydrogen supply chains.
- Enable land-use planning for hydrogen facilities and on-site renewable energy projects.

- The Scenario Flow outlines the key steps airports can follow to reach the appropriate factsheet. It includes four main elements:
  - Number of Passengers
  - Traffic mix by range
  - Macro environment factors
  - Micro environment factors



Step 1 - Airport type

The Airport Categorization is based on two key principles:

- **Passenger Category Analysis:** Minimum, maximum, and average proportions of each aircraft type operating within each passenger category.
- **Logical Alignment:** Thresholds were refined to ensure logical consistency and practical applicability

The following types of airports were identified:

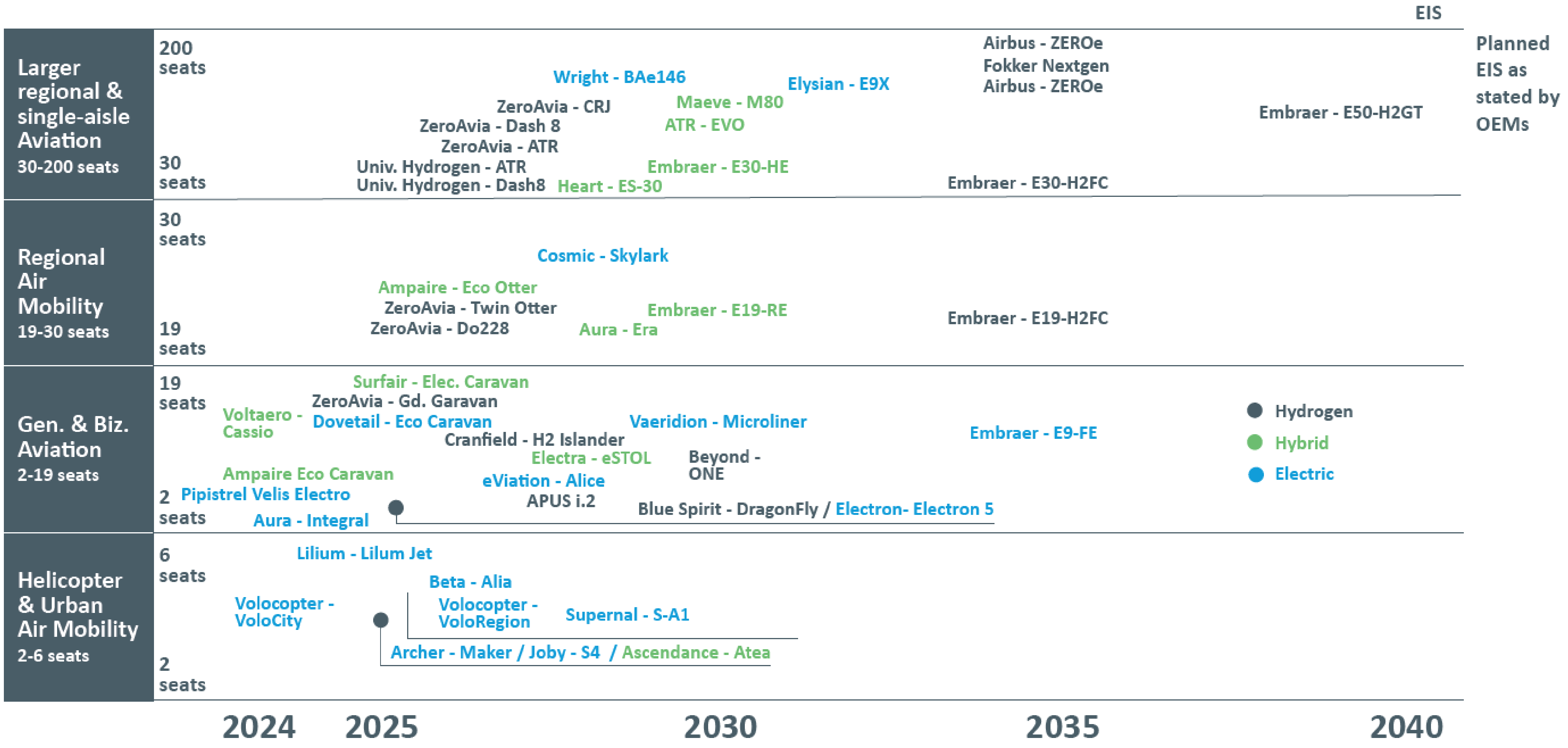
- **General aviation** (medical, fire, school, private) with less than 2.5 daily Instrument flight rules (IFR) movements or others
- **Domestic/Regional Short** with a small number of passengers and relatively short-range aircraft type (e.g., Highlands and Islands Airports)
- **Regional Medium-Long** with a relatively small to large number of passengers and short-medium range aircraft type (e.g., Rome Ciampino, Toulouse - Eindhoven)
- **International Hub** - large number of pax and wide range of aircraft type (e.g., Frankfurt – Istanbul)

***These categories are not binding for all airports, as all airports have different types of activities and might identify themselves in another category. For example, an airport that focuses on cargo serves a small number of passengers but operates long-range flights, making that airport fit into the 'International Hub' category more than into the category it was placed in.*

Step 1 - Aircraft type

AZEA published an Overview of aircraft developments and their announced entry-into-service (EIS) dates.

Note: Certification times are not always taken into consideration.



Source: **AZEA Vision: Flying on electricity and hydrogen in Europe** (June 2024).

Steps 2 and 3 support schemes coming soon

Between airport categorisation and the adoption of a specific infrastructure configuration, steps 2 (airport location space and environmental constraints) and 3 (energy [electricity/H2] provision constraints) are mandatory but still need to be properly analysed.

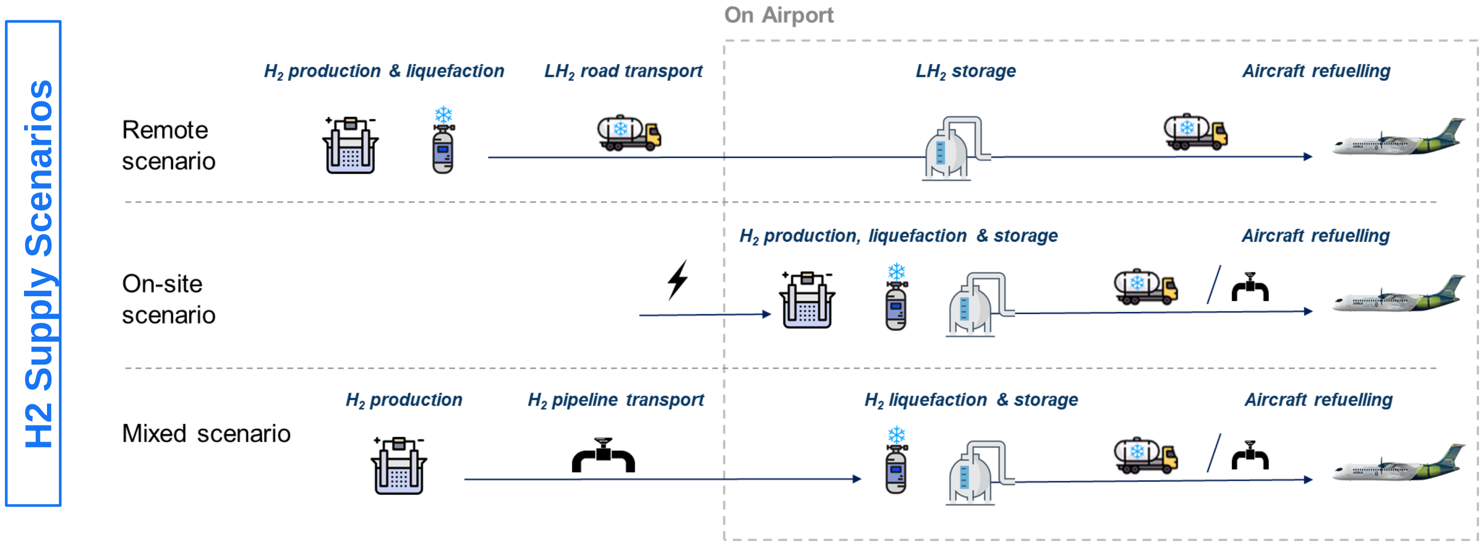
This link between a specific airport configuration regarding traffic demand and mix (including novel aircraft operations share) and a suitable infrastructure development roadmap will be available as an output of the infrastructure options analysis currently in progress (WP2).

This WP is developing the output of WG2, which was made available in Q4 2024 in terms of energy infrastructures and demand.

Infrastructure factsheets overview for H2 aircraft

The infrastructure factsheets provide general guidelines for implementing H2 at the airport in different configuration scenarios.

- The **Infrastructure workstream** under the AZEA group 3 will analyse all the possible infrastructure configurations for supplying H2 at the airport
- The H2 supply is defined by the **three scenarios** as per the AZEA set-up
- For each scenario, a **factsheet** is then produced with a general description, along with **scenario requirements** (infrastructure and regulations) and a definition of roles and responsibilities for the airport
- Each factsheet is also aimed at a specific **airport category** (GA/Regional, Regional short, Regional Medium, Regional Long, International hub) as per the AZEA guidelines



Factsheets

Infrastructure factsheets overview for H2 aircraft

The factsheets cover the entire hydrogen supply chain to airports, encompassing options with varying level of CAPEX intensity

SUPPLY

- **Factsheet 1** – Supply gaseous hydrogen by truck
- **Factsheet 2** – Supply gaseous hydrogen by pipeline (new or refurbished)
- **Factsheet 3** – Supply liquid hydrogen by truck

SUPPLY/ REFUELLING

- **Factsheet 4** – Liquid hydrogen by tank swapping

LIQUEFACTION, STORAGE & COMPRESSION

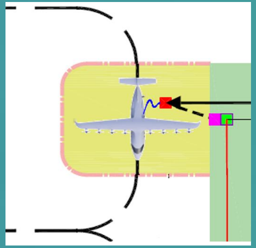
- **Factsheet 5** – Hydrogen liquefaction and storage
- **Factsheet 6** – GH2 Storage and Compression

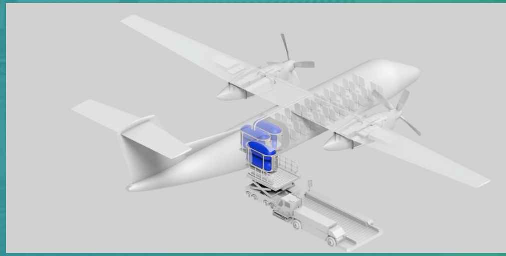
REFUELLING

- **Factsheet 7** – Liquid hydrogen refuelling by truck
- **Factsheet 8** – Liquid hydrogen refuelling by hydrant
- **Factsheet 9** – Gaseous hydrogen refuelling by truck
- **Factsheet 10** – Gaseous hydrogen refuelling by fixed/mobile station

Factsheets

- **Supply Chain Set-up**
  - ❑ Factsheet A – Electricity supply for 100% electric-powered aircraft
  - ❑ Factsheet B – Electricity supply for Hybrid-electric powered aircraft
  - ❑ Factsheet 1 – Supply Gaseous hydrogen by truck
  - ❑ Factsheet 2 – Supply Gaseous hydrogen by pipeline
  - ❑ Factsheet 3 – Supply Liquid hydrogen by truck
  - ❑ Factsheet 4 – Supply Liquid hydrogen by tank swapping
  - ❑ Factsheet 5 – GHG Storage and Compression
  - ❑ Factsheet 6 – Hydrogen Liquefaction and LH2 storage
  - ❑ Factsheet 7 – LH2 refuelling by truck
  - ❑ Factsheet 8 – LH2 refuelling by pipeline
  - ❑ Factsheet 9 – GH2 refuelling by truck
  - ❑ Factsheet 10 – Gaseous hydrogen refuelling by fixed/mobile station

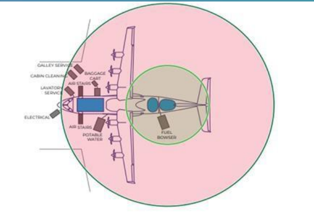



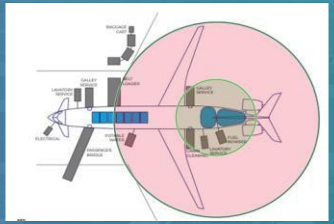
Factsheets

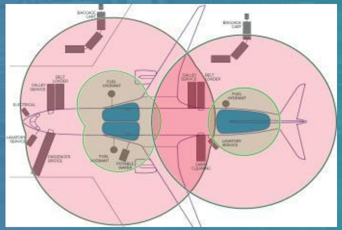
Operational Issues H2/Electric/Hybrid-electric

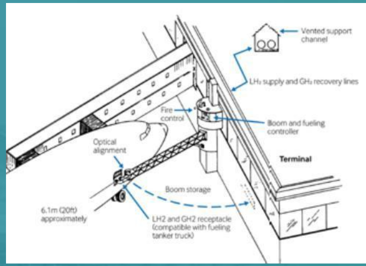
Hydrogen aircraft

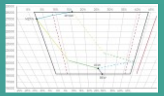
- ❑ Refueling safety zone
- ❑ Stand configuration/design & allocation
- ❑ Dedicated areas/Remote stands
- ❑ Refuelling with pax on board
- ❑ Weight and balance limitations and different turnaround milestones (A-CDM)
- ❑ Firefighting and rescue and emergency



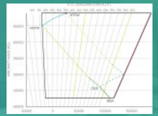




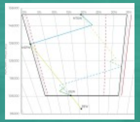




Regional concept



Narrowbody concept



Midsize concept

Factsheets

Operational Issues H2/Electric/Hybrid-electric

Hybrid-electric aircraft

- ❑ Stand configuration/design & allocation
- ❑ Battery charging and refuelling of SAF with passengers on board
- ❑ Thermal/ Climate condition
- ❑ Weight and balance limitations and different turnaround milestones (A-CDM)
- ❑ Firefighting and rescue and emergency
- ❑ Storage areas security risk

ANNEX – Infrastructure and Operation Factsheets

Infrastructure

AZEA WG3 – WP1

Infrastructure factsheets

Factsheet A – Electricity supply for 100% electric-powered aircraft

Airport category: GA/Regional, Domestic - Regional short, Regional Medium, International hub

General description: The first aircraft categories requiring electricity will be eVTOL, General Aviation and RAT/RAM with an entry-into-service between 2030-2035. General Aviation and Turboprop aircraft may also adopt an all-electric propulsion system in the following years. Electrical power is not suited for narrow or wide-body aircraft. Large airports could consume 5-10 times more electricity by 2050 than they do today, to support alternative propulsion.

Requirements / Preliminary steps:

1. Have sufficient charging capability at the airport to charge electrical aircraft
2. Development of new renewable capacity to match the demand for electrons needed to provide green electricity to electrical aircraft (e.g., Solar Panel Park)
3. Safety and regulatory study for battery pack flammability

Source: **Kate O'Connor, First Electric Aircraft Charging Station Built (**September 2017**)**

Roles and responsibilities for the airport: Estimate the demand for electrical energy needed to supply electric planes. The estimate should include the entire electrification of airport operations. Regular contact with the regional and national authorities for the enhancement (or construction, if necessary) of a high-tension electrical grid in the vicinity of the airport. Plan investments for an enhancement of the underground electrical grid in the airport airside area and for the procurement and installation of new electric fast chargers located at each stand dedicated to all-electric powered aircraft. Collaboration in the safety and regulatory study for electrical energy recharging operations and battery pack flammability. Total electric power demand is to be assessed for all consumers at the airport, including electric cars, buses, push-back tractors, PAX-buses, and hybrid-electric aircraft. A Standardization of loading plugs and loading stations might also be necessary.

Key stakeholders involved: Electrical grid primary transmission and dispatching operator, electrical energy supplier, Airport Infrastructure team

Expected Investment (range): $$$$

Timeline – roadmap/maturity: Long-term, large volumes.

Example Airports:

Reference documents:


In collaboration with McKinsey & Company

WORLD ECONOMIC FORUM

Target True Zero: Delivering the Infrastructure for Battery and Hydrogen-Powered Flight

WHITE PAPER

APRIL 2023


CATAPULT

ZERO EMISSION FLIGHT INFRASTRUCTURE 2

Hydrogen Infrastructure Options for Airports

January 2023


NATIONAL ACADEMIES

Preparing Your Airport for Electric Aircraft and Hydrogen Technologies (2022)

Factsheet B – Electricity supply for Hybrid-electric powered aircraft

Airport category: GA/Regional, Domestic - Regional short, Regional Medium, International hub

General description: The first aircraft categories requiring electricity will be RAT/RAM with an entry-into-service between 2030- 2035. These might be newly designed aircraft or modified turboprop aircraft. Some hybridization will be needed for the first aircraft on the market to allow an acceptable operational range for small, narrow-body aircraft with up to 19 seats initially. With the improvement of battery efficiency – some larger aircraft may be equipped with a hybrid-electric powertrain. Large airports could consume 5-10 times more electricity by 2050 than they do today to support the charging of hybrid-electric aircraft.

Requirements / Preliminary steps:

1. Have sufficient charging capability at the airport to charge electrical aircraft simultaneously
2. Develop of new renewable capacity to match the demand for electrons needed to provide green electricity to electrical aircraft (e.g., Solar Panel Park)
3. Safety and regulatory study for battery pack flammability and simultaneous operations on the ground

Roles and responsibilities for the airport: Estimate the demand for electrical energy needed to supply electric aircraft. The estimate should include the entire electrification of airport operations. Regular contact with the regional and national authorities for the enhancement (or construction, if necessary) of a high-tension electrical grid in the vicinity of the airport. Plan investments for an enhancement of the underground electrical grid in the airport airside area and for the procurement and installation of new electric fast chargers located at each stand dedicated to Hybrid-electric powered aircraft. Back up by the use of mobile power bank trolleys. SAF, Biofuel or JET A1 to be provided by truck to the parking area. Simultaneous fuelling operations to be clarified/ assessed. Total electric power demand is to be assessed for all consumers at the airport, including electric cars, buses, push-back tractors, PAX-buses, and hybrid-electric aircraft. Collaboration in the safety and regulatory study for electrical energy recharging operations and battery pack flammability. A Standardization of loading plugs and loading stations might also be necessary.

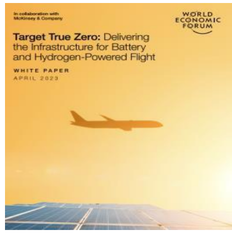
Key stakeholders involved: Electrical grid primary transmission and dispatching operator, electrical energy supplier, Airport Infrastructure team

Expected Investment (range): $$$$ / **Initial investments for 3 chargers & infrastructure: $ (400 kE)**

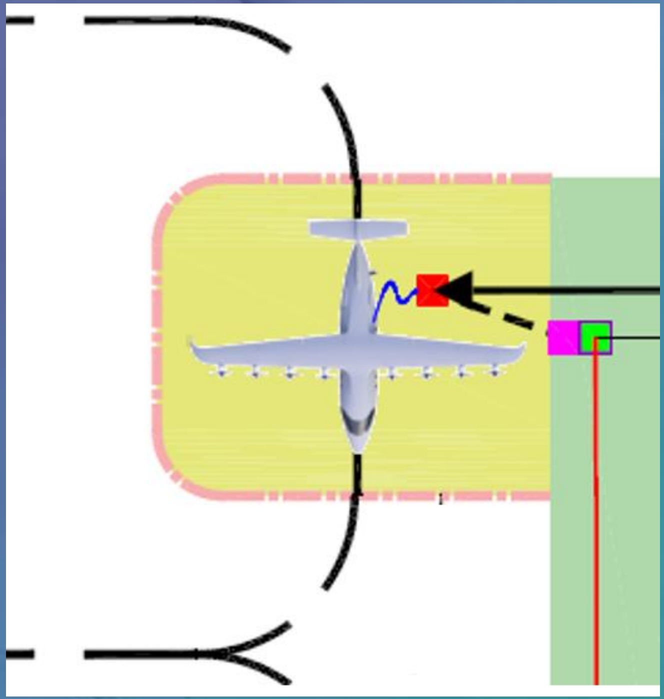
Timeline – roadmap/maturity: Long-term, large volumes.

Example Airports: No example airports yet.

Reference documents:



Example of configuration:

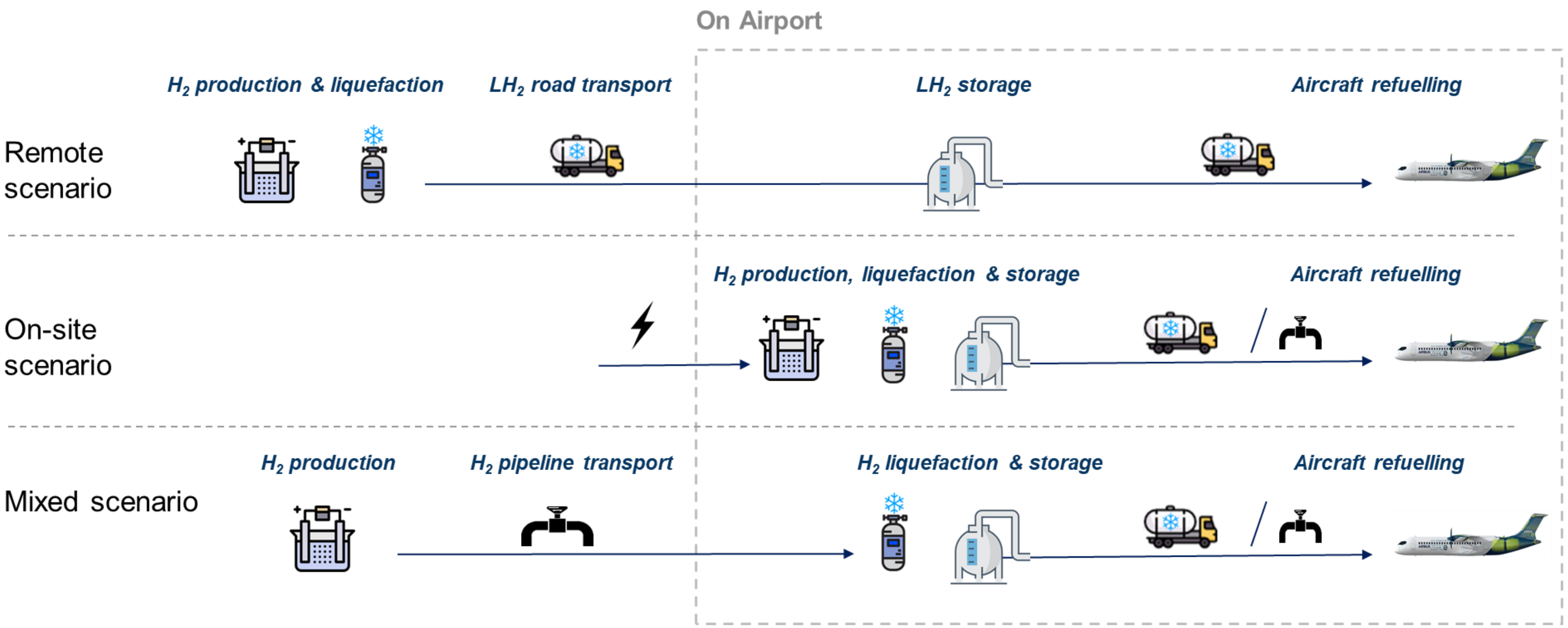


Initial requirements (example):

- 2 or 3 High power chargers of 360 kW each
- Dedicated stand for Hybrid-Electric A/C
- 3 phases 400V provided to chargers (560 A, 385 kVA @ 50 Hz)

Hydrogen for aviation, airport supply scenarios

Energy supply scenarios for hydrogen to the aerodrome were centralised GH2/LH2 supply via truck transport is expected to be the primary option for the first years of deployment - could also be executed by using exchangeable, centrally-refilled hydrogen tanks



The new supply chains that will be developed to deliver h2 to airports will also significantly impact airports' infrastructure, spatial planning and operations

Factsheet 1 – Supply Gaseous hydrogen by truck

Airport category: GA/Regional, Domestic - Regional short, Regional Medium

General description: The supply of gaseous hydrogen by truck is expected to be a first step to delivering hydrogen to airports that have H2 demand for non-aviation transportation GSE or aviation purposes. The infrastructure to deliver gaseous hydrogen is well understood and available from other industries and this process has the least amount of operational and infrastructure impact on the airport. It is better suited for lower H2 volumes, and this is more likely in the short term.

Requirements / Preliminary steps:

1. Infrastructure and areas for GH2 delivery, potentially GH2 storage and refueller truck parking, as well as the GH2 distribution to aircraft
2. Safety and risk assessments as well as regulatory approvals

Roles and responsibilities for the airport: Plan for an area for GH2 storage - Estimates for the demand for GH2 on the platform will depend on the H2 off-takes and growth projections. Define an area on the airport for the GH2 storage and truck parking as well as its distribution for aircraft refuelling

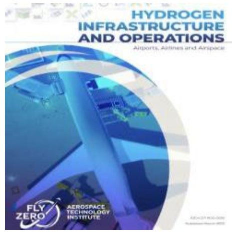
Key stakeholders involved: Airport Co, Gaseous hydrogen supplier, GH2 storage facility stakeholders, Infrastructure investors, Transmission System Operators (TSOs) /refuellers, Airlines

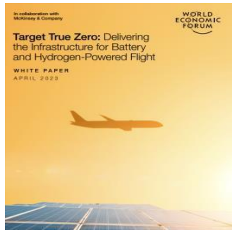
Expected Investment (range): $$

Timeline – roadmap/maturity: Short-term, medium technology maturity

Example Airports: Rotterdam, Bristol

Reference documents:





Source: **Air Products**

Factsheet 2 – Supply Gaseous hydrogen by pipeline

Airport category: Regional Medium, Regional Long, International hub

General description: Gaseous hydrogen by pipeline to or near the airport provides a feasible way for the airport to have a strong and easily scalable supply of hydrogen. This is more likely to be used for liquid hydrogen, given the higher H2 demands that a pipeline can serve and the higher expected need for liquid hydrogen. In this scenario, it is important that the airport then has the ability to liquefy hydrogen and store it on-site or near the site. This is energy intensive and, like all fuel facilities, has safety implications. This scenario is likely to provide the best mode of supply for large airports

Source: **Getty Images**

Requirements / Preliminary steps:

1. National/regional /local hydrogen pipeline backbone in the vicinity of the airport
2. Coordination with the national Transmission System Operator and national regulatory authorities on the hydrogen infrastructure planning envisaged at the regional and national level, including connection to the European Hydrogen Backbone
3. Safety and risk assessments as well as regulatory approvals

Roles and responsibilities for the airport: Regular contact with the regional and national regulatory authorities to ensure that the airport is adequately supplied by a pipeline connection to the national and European grid in the vicinity of the airport including backbone spur lines. Make available an area on the airport site (or find an area close to the airport) for the liquefaction plant and the storage of the LH2 and associated LH2 storage, conditioning and vehicle operations

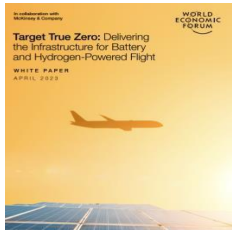
Key stakeholders involved: Gas hydrogen supplier, Transmission System Operators (TSOs), on-site liquefaction and storage stakeholders, Infrastructure investors, Infrastructure operators, LH2 suppliers, Airport Co, Airlines

Expected Investment (range): $$$$

Timeline – roadmap/maturity: Long-term, large volumes. Current maturity at a technical level is high.

Example Airports: No example airports yet. Large-scale study of Liquid hydrogen to Chicago O'Hare airport from NASA, Project Napkin at LHR and current studies at YYZ,YVR,YUL,IAH amongst others

Reference documents:



Factsheet 3 – Supply Liquid hydrogen by truck

Airport category: GA/Regional, Domestic - Regional short, Regional Medium, Regional Long, International hub only for first POCs

General Description: The supply of Liquid hydrogen by truck is likely to be a first step to delivering hydrogen to airports that require liquid hydrogen at their airport. Technology to deliver liquid hydrogen is available from other industries and it has been shown liquid hydrogen can be transported relatively long distances. It is not suited for extremely large LH2 volumes, but these are not expected in the short term. Liquid hydrogen could also be vaporised for GH2 supply if required in an airport.

Requirements / Preliminary steps:

1. Delivery and parking infrastructure for LH2 delivery
2. Static LH2 storage (with size depending on the volume of consumption)
3. Versatile trucks that can deliver airside and drive landside (different vehicles may be used for LH2 supply and refuelling) although this is not considered feasible beyond early stages as demand grows
4. Safety risk assessments and regulatory approvals

Source: **Air Products**

Roles and responsibilities for the airport: Make suitable land available on the airside airport site for LH2 parking, storage and conditioning and refueller parking with suitable location zoning and approval. LH2 storage requirements should be a function of the nature of the supply chain for LH2

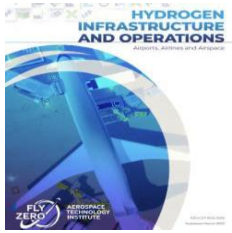
Key stakeholders involved: Liquid hydrogen supplier, Infrastructure investors, Infrastructure and Truck providers, Airports, and Infrastructure operators.

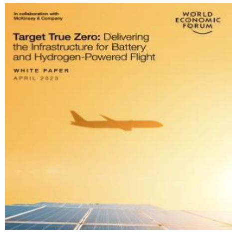
Expected Investment (range): $$

Timeline – roadmap/maturity: Short-term, medium technology maturity

Example Airports: Rotterdam, Hamburg, Cranfield, Bristol.

Reference documents:





Factsheet 4 – Supply Liquid hydrogen by tank swapping

Airport category: GA/Regional, Domestic - Regional short, Regional Medium, International hub

General description: Supply of Liquid hydrogen by swapping tanks, a short-term ready solution, is a way to deliver hydrogen to airports through a system that utilizes modular capsule technology that safely stores hydrogen during transport and acts as modular fuel tanks that are loaded directly onto aircraft. This solution is more suited for regional aircraft.

Requirements / Preliminary steps:

1. LH2 swapping tanks development
2. LH2 swapping tank filling outside of the airport and depot to store the filling modules;
3. Safety and regulatory study

Roles and responsibilities for the airport: Make available an area on the airside airport site for LH2 swapping tanks storage (if necessary), compliant with safety and regulations.

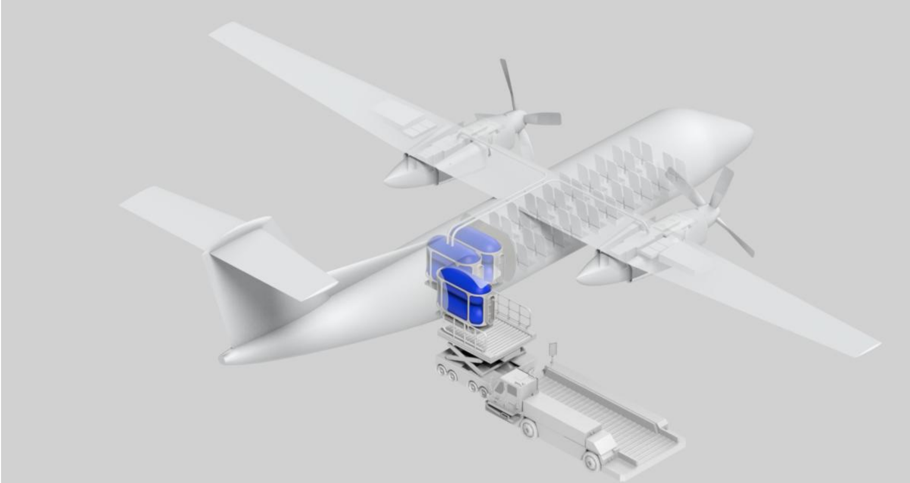
Key stakeholders involved: Liquid hydrogen supplier, aircraft tank supplier

Expected Investment (range): $$$

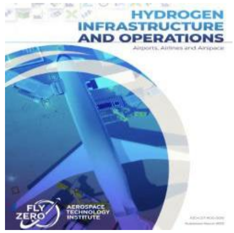
Timeline – roadmap/maturity: Long-term, medium technology maturity on storage, low technology maturity (on aircraft aspects)

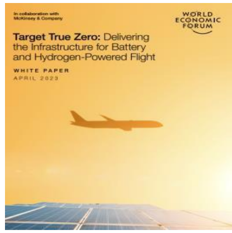
Example Airports:

Reference documents:



Source: ***Universal Hydrogen***





Factsheet 5 – Gas Hydrogen Storage and Compression

Airport category: Regional Medium, Regional Long, International hub

General description: Gaseous hydrogen, whether supplied to the airport or produced on-site, must be stored at suitable pressure in suitable pressure-rated hydrogen storage tanks within the airport. This will be the case as the volume grows beyond just servicing via mobile refueller filled offsite only. The pressures need to be suitable for decanting into refuellers or supply to other sources via pipeline. However, in many cases, compression will be needed to provide the pressures required for service. This mode of supply will also be similar to gaseous hydrogen used for non-aviation use cases. This will require GH2 storage, H2 supply panels, pipeline connections and a compressor(s). Storage quantities can scale as demand grows.

Requirements / Preliminary steps:

1. Development/selection and suitable location of a GH2 storage, supply panels and compressor to supply high-pressure GH2 of suitable quantity and quality. It is expected that industrial H2 design and construction standards can be used.
2. Operational and location study with airport and link to non-aviation use as appropriate
3. Safety risk assessment and regulatory approvals

Roles and responsibilities for the airport: land availability, electricity capacity availability , zoning and siting, support in approvals and risk assessment

Key stakeholders involved: GH2 supplier, airport, Infrastructure providers

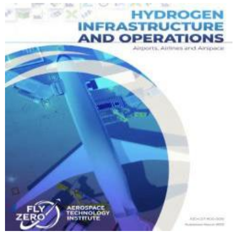
Expected Investment (range): $$$

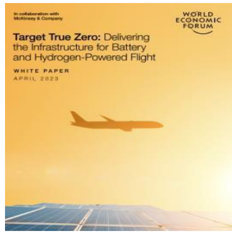
Timeline – roadmap/maturity: Short-term, high technology maturity as processes well understood

Example Airports: Rotterdam, Toulouse Blagnac, Lyon St Exupery, Toronto Pearson

Reference documents: NFPA 2, NFPA 55, ISO TR 15916, SAE AS7373, ISO 11119, ASME 31.12, UK COMAH regulations and equivalent international codes

Source: **Groupe ADP – Air Liquide**





Factsheet 6 – Hydrogen Liquefaction and LH2 storage

Airport category: Regional Medium, Regional Long, International hub

General description: Gaseous hydrogen supplied to /or near the airport (or produced at the airport) can be converted to liquid by a liquefaction plant and then pumped into cryogenic storage tanks located near or on the airport. The site requires equipment and facilities to liquefy hydrogen and store this liquified hydrogen on an airport site or, more likely, in close proximity to the airport for larger airports especially. This is energy-intensive and, like all fuel facilities, will have safety implications.

Requirements / Preliminary steps:

1. Involvement of companies with a background and experience in liquefaction and cryogenic storage
2. Safety risk assessments and regulatory approvals
3. GH2 supply as feed for the LH2 liquefaction plant via truck or pipeline

Source : **NASA**

Roles and responsibilities for the airport: land area on the airport site or in close proximity to the airport for the liquefaction plant and the storage of the LH2, Electricity capacity availability, GH2 pipelines and easements, plus parking areas for LH2 trucks /refuellers

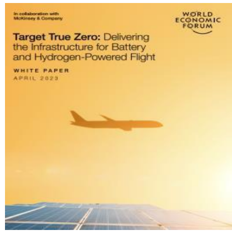
Key stakeholders involved: GH2 supplier, on-site liquefaction and storage stakeholders, airport cos, Investors, Transmission System Operator (TSO)

Expected Investment (range): $$$

Timeline – roadmap/maturity: long-term, large volumes. Current maturity is medium to high

Example Airports: No example airports yet. Large-scale study of Liquid hydrogen to Chicago O'Hare airport from NASA, Canadian Airport feasibility studies at Toronto /Montreal/Vancouver with Airbus and ZeroAvia

Reference documents:



Factsheet 7 – LH2 refuelling by truck

Airport category: GA/Regional, Regional short, Regional Medium, International hub

General description: In the short to medium term, it is expected that LH2 refuelling into an aircraft will be carried out by a refueller truck. Technology to refuel liquid hydrogen by truck is currently in development and is expected prior to entry into service of LH2-powered aircraft.

Requirements / Preliminary steps:

1. Development of LH2 truck that can operate on the apron to refuel the aircraft;
2. Possible multifuel stands for LH2 refuelling by truck operations alongside JET A1/SAF refuelling;
3. Safety risk assessment and regulatory approvals

Roles and responsibilities for the airport: Design and construction, if needed, of new/compatible multifuel stands or preferably reuse of existing stands in compliance with safety risk assessment and any regulatory requirements for LH2 refuelling operations by trucks. OEMS and technology providers are also exploring technological improvements to minimize the impact on the turnaround time of the aircraft with the most cost-efficient trade-off between technical complexity and efficiency (bowsers configuration and connections).

Key stakeholders involved: Liquid hydrogen equipment suppliers, infrastructure refuelling providers and airlines.

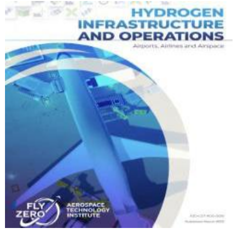
Expected Investment (range): $$$$

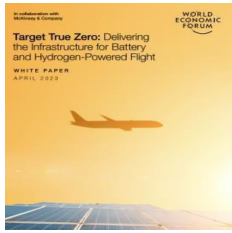
Timeline – roadmap/maturity: Short-term, medium technology maturity, CONOPS under development via SAE 8466, SAE 8999 & ISO TC 137 WG2

Example Airports: SEA Milan Airports (in collaboration with other partners, will design a new stand for LH2 refuelling and test this technology in the next few years), Groupe ADP and VINCI, Airbus & Zeroavia feasibility studies with Canadian Airports (YYZ,YUL,YVR)

Source **: Airbus ZEROe concept**

Reference documents:





Factsheet 8 – LH2 refuelling by pipeline

Airport category: Regional short, Regional Medium, International hub

General description: In this scenario, the liquid hydrogen is pumped from the storage tank through underground cryogenic pipelines to the apron and hydrant dispenser vehicles will provide a connection between the aircraft and the pipeline. The major challenge is the cost, long-distance LH2 pipeline technical feasibility in sub-surface pipelines and managing boil-off effectively & efficiently. The technology to refuel liquid hydrogen by pipeline is not available at present. Given the expected cost and technical and operational complexity, this process will have a big impact on the airport's infrastructure investment, which is not expected soon. It is suited for larger volumes and, therefore, has a long-term time horizon.

Requirements / Preliminary steps:

1. Technical maturity of long-distance LH2 sub surface pipelines and the associated cryogenic challenges
2. Development of an underground cryogenic pipeline network on the apron;
3. Upgrading of stands to allow LH2 refuelling by hydrant dispenser vehicles;
4. Design of LH2 hydrant dispensers and associated couplings that can manage flash gas from the transfer and boil-off gas from the aircraft
5. Safety risk assessments and regulatory approvals

Roles and responsibilities for the airport /H2 supplier/Infrastructure developer: Thermodynamic analysis, solving cryogenic challenges, design and construction of a new underground cryogenic pipeline network on the apron to connect the LH2 storage tanks to the stands. Design and construction of new stands and/or upgrading of existing stands – the same size as current stands, for retrofit aircraft initially – in compliance with safety and regulations for LH2 refuelling operations by hydrant dispenser vehicles.

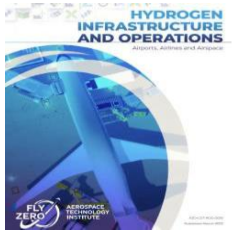
Key stakeholders involved: Liquid hydrogen suppliers, LH2 airport handling companies, LH2 engineering design companies, LH2 refuelling Transmission System Operator (TSO), Airport companies, Airlines, Infrastructure providers, Infrastructure investors, Infrastructure operators

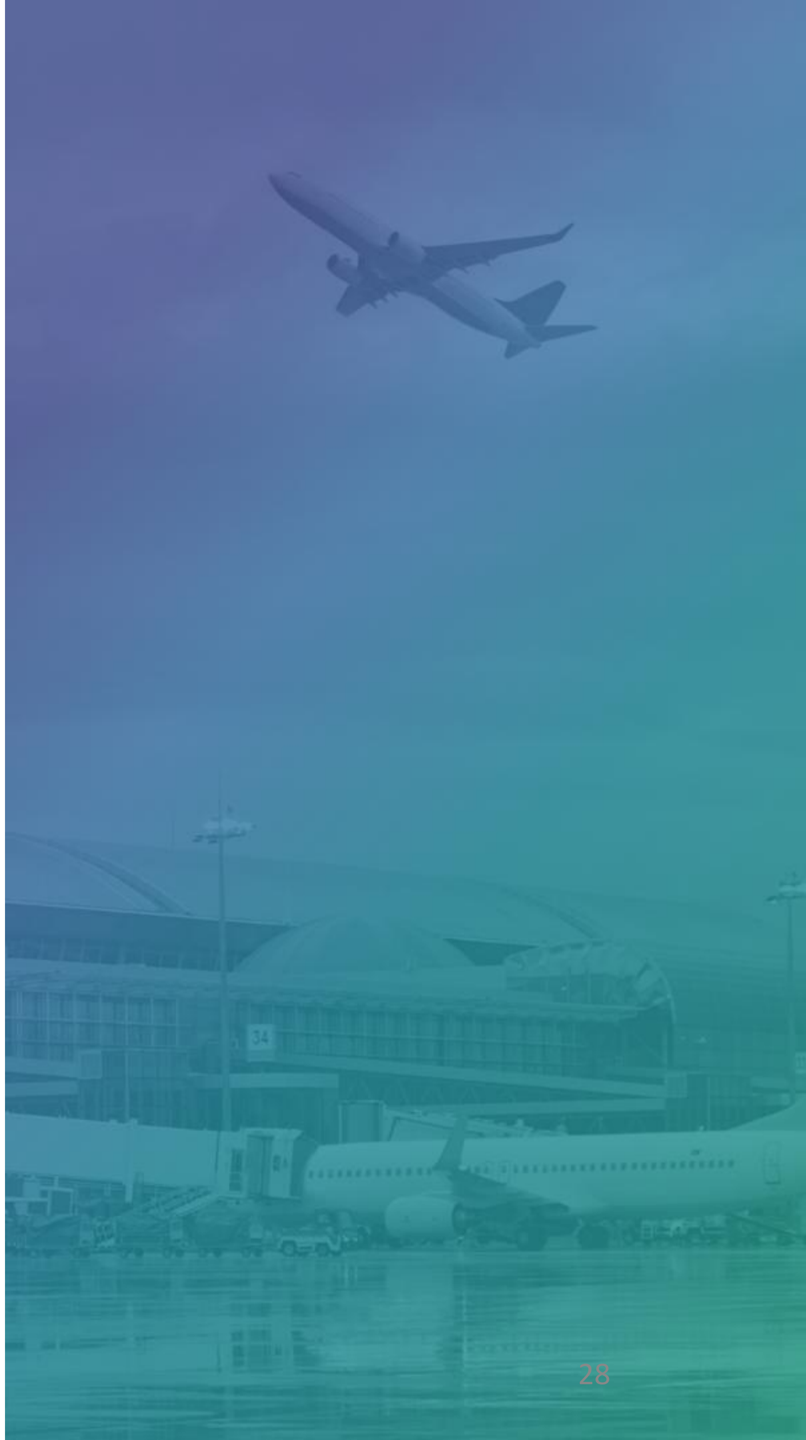
Expected Investment (range): $$$$$

Timeline – roadmap/maturity: Long-term, large volumes. Current technical maturity is very low and no current development has commenced

Example Airports:

Reference documents:





Factsheet 9 – GH2 refuelling by truck

Airport category: GA/Regional, Domestic - Regional short, Regional Medium

General description: In the short term, one of the easiest and fastest ways to refuel gaseous hydrogen in an aircraft is to carry out the refuelling operation by refueller truck. The truck will require a high-pressure GH2 supply at the airport from GH2 storage or an external GH2 supply source off the airport and a distribution system on board. Ensuring the truck has adequate hydrogen pressure for refuelling is crucial. Having the appropriate GH2 pressure on the refueller to suitably refuel the aircraft will be important. It is expected that for GH2, refuelling by truck will be both the short-term and long-term solution.

Requirements / Preliminary steps:

1. Development of a GH2 refuelling truck that can operate on the apron to refuel the aircraft and match the aircraft specifications (high-pressure, large GH2 quantity, competitive refuelling time). It has to be developed based on the current refuelling standards of the other industries, and it is expected that SAE J2601 Protocols for Heavy-duty transport can be adopted with ease. If cooling is needed, the (electrical) power required to generate enough cooling could be integrated into the truck or supplied by the airport. There are existing refuellers which meet this requirement and the next step is to lower the cost of this equipment.
2. The refuelling vehicle could also be DOT/MOT certified for road use, enabling it to serve as a hydrogen distribution/supply vehicle
3. Operational impact study with Airports/Airlines to address operational issues
4. Safety risk assessment and regulatory approvals

Roles and responsibilities for the airport: The definition of a dedicated area for GH2 delivery and storage and confirmation of the use of refuelling gates to meet design and safety requirements. Training as needed - airport staff on hydrogen safety, refuelling staff on refuelling procedures, emergency response etc.

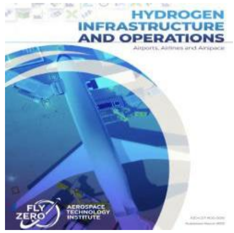
Key stakeholders involved: Infrastructure providers, Transmission System Operator (TSO), GH2 suppliers, GH2 aircraft OEM's, Airlines

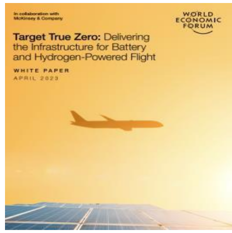
Expected Investment (range): $$

Timeline – roadmap/maturity: Short-term, low technology maturity

Example Airports:

Reference documents:





On-site storage and mobile bowser

Source: **ZeroAvia**

Factsheet 10 – GH2 refueling by fixed/mobile station

Airport category: GA/Regional, Domestic - Regional short, Regional Medium

General description: In the short term, one way to refuel gaseous hydrogen in an aircraft is to carry out the refuelling operation using a fixed or mobile station that is located in one location. Considering the current technologies and standards already available for the automotive industry, fixed/mobile station seems a potential short-term option despite its operational challenges to the airline and airport.

Requirements / Preliminary steps:

1. Development / Selection and suitable location of a GH2 refuelling station that can operate on the apron to refuel the aircraft and match their specifications (high-pressure, large GH2 quantity, competitive refuelling time). This device should meet the required protocols to ensure safe operation. It is expected that this will likely be SAE J2601 for Heavy-Duty transport or equivalent protocols for higher-pressure needs.
2. Areas to implement GH2 refuelling stations (ATEX areas) and provide required electrical power (for cooling generation if required)
3. Operational impact study with airport and airlines
4. Safety risk assessment and regulatory approvals

Roles and responsibilities for the airport: Design and construct suitable areas airside to accommodate the station in compliance with safety and current regulatory standards for GH2 aviation refuelling operations by the station. Staff Training as needed - airport staff on hydrogen safety, refuelling staff on refuelling procedures and emergency response.

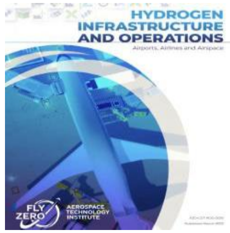
Key stakeholders involved: Airports, Aircraft ground handlers, Airlines, GH2 suppliers, GH2 aircraft OEMs, Transmission System Operator (TSO)

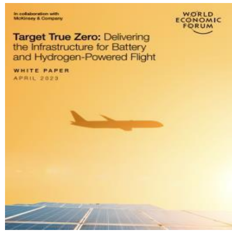
Expected Investment (range): $$

Timeline – roadmap/maturity: Short-term, medium technology maturity; Not expected to be a long-term solution as the number of H2 flights scales

Example Airports:

Reference documents:





Fixed station

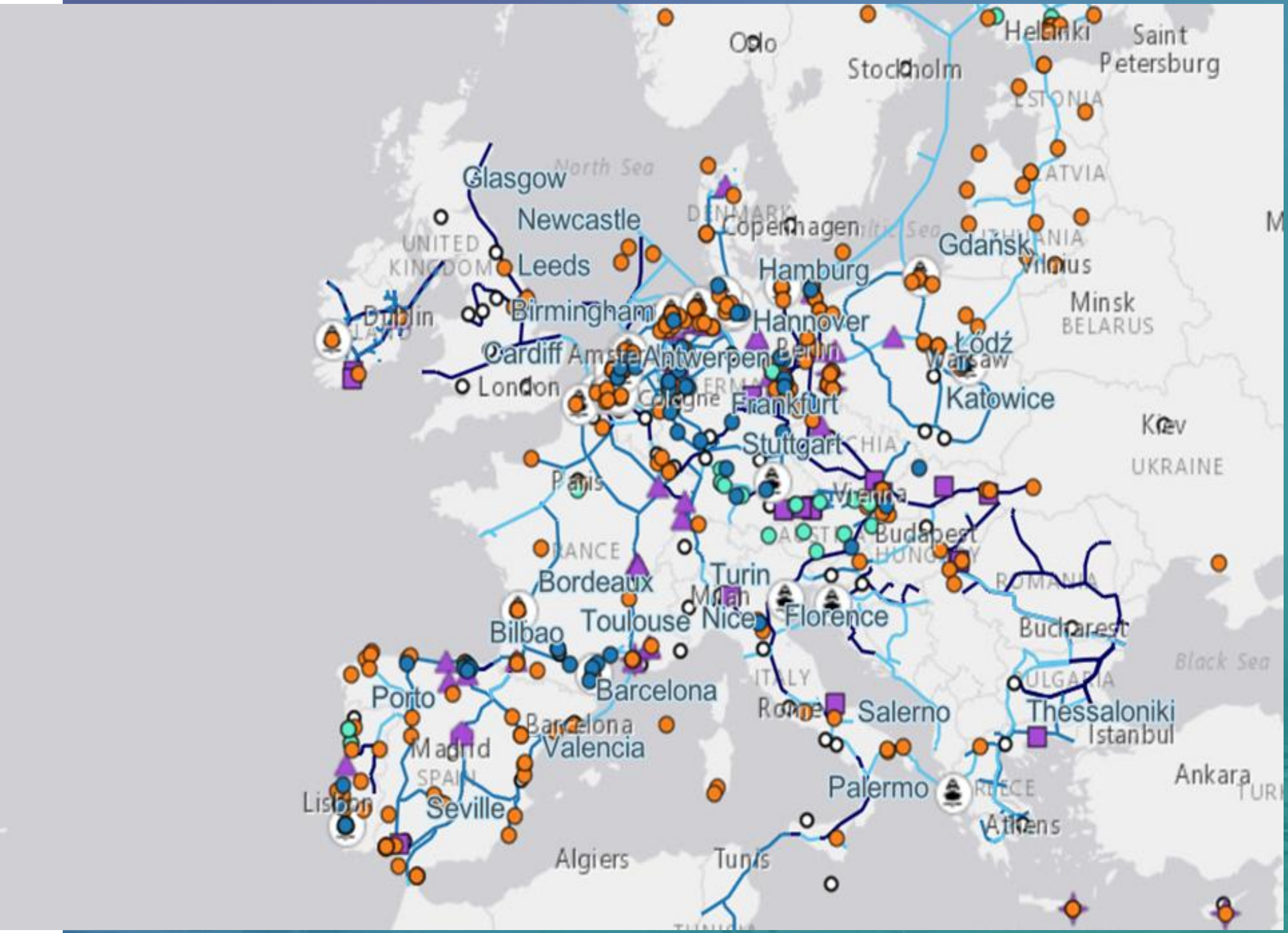
Source: **HYPORT**

Mobile station

Source: **Air Products**

Examples of key stakeholders: Role of TSOs/ HNTOs

- Up until now, **Transmission System Operators (TSOs) have been responsible for operating the transmission network for the transport of natural gas**.
- As many of the existing natural gas pipelines are to be repurposed to transport hydrogen and new pipelines are also to be built for this purpose, **most of the TSOs will become ''hydrogen network operators'' (HTNOs) of the hydrogen transmission network** (definition provide in the Gas & Hydrogen Decarbonization Directive).
- TSOs from EU Member States were members of **ENTSOG, a cooperation initiative of European gas TSOs**. The role of ENTSOG as regards hydrogen will be replaced as of 2025 by the **European Network of Network Operators for Hydrogen (ENNOH).**
- ENTSOG/ ENNOH participates in the development of the **H2 Infrastructure Map** (in alignment with the European Hydrogen Backbone Initiative) and collects hydrogen transmission projects in the **bi-annual Ten-Year Network Development Plans (TYNDP)** .



Hydrogen Infrastructure Map: A Joint Initiative by ENTSOG, GIE, EUROGAS, CEDEC, GD4S and GEODE

Recommendations for engagement with TSOs/HNTOs & ENTSOG/ENNOH

1. For airports, early engagement with existing TSOs and future HNTOs will be essential to ensure that the required volumes of hydrogen are adequately supplied to airports:

- As a first step, the existing links to airports in the planned national hydrogen networks, as well as the existing gaps in the planned infrastructure, should be analyzed. As an example, airports requiring a direct connection to the hydrogen network should be identified. Ongoing projects at airports should be also mapped in order to better understand which airports could be more easily integrated in the hydrogen network.
- Airports should seek early alignment with the ongoing work of TSOs/ future HNTOs and national regulatory authorities to make sure that the planning of the national hydrogen networks and of the cross-border links considers the required hydrogen supply of airports and that airports are well integrated in the hydrogen networks. Airports should regularly consult the projects in the TYNDPs.

2. In this transition period, it will be also important for airports to engage with ENTSOG and the recently launched ENNOH.

3. TSOs/HNTOs should be also invited to become members of AZEA could be particularly helpful to strengthen this necessary engagement.

EU Member State	TSO/Potential HNTOs
Belgium	Fluxys Interconnector Fluxys
France	GRTgas/ Terega
Denmark	Energinet
Germany	OGE, Ontras, bayernets, Fluxys TENP, Gascade, GTG Nord, Gasunie, GRTgaz Deutscheland, Thyssengas
Italy	Snam, SGI
Netherlands	Gasunie, bbl company
Spain	Enagas

Examples of TSOs at the EU level and future potential HNTOs (see complete overview here)

Operational issues

H2 Operational Issues at Airports

Fuelling Safety zones

Intro: One of the key issues to be addressed as an industry is the safety zones around the refuelling process. Assessing the appropriate zones is the subject of significant industry effort in various industry working groups for both gaseous and liquid hydrogen. Issues to consider because of the outcome include:

Open issues:

- **Will the safety zones differ from existing fuels, and if so, how will this impact other turnaround activities? This includes both refuellers and refuelling points.**
- **What are the risks of multifuel aircraft stands, and can other aircraft be refuelled on adjacent aircraft stands, and what implications (if any) does this have on airport operations?**
- **Are there any differences in these considerations for LH2 or GH2?**

Fuelling Safety zone

Fuelling safety zone needs to take into consideration different aircraft concepts and be flexible to adapt to progressively shortening safety distances

- **The different H2 aircraft concepts** will influence the refuelling point and the location of the consequent safety exclusion zone.
- **Fuel handling procedures to enable** the refuelling companies to meet the refuelling standards and safety zones. It is noted that these could change over time as technology and understanding of the risks improve.
- **Operational procedures** like refuelling with passengers on board or engine running will require dedicated acceptable means of compliance (AMC)

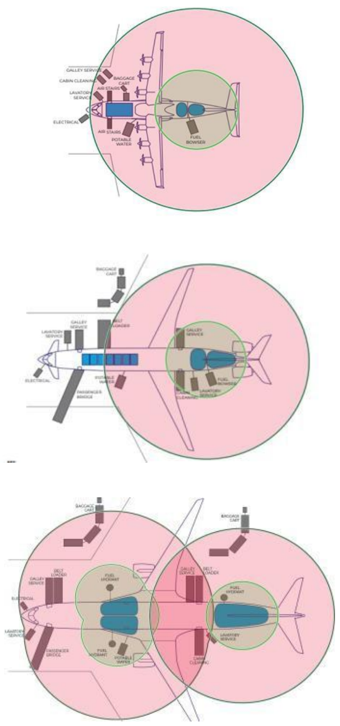
Suggested improvement

- Required fuelling **Safety zone around LH2 refuelling activity and equipment.** The safety zone around refuelling for LH2 is under industry consideration
- **LH2 boil-off or LH2 leakage management** should be considered in the refuelling system design
- The **refuelling point** which will be the reference for this distance **will also change** (tail or nose refuelling, instead of under-wing).

Further Considerations

- **Safety perimeter** from refuelling point/facilities will depend on refuelling location, (tail or nose refuelling, instead of under-wing)
- **Safety zones** around refuelling trucks **to be determined**

- Safety distances **may be adjusted or decrease** as new data providing confidence in technology, enabling parallel activities
- **Regulation and H&S measures implications**



Exemplary illustration of Regional, narrowbody and midsize aircraft concepts fuel safety zones

Source: SEA Milan company data, Arthur D. Little analysis, FlyZero - Hydrogen Infrastructure and Operations, Clean Sky2, ACI-ATI Hydrogen report

H2 Operational Issues at Airports

Stand configuration design

Intro: The size (might be bulkier or longer) and parking location for both GH2 and LH2 refuellers and the impact on turnaround activities needs to be considered. Further considerations should include refuelling points for various aircraft designs as well as further space requirements.

Open issues:

- **How much H2-powered aircraft traffic can we expect from future forecasts?**
- **What challenges will this demand create for aircraft apron areas due to hydrogen refuelling?**
- **Are longer gates than the current ones required for new airframe designs in order to keep the operations safe and practical?**
- **Would longer stands impact the airport traffic capacity?**
- **Would longer stands impact the planned airport future design?**
- **Are changes required to integrate on-ground operations with GH2/LH2?**

H2 Operational Issues at Airports

Dedicated areas/Remote stands

Intro: Will the advent of hydrogen in airports require dedicated aircraft parking areas?

Open issues:

- **How much traffic can we expect from future forecasts? Is there a real risk of saturating apron areas due to hydrogen refuelling? How to design multi-modal refuelling airports? Are stands designed and allocated based on fleet mix or energy mix?**

Aircraft Refuelling with passengers on board

Intro: The refuelling with passengers on board involves specific procedures (emergency exit, presence of pax stairs, VVF etc.)

Open issues:

- **What are the risks and challenges that must be considered for refuelling with pax on board with different fuels? How should this risk be suitably assessed, and what mitigations are available that are suitable?**
- **Will there be an initial testing phase once the risks are addressed /mitigated suitably?**

Stand configuration/allocation

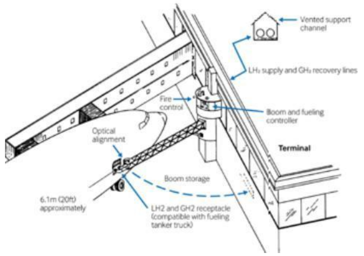
Stand configuration will also need to take into consideration updated aircraft designs, modified refuelling processes, gates compatibility and the increased traffic from fuel trucks of varying types

NOT EXHAUSTIVE

- It is proposed to implement the factsheet with some further considerations
- The future challenge will be addressing a stand configuration which will need to be flexible and accommodate different aircraft designs including LH2 powered aircraft (in the long-term) as well as standard aircraft which will use JET A1 and Sustainable Aviation Fuels
- Congestion around the stand, especially for larger airports, will be increased due to the presence of LH2 refuelling trucks that can impact regular operations.
- Some consideration should be needed to switch to LH2 pipeline refuelling in the medium-long term as technology develops

Suggested improvement

- Consider **minimal infrastructure updates** to accommodate **short-range aircraft designs**
- **Medium-range and long-range** LH2 aircraft of the new design may require additional length to allow larger fuel volumes or new internal configurations. Fuel tanks may be allocated both at the back and front of the aircraft
- **Refuelling by trucks**: due to low LH2 volumetric density, it is possible that more or larger trucks would be required to transport the same amount of energy.
- **Refuelling by pipeline**: concept design to directly connect the **pipeline to the loading bridge**



Modification to Pax LB (NASA concept)

Further Considerations

- Consider the need for **sizable terminal and stand infrastructure investments** to accommodate longer aircraft.
- Longer aircraft may lead to **constraints on aircraft gate assignments**, which may increase turnaround times designs and reduce overall infrastructure flexibility
- **Gate compatibility and constraints** to be addressed to accommodate larger aircraft
- Larger or **more trucks may increase** traffic at the ramp and could cause congestion. As technology evolves, consider **autonomous vehicles for refuelling** (robotic handling of refuelling pipes) to speed up fuel transfer for larger aircraft and reduce ramp traffic
- **Modification to LB** would imply a more intrusive modification

Constrained ACT stand

Source: SEA Milan company data, Arthur D. Little analysis, FlyZero - Hydrogen Infrastructure and Operations, Clean Sky2, ACI-ATI Hydrogen report

H2 Operational Issues at Airports

Weight and balance limitations and different turnaround milestones (A-CDM)

Intro: Is the likely design of new clean sheet H2 powered aircraft expected to impact turnaround procedures and timing? Considering baggage/cargo loading and unloading procedures, rear tanks may severely affect the current way to proceed (ambulant docking, turnaround milestones within airport systems of coordinated airports, and loads computation and loading sequence).

Open issues:

- **Does the expected location of H2 fuel tanks impact the sequence and timing of operations compared to existing aircraft designs powered by JETfuel?**
- **Will the use of LH2 as a fuel necessitate changes in the regulations governing the transportation of dangerous goods in aircraft cargo holds?**

Weight and balance limitations

Different aircraft concepts and fuel tanks position will impact the ground handling operations

NOT EXHAUSTIVE

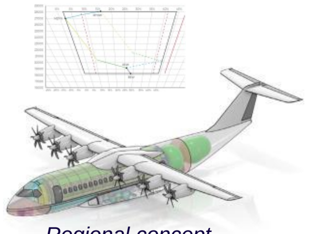
- The different LH2 aircraft concepts seen until now brings implications for loading, unloading and refuelling procedures
- Different weights and balances as well as the centre of gravity for each concept means **different handling procedures** to be applied
- **Each aircraft concept** due to its specific fuel tank design **will need a specific procedure**, and this shall be **adapted** to allow for concurrent operations at nearby stands

Suggested improvement

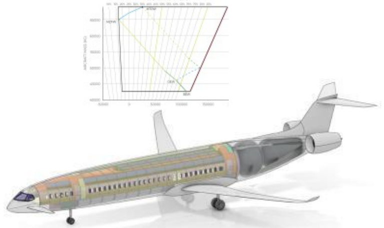
- Passenger and cargo loading/unloading and certain aspects of refuelling **procedures** need to be adapted to different aircraft concepts
- Different aircraft concepts imply **different weights and balances** of the aircraft during refuelling and loading/unloading procedures
- **Regional aircraft** should follow the loading scenario: Fuel⇨ Passengers ⇨ Cargo
- **Narrowbody aircraft** should follow the loading scenario: Fuel⇨ Passengers ⇨ Cargo
  - **Midsize aircraft** should follow the loading scenario: Fuel (fwd. tanks) ⇨ Fuel (aft tanks) ⇨Cargo (fwd. hold) ⇨Cargo (aft hold) ⇨Passengers

Further Considerations

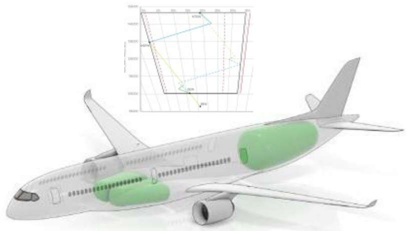
- **Avoid tipping** due to positioning of the fuel tanks (aft) by monitoring the Centre of Gravity
- For **narrowbody aircraft** loading of Pax and Cargo needs to happen from **forward to aft** to avoid tipping
- Consider **additional procedures** for **short-range hybrid** (fuel cells+H2) aircraft with fuel tanks positioned inside the wings.



Regional concept



Narrowbody concept



Midsize concept

Source: SEA Milan company data, Arthur D. Little analysis, FlyZero - Hydrogen Infrastructure and Operations, Clean Sky2, ACI-ATI Hydrogen report

H2 Operational Issues at Airports

Firefighting and rescue and emergency

Intro: Wider flammability limits 4% - 75%. Hydrogen is known to have properties different from JET A1, and these will impact emergency procedures and firefighters' operations. These include:

- Much higher dispersion rates in gaseous form
- Lower ignition energy
- Lower radiant heat
- Slower flame speed
- Cryogenic temperatures for LH2 and higher pressures for GH2

Time should be allocated to identify and develop safety procedures appropriate for both GH2 and LH2.

Open issues:

- **What firefighting procedures and equipment must vary for the specific fuel?**
- **In the event of a fire or incident involving a landing aircraft, firefighters will need to adjust their equipment and procedures according to the specific type of fuel the aircraft is carrying**

Firefighting, rescue and emergency

The properties of H_2 (GH2 or LH2) must be carefully considered to avoid leaks and spills. Dedicated procedures must be followed in case of accidental H_2 hose pullouts.

NOT EXHAUSTIVE

- **Firefighting procedures** need to consider the different properties of H2 versus other fuels
- **Leak management** becomes crucial, especially in transport and refuelling
- **Spillage** of H2 during refuelling could potentially become ignited
- Emergency procedures to be also implemented in case of H2 hose accidental pull out and **H2 leakage mix with other hazardous materials**

Suggested improvement

A considerably weaker spark is required **to ignite hydrogen** than to ignite other flammable hydrocarbon gases. H2 has a wider flammability limit than existing fuels, creating a wider envelope of risk. This is mitigated by the high dispersion rates. For this reason:

- **unprotected flames and sparks** should be **kept away** from any hydrogen handling infrastructure, vessel or vehicle
- Special attention to **avoiding any leakages,** especially in places where the hydrogen can be constrained and not allowed to evaporate and/or diffuse quickly

Further Considerations

- Consider hydrogen standards and leak management procedures in the wider industry and how these can be adapted to airports
- Consider cases that might occur during refuelling operations, where there could be a **spillage of LH2** which is not immediately ignited– resulting in dispersion of a flammable hydrogen gas cloud which could **subsequently become ignited**, resulting in an explosion or flash fire
- Consider **emergency procedures** and equipment in **case of H2 flexible hose pullout** and H2 leakage including mixing with hazardous and other materials.
- Consider concrete pavement on parking stand spots that are at risk of spillage, resulting in asphalt impacts due to LH2 (this aligns with NFPA2).

Source: **Corpo Nazionale dei Vigili del Fuoco**

Source: SEA Milan company data, Arthur D. Little analysis, FlyZero - Hydrogen Infrastructure and Operations, Clean Sky2, ACI-ATI Hydrogen report

Hybrid / Electric Operational Issues at Airports

Dedicated areas/Remote stands

Intro: Charging infrastructure will need to be installed both at the remote stands and at the most frequently used stands near the terminal.

Trolleys with battery power banks should only be used as backups for use when the nominal parking stands are not used.

Source: **Paul Brinkmann/ Aerospace America**

Open issues:

- **Will it be possible to dedicate stands for use by hybrid-electric A/Cs?**

Battery charging and refuelling of SAF/JETA1 with pax on board

Intro: The battery charging & SAF/JETA1 refuelling with passengers on board involves specific procedures (emergency exit, presence of passenger stairs, VVF, etc.). Due to the procedures with the new refuelling method, it is presumed that there is an initial testing phase. Will it be allowed to charge the batteries, refuel and disembark/ embark pax simultaneously?

Open issues:

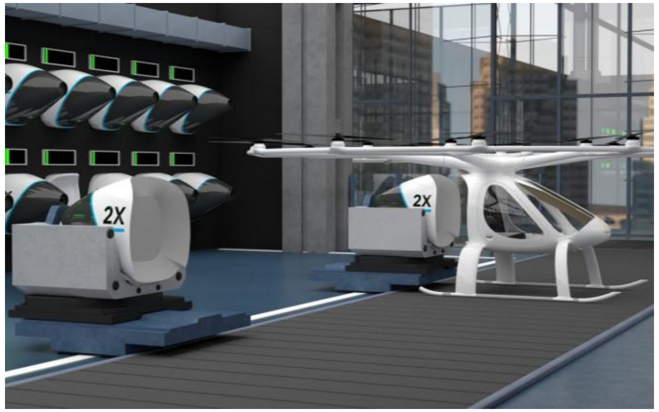
- **Acceptability of simultaneous activities (same question for H2): Battery charging, refuelling and PAX disembarking/ embarking at the same time?**

Hybrid / Electric Operational Issues at Airports

Thermal/Climate condition

Intro: Battery temperature management during extended ground stay/extreme cold operations.

Trolleys with battery power banks should only be used as backups for use when the nominal parking stands are not used.



Source: **Volocopter**

Open issues:

- **Aircraft equipped with batteries must be charged overnight, or batteries kept at an acceptable (TBC) temperature during extended ground stays.**

Weight and balance limitations and different turnaround milestones (A-CDM)

Intro: Battery-powered aircraft or hybrid/electric aircraft will have a heavier landing weight than conventional current aircraft.

Open issues:

- **Runways need to be fully able to withstand aircraft operating with the same take-off and landing weight.**

Hybrid / Electric Operational Issues at Airports

Firefighting and rescue and emergency

Intro: Battery thermal runaway issues are known to have highly flammable properties, which could drastically affect current procedures and firefighters' operations.

<u>Open issues</u>:

- **Can the current response time, procedures, techniques, firefighters' category, and airport patterns and configuration ensure the same level of safety with this new technology?**
- **Is there a need to develop new extinguishing technologies?**

Source: **Fire and Emergency Services Training Institute**

Electric A/C Operational Issues at Airports

Storage area's security risk

Intro: Airport storage areas for big battery packs for A/C charging.

<u>Open issues</u>:

- **The storage areas for the storage/ parking & charging areas for the large battery packs to be used for electric and hybrid electric aircraft charging will need to be designed with consideration for fire risk.**

Source: **Airbus**

The Alliance is a voluntary initiative of private and public partners who share the objective of preparing the entry into commercial service of hydrogen-powered and electric aircraft.

The aim is to bring the actors from across the ecosystem together and start planning for the rollout of these aircraft. The involvement of smaller industry players and start-ups working on climate-neutral air transport solutions will be especially welcome.

AZEA website

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European Commission

Alliance for
Zero-Emission Aviation

PREPARING EUROPE FOR
HYDROGEN & ELECTRIC
FLIGHT

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