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Hydrogen as a catalyst for decarbonisation

Contents

Executive Summary

Maximising the aviation sector's contribution to achieving net zero carbon emissions through hydrogen as an aviation fuel

Airports worldwide continue to make significant progress in reducing their carbon emissions, but without decarbonising aircraft, overall reductions from the aviation sector will be limited. Meanwhile, the aerospace industry is working hard to decarbonise aircraft through the design and development of new methods of propulsion. While rapid progress continues in the development of sustainable aviation fuel (SAF) and battery-electric propulsion, hydrogen is being explored as a potential zero-carbon emission fuel.

Hydrogen has been identified as a fuel that can enable commercial aircraft to operate with zero carbon dioxide (CO2) emissions. However, the future of widespread use of zero CO2-emission aircraft is more than a decade away and will require airports to make significant capital investment in hydrogen storage and refuelling infrastructure.

In the meantime, Jacobs has identified the following recommendations for airport owners and operators that build on the UK Aerospace Technology Institute FlyZero report **"Airports, Airlines, Airspace - Operations and Hydrogen Infrastructure":**

- Airport owners and operators should consider using hydrogen in on-ground applications as part of their strategy to decarbonise their Scope 1 emissions in the short- term
- Investing in hydrogen delivery, storage and refuelling infrastructure for some applications will enable airports to become comfortable with using hydrogen, particularly in relation to managing operations
- Undertaking early adoption of hydrogen will create momentum to implement the significant infrastructure that will be needed to support the operation of hydrogen fuelled aircraft
- Ensuring this early adoption of hydrogen involves the creation of an integrated hydrogen ecosystem around an airport that uses hydrogen to decarbonise public transport, logistics, cooling and heating
- An airport can become the catalyst for decarbonisation in its surrounding region by forming partnerships across various regional actors: government, airlines, hydrogen companies, local and national transport providers, and local businesses
- The private sector will be encouraged to make the significant investment in the infrastructure required for hydrogen, knowing there will be a positive return on investment based on short-term and forecast demand.

Introduction

The aviation sector is a major contributor to global greenhouse gas (GHG) emissions. If the current rate of growth continues unchecked, the International Civil Aviation Organisation (ICAO) predictions show a tripling in CO_2 emissions by 2050[1]. While other sectors are investing heavily in reducing their emissions, aviation seems to be falling behind, meaning that it risks being left behind in the race to net zero.

1 Commonwealth Scientific and Industrial Research Organisation (CSIRO) – Opportunities for hydrogen in commercial aviation

Emission Scopes

Airports, as the origin and destination point of aircraft, are a key focus when considering how the aviation sector can decarbonise. GHG emissions, including those associated with airports, can be categorised into three scopes:

- **Scope 1 emissions** are generated from a source owned and controlled by the airport, e.g., the consumption of gas, diesel, and refrigerants. It is estimated that an airport's scope 1 emissions account for 5% of their total emissions[2].
- **Scope 2 emissions** relate to the emissions generated in the production of purchased or acquired electricity, steam, heat, and cooling.
- **Scope 3 emissions** relate to the emissions generated from use of the airport's facilities by other parties, particularly the emissions from the aircraft that depart from or arrive at the airport and the emissions generated by ground travel into and out of the airport[3].

In the context of airports their scope 3 emissions are the most significant, with, for example, around 80% of global aviation sector emissions coming from flights longer than 1,500km[4].

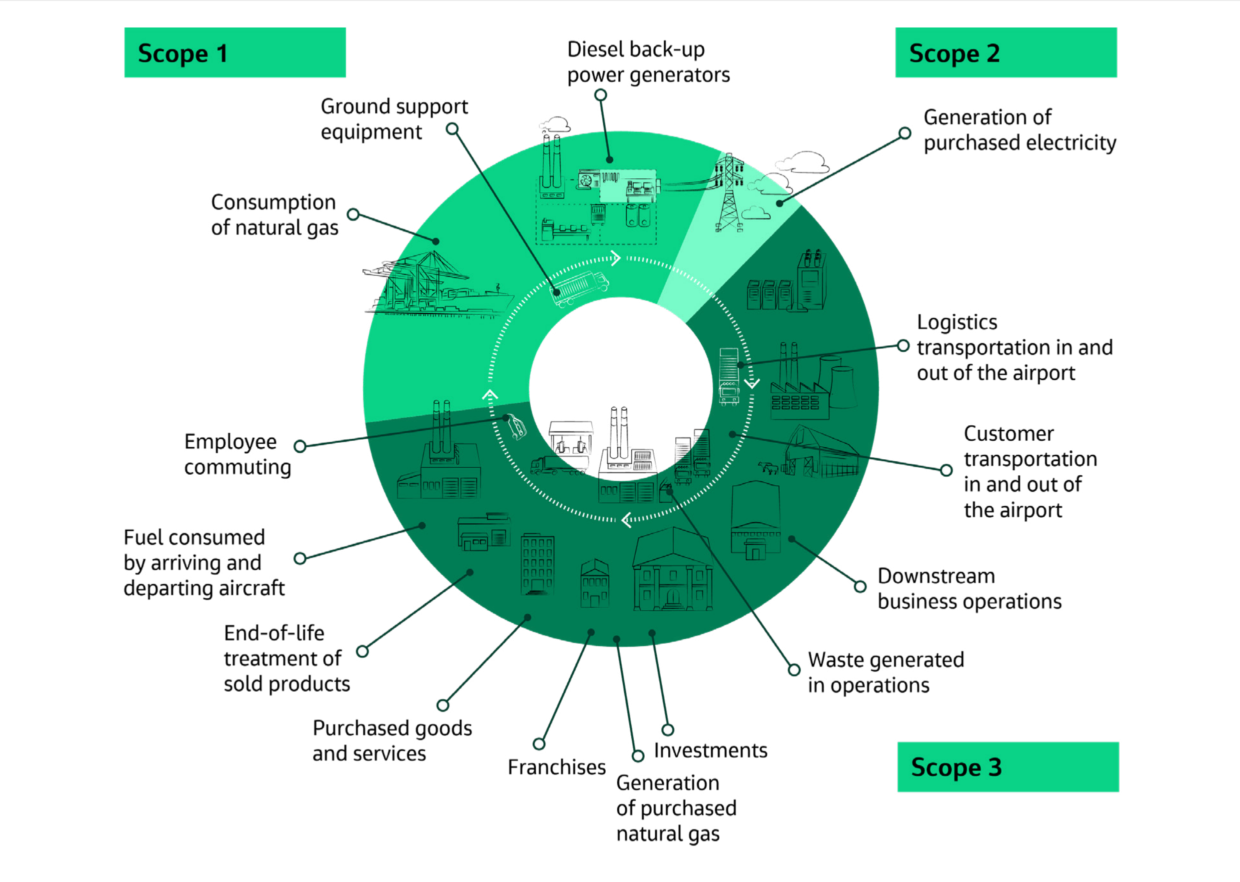


Figure 1: Examples of Scope 1, 2 and 3 emissions related to an airport (for illustration purposes only)

2 European environmental agency (greenhouse gas inventory 2018)
3 Greenhouse Gas Protocol: Scope Guidance
4 Air Transport Action Ground, Facts and Figures

Airport Climate Action Plans

The bias of emission generation towards scope 3 highlights the interconnectivity of airports within a system and shows that they cannot achieve the aims of net zero alone. Climate Action Plans published by airports including Brisbane, Heathrow, San Francisco, Munich, Budapest and Vancouver identify the need to integrate Scope 3 emissions sources into the airport's carbon solutions. The trend seen by Jacobs shows recognition that multiple entities have influence over the environmental impact of airports with key actions for reducing emissions both "in the air" and "on the ground"[5].

The journey towards zero-carbon flight is being approached in three stages; 1. the optimisation of current technology e.g., new conventional aircraft; 2. the adoption of new, but available, technologies, for example Sustainable Aviation Fuel (SAF); e.g., change the fuel, and 3. the long-term development of innovative technologies; e.g., changing the aircraft[6].

With the long term-goal of aviation being the implementation of innovative technologies as a means of overcoming current emission levels, research into these innovations has identified hydrogen as a fuel for the future. When used in a fuel cell or a jet engine, it creates zero carbon dioxide emissions and if produced using renewable energy through the process of electrolysis ("green hydrogen"), then the end-to-end system (well to wheel) is zero emissions.

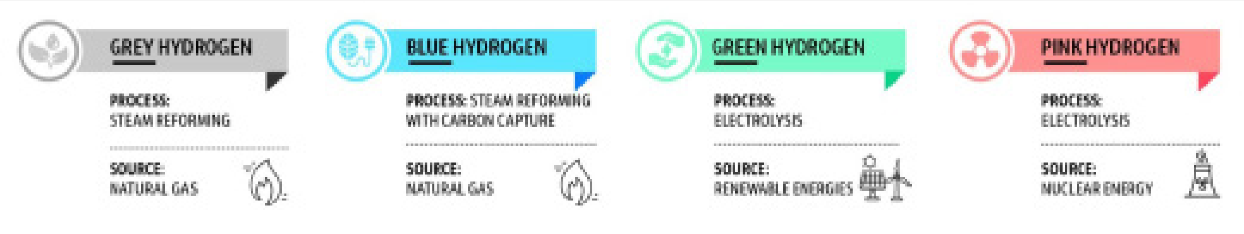
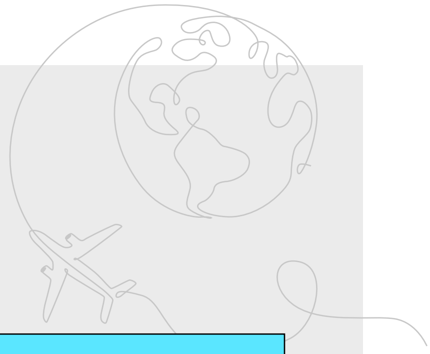


Figure 2: Types of hydrogen

The move towards zero emission flight is a long-term goal with the development of technology and concept aircraftalready taking place. Manufacturer Airbus is expectingto "achieve a mature technology readiness level for a hydrogen-combustion propulsion system by 2025"[7] and has identified this fuel as potentially providing a net-zero commercial aircraft solution by 2035[8]. It is estimated that the use of hydrogen propulsion could reduce the climate impact of flights by 50 to 75 percent[9]. With the steady reduction in the cost of renewable energy sources and the rapid performance improvements of hydrogen production technologies, hydrogen is likely to become a competitively priced and accessible fuel[10]. As part of the technology of hydrogen powered aircraft the storage of liquidhydrogen on an aircraft will be preferred to hydrogen gas due to its superior energy density and lighter tanks[11].
(See box on next page).

5 Heathrow's Net Zero Plan, February 2022
6 Heathrow's Net Zero Plan, February 2022
7 Information from Airbus Zero website page on March 22, 2022
8 Information from Airbus Zero website page on March 22, 2022
9 Information from hydrogen-power aviation: A fact-based study of hydrogen technology, economics, and climate impact by 2050. Report undertaken by McKinsey & Company for the Clean Sky 2 JU and Fuel Cells and hydrogen 2 JU (hereafter the Joint Undertakings).
10 Commonwealth Scientific and Industrial Organisation (CSIRO) – Opportunities for hydrogen in commercial aviation
11 Airbus - How to Store Liquid Hydrogen for Zero-Emission Flight - Hydrogen Central



Benefits of liquid hydrogen vs. gaseous hydrogen:

- Liquid hydrogen's energy density is 43% greater than hydrogen gas compressed to 700 bar
- The weight of liquid hydrogen storage tanks are significantly less than 700 bar storage tanks

  Mass of hydrogen as a percentage of the mass of hydrogen + tank:

  ✓ Liquid hydrogen = 30%

  ✓ Compressed gas = 10%

Challenges of using liquid hydrogen:

- Hydrogen becomes a liquid a -253°C
- Handling liquid hydrogen has safety risks relating to cryogenic burns to people and leakage from pipes and valves
- It must be carefully handled during refuelling operations with an exclusion zone to prevent close by human activity during the refuelling process
- Storage and distribution by truck requires special double walled highly insulated tanks to minimise the rate the liquid hydrogen "boils-off" back to a gas
- Distribution by pipeline will be limited to distances within an airport

If liquefaction of hydrogen gas takes place at an airport, additional land and power will be required.

While the need for energy transition is often highlighted as being vital for "in air" emission reductions, the importance of energy transition solutions across all aviation related scope generators, including those on the ground should not be underestimated. Many of the published airport climate action plans have actions that focus on ground-based technologies, such as switching from natural gas and diesel vehicles, with forward-thinking airports and ground handlers already shifting towards the use of electric ground handling vehicles in a bid to tackle their carbon impact. Despite these meaningful improvements to in air and on the ground emissions, there is further opportunity to link-up a system-wide strategy.

Hydrogen Implementation

Jacobs suggests that an interconnected approach to aviation energy transition provides the solution for achieving long term in air objectives, while enabling wider reductions to on the ground emission generation. As hydrogen can be used to support a range of energy demands such as heating, cooling, electrical systems and mobility propulsion systems e.g. cars, buses, baggage handling systems (BHS), freight, trucks, trains, its versatility offers the opportunity to integrate aviation's climate goals.

As part of Jacobs' work on the Aerospace Technology Institute's (ATI) FlyZero project, ATI specified three potential airport infrastructure scenarios for the supply and storage of hydrogen for use in fuelling hydrogen powered aircraft:

- Scenario 1 - the delivery of liquid hydrogen directly to the airport by truck
- Scenario 2 - the use of a hydrogen gas pipeline with on-site liquefaction
- Scenario 3 - the use of electrolysis for hydrogen production on site at the airport.

As has been published in the ATI's report[12], Scenario 1 is identified to be the initial starting point for all airports, with the transition to Scenario 2 being undertaken by medium and large airports as hydrogen demand increases.

Larger airports such as Sydney, Melbourne and Brisbane will need to transition to a gas pipeline supply with on-site liquefaction, relatively quickly after the start of operation of large hydrogen aircraft. Without a gas pipeline their supply of hydrogen by truck could be disrupted by traffic congestion outside the airport and at the point of off-loading within the airport.

Due to the length of time that it takes to plan, design, consult, and implement new airport infrastructure, airport owners and operators will need to make provision for the delivery and storage of hydrogen long before the start of demand for aircraft refuelling in the early to mid- 2030s. This is a relatively close mid-term milestone and presents an immediate opportunity for hydrogen to become the catalyst for the decarbonisation of an airport's Scope 1, Scope 2 and ground-based Scope 3 emissions.

12 FlyZero Reports Archive - Aerospace Technology Institute Aerospace Technology Institute (ati.org.uk): Airports, Airlines, Airspace - Operations and hydrogen Infrastructure

Hydrogen Applications and Infrastructure

Hydrogen has the potential to significantly contribute to the decarbonisation of sectors of our economies that can be classified as “hard-to-abate”. These are areas where battery technologies are unable to meet the performance requirements or where it would be too expensive to replace an existing gas distribution system with an electrical system.

In the context of an airport and its adjacencies, Table 1 represents the types of hydrogen applications that could be implemented in short- to medium-terms, i.e., from now to the next ten years.

Table 1: Types of hydrogen applications that could be implemented in short- to medium-terms

Hydrogen Application	Possible Required Infrastructure
▪ Hydrogen fuel cell powered on airport ground support ▪ Hydrogen fuel cell powered on airport buses and other vehicles	▪ On-airport hydrogen gas storage tanks ▪ Delivery of hydrogen gas by truck ▪ On-airport hydrogen refuelling station ▪ On-airport maintenance facility for fuel cell systems
▪ Hydrogen fuel cell powered logistics trucks operating from adjacent businesses ▪ Public transport buses to and from the airport	▪ Off-airport hydrogen gas storage tanks ▪ Delivery of hydrogen gas by truck ▪ Off-airport hydrogen refuelling station ▪ Off-airport maintenance facility for fuel cell systems
▪ Fuel cell back-up power systems for terminals and safety critical equipment	▪ Fuel cell – battery back-up power package ▪ Hydrogen gas storage tanks
▪ Hydrogen blend in the natural gas distribution grid for heating and cooking applications in on-airport buildings	▪ Hydrogen injection into the regional gas distribution pipe network (max 20% blend)
▪ 100% hydrogen gas for heating and cooking applications in on-airport and off-airport buildings	▪ New gas transmission/distribution pipe network ▪ Modifications to existing heating and cooking ▪ equipment

Hydrogen Roadmap

By starting to use hydrogen in the short-term, and therefore implementing the required supporting infrastructure that is shown above, an incremental roadmap can be adopted that will prepare an airport and its stakeholders for the commencement of hydrogen powered commercial flights later.

Figure 3 shows a possible roadmap for hydrogen utilisation and infrastructure implementation at airports. The graph uses forecast aircraft hydrogen demand data for the UK as we are not aware of equivalent Australian airport estimates. Given the integrated global nature of the aviation sector, the rate of increase in hydrogen demand is likely to be similar for Australia, even though adoption might be a few years later.

The roadmap displays three key messages set along a common timeline. The top line graph shows forecast demand for hydrogen required to fuel regional, narrow body and mid-sized aircraft. This denotes a projected boom in demand for hydrogen between 2030 and 2050. Below, the phasing of delivery scenarios is mapped for small, medium, and large airports, with the transition between bowser and hydrant delivery acknowledged for medium and large airports. Then a series of hydrogen applications is presented which can take place additionally to fuelling aircraft for flight and taxi. Finally, the timeline of hydrogen infrastructure implementation based on the demand scenario for aircraft, and this would also support the non-aircraft fuelling opportunities.

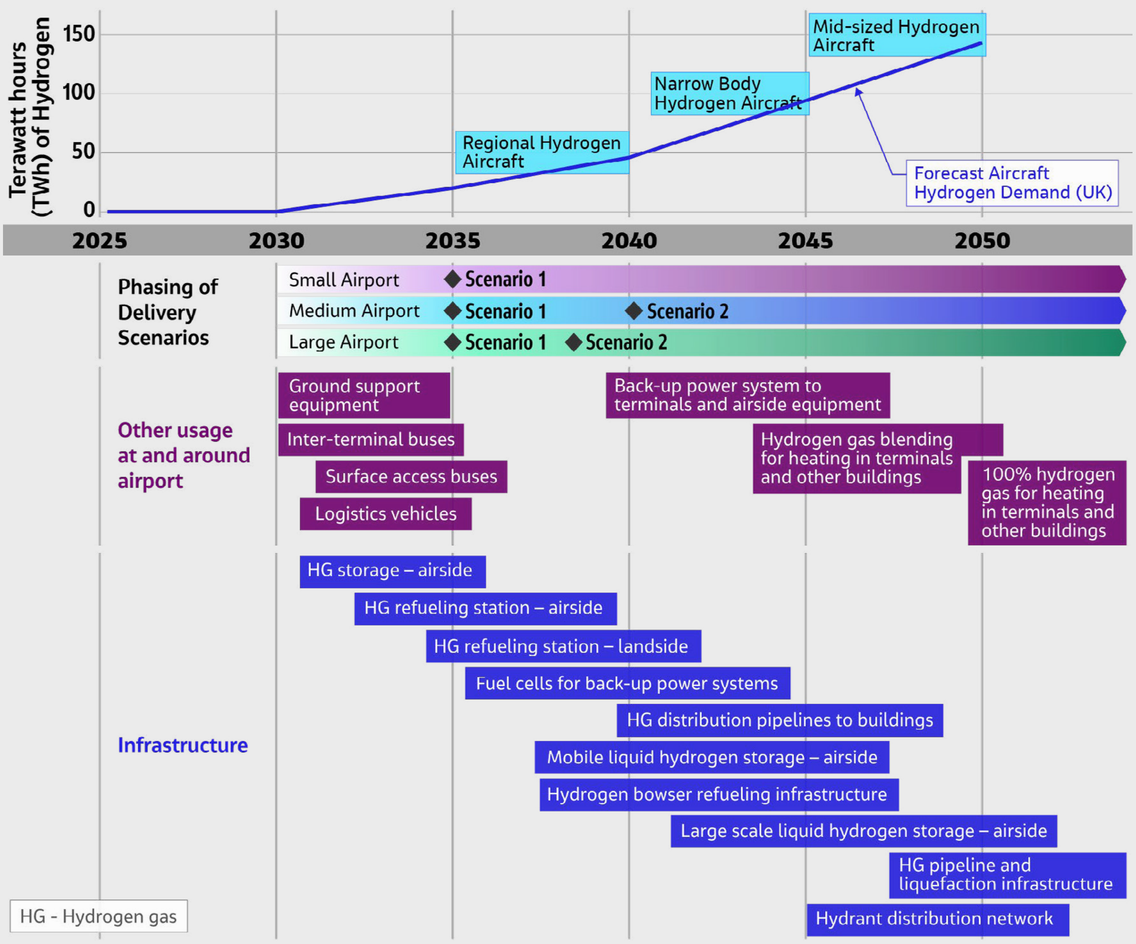


Figure 3: A possible hydrogen implementation roadmap developed by Jacobs

In this way, and through the stages of the roadmap, an airport could become a hub for the distribution of hydrogen to surrounding businesses and transport providers. The adoption of a collaborative partnership between these adjacent stakeholders would encourage all the Scope 3 on the ground emitters to move rapidly along their own decarbonisation journeys, with the adoption of hydrogen heating, ground transportation and operations.

This report identifies the challenges that implementing hydrogen infrastructure is going to pose to airports, with high costs creating the challenge of how to raise sufficient funds. However, there are revenue opportunities in airports developing partnerships with various actors including: governments, airlines, hydrogen companies, local and national transport providers, and local businesses.

The Australian government has already set-out the need to create a holistic approach to the use of hydrogen (see box below). This means the initial capital costs can be distributed across a wide range of hydrogen users with the effect that the unit cost of hydrogen will be lower than if each individual user tried to go their own way, reducing the first mover disadvantage, whereby the initial developer of an innovative system pays a premium that later adopters can avoid.

> "A key element of Australia's approach will be to create hydrogen hubs – clusters of large-scale demand. These may be at ports, in cities, or in regional or remote areas, and will provide the industry with its springboard to scale. Hubs will make the development of infrastructure more cost-effective, promote efficiencies from economies of scale, foster innovation, and promote synergies from sector coupling. These will be complemented and enhanced by other early steps to use hydrogen in transport, industry and gas distribution networks, and integrate hydrogen technologies into our electricity systems in a way that enhances reliability."
> Australia's National Hydrogen Strategy (2019)

The associated costs will vary significantly depending on the infrastructure scenario selected and as discussed this will likely transition over time. Therefore, the initial investment based on the Scenario 1 approach will be a lower cost than capital intensive hydrogen pipelines or electrolysis and can potentially be based directly on airport vehicles as the main driver for an anchor demand thus reducing uncertainty. As pressure continues to grow from consumers for businesses to demonstrate that they are achieving emission reduction and wider sustainability targets, an expanding hydrogen network will create further economies of scale as more actors invest in the infrastructure.

Not only can the airports, and the actors within a partnership, offset some of the hydrogen infrastructure's capital expenditure by sharing it across a hydrogen network, but this approach will also create opportunities for the private sector to act as a funding partner. Jacobs initial assessment indicates that the use of hydrogen as an aviation fuel has the potential to represent an attractive opportunity for private investors to fund the required infrastructure. In consideration of this as a medium to long term opportunity it seems to make sense that airports could engage with private investors in the short term to start the pathway to build out hydrogen infrastructure through investment in early implementation schemes.

While there remain challenges to enable the wide scale use of hydrogen at airports, which include the availability of sufficient green hydrogen and finding space for significant amounts of hydrogen storage, the benefits that could be realised by early implementation of hydrogen are significant.

The UK government is targeting 2 GW of low carbon hydrogen production capacity to be in the pipeline by 2025 and a revised and increased ambition for 10 GW by 2030[13], the expectation is that the availability of green hydrogen will increase quickly to facilitate the methods outlined in Scenarios 1 and 2. Although for Scenario 2, the construction of pipelines would either require hydrogen production to be located nearby or for there to be existing pipelines to connect into. Other challenges include:

Challenge	Description
Airport master planning	Hydrogen infrastructure at airports, particularly storage and liquefaction will require substantial dedicated areas of land that are located away from passenger terminals and close to hydrogen delivery routes. Identifying a single location at large airports may not be possible, requiring the facilities to be split across multiple locations. Splitting the facilities will create challenges integrating the needs of the hydrogen infrastructure into an airport's masterplan. Prioritising the masterplanning of infrastructure required to integrate hydrogen within airports is required to manage costs.
Forecasting infrastructure size	The implementation of hydrogen infrastructure should follow a roadmap that mirrors the roll-out of hydrogen powered aircraft. However, the infrastructure will need to be planned and constructed in advance of aircraft coming into service, generating risks of infrastructure being completed too early or too late.
Availability of sufficient production of green hydrogen	The supply of hydrogen to the aviation sector will be a major contributor to the overall production of green hydrogen in a region. This production will need to be planned as part of an overall integrated hydrogen hub that has sufficient capacity to meet the demands of multiple off-takers without creating competition for supply which would drive high and unsustainable prices.
Delivery of hydrogen to airports	A hydrogen production hub will most likely be located multiple kilometers from an airport. The reliable and cost-effective distribution of the hydrogen to the airport will create logistical challenges if it is delivered by road and implementation and cost challenges if delivered by a pipeline.
Infrastructure technical and operational complexity	The hydrogen infrastructure at airports will consist of multiple subsystems (unloading, storage, distribution and refueling) all of which will need to operate seamlessly and reliably on a 24/7 basis. Creating and operating this system will be complex and will require the development of new technologies such as liquid hydrogen hydrant networks.

13 Hydrogen investor roadmap: leading the way to net zero

Challenge	Description
Safety regulations	Although hydrogen storage and distribution systems have been successfully built and operated in industrial settings, the safety management expectations at airports will be considerably greater. Placing greater emphasis on safety testing, standards, compliance and safety control systems. In addition, the fire and rescue services at airports will need additional equipment and specific training to manage hydrogen incidents.
Sources of financing	The private sector are unlikely to finance the costs associated with construction of the hydrogen infrastructure at airports without considerable support from government to insulate developers from the uncertainty of the capital costs and build-up of demand.
High capital costs	Currently the capital costs of elements of a hydrogen infrastructure system such as liquefaction units, storage tanks and pipelines are significantly more expensive than any comparative existing subsystem of a kerosene refuelling network.
Implementation complexity	Elements of the hydrogen infrastructure such as storage tanks and hydrant networks will need to be built alongside existing infrastructure at the airport without impacting airport operations during the construction phase.
Impact on airport and airlines operations	The use of hydrogen infrastructure and the operation of hydrogen fueled aircraft will have a significant impact on airports as they will need to maintain parallel fuel systems until full integration of alternative sustainable fuels is achieved. Airlines will be impacted through extended turn-around times due to more frequent refuelling and passenger safety concerns.

The development of hydrogen partnerships will generate resilience in the agreements to produce hydrogen because demand will not be significantly affected if some businesses fail to adopt hydrogen at the rate that has been planned. Early implementation, ahead of the adoption of hydrogen for aircraft refuelling, will also enable airports to gain experience in using hydrogen in self-controlled applications, and ensure the right infrastructure is in place, by the time demand for hydrogen from airlines commences.

Jacobs recommends that hydrogen infrastructure plans for on the ground applications in the roadmap are aligned with the medium and long-term phasing of infrastructure needed for aircraft refuelling – shown in Table 2, which has been developed using data from ATIs Airports, Airlines, Airspace - Operations and Hydrogen Infrastructure' report.

Airport Size	2035	2040	2045	2050
Large	Liquid Hydrogen Delivered	Gas Pipeline and Liquefication	Gas Pipeline and Liquefication	Gas Pipeline and Liquefication
Medium	Liquid Hydrogen Delivered	Gas Pipeline and Liquefication	Gas Pipeline and Liquefication	Gas Pipeline and Liquefication
Small	Liquid Hydrogen Delivered	Liquid Hydrogen Delivered	Liquid Hydrogen Delivered	Liquid Hydrogen Delivered

Table 2: from ATI report 'Airports, Airlines, Airspace - Operations and Hydrogen Infrastructure':
Likely airport hydrogen delivery scenarios. Source: ATI, 2022, page 17

In the short-term, hydrogen, for use in ground equipment, and other mobility and utility applications, could be delivered by truck, as a liquid[14]. This will support the case for an airport to construct liquid hydrogen storage and gaseous refuelling facilities. The cost of transport fuel in this method would be low in comparison to other scenarios making hydrogen as accessible as possible. This is in line with the view that wider emission reductions, outside of just the aircraft, needs to take place. Within each of the scopes there should also be consideration for reducing the vehicle emissions created by the bowser operation, such as implementation of electric or hydrogen bowser operations.

As hydrogen powered aircraft are introduced and demand for liquid hydrogen as an aircraft fuel increases, the focus will shift towards building large scale liquefaction and storage systems, and hydrant pipe networks for refuelling. By introducing the use of hydrogen at an early stage this transition will be more efficient than if the construction of the hydrogen infrastructure is only focussed on what is needed for aircraft refuelling, making airports, and hydrogen, the catalyst for decarbonisation both on and off the airport.

In summary, hydrogen, as a versatile zero emission fuel, could be the core component around which the decarbonisation of aviation is implemented, by incrementally building the hydrogen supply and distribution of infrastructure from a short-term starting point. To enable this, airport operators and owners need to take the initiative to build partnerships with businesses, and other transport operators in their local areas, to initiate the use of hydrogen in the immediate term.

14 As a liquid hydrogen is required as an aviation fuel because of its greater energy density (MJ/Litre) in comparison to compressed hydrogen gas

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