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MINISTRY OF BUSINESS,
INNOVATION & EMPLOYMENT
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Pilot Hydrogen Hubs for Trialling Advanced Aviation in New Zealand

contents

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Executive Summary

New Zealand has set out goals for achieving net zero GHG (greenhouse gas) emissions (other than biogenic methane) by 2050. In 2019, domestic and international aviation accounted for 6% of New Zealand's total gross GHG emissions.

Whilst this is a relatively small contribution compared to other sectors, if New Zealand is to achieve its net zero goal by 2050, domestic and international aviation emissions must be reduced.

A range of technologies are being developed to decarbonise aviation – hydrogen may play a key role in a number of these technologies. Green hydrogen is seen as one of the most viable zero carbon emission fuel with potential to scale to large aircraft utilising fuel cell, gas turbine and hybrid systems.

Increased momentum for hydrogen hubs at airports is largely coming from Europe, with France, Italy and Germany linking into the Airbus European hydrogen hub network. In addition, other countries like Japan and Korea — often seen as hydrogen pioneers, are investigating hydrogen hubs at airports. Currently, New Zealand has limited supply of green hydrogen. Green gaseous and liquidous hydrogen production will be required to enable the transition to zero emissions aviation.

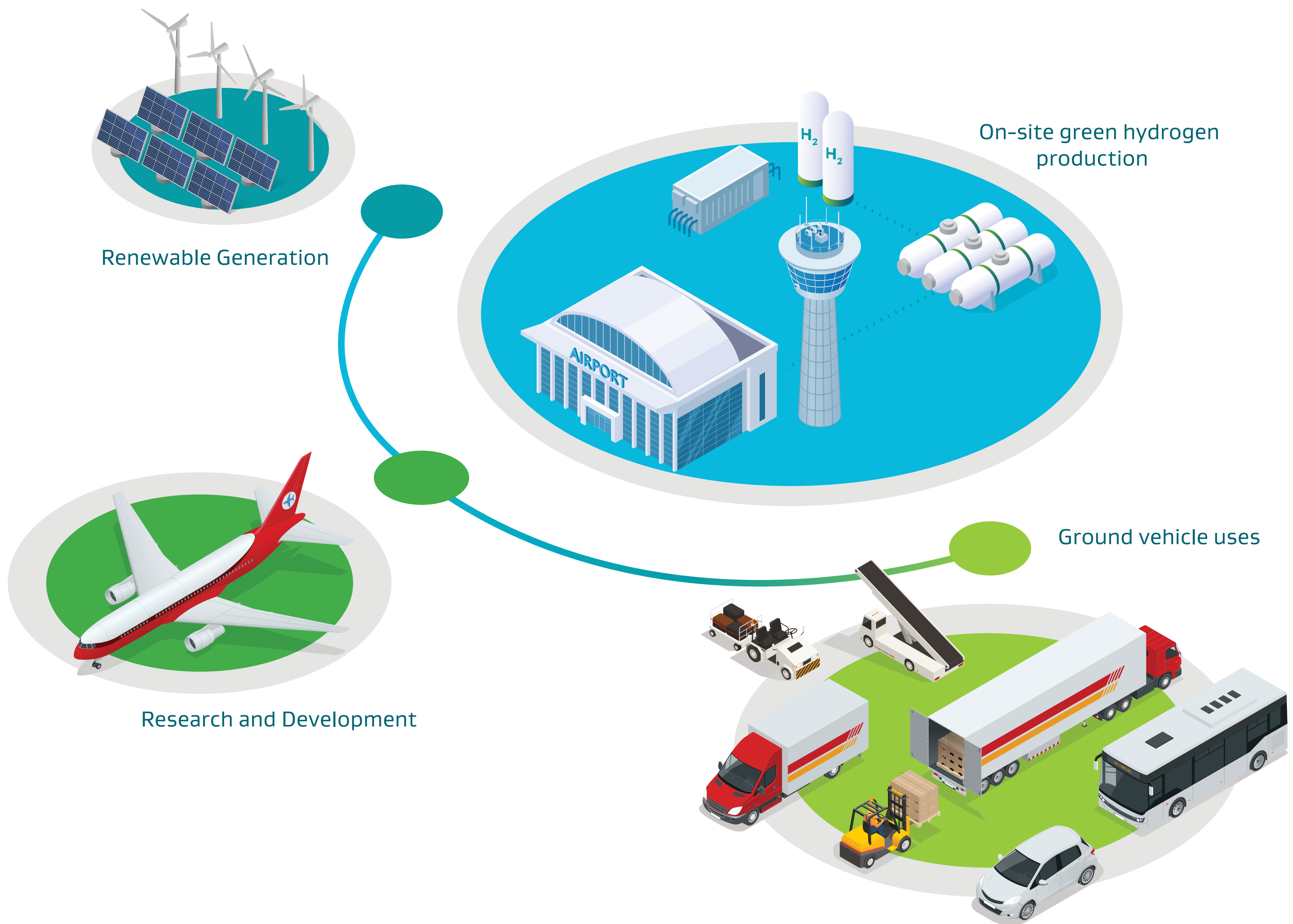
Whilst New Zealand has a number of challenges to overcome, by leveraging it's advantages, New Zealand has a significant decarbonisation opportunity. A pilot green hydrogen hub is expected to provide local, regional, national and global benefits to New Zealand. These benefits include: attracting businesses and research and development; supporting wider social, cultural and economic development and regeneration; collaboration amongst industrial stakeholders and the opportunity to re-shape the role of employment land in cities.

The pilot green hydrogen hub

The pilot hub at a New Zealand airport will be defined as a physically centralised green hydrogen production facility primarily for airport use with capacity to integrate a number of hydrogen-based services whilst connecting with local community and allowing for future phased expansion.

Primary airport uses could include green hydrogen supply to airport vehicles, airport energy demand and future aircraft. The pilot hub will likely provide hydrogen for airport ground vehicles first, until hydrogen technology for air transport is developed.

Pilot H2 Hub



The benefits of co-locating hydrogen production at the airport or near the airport will help trial, test, and develop clean energy technologies for aviation. It will also build a thriving clean energy ecosystem, reshape the role and function of employment land and upskill the local labour force.

Early 2020's	Late 2020's	Mid 2030's
Preliminary studies into airport infrastructure and energy requirements	Ramp up of hydrogen infrastructure deployed worldwide	Widespread commercial use of hydrogen aircraft

Introduction

The purpose of this report is to inform the New Zealand Government of the:

Rationale behind utilising a pilot green hydrogen hub at New Zealand airport(s)

Key elements that could be included within the pilot green hydrogen hub

This report looks to support New Zealand's ambition to be a world leader in the trialling, testing and development of clean energy technologies for aviation, and in the process, build a thriving and innovative clean energy ecosystem in New Zealand.

Ultimately, the goal is to foster an advanced aviation and clean energy ecosystem, attract international R&D investment, and accelerate commercial uptake of new technology in New Zealand and globally.

A pilot green hydrogen hub at an airport provides the ideal testbed to accelerate the aviation industry's transition to hydrogen technologies. With access to green hydrogen the airport stakeholders, local businesses and research bodies would be empowered to undertake research studies, trials or even to purchase hydrogen-based technologies.

Part 1 of this project addresses two fundamental questions critical to this study. Firstly, to identify the benefits of a hydrogen hub and its positioning at an airport.

The Part 1 project scope provides a literature review and rationale for setting up a pilot green hydrogen hub.

Assumptions

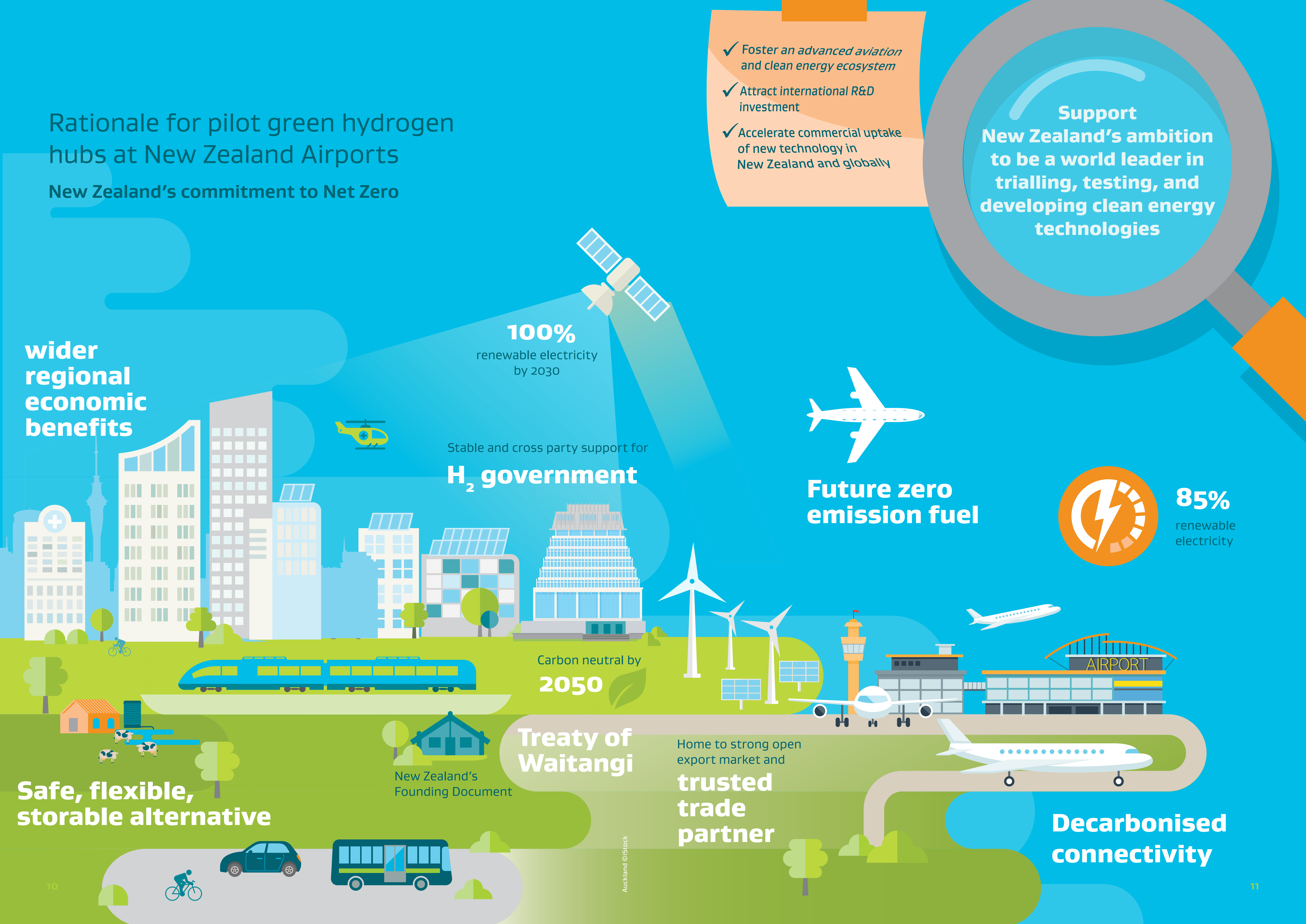
- The pilot hydrogen hub shall produce **green hydrogen** (as defined below, hydrogen produced through renewable methods such as electrolysis with zero carbon electricity)
- The pilot green hydrogen hub shall have **access to 100% renewable electricity**. However, New Zealand's grid should not be a barrier to initial deployment of pilot hydrogen hub as grid is approximately 85% green.
- **No detailed economic modelling** to be provided.
- **No hydrogen storage regulations** have been outlined in New Zealand at time of writing this report.
- **Stakeholder engagement is a critical** part of this project. We anticipate the hydrogen hub will be led by stakeholders with government in a supporting role. Stakeholder engagement will be led by MBIE. MBIE engaged with a range of stakeholders in government and in the hydrogen sector to explore potential interest in this scoping study. The scope of the report has been informed by the stakeholder engagement. Stakeholders mentioned in this report have had the chance to review the report before publication to fact check it and to ensure that no confidential information has been included. Ultimately a hydrogen hub will be led by stakeholders with Government in a supporting role.

Definitions

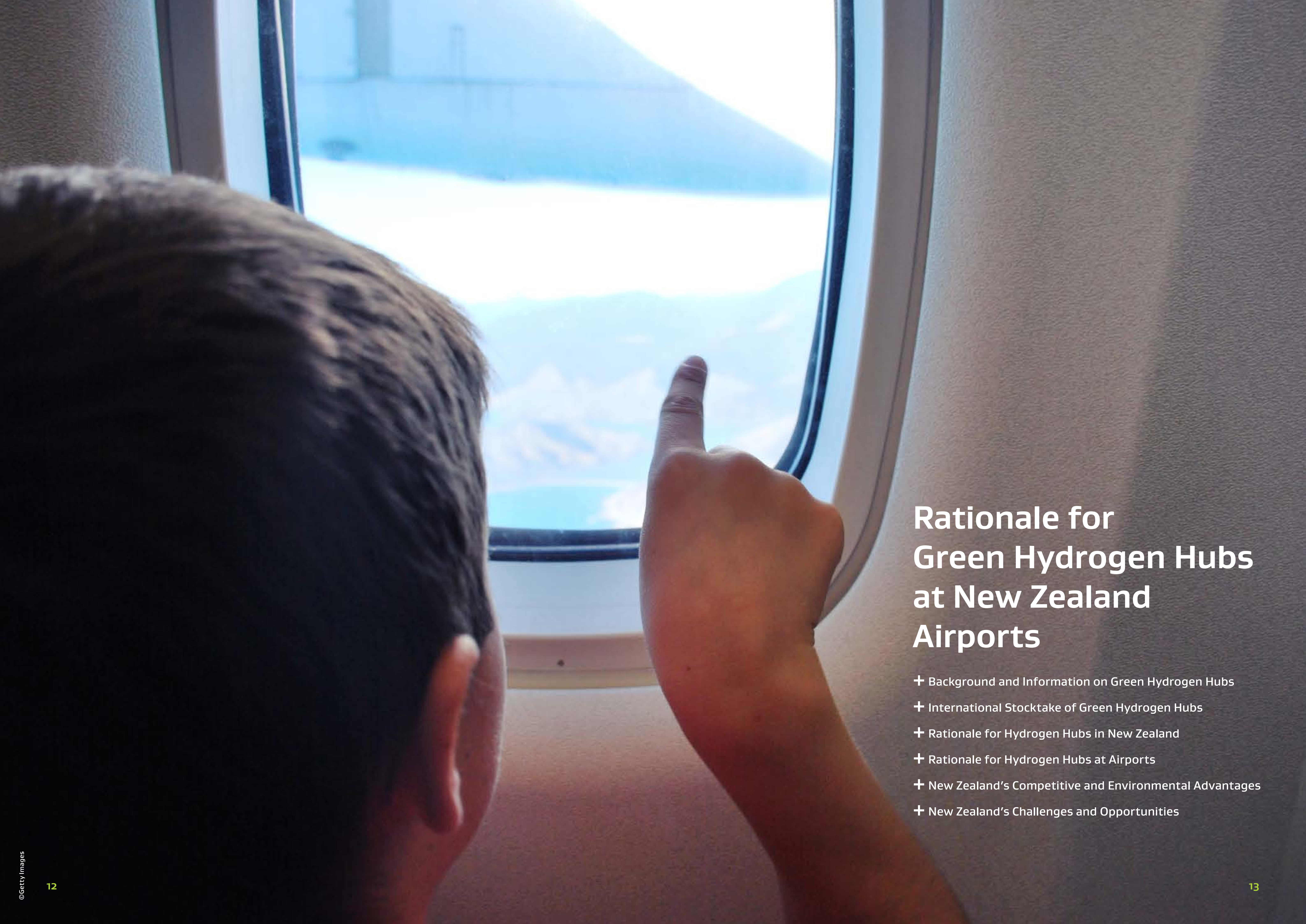
Hydrogen	Hydrogen produced though all process forms (grey, blue, green, etc)
Green Hydrogen	Hydrogen produced through renewable methods such as electrolysis with zero carbon electricity
TRL	Technology Readiness Level
MOU	Memorandum of Understanding
SAF	Sustainable Aviation Fuel
LH2	Liquid Hydrogen
IPCC	International Panel on Climate Change
GHG	Greenhouse Gas
CO_2-e	Carbon Dioxide equivalent emissions
MBIE	Ministry of Business, Innovation and Employment
IEA	International Energy Agency

Rationale for pilot green hydrogen hubs at New Zealand Airports

New Zealand's commitment to Net Zero



Auckland ©iStock



Rationale for Green Hydrogen Hubs at New Zealand Airports

- Background and Information on Green Hydrogen Hubs
- International Stocktake of Green Hydrogen Hubs
- Rationale for Hydrogen Hubs in New Zealand
- Rationale for Hydrogen Hubs at Airports
- New Zealand's Competitive and Environmental Advantages
- New Zealand's Challenges and Opportunities

Rationale for Green Hydrogen Hubs at New Zealand Airports

This section of the report aims to set out the rationale for setting up a pilot hydrogen hub at airport(s) in New Zealand. It includes information on why hydrogen hubs are being considered; stocktake of international hydrogen hubs at airports; the potential benefits to New Zealand and its aviation industry; and New Zealand's advantages, challenges, and opportunities with regards to green hydrogen hubs.

Whilst hydrogen is not the sole option to decarbonise aviation, it will play a part in the wider decarbonisation effort alongside electrification and sustainable aviation fuels.

Background and Information on Green Hydrogen Hubs

Awareness of the effects of fossil fuels on the climate has increased, highlighting the requirement for large scale behavioural changes. This global recognition has sparked a drive to pursue alternate solutions to mitigate and adapt to climate change with the aim of providing a safer, more sustainable and resilient future.

Nations around the world have declared climate emergencies. In the recent IPCC report, it is outlined that the current estimate of the remaining carbon budget from 2020 onwards for limiting warming to 1.5°C with a probability of 50% has been assessed as 500 Gt CO_2, and as 1150 Gt CO_2 for a probability of 67% for limiting warming to 2°C. Additionally, in 2019, approximately 34% of total net anthropogenic greenhouse gas emissions came from the energy supply sector, 24% from industry, 22% from agriculture, forestry and other land use, 15% from transport and 6% from buildings.[1]

In cognisance of a required climate response, the Kyoto Protocol was developed in 2005 which committed parties to internationally binding greenhouse gas emission reduction targets. The targets set by parties worldwide have become more ambitious and broader across various sectors in recent years. At the COP26 conference in Glasgow, a major outcome was achieved in setting up the International Aviation Climate Ambition Coalition.

1 IPCC sixth assessment report IPCC_AR6_WGIII_SummaryForPolicymakers.pdf

In addition to the benefits to global aviation industry in terms of advancing the use of hydrogen in what is otherwise a hard to abate sector.

This was in response to the need for international action on tackling aviation emissions given the global nature of the sector, of which New Zealand was a signatory. Another outcome was the Zero Emissions Vehicles Transition Council 2022 Action Plan, highlighting global desire to decarbonise ground and air transport.[2]

Ultimately, both the IPCC report and the COP26 outcomes highlight that more is required to drive down emissions and at an accelerated pace to mitigate further environmental deterioration.

Various methods of decarbonisation have been developed, trialled, and deployed. Green hydrogen has gained strong global interest and is increasingly seen as a major mitigation method to decarbonise energy and other industrial sectors. When hydrogen is generated by renewable energy sources, it is a zero carbon energy vector, which offers a safe, flexible, storable alternative to fossil fuels. Due to hydrogen's gravimetric energy density, it is pursued as a future zero emission alternative for long distance transport.

In addition, hydrogen's potential to decarbonise a range of sectors has garnered increased research and development. Innovative solutions are being developed that enable and embed hydrogen integration across sectors – this has the advantage of leveraging system wide decarbonisation.

To enable the use of hydrogen to decarbonise infrastructure, green hydrogen production facilities are required. A hydrogen hub is a physically centralised hydrogen production facility with capacity to enable the integration of several hydrogen-based services to decarbonise multiple systems simultaneously.

This report will outline the definition of a pilot green hydrogen hub in relation to its primary integration and primary use case with a New Zealand airport.

There has been progress worldwide to set up hydrogen hubs, particularly in proximity to airports. Countries such as Germany, France, Italy, Denmark, USA, Korea, Australia and the UK have agreed memorandums of understanding with key aviation industry stakeholders including aircraft manufacturers, airport and airline operators to enable the development of hydrogen hubs. This signifies the beginning of a shift in aviation fuelling infrastructure worldwide.

New Zealand's recent actions include publishing a 'Hydrogen Vision' and signing Memorandums of Understanding with Japan[3] and Singapore[4] for cooperation on hydrogen technology. This has encouraged Japanese companies such as Obiyashi to invest in pilot hydrogen projects in New Zealand, such as at the Ports of Auckland. From a research and development perspective, an international green hydrogen alliance has been formed between Germany and New Zealand, with the University of Otago co-leading.[5]

2 COP 26 International Aviation Climate Ambition Coalition – UN Climate Change Conference (COP26) at the SEC – Glasgow 2021 (ukcop26.org)
3 NZ and Japan H2 MOU New Zealand signs hydrogen agreement with Japan | Beehive.govt.nz
4 NZ and Singapore H2 MOU Hydrogen arrangement signed with Singapore | Beehive.govt.nz
5 Germany – New Zealand Green Hydrogen R&D Alliance 20 October 2021, Funding in hand for German-NZ Green Hydrogen alliance, News, University of Otago, New Zealand

In addition, New Zealand and South Korea have signed a Letter of Intent to progress a partnership to investigate the development of a large-scale liquid hydrogen supply chain from New Zealand to South Korea. The study is aimed at identifying the economic feasibility and core technologies required to develop the liquid hydrogen supply chain using renewable electricity in New Zealand with the green hydrogen imported into South Korea for distribution to a range of consumers.[6]

This signifies increased direction and momentum behind utilising hydrogen within New Zealand's infrastructure across sectors.

International stocktake of Green Hydrogen Hubs

Globally, the demand for green hydrogen supply and hydrogen hubs at airports is growing. Notably, in Europe, Airbus, Air Liquide and VINCI Airports have formed a partnership to create an airport network for hydrogen aircraft.[7]

Airbus, one of the major aircraft manufacturers, view hydrogen as a promising zero-emissions technology to reduce the aviation industry's impact on the climate.[8] They have announced ambitions to develop the world's first zero-emission commercial aircraft by 2035, which includes three ZEROe concepts.

The concepts are hybrid hydrogen aircraft, meaning they utilise liquid hydrogen combustion with oxygen through modified gas turbine engines and are complemented with hydrogen fuel cells to generate electric power.[9]

For hydrogen aircraft to be a possibility for the aviation industry to decarbonise, green hydrogen supply will be required at airports. The on-site production and liquefaction of hydrogen could be a promising option for airports to meet their individual energy needs, ground transport fleet fuel needs and zero emission aircraft needs.

Co-locating the hydrogen production at the airport or near the airport would eliminate the need for transport to and from off-site hydrogen production facilities, which would further reduce emissions. This would enable the possibility for airports to become future energy ecosystems with hydrogen production at their core, as illustrated in Figure 1.[10]

6 NZ and Korea H2 Letter of intent New Zealand seeks to develop large-scale liquid hydrogen exports (h2-view.com)

7 European hydrogen hub at airport network Airbus Looks to Build European Airport Network for Hydrogen Aircraft with New Partnership - Aviation Today

8 Airbus hydrogen ambition Hydrogen | Airbus

9 Airbus ZEROe ZEROe - Zero emission - Airbus

10 Airbus Hydrogen Hub at Airport Concept image Tomorrow's airports: future energy ecosystems? | Airbus

A snapshot of global airports that are progressing hydrogen projects.

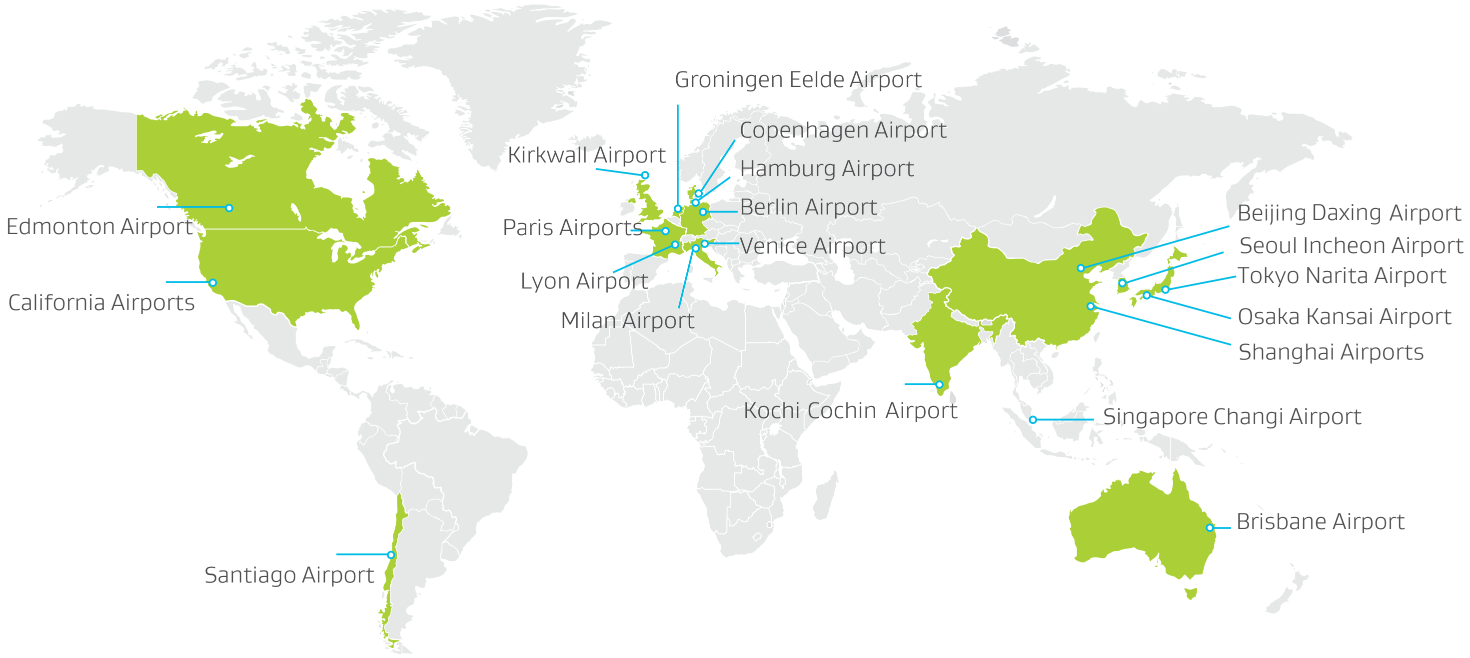


Figure 2: Map of global hydrogen hub at airports examples

STOCKTAKE OF INTERNATIONAL AIRPORT HYDROGEN HUBS

According to the World Energy Council's 2021 working paper on national hydrogen strategies, 12 countries had published hydrogen strategies and a further 19 countries were still to do so.[11] These strategies outline each country's national approach to develop a successful hydrogen economy to meet hydrogen production ambitions by a specified time.

11 World Energy Council National Hydrogen Strategies published: Working Paper: Hydrogen on the Horizon: National Hydrogen Strategies | World Energy Council

According to CSIRO HyResource at the time of writing this report, 18 countries had released national hydrogen strategies including UK, Canada, Germany, Japan, South Korea, Chile, France, Spain and Morocco. Other countries such as Finland and Paraguay have released roadmaps and China and India have released policy guidelines, with ambitions to release national strategies in near future.[12] Spain, Portugal, Hungary, and Norway have national hydrogen strategies published, however no hydrogen hub at airport information was found.

Out of the countries that have released national hydrogen strategies, the potential for hydrogen hubs at airports has been investigated (where information has been publicly available).

Appendix 5.1 compiles information regarding plans for hydrogen hubs at airports globally. Please note this is not exhaustive and is illustrated to highlight the scale of demand and potential for hydrogen at airports in the near future.

A snapshot of global airports that are progressing hydrogen projects is shown below in Figure 2. Further details about the activities at each airport can be found in Appendix, p56.

INTERNATIONAL STOCKTAKE OF AIRPORT HYDROGEN HUBS SUMMARY

Twenty international airports with hydrogen projects have been included in this report. However, this number is likely to increase given the international drive to curb greenhouse gas emissions, ambitious announcements from key stakeholders within the aviation industry and increased scrutiny over carbon emissions via international travel.

Increased momentum for hydrogen hubs at airports is largely coming from Europe, with France, Italy and Germany linking into the Airbus European hydrogen hub network. Europe has set the stage for hydrogen scale-up with:

- The European Green Deal which outlines EUR 0.6 trillion investment to achieve no net emissions of greenhouse gases by 2050 while decoupling economic growth from resource use.[13]
- The EU Hydrogen Strategy outlining key actions such as releasing a call for proposals for green airports and ports under Horizon 2020 funding and steering the development of key pilot projects that support hydrogen value chains.[14]

EU focus is on increasing electrolyser capacity for 'green' hydrogen production and expanding its use to industrial sectors and transport - targeting 40 GW of electrolyser capacity by 2030.[15] Norway and the Netherlands are pursuing both 'blue' and 'green' hydrogen. Southern Europe is prioritising the scale up of 'green' hydrogen production, due to its high solar irradiance.

12 CSIRO International Hydrogen Policy publications International – HyResource (csiro.au)
13 European green deal A European Green Deal | European Commission (europa.eu)
14 EU Hydrogen strategy EUR-Lex - 52020DC0301 - EN - EUR-Lex (europa.eu)
15 EU 2030 green hydrogen targets EU 2030 Green Hydrogen Target Requires Huge Renewable Power (marketinsidedata.com)

Germany is focusing on local 'green' hydrogen production and will also be importing from the Middle East, North Africa, Australia and Chile.

Significant pursuits are also being made from Asia, with Japan and South Korea being seen as hydrogen pioneers. Japan and South Korea were the first to introduce the idea of a hydrogen economy and have focused efforts on industry and transport to decarbonise at scale.

Japan has projected a hydrogen requirement of 3 million tonnes per year by 2030 and 20 million tonnes per year by 2050. This includes mobility targets of 200,000 fuel cell electric vehicles by 2025 and 800,000 fuel cell electric vehicles by 2030, in addition to 320 hydrogen fuelling stations by 2025 and 900 by 2030. To achieve this Japan will be relying heavily on hydrogen imports. Japan has committed USD 2.7 billion to develop an international hydrogen supply chain.[16]

South Korea's industrial conglomerates have announced a combined investment of USD$ 36.3 billion in the hydrogen value chain by 2030. The South Korean Ministry of Trade, Industry and Energy has reported a USD$ 1.07 billion investment for the following: to establish a green hydrogen production cluster in North Jeolla Province; a blue hydrogen production cluster in Incheon; a hydrogen storage and transportation cluster in Gangwon Province; a hydrogen mobility cluster in Ulsan and a hydrogen fuel cell cluster in North Gyeongsang Province.[17]

China, Japan, and South Korea are leaders in fuel cell technology and are increasingly shifting towards hydrogen cars, trucks and buses, including rolling out refuelling infrastructure. Having a hydrogen supply chain offers advantages over battery electric vehicles due to similarities to existing fuel supply chains such as LNG.

China, USA, Russia, and India have yet to publish national hydrogen strategies, but have been noted due to their geo-political influence. Their initial policy announcements illustrate their ambition to transition to hydrogen.

China is the largest hydrogen producer in the world (mainly 'grey' hydrogen). In 2020, China's hydrogen production accounted for roughly a third of the world's total. It is estimated that China will require an estimated 130 million tonnes of hydrogen per year by 2050.[18] As shown in Table 16 in the Appendix, China is already considering hydrogen use at airports with information available for Shanghai Airport.

The **USA** has made slow progress to advance green hydrogen deployment, largely due to resistance from their oil and gas sector. The USA's return to the Paris Agreement will likely mean growth of its 'blue' hydrogen production, as this will take advantage of their significant carbon storage capacity. Within the USA, California, Texas, and Louisiana are recognised as the major hydrogen producing states.

16 Japan Hydrogen Strategy Japan's Hydrogen Industrial Strategy | Center for Strategic and International Studies (csis.org)
17 South Korea Hydrogen strategy Hydrogen law and regulation in South Korea | CMS Expert Guides
18 China Hydrogen policy Hydrogen law and regulation in China | CMS Expert Guides

California leads in 'green' hydrogen efforts and plans 1,000 hydrogen refuelling stations by 2030.

The USA has released a hydrogen roadmap that outlines a competitive hydrogen industry which can meet 14% of USA energy demand by 2050.[19] In addition, US based airline Delta signed a Memorandum of Understanding to become the first US based airline to collaborate with Airbus on the research and development of hydrogen-powered aircraft and supply chain infrastructure required to make the transition.[20]

In **India**, the growth of hydrogen has been driven by industry, for example the Indian Oil Corporation and Reliance is looking at'blue' hydrogen. The government has announced aims to utilise the country's vast renewable resources to produce green hydrogen. As part of their upcoming hydrogen strategy, international transmission charges will be waivered for 25 years for green hydrogen and ammonia projects commissioned before 30 June 2025.[21]

The Indian Oil Corporation is establishing two green hydrogen production facilities and aim to fuel 10% of their refining processes with hydrogen by 2030. They have also partnered with Cochin International Airport to build a green hydrogen plant using on-site solar to fuel local buses.

Russia's hydrogen strategy outlines them as a world leader in hydrogen export, targeting 20% of the global market by 2030 with 2 million tonnes per year by 2035 and 15-50 million tonnes per year by 2050. Russia is exploring all hydrogen options: 'blue' in its oil and gas regions; 'green' in areas with hydropower; 'yellow' with nuclear powered electrolysis. It plans to export 'blue' hydrogen from the sub-Arctic region and 'green' hydrogen and ammonia from the Far East, mainly aimed at export to China and Japan.[22]

19 USA Hydrogen policy Hydrogen law and regulation in the US | CMS Expert Guides
20 USA Delta Airlines and Airbus Hydrogen fuel A Decarbonized Future for Flight: Delta and Airbus Collaborate to Pull Forward The Future of Hydrogen Fuel - Hydrogen Central (hydrogen-central.com)
21 India interim hydrogen announcement (6) India's new interim H2 strategy 'will push down cost of green hydrogen by up to 75% by 2030' LinkedIn
22 Russia hydrogen policy RUSSIA'S HYDROGEN UP | Energy Central

Significant developments in other countries

UNITED KINGDOM

No publicly available information on hydrogen hubs at airports has been found for the United Kingdom other than the hydrogen combined heat and power installation at Kirkwall Airport in Orkney.

The UK views hydrogen as a significant energy vector to decarbonise the aviation industry and strives to become a centre of hydrogen aviation innovation. Outside of aviation the UK has already deployed a substantial number of hydrogen research and development projects.[23]

The aviation sector has already received substantial backing from the UK Government to investigate technology options. Aerospace Technology Institute, a collaboration between UK government and industry has already invested £1.6 billion to fund research and development. One of the key projects, FlyZero, aims to realise zero-carbon emission commercial aviation by 2030. Hydrogen formed a significant part of the FlyZero studies, with their reports concluding that liquid hydrogen presents the most suitable fuel for commercial aviation.

The FlyZero studies considered a broad range of matters including the impacts on airports, airlines and airspace and the required changes to operations and infrastructure.

ZeroAvia the company trialling and developing hydrogen powered aircraft is based in the UK and works closely with over 50 consultant partners worldwide to develop both new hydrogen aircraft and hydrogen-powered engine options for current airframes.[24] Hypoint has opened an aviation technology innovation location are further developing air-cooled fuel-cells for small-sized rotary craft such as drones and air taxis and is in partnership with ZeroAvia for larger scale engines.[25]

ZeroAvia plans to work with industry partners to build out the refuelling ecosystems for hydrogen at airports globally. Shell is a fuelling partner, and ZeroAvia has also partnered with Octopus Hydrogen to help power its current flight-testing programme in the UK.

In addition, ZeroAvia is developing one of the world's first commercial zero-emission routes from London to Rotterdam the Hague Airport in conjunction with Royal Schiphol Group. ZeroAvia will begin flight-testing of its hydrogen-electric powertrain using its Dornier-228 testbed aircraft.

This work, part of the HyFlyer II project, will deliver a fully certified 600kW model for aircraft of up to 19-seats in 2024 and is supported by the UK Government's Department for Business, Energy and Industry Strategy (BEIS), Aerospace Technology Institute (ATI) and Innovate UK through the ATI Programme. The company plans to scale up its technology to 40-80 seat aircraft by 2026, with ground tests of the 1.8 megawatt power plant prototypes starting this year.[26]

23 UK Hydrogen projects Hydrogen in the UK - Hydrogen UK (hydrogen-uk.org)
24 ZeroAvia https://www.zeroavia.com/
25 HyPoint facility opening https://simpleflying.com/hydrogen-uk-innovation/
26 Zero Avia ZeroAvia | ASL Aviation | Zero Emission Freight Operations

AUSTRALIA

Australia has budgeted AUD$ 500 million to develop seven 'green' hydrogen hubs, a clean hydrogen certification scheme and carbon capture and storage infrastructure in line with the Australian National Hydrogen Strategy launched in 2019.[27]

The Asian Renewable Energy Hub plans to install 26 GW of renewable solar and wind generation capacity in the Pilbara in northern Western Australia. Up to 23 GW of this energy will be used to generate green hydrogen and ammonia for export to Asia. The first 15 GW are expected to begin construction in 2026 with export from 2028.[28]

NORTH AFRICA

Egypt is expected to release a hydrogen strategy in June 2022 and have five active hydrogen projects underway, including electrolysers, storage facilities and a liquid hydrogen hub at Port Said to support export.[29] The country aims to have 4 GW of generation capacity by 2030 with plans to convert existing gas pipelines to allow transport directly to Europe.[30]

Morocco established the National Hydrogen Commission in 2019 with the goal of becoming a world leader in hydrogen production and export. The country was also identified by the International Renewable Energy Agency as one of the top five countries that could emerge as global hydrogen suppliers. Morocco aims to have a 100MW electrolyser in operation by 2025 and focus on exports to Europe.

26 Zero Avia ZeroAvia | ASL Aviation | Zero Emission Freight Operations

27 Australian hydrogen hubs https://smallcaps.com.au/australian-government-hydrogen-hub-carbon-capture-greenhouse-targets/#:~:text=The%20Australian%20Government%20will%20invest%20%24275.5%20million%20to,%24263.7%20million%20for%2 carbon%20capture%20and%20storage%20projects.

28 Asian Renewable Energy Hub https://asianrehub.com/

29 Egypt hydrogen strategy https://www.power-technology.com/comment/egypt-hydrogen-strategy/

30 Egypt hydrogen export https://www.cnbc.com/2022/04/26/masdar-signs-deal-for-major-green-hydrogen-projects-in-egypt.html

Rationale for Hydrogen Hubs in New Zealand

New Zealand has set out goals for net zero emissions of all GHG (other than biogenic methane) by 2050. In 2019, domestic and international aviation accounted for 6% of New Zealand's total gross GHG emissions. Whilst this is a relatively small contribution compared to other sectors, if New Zealand is to achieve its net zero goal by 2050, domestic and international aviation emissions must be reduced.

Green hydrogen is considered by leading industry experts to be the most viable zero carbon emission fuel with potential to scale to large aircraft utilising fuel cell, gas turbine and hybrid systems. To enable the deployment of green hydrogen systems at airports, supply of hydrogen is required.

Currently, New Zealand has limited supply of green hydrogen and therefore, green gaseous and liquidous hydrogen production will be required to enable the transition to zero emissions aviation and reduce New Zealand's aviation GHG emissions. Setting up pilot green hydrogen hubs at airports can aid the net zero transition and consequently provide additional benefits.

NEW ZEALAND GHG EMISSION TARGETS

The key reason decarbonisation initiatives are being deployed worldwide is to mitigate the effects of climate change. Nations worldwide are setting greenhouse gas emission goals to enable this mitigation. New Zealand has set domestic targets under the Climate Change Response Act to achieve:

- Net zero emissions of all GHG other than biogenic methane by 2050
- 24 to 47 per cent reduction below 2017 biogenic methane emissions by 2050, including 10 per cent reduction below 2017 biogenic methane emissions by 2030

In addition, New Zealand has set a Nationally Determined Contribution target to reduce net emissions by 50% of net emissions below the gross 2005 level by 2030.[31] In the Government's emissions reduction plan published in May 2022, three emissions budgets were set out from 2022 to 2035 with a total emissions budget of 20 Mt CO_2e, as shown in Table 1.

Table 1: New Zealand EmissionsBudget 2022-2035[32]

Budget Period	2022–25	2026–30	2031–35
All Gases, (AR5)	290 Mt CO_2e	305 Mt CO_2e	240 Mt CO_2e
Annual Average	72.5 Mt CO_2e	61 Mt CO_2e	48 Mt CO_2e

31 New Zealand's greenhouse gas emissions targets Greenhouse gas emissions targets and reporting | Ministry for the Environment

32 New Zealand emissions reduction plan Emissions budgets and the emissions reduction plan | Ministry for the Environment

NEW ZEALAND GHG EMISSIONS

Note: 2019 is taken as the representative year of carbon emissions due to the impacts on the COVID-19 pandemic on New Zealand activities.

In 2019, the New Zealand transport sector emitted 14,655 kt CO_2-e emissions, 17% of the total 81,617.06 kt CO_2-e emissions across all sectors. Transport emissions are predominantly road transport, with domestic aviation accounting for 1,025.06 kt CO_2-e emitted, 7% of the total reported transport emissions and 1% of total emissions.[33]

Figure 3 illustrates New Zealand's emissions contributions by sector in 2019.

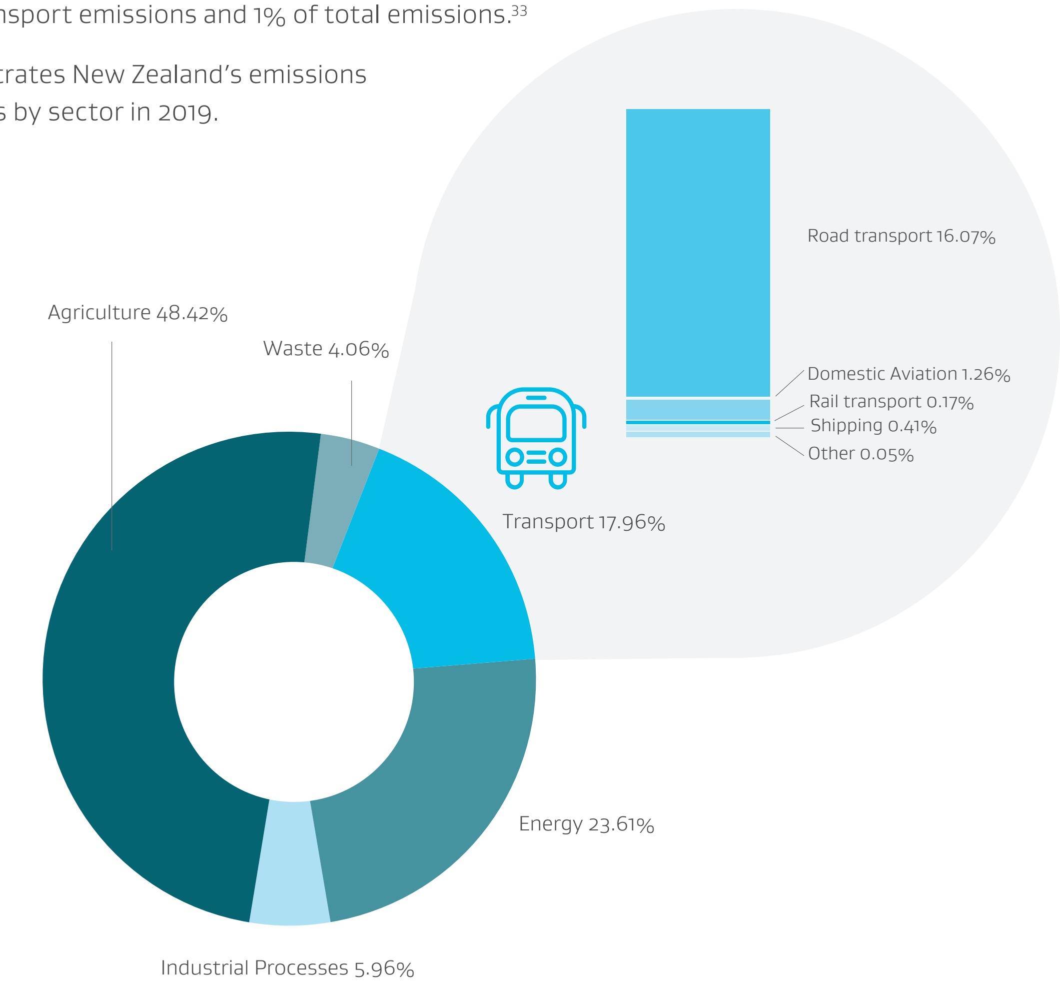


Figure 3: New Zealand's emissions by sector in 2019%

33 New Zealand emissions report NZ's Interactive Emissions Tracker (mfe.govt.nz)

ACCOUNTING FOR INTERNATIONAL CARBON EMISSIONS

The IPCC guidelines for the preparation of greenhouse gas inventories and the United Nations Framework Convention on Climate Change (UNFCCC) reporting guidelines outline that emissions from international aviation and maritime transport, known as international bunker fuel emissions, should be calculated as part of the national greenhouse gas inventories of parties, but should be excluded from national totals and reported separately.[34]

In 2019, New Zealand's total international bunker fuel greenhouse gas emissions were 4,912.4 kt CO_2-e with international aviation contributing 79.2% of this with 3,893.6 kt CO_2-e emissions. International aviation emissions are 3.8 times greater than domestic aviation emissions.[35] When considering domestic and international aviation emissions together, they account for 6% of New Zealand's total gross greenhouse gas emissions.[36]

NEW ZEALAND AIRLINE GHG EMISSIONS

Air New Zealand is the largest airline operator in New Zealand. Operating domestic and international flights. When considering Air New Zealand emissions in 2019:[37] Air New Zealand's emission in 2019 equalled 3.9 tonnes CO_2.

83.7%	16%	0.3%
emissions are accounted via their international flights	emissions are accounted via their domestic flights	emissions are accounted via their ground operations include aircraft operating on ground such as taxiing and maintenance

As illustrated by Air New Zealand's emissions spread, air transport is the largest contributor to aviation emissions. Therefore, a method to decarbonise air transport is required to tackle aviation GHG emissions.

DECARBONISATION PATHWAY – GREEN HYDROGEN

The Aerospace Technology Institute led a project called 'FlyZero', which produced a report investigating zero-carbon emission commercial flight. The report published in March 2022, concluded that green liquid hydrogen is the most viable zero carbon emission fuel with potential to scale to large aircraft utilising fuel cell, gas turbine and hybrid systems.[38] This is due to liquid hydrogen being an energy dense, lightweight, zero carbon emission fuel.

By deploying hydrogen production for airport use, whether that is for air transport, airport ground transport or airport energy requirements as a direct effect decreases airport, airline, and in future, domestic and international aviation carbon emissions.

To enable the deployment of green hydrogen systems at airports, supply of green hydrogen is required. Currently, New Zealand has limited supply of green hydrogen and therefore, green gaseous and liquidous hydrogen production will be required to enable the transition to zero emissions aviation and reduce New Zealand's aviation GHG emissions.

34 Emissions reporting guidelines Emissions from fuels used for international aviation and maritime transport | UNFCCC
35 New Zealand energy sector greenhouse gas emissions | Ministry of Business, Innovation & Employment (mbie.govt.nz)
36 New Zealand GHG Inventory 1990-2020 New Zealand's Greenhouse Gas Inventory 1990–2020 | Ministry for the Environment34
37 https://p-airnz.com/cms/assets/PDFs/air-nz-ghg-inventory-report-2020.pdf
38 FlyZero executive summary FZO-ALL-REP-0003-FlyZero-Executive-Summary.pdf (ati.org.uk)

Setting up pilot green hydrogen hubs at airports can aid the transition to net zero by kick starting the uptake of hydrogen-based technologies.

POTENTIAL NZ AVIATION HYDROGEN DEMAND

In 2019, domestic aviation contributed 1,025 kt CO_2-e and international aviation contributed 3,893.6 kt CO_2-e. This equates to approximately 1.67 million tonnes of jet fuel and if replaced with hydrogen would require a total of roughly 590,000 tonnes hydrogen. To produce this amount of hydrogen (with today's technology), an electrolyser installation of 3,155 MWe would be required to produce all NZ Aviation hydrogen for 2019. Assuming the electrolyser operates at 72% efficiency and with 100% capacity factor. Please note this value is for reference, there are other decarbonisation options that will aid the drive to emissions free aviation

Additional problems solved

In addition, to the key driver of tackling climate change by decarbonising existing infrastructure, other issues can be solved by implementing green hydrogen hubs. These include:

ECONOMIC

- Security of supply - economic resilience of domestic fuel supply
- Lack of cooperation between key stakeholders across sectors – The capability for hydrogen to be utilised across multiple end uses creates an opportunity for collaboration and cooperation between companies and investors.
- Private investor hesitation in hydrogen
- Continued investment and promotion of national direction in renewables

SOCIAL

Unemployment and up skilling – Greater educational attainment and employment opportunities

POLITICAL

- International cooperation uncertainties – Deployment of a green hydrogen hub signifies to the international community that New Zealand sees hydrogen as a part of the solution for aviation.
- International carbon emissions accounting
- Regain public trust – Public protest at lack of action with regards to climate mitigations
- Continue New Zealand green credentials – IPCC highlighted carbon emissions per capita not great in New Zealand. Show a path to promote a environmentally conscious country

TECHNICAL

Collaboration between industry and academia to innovative follow-on decarbonisation solutions.

ENVIRONMENTAL

Improve local air quality – Reduced particulate matter being emitted will improve the air quality of local area which consequently improves the health and well-being of the local community.[39]

39 Air quality consequences Health consequences of air pollution on populations (who.int)

Rationale for Hydrogen Hubs at Airports

The largest airports across New Zealand already serve as a hub of business activity for their region. Their existing infrastructure and connectivity mean they are well suited to accommodate a pilot green hydrogen hub and to initiate the transition for the aviation sector and the local region.

A range of technologies are being developed to solve the zero-emissions aviation challenge. Hydrogen plays a key role in a number of these technologies. An airport pilot hub(s) would play a vital role in upskilling the aviation workforce to safely handle hydrogen on airport. Ground service vehicles and back-up power offer an immediate opportunity to decarbonise airport operations, with aircraft uses expected to grow over the medium and long-term.

ESTABLISHED HUBS OF ACTIVITY AND BUSINESS

Airports and their surrounding developments provide the ideal environment to develop a hydrogen hub. Serving commercial airlines and cargo operators the larger airports have well established transport and utilities infrastructure in place, minimising the capital expenditure required for a hydrogen hub. They are typically well connected to a public transport network, with overnight bus storage or refuelling stations creating the opportunity for hydrogen vehicles. Local industrial sites adjacent to the larger airports are also common, with a wide variety of businesses that could benefit from the availability of hydrogen.

As the focal point of local business activity, larger airports have significant influence over the businesses in their local vicinity. Smaller cargo or logistics companies associated with the airport would likely struggle to fund a transition to hydrogen or an equivalent technology on their own, but with an airport hub leading the way, others could take up the opportunity. With a broad range of activities in close proximity to the airport there is a likely baseline demand for the hydrogen to support the investment.

SIGNIFICANT STUDIES INTO HYDROGEN BY THE SECTOR

With regards to clean aviation, global research studies indicate several ways hydrogen could be employed to power aircraft. Airbus and Boeing are undertaking significant research into its application for powered flight. Airbus recently announced as part of their ZEROe project that they expected to achieve a mature technology readiness level for a hydrogen-combustion propulsion system by 2025.[40]

On page 16 of this report, the significant research and investments taking place around the world is highlighted with increasing momentum as more nations and industries outline their environmental targets. Collaborations between governments, airlines, airports, energy providers are increasingly common to consider the impacts of the new technology across the industry.

New Zealand has already developed a reputation for being at the forefront of new sustainable technologies. In 2008, the national carrier – Air New Zealand – flew one of the world's first test flights powered by biofuels[41].

40 ZEROe – Zero emission – Airbus

More recently they have established a Memorandum of Understanding (MoU) with Airbus, one of the world's leading aircraft manufacturers, to investigate Hydrogen technologies. The airline is therefore well positioned to be early adopters of the technology as it progresses to market.

HYDROGEN IS ONE OF MANY DECARBONISING SOLUTIONS FOR AVIATION

Whilst the focus of this report is specifically on the hydrogen hubs and their potential applications, it is important to note that a range of fuel/power technologies are under consideration by the aviation industry with the goal of minimising the carbon emissions.

Battery technologies have made significant developments in recent years and present a strong contender for the short-haul market. In 2020, the New Zealand regional airline Sounds Air signed a letter of intent with Heart Aerospace to purchase their 19-seater electric aircraft (ES-19), a significant step towards a net zero future.

There are however challenges for the battery aircraft to overcome. Battery lifecycles and recharging times are of particular focus for airlines. Replacement and responsible disposal of the batteries will need to be factored into the long-term operating costs. Equally, for airlines operating aircraft on 2 or more legs in a day, the time on ground should be kept to a minimum. With battery recharging expected to require more time than standard refuelling, airlines may need to adjust their route planning or purchase additional aircraft compared to other power types such as hydrogen.

Bio Sustainable Aviation Fuels (SAF) are blended into the JET A1 fuel by airlines today, retaining the existing engine systems whilst reducing their carbon emissions. Demand for SAFs is expected to grow significantly over the next decade, providing airlines with a proven way to reduce their emissions for the long-haul market until other technologies become available. However, this technology does still result in carbon emissions as opposed to the preferred zero emissions solution. When considering the broader aviation market uptake, production rates and land intensity present considerable barriers for this technology to overcome. Air New Zealand and MBIE recently signed a memorandum of understanding to run a request for proposal process inviting industry leaders to demonstrate the feasibility of operating a SAF plant at a commercial scale.

Hydrogen, however, is currently viewed by many in the industry as critical to the future of a net zero aviation industry. Combined with carbon capture technologies, green hydrogen has the potential to form Synthetic SAFs that can be blended into the fuels used by current aircraft engine technology. Hydrogen fuel cell technology is under investigation by some companies but there are a number of technical challenges to overcome that limit its potential for larger commercial aircraft. Hydrogen combustion engines require significant research and development but current industry reports suggest liquid hydrogen is the optimum form for commercial aviation. The extremely low temperatures required to maintain the hydrogen in a liquid state do however present significant engineering challenges for the industry to overcome.

41 Air New Zealand – Climate Leaders Coalition

New Zealand's Competitive and Environmental Advantages

New Zealand has several competitive and environmental advantages when it comes to the deployment of a green hydrogen hub as demonstrated in Table 2 below.

Advantage	Rationale, description
Renewable electricity access, growth and cost	**NZ electricity grid make up** New Zealand's grid electricity is largely produced from renewable energy sources. In 2021, New Zealand net grid generation was from an estimated 85% renewable sources. The largest grid contributions were from hydro, 57%, geothermal, 18%, and wind 6%.[42] This is advantageous as there is already readily available renewable electricity sources which can enable green hydrogen production via the national grid. This will accelerate deployment of hydrogen hubs or expanded upon in future. **Future renewable grid electricity make up** New Zealand currently aims to transition to a 100% renewable electricity grid by 2035.[43] However, more recent announcements aim for 100% renewables by 2030.[44] Therefore, any hydrogen hub connected to the grid after 2030 should be producing green hydrogen. In addition, the forecasted growth of electrical generation will be from solar and wind due to their continued cost reductions. This presents an opportunity for hydrogen to aid the curtailment issues of variable renewable generation as hydrogen production could take advantage of the curtailment cost offerings. **Grid electricity costs** New Zealand grid wholesale costs for Q1 2022 were on average approximately 18.5 US c/kWh. This is similar to Australia with 17.6 US c/kWh but considerably lower than the OECD average cost of 24.2 US c/kWh.[45] However, within New Zealand there is regional variation relative to the proximity of generation and consumer nodes which affects operating costs of hydrogen production. With continued cost reductions in New Zealand for renewable energy generation technologies, as well as scaling up of hydrogen production, the IEA estimate the cost of producing hydrogen from renewable energy could fall by 30% by 2030.[46]
Industrial stakeholder support	Major New Zealand industrial stakeholders have set targets to decarbonise, including: New Zealand's national airline, Air New Zealand, which has approximately 80%[47] market share of domestic aviation, has committed to being net zero by 2050 and has stated intent to start flying zero-emission aircraft in the next five years.[48] Air New Zealand were the second airline globally to announce ambitious science-based emissions reduction target.[49] Ministry of Transport have confirmed the decision to participate in the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) by the ICAO. This will be enforced by the Civil Aviation Bill introduced to parliament in 2021 which will require all airlines to produce emissions reports and monitoring plans that include requirements for offsets of carbon emissions.[50] In addition, Christchurch Airport and Hamburg Airport have an MoU to prepare for the future use of green hydrogen as an emission free energy carrier in aviation, promoting hydrogen use and exploit joint synergies. Support from industrial stakeholders is critical to fully realise the benefits of hydrogen hubs in New Zealand.
Existing infrastructure	New Zealand has existing gas transmission and distribution pipelines which could be retrofitted to enable transport of green hydrogen or allow injection of green hydrogen to allow gas blends – decarbonising its gas network. Noting that these pipelines are a combination of polyethylene and steel, the latter of which is not suitable for delivering hydrogen due to degradation by embrittlement. The gas pipeline distribution network is only in the North Island, with no reticulated piping in the South Island. In addition, existing hydrogen production facilities can help increase hydrogen resilience of any newly deployed hub.

42 New Zealand Electricity grid make up MBIE Electricity statistics | Ministry of Business, Innovation & Employment (mbie.govt.nz)
43 New Zealand 2035 zero carbon grid target New Zealand Aims to Transition to 100% Renewables by 2035 (futurism.com)
44 New Zealand 2030 zero carbon grid announcement Election 2020: Labour pledges 100 per cent renewable power by 2030 | Stuff.co.nz
45 Energy Council of Australia International Energy Price Comparison https://www.energycouncil.com.au/news/international-electricity-price-comparisons/
46 IEA The Future of Hydrogen report – Analysis
47 Air New Zealand domestic aviation market share AIR (Air New Zealand Ltd) (morningstar.com)
48 Air New Zealand zero emissions aircraft aims Air New Zealand aiming to fly zero emissions aircraft in five years' time | RNZ News]
49 https://www.airnewzealand.co.nz/press-release-2022-airnz-second-airline-globally-to-announce-ambitious-science-based-emissions-reduction-target
50 Ministry of Transport CORSIA CORSIA | Ministry of Transport

Table 2, continued below.

Advantage	Rationale, description
Future infrastructure	Large scale green hydrogen production plant of 600MW with a primary export use planned in the South Island by Southern Green Hydrogen. An initiative set up between Meridian and Contact Energy. If this comes to fruition, it could provide additional hydrogen supply to hydrogen hubs around New Zealand. Increasing the resilience of New Zealand's green hydrogen network.[51]
Previous Renewable experience	New Zealand has history of successfully developing renewable resource and energy projects such as the hydrogen projects mentioned below this table. As well as other renewables projects, the New Zealand government launched Ara Ake in July 2020, focused on developing green hydrogen solutions, offshore wind and carbon capture and storage. Ara Ake aims to support energy innovators to ensure new energy solutions are successfully deployed.
New Zealand's international status	New Zealand is a trusted international trading partner. New Zealand is, and is seen as, a clean and green country. This image has significant export value and our environmental image is a key driver of the value of goods and services in the international marketplace. This provides us with an ability to attract international research and funding into renewables projects. The New Zealand Government has recognised the benefits of leveraging its competitive advantage early on and has recognised hydrogen as a key part of the New Zealand energy future. The government has developed the Vision for Hydrogen in New Zealand and commissioned hydrogen scenarios from which a Hydrogen Roadmap will be developed. The government is also developing regulatory policy for hydrogen to enable the safe and consistent deployment of hydrogen projects. This commitment has earned New Zealand international recognition which is reflected by international agreements signed with Japan, South Korea and Singapore. New Zealand has previously signalled its intent to decarbonise and utilise hydrogen within its future energy economy. This report will provide a strong signal to the aviation industry and international audience that New Zealand has serious intent to become a world leader in the development of a future hydrogen economy. New Zealand demonstrates excellence in aerospace engineering, and relative regulatory agility for aerospace. New Zealand airports also have the capability and capacity for this infrastructure. There are several existing projects for decarbonising aviation in New Zealand, with Meridian's ElectricAir partnership launching the country's first electric aircraft from Christchurch Airport and Boeing and Kitty Hawk's Cora autonomous air taxi under development with agreement to launch operations in Christchurch. In addition, the New Zealand Space Agency have undertaken Aerospace Integration Trials creating an innovative ecosystem enabling companies to grow such as Wisk and Aeronavics.[52]
Commitment to net zero	As mentioned on p23, New Zealand has committed to reaching a carbon neutral economy by 2050. This will help to drive interest and investment into hydrogen, including pilot studies such as this as we move towards this clean, green future. EECA commission quarterly surveys of the public opinions on climate change. These surveys highlight strong support from the public for climate change action from the government and businesses, as well as a willingness to make personal choices that reduce the effects of climate change. The most recent survey from Q4 2021 shows 74% of the population believe the Government needs to do more to help reduce New Zealand's impact on the environment and 78% believe the government should provide incentives to encourage behaviours that protect the environment. This is consistent with 73% of the population who are willing to make changes to their personal behaviour to reduce impact on the climate.[53] There is strong support from iwi to act towards climate change with some such as Ngāi Tahu developing climate change strategies that outline the direction and actions that the iwi will take.[54] The Iwi Chairs forum is a nationwide meeting of iwi representatives to coordinate collective action on issues and advocate for change. Within this group there is a Climate Change Group which has called for a bigger and faster response from government and has committed to supporting iwi to transition away from a fossil fuel-based economy in a just way.[55]

51 Southern Green Opportunity Southern Green Hydrogen
52MBIE Airspace Integration Trials Airspace Integration Trials | Ministry of Business, Innovation & Employment (mbie.govt.nz)
53 EECA Consumer Monitor https://www.eeca.govt.nz/assets/EECA-Resources/Research-papers-guides/EECA-consumer-monitor-Q2-2122.pdf
54 Te tāhu ir te whāriki Climate Change Strategy https://ngaitahu.iwi.nz/environment/policy/climate-change-strategy/
55 Iwi leaders to take action on climate change https://waateanews.com/2019/05/08/iwi-leaders-to-take-action-on-climate-change/

Additionally, there are several hydrogen installations operating in New Zealand already producing green hydrogen and some that are to be completed in the near future. This offers opportunity for these projects to act as 'companion projects' with potential integration and security of supply for any pilot green hydrogen hub deployed at airports. Figure 9 in the appendices illustrates the existing location of hydrogen projects in New Zealand. Notably, the following projects and installations are of relevance for the pilot green hydrogen hub at airport(s).

AIR NEW ZEALAND / AIRBUS

Airbus and Air New Zealand have launched a partnership agreement to analyse the impact hydrogen-powered aircraft may have on its network, operations and infrastructure. Meanwhile, Airbus will share expected aircraft performance and ground operations characteristics to support Air New Zealand in its decarbonisation roadmap. The goal of the study is to prepare Air New Zealand to begin operating hydrogen-powered aircraft from 2030.[56]

PORTS OF AUCKLAND

The Ports of Auckland installed a pilot sized hydrogen electrolyser to demonstrate the technology on a small scale. Through a partnership with Auckland Transport hydrogen is produced for fuel cell buses as part of a 2-year trial. The electrolyser acts as a hub to refuel port-based vehicles such as trucks and container handling equipment. In addition, the hydrogen produced will be available for Hyundai's to five Xcient fuel cell trucks for freight handling.[57]

56 Air New Zealand and Airbus Project Airbus and Air New Zealand to study potential for hydrogen-powered aircraft | Airbus
57 Ports of Aucklادn hydrogen facility https://www.poal.co.nz/media/ports-of-auckland-to-build-auckland%E2%80%99s-first-hydrogen-production-and-refuelling-facility
58 Hiringa and Balance hydrogen hub project
59 Hiringa refueling network Hydrogen Refuelling Network | Hiringa Energy 2022

HIRINGA / BALANCE AGRI-NUTRIENTS HYDROGEN HUB

Hiringa and Ballance Agri-nutrients have proposed a renewable energy hydrogen hub at Ballance's Kapuni ammonia-urea plant with the aim to fuel heavy transport. There is a plan to construct up to four large wind turbines to supply renewable energy to the Kapuni site and power electrolysers to produce hydrogen as the feedstock to the ammonia-urea plant or for supply as 'zero-emission' transport fuel.[58]

TUAROPAKI TRUST / OBIYASHI CORPORATION MOKAI

Halcyon Power is a joint venture between Tuaropaki Trust and Obayashi Corporation that developed the first operational green hydrogen electrolyser in Taupō. The plant is adjacent to the Tuaropaki geothermal power station and opened in 2021 with the ability to produce 180 tonnes of green hydrogen per year.

HIRINGA FUELLING STATIONS

Hiringa is building a green hydrogen production and refuelling network across New Zealand focused on the heavy transport sector. The first four stations are to be located in Hamilton, Palmerston North, Auckland and Tauranga, and are due to be operational in 2022. An additional 20 stations are planned to be operational by 2026. The network can provide hydrogen for multiple applications including aviation. Initial locations have been prioritised to provide aggregation of suitable fleets in industrial complexes, commercial & logistics hubs and ability to service ports and airports.[59]

NZ AVIATION HYDROGEN CONSORTIUM

An MoU has been agreed between Airbus, Air New Zealand, Christchurch Airport, Fabrum, Hiringa and Fortescue Future Industries to progress hydrogen use at NZ Airports.

New Zealand's Challenges and Opportunities

New Zealand will need to overcome challenges to achieve a safe, sustainable and resilient future energy system. In the context of establishing green hydrogen hub(s) at airport(s) there are specific challenges that should be addressed. The challenges outlined require mitigation to successfully develop an at scale hydrogen economy, to support New Zealand and its aviation sector to achieve their decarbonisation goals. These challenges are outlined at a high level below.

It is assumed this table relates to a full scale hydrogen hub(s) in which a pilot will help drive transition.

Table 3: Challenges and Opportunities to deploying green hydrogen hubs at New Zealand Airports

Advantage	Challenge	Opportunity
Monetary investment	• First mover risk. • Methods available to stimulate private and public investment in new technologies to mitigate first mover risk. • Lack of investor confidence in future of hydrogen hubs. Government can help grow investor confidence by outlining a national energy strategy and a national hydrogen strategy. • Public funding routes for hydrogen hub design and development to stimulate private investment.	• Provide methods to stimulate investment in new technologies to mitigate first mover risk • Provide clear strategy and investment opportunities for key stakeholders • Provide public funding routes for hydrogen hub design and development to stimulate private investment.
Hydrogen standards and regulations	• Lack of safety, regulatory or policy framework for Hydrogen which will create barriers to certification and consenting. • This is a challenge that is currently being tackled by other countries. New Zealand has the opportunity to provide leadership with regards to hydrogen standards and regulations for hydrogen.	• Provide a clear framework for hydrogen safety, regulations and policy • Provide global leadership on hydrogen standards and regulations.
National electrical infrastructure	• Additional renewable electricity generation deployment to keep up with demand for green hydrogen hubs. Electricity use in New Zealand is forecast to increase as we look to achieve our goals of a carbon neutral economy by 2050. • Additional renewable electricity generation deployment to keep up with demand for green hydrogen hubs. Electricity use in New Zealand is forecast to increase as we look to achieve our goals of a carbon neutral economy by 2050. • National electrical grid infrastructure development to ensure sufficient capacities are available at hydrogen hub locations to enable green hydrogen production.	• Couple decarbonisation of heat, industrial and transport alongside electrical grid decarbonisation • Utilise curtailment of future renewable generation sources to optimise hydrogen cost effectiveness • Ensure additional domestic flight routes are enabled by zero emissions aircraft.

Table 3, continued below.

Advantage	Challenge	Opportunity
National electrical infrastructure *Continued*	• Aviation industry growth targets. New Zealand is reliant on air transport to connect it's regions. Sufficient renewable generation is required to meet zero emissions connectivity targets across regions including regions that are currently not connected. • There is an imbalance in the energy production and consumption nodes between the North and the South Island. The North Island consumes 63% of electricity in the country while the South Island consumes 37%. • Electricity cost variation across the year, in the period July 2021 to May 2022, prices in New Zealand fluctuate between by approximately 50$/MWh to 300$/MWh. If a direct connection to renewables is available this will aid electricity pricing volatility.	• Couple decarbonisation of heat, industrial and transport alongside electrical grid decarbonisation. • Utilise curtailment of future renewable generation sources to optimise hydrogen cost effectiveness. • Ensure additional domestic flight routes are enabled by zero emissions aircraft.
Stakeholder engagement	• Public perception of hydrogen. Strong community engagement will be required to ensure successful deployment of hubs at scale. • Lack of stakeholder confidence in new technology particularly at scale. By deploying pilot scale hubs initially or tapping into learning lessons from global pilot hubs, confidence in technology can move ahead at a more accelerate pace.	• Illustrate to public, government initiative to mitigate the effects of climate change. Gain public trust. • Establish stakeholder confidence in new technology by enabling pilot green hydrogen hub deployment and disseminating lessons learnt. • Engagement with the international community for developing solutions will provide better access to global lessons learnt. • Collaboration with Māori and iwi
Collaboration/ systems integration	• Lack of integration with other use case uses (e.g. local industry or transport) to generate demand. A hydrogen economy being established in the medium term will be required. • Engagement with the international community for developing solutions will provide better access to global lessons learnt.	• Foster collaboration amongst stakeholders by coupling hydrogen use cases • Opportunity to signify to the international community that New Zealand sees hydrogen as key energy element in their future
Hydrogen technology	• Commercial viability of hydrogen hub technologies compared with existing infrastructure. Cost reductions and efficiency improvements of key technology required to be cost competitive. • Technology Readiness Level of technologies associated with liquid hydrogen and hydrogen derived fuels. • System integration with airport side needs.	• Provide a platform for novel hydrogen technology development • Opportunity to cooperate with international partners to accelerate green hydrogen development to make hydrogen cost effective and enable the sharing of knowledge and best practices. • Learn from hydrogen hubs at airports from around the world.
Skills and resource	• Lack of skilled workforce and resources to construct hydrogen hubs at speed. Note this is a challenge across all novel decarbonisation technologies.	• Up-skill workforce for future energy system early.

In addition to the opportunities sourced from the challenges described in Table 3, additional opportunities are detailed below:

- Closure of the Marsden Point refinery means 100% of liquid fuel will be imported. There is an opportunity to displace some of this using domestically produced green hydrogen.
- Provide leadership in tackling international bunker fuel emissions.
- Expand use cases of hydrogen
- Launch domestic hydrogen flight route
- Promote New Zealand green credentials and responsibility to be an environmentally conscious country
- Improve local air quality
- Allows New Zealand the leadership platform to enter into the global supply chain where the country's relative scale might otherwise preclude access to purchase early adoption novel propulsion aircraft.

Alignment with wider government work and goals

The government action plan to address climate change and achieve the goal of net zero emissions by 2050 is legislated by the Climate Change Response (Zero Carbon) Amendment Bill 2019.[58] This acts as the overarching document to guide decarbonisation in New Zealand and informs policy development by ministries. The Ministry of Business, Innovation and Employment has jurisdiction over energy and is in the process of developing several policies to promote hydrogen and zero-carbon energy in New Zealand.

MBIE completed the Vision of Hydrogen in New Zealand Green Paper in 2019 which identified the opportunities for hydrogen in transport, industry, electricity generation and storage. MBIE are also developing a Hydrogen Roadmap that will outline the steps to be taken to realise this vision and is undertaking regulatory review to understand what regulation needs to be in place to safely enable hydrogen development.

MBIE is also undertaking or supporting several projects that are continuing to advance the development of hydrogen in New Zealand, which includes this report on hydrogen hubs in airports. The relation between these projects is shown in Figure 4 opposite.

58 Climate Change Response (Zero Carbon) Amendment Bill 2019 https://www.parliament.nz/en/pb/bills-and-laws/bills-proposed-laws/document/BILL_87861/climate-change-response-zero-carbon-amendment-bill

The relation between these projects is shown in Figure 4 below.

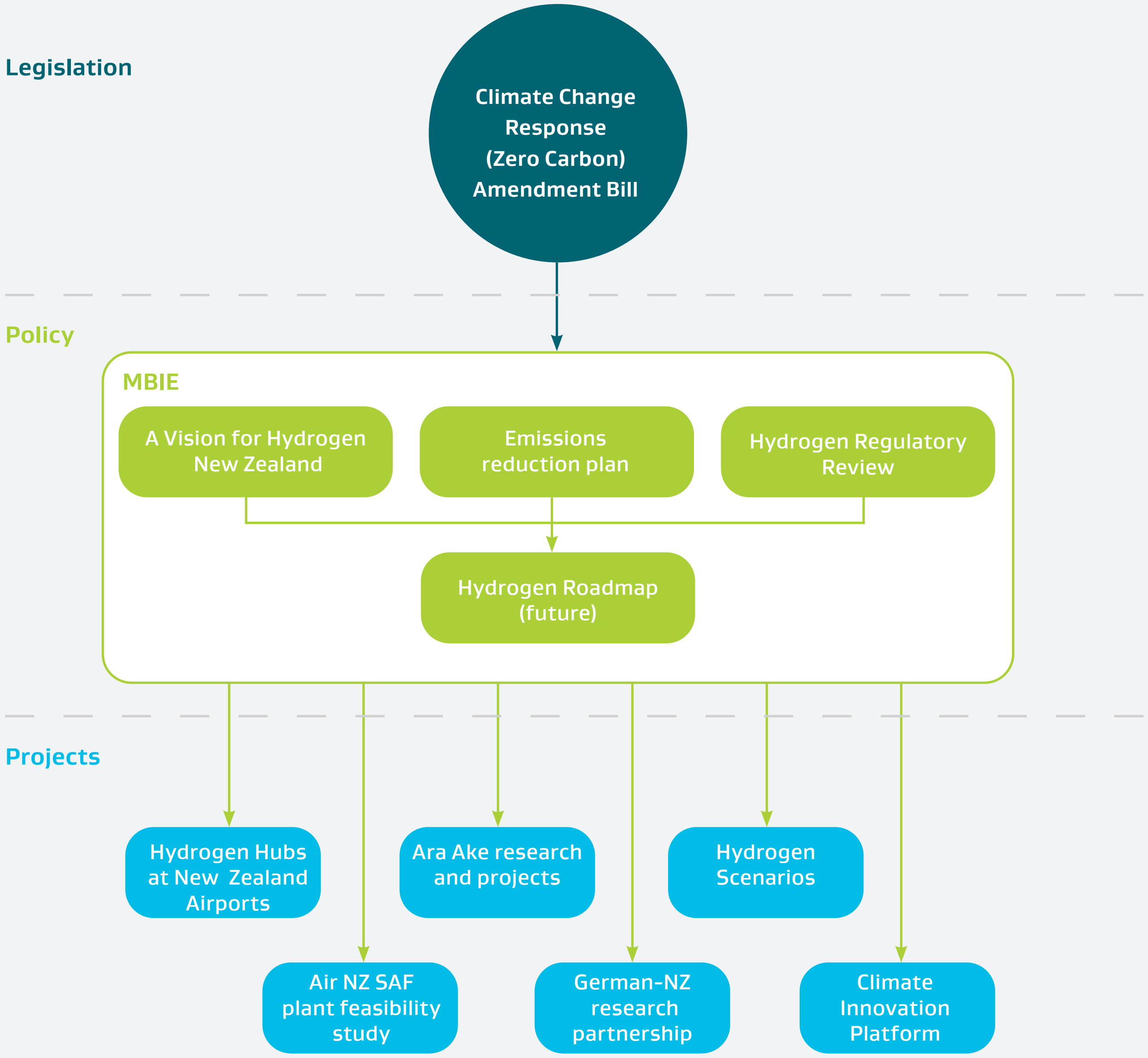


Figure 4: New Zealand Government work for hydrogen

©Alamy

Pilot Green Hydrogen Hub

- Definition
- Benefits and outcomes of a pilot
- System Element Options
- System Element Selection for Pilot Hydrogen Hub
- Considerations for Scale Up of a Hydrogen Hub at Airport(s)

Pilot Green Hydrogen Hub

This section of the report defines what a pilot green hydrogen hub at an airport(s) is in the context of New Zealand, the benefits of a pilot and the system element options and likely pilot green hydrogen hub elements.

Definition

The aim of the pilot hydrogen hub is to enable New Zealand and its airports/ aviation industry to achieve their decarbonisation goals by using low greenhouse gas emissions hydrogen and hydrogen derivatives, including synthetic fuels. In addition to attracting R&D from overseas to New Zealand and creating an ecosystem for innovation. This will involve substituting novel technologies for existing carbon emitting infrastructure primarily within the airport space. The hub also aims to enable flexibility to decarbonise several other end uses outside of the airport boundary through whole systems integration in future expansions.

Recognising these aims, the pilot New Zealand airport hydrogen hub will be defined as a physically centralised green hydrogen production facility primarily for airport use with capacity to integrate a number of hydrogen-based services whilst connecting with local community and allowing for future phased expansion.

Primary airport uses can include green hydrogen supply to airport vehicles, airport energy demand and future aircraft. The pilot hub could provide hydrogen for airport ground vehicles first, until hydrogen technology for air transport is developed.

Hydrogen services could include:

- Green hydrogen supply to industrial processing facilities, gas network injection, gas fired power station decarbonisation, ground transport re-fuelling (cars, buses, heavy duty, logistics)
- The ability to connect with other national and international hydrogen hubs via business enterprise, academic research, and industry workforce up-skilling.

Benefits and outcomes of a pilot

Deploying green hydrogen hubs at pilot scale will support New Zealand's ambition to be a world leader in trialling, testing, and developing clean energy technologies for aviation, and in the process, build a thriving and innovative clean energy ecosystem. It will also create opportunities for wider social and economic benefits to be realised across the pilot locations.

Economic development is at the forefront of most local planning policies across New Zealand, setting out the strategic direction for long term sustainable growth of industries and in turn, the growth of jobs. Introducing hydrogen hubs at pilot airports creates an opportunity to re-shape the role and function of employment land in cities across New Zealand, particularly for precincts near airports.

For industries likely to be the end users of hydrogen, such as manufacturing, electricity, gas and waste services, construction and transport, postal and warehousing, it will strengthen economic links to pilot airports and assist in decarbonising the supply chain, paving the way for a resilient future. It also brings ample opportunities for industry diversification and attraction of entrepreneurs and start-ups seeking reliable and renewable energy.

Building on the opportunities for economic development, hydrogen hubs can influence growth in research and development. Deploying green hydrogen at pilot airports creates the opportunity for wider regional economic benefits including attracting investment in the generation of new ideas and research, further exposing industries in pilot locations to new markets.

Opportunities for research and development may be realised in pilot- locations with high contribution to regional GDP, forecast industry growth, existing clusters and links to universities. Some pilot airport locations face constraints limiting growth or expansion opportunities such as Wellington, Queenstown, and Nelson. As a result, the ability to leverage investment in research and development associated with hydrogen hubs will need to be realised through clustering or intensification of existing land uses.

There are benefits associated with job creation and upskilling the local labour force, supporting wider economic and social development of the region. The delivery of hydrogen hubs at pilot locations will likely generate a diverse mix of jobs from ground operation to technology advancement, creating equal opportunities for the skilled and unskilled population. Cities in New Zealand with projected population and job growth and long-term access to a strong labour force catchment are well positioned to respond to increased demand for labour.

Deploying hydrogen hubs at pilot locations will introduce diverse job types to the pilot locations. This will be particularly relevant for economies made up of a labour force with transferable skills. A benefit for other pilot locations is the opportunity for the population currently employed in airport operations to retrain or upskill. Investing in retraining or upskilling will contribute to a resilient and successful hydrogen hub and requires programmes and qualifications for training and development.

System Element Options

This section assesses the potential pilot green hydrogen hub system element options and rationalise why some system elements are more likely and beneficial for inclusion of a pilot.

For the system elements included, a technology readiness level is assigned. Please see Table 4 for TRL scale reference.

Table 4: Technology Readiness Level Chart

Stage	TRL	Description
Deployment	9	Actual system proven in operational environment
	8	System complete and qualified
	7	Prototype demonstration in operational environment
Development	6	Technology demonstrated in relevant environment
	5	Technology validated in relevant environment
	4	Technology validated in lab
Research	3	Experimental proof of concept
	2	Technology concept formulated
	1	Basic principles observed

HYDROGEN SUPPLY INFRASTRUCTURE

Hydrogen supply infrastructure consists of production, transport, storage and end use. The production of hydrogen and its respective end uses affect the infrastructure along the supply chain. Further detail of each is provided in subsequent report sections. Hydrogen production, storage and transport are discussed at a high level on pages 39-45 respectively.

Table 5: the pilot green hydrogen hub at New Zealand Airport(s) infrastructure system element options

Electrical Source	Hydrogen Production	Hydrogen Compression	Hydrogen Storage	Hydrogen Transport	Airport uses
Renewable grid source	PEM Electrolyser	Gas Compressor	Low Pressure Tanks	Hydrogen Dispenser	Ground Service Equipment
Renewable energy generator	Alkaline electrolyser	Liquefier	Pressurised tanks	Hydrogen trailer	Airside Cars
	Solid Oxide Electrolyser		Liquefaction – Cryogenic Tanks	Hydrogen tanker	Power Generation
	Membrane free electrolyser		Pipeline storage	Liquid H2 Bowser Re-fuelling System	Landside Buses
				Liquid H2 Hydrant Re-fuelling System	Aircraft
				H2 Pipeline	

HYDROGEN PRODUCTION ELEMENTS

There are several methods available to produce hydrogen, for the purposes of this report only green hydrogen electrolysis options are considered. A brief description, technology readiness level, advantages and disadvantages are outlined for each green hydrogen production option in Table 6.

Within New Zealand, Fabrum supply a membrane free electrolyser comparable to a PEM electrolyser but with a reduced water requirement.

Table 6: Hydrogen Production Technology Summary [60] [61]

Technology	Description	TRL	Advantages/ Disadvantages
Membrane Free Electrolyser	Uses cryogenic gas separation to produce high purity oxygen and hydrogen 78% stack efficiency 451kg H2/day for 1.1MW size 25 year lifespan	9	Advantages • Longer operating life than PEM • Low maintenance • No rare earth catalytic metals used • Reduced water requirements Disadvantages • Limited commercial use cases
PEM Electrolyser (Proton Exchange Membrane)	Uses a solid electrolyte which is ionically conductive polymer to exchange and separate hydrogen and oxygen. Stack life is approximately 80,000hrs Current commercial scales ~5 MW ~5.3 Kilowatt-hr required per m³ of hydrogen product 65-80% efficiency 20 – 200°C operating temperatures	9	Advantages • Relatively small footprint due to compact design, attractive in areas with restricted land availability • Offer flexible operation due to fast dynamics (response to start up, shutdown, changes in production rates) • Can produce compressed hydrogen up to 40 barg without the use of compressor Disadvantages • High cost of materials used for membrane and electrodes – Overall costs are currently higher than those of alkaline electrolysers, and they are less widely deployed
Alkaline Electrolyser	Electrodes are immersed in a liquid electrolyte, separated by a separator that only allows transport of ionic charges. Current commercial scales ~10 MW ~4.4 Kilowatt-hr required per m³ of hydrogen product 60-70% efficiency 20 – 200°C operating temperatures	9	Advantages • Low capital costs due to avoidance of rare materials • Higher durability due to an exchangeable electrolyte Disadvantages • Requires separate compression system to pressurise hydrogen • Slow dynamics (slow response to production changes) • Corrosive liquid electrolyte • Requires maintenance of Alkaline solution
Solid Oxide Electrolyser	Least developed electrolysis technology. They have not yet been commercialised, although individual companies are now aiming to bring them to market SOECs use ceramics as the electrolyte and have low material costs They operate at high temperatures and with a high degree of electrical efficiency Key challenge to reduce costs is to decrease operating temperature to prevent material degradation Current commercial scales: Not commercially established ~3 Kilowatt-hr required per m³ of hydrogen product More than 90% efficiency 700°C operating temperatures	6-7	Advantages • Can operate a solid oxide electrolyser in reverse i.e. converting hydrogen back into electricity • Lower energy demand Disadvantages • Not commercially available yet • Requires high temperature steam which leads to other problems

60 IEA The Future of Hydrogen report – Analysis, p. 44
61 CSIRO Opportunities for Hydrogen in Aviation report – p.29

HYDROGEN STORAGE ELEMENTS

The current state of technology allows hydrogen to be compressed, liquefied, or attached to a chemical carrier. Each of these methods have different TRLs, advantages and disadvantages. Table 7 outlines a description, TRL and associated advantages and disadvantages for each storage method.

Table 7: Hydrogen Storage Technology Summary[62]

Technology	Description	TRL	Advantages/ Disadvantages
Low pressure tanks	Used for stationary storage where low quantities of hydrogen are required with available space.	9	Advantages • Established technology Disadvantages • Poor volumetric density
Pressurised tanks	Pressure is increased via mechanical device in the cylinder. Hydrogen can be stored up to pressures of 200 bar in steel cylinders and up to 900-1000 bar in composite cylinders. Can be used for stationery and transport storage.	9	Advantages • Established technology Disadvantages • Mid volumetric density • Energy intensive process
Liquefaction – Cryogenic Tanks	Multi-stage compression and cooling. Hydrogen is liquefied and stored at −253°C in cryogenic tanks. Can be used for stationary and transport storage.	9	Advantages • Higher volumetric storage capacity Disadvantages • Requires advanced and more expensive storage material
Liquefaction – Cryo-compressed	Hydrogen is stored at cryogenic temperatures combined with pressures of 300bar.	9	Advantages • Higher volumetric storage capacity Disadvantages • Requires advanced and more expensive storage material
Pipeline storage	Hydrogen is stored in pipelines by altering pipeline pressure.	9	Advantages • Utilises existing infrastructure • Easy technique to store hydrogen at scale
Chemical Conversion – Ammonia	Hydrogen can be converted to ammonia. Seen as a strong contender for long distance storage of hydrogen. Unlikely to be considered in the airport pilot hub due to relatively short distances to transport hydrogen.	9	Advantages • Ammonia liquefies at negative 33°C and therefore cheaper to transport than hydrogen Disadvantages • Ammonia is toxic Requires energy to convert H2 to ammonia and back
Chemical conversion – Liquid Organic Hydrogen Carriers	Involves loading a carrier molecule with hydrogen such as methylcyclohexane. Seen as a strong contender for long distance storage of hydrogen. Unlikely to be considered in the airport pilot hub due to relatively short distances to transport hydrogen.	9	Advantages • Cheaper than hydrogen over long distances (i.e. shipping NZ to Japan) Disadvantages • Energy intensive to load/ unload molecule with hydrogen

62 IEA The Future of Hydrogen – Analysis, p. 75

HYDROGEN TRANSPORT ELEMENTS

One of the biggest cost implications for hydrogen is transport between supply and end use. Appropriate transport pathways need to be considered in conjunction once supply and demand parties have been identified. Table 8 outlines elements which could deployed in the pilot hydrogen hub at an airport to deliver hydrogen.

Table 8: Hydrogen Transport Technology Summary

Technology	Description	TRL
Hydrogen Dispenser	Used to provide efficient transfer of hydrogen to the end user, includes a high accuracy flow measurement. Typically, hydrogen at 350 bar is required for buses and 700 bar for cars, with tank fill times approximately 3-5 minutes for a car and 10-15 minutes for a bus.	9
Hydrogen trailer	Used to transport of hydrogen in gaseous and liquid form on roads. Consists of long storage tubes up to 250-300 bar pressure.	9
Hydrogen tanker	Liquid hydrogen is transported as a liquid in super-insulated, cryogenic tanker trucks. Potential for boil-off losses over long distances	9
Liquid H2 Bowser Re-fuelling System	To easily transport and distribute hydrogen for aircraft, hydrant pits and drums. It's a transportable fuelling system which can be used for both filling and emptying. Zero vapour emission, efficient and variable flow rates.	3-6
Liquid H2 Hydrant Re-fuelling System	A hydrant fuelling system provides all the necessary equipment and controls to deliver clean, dry fuel to fuelling points in the aircraft parking apron. The system includes a minimum of two operational storage tanks, but it does not include bulk storage. Fast, safe and reliable.	1-3
H2 Pipeline	For transferring gaseous hydrogen on long distances similar to gas pipelines. Potential for converting natural gas pipeline to hydrogen gas pipeline High initial cost, low operation cost, leakage control required.	9

HYDROGEN AIRPORT ELEMENTS

The baseline hydrogen supply, infrastructure and skilled labour associated with a pilot green hydrogen hub could serve as an effective enabler for a broad range of local industries, not only the airport stakeholders. Table 9 outlines airport relevant system elements which could utilise hydrogen.

Table 9: Hydrogen airport applications summary

Equipment on or adjacent to airport	Description	TRL	Commentary
Ground Service Equipment	Baggage / Cargo tractors / loaders	7-8	+ Short refuelling times to allow continuous use (1-3 minutes) + Simplified refuelling infrastructure, potentially at single location on airport. – Adaptation required from alternate vehicle designs
	Aircraft Pushback and taxiing tugs	7-8	+ Demo vehicles have shown the ability of hydrogen powered tugs to pull larger aircraft
	Forklifts	9	+ Well established in industrial sector + Short refuelling times to allow continuous use (1-3 minutes) + Minimal changes to operation
	Buses on airport (transporting passengers and staff)	9	+ Short refuelling times to allow continuous use (3-5 minutes) + Simplified refuelling infrastructure, potentially at single location on airport.
Airside Cars	Security cars patrolling the perimeter Airside operations vehicles	9	+ Available on the market + Simplified refuelling infrastructure, potentially at single location on airport.
Power Generation	Back-up power supplies for buildings and systems	9	+ Available on the market. + In some cases, hydrogen and other renewable resources could provide the primary power system for smaller airports, avoiding significant costs required to connect the airport to the power grid.
	Ground Power Units (GPU)	4	+ Reduces the fuel burn of the aircraft and the need for the APU. + The EU has recently invested 25 million euros into the development of Hydrogen GPUs expected to complete in 2025.
Landside buses	Public transport or shuttle buses associated with the airport	9	+ The airport is often a key destination on public transport networks and could serve as a refuelling point for buses. – Requires broader commitment by bus operators to transition across to hydrogen
Aircraft	Synthetic Fuels	6	+ A drop-in fuel that could work with existing aircraft engines + A promising bridging solution to minimise emissions whilst liquid hydrogen combustion engines are developed. – Significant testing and certifications required before the fuels can be approved for commercial flights. – Significantly reduces carbon emissions for the sector but not all.
	Fuel-cell Technologies	6	+ Zero emissions power option, only water vapour as the by-product. + Avoids the need for liquefaction and advances in storage systems – Technology advances needed to resolve the weight challenges of new engine system.
	Liquid Hydrogen Combustion	3	+ New engine technology identified by the UK research project – Fly Zero – as the most promising alternate to current Jet Fuel technology. – Requires significant advances in storage and handling of liquid hydrogen. – Full impact of combustion emissions on global warming still to be investigated further.

Prominent Hydrogen Aircraft Concepts

FLYZERO – PART OF THE UK'S AEROSPACE TECHNOLOGY INSTITUTE

As part of the FlyZero project, 3 zero emissions aircraft concepts were set out:

Regional concept – Fuel Cell Engine system (Gaseous Hydrogen) – Intended capability to carry 75 passengers up to 800 nmi at a speed of 325 knots.

Narrowbody concept – Hydrogen Combustion Engine System (Liquid Hydrogen) – Intended capability to carry 179 passengers up to 2400 nmi at a speed of 450 knots.

Midsize concept – Hydrogen Combustion Engine System (Liquid Hydrogen) – Intended capability to carry 279 passengers up to 5750 nmi at a speed of 473 knots and an operational range of 5250 nmi. The FlyZero report concluded that this concept could address 93% of existing long haul scheduled flights and consequently the majority of emissions in this market. This includes flights from London to Auckland (9991 nmi) requiring one stop.

ZERO AVIA

Initially focussed on the regional and short-haul flights, the fuel-cell engine system would utilise hydrogen.

CSIRO AND BOEING

Whilst a conceptual aircraft was not developed, the collaborative study between CSIRO and Boeing identified the potential for Synthetic Aviation fuels to provide a bridging solution between current fossil fuels and hydrogen combustion engines.

ALL ROADS LEAD TO HYDROGEN

Regardless of whether fuel cell, combustion or conventional engines (with synthetic fuels) prove to be the successful solution, the common element through all technologies is the reliance on hydrogen.

For this reason, the focus of government and the aviation industry should be to secure the production, operational procedures and infrastructure as soon as possible, such that the technology can be brought to market immediately after certification.

Powertrain timeline

Figure 5: Zero Avia milestone targets[63]

63 First Practical Zero Emission Aviation Powertrain | USA & UK | ZeroAvia

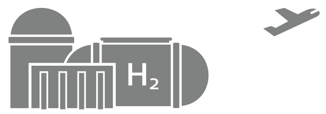
System Element Selection for Pilot Hydrogen Hub

As previously highlighted, the main pathway to decarbonise aviation is via air transport with liquid green hydrogen. Ideally, the supply of liquid green hydrogen to airports would be similar to how jet fuel is supplied to airports today via tanker or pipeline (depending on airport size). Liquid hydrogen requires transportation by tanker due to the conditions required to keep the hydrogen in liquid form.

Three options exist for liquid green hydrogen supply at airports:

1. **Hydrogen generated off site, transported via pipeline to airport and liquified on site**
   There are no existing pipelines connecting airports to hydrogen production facilities. Demand for initial hydrogen use will be low and will not warrant the capital cost of installing a pipeline.

2. **Hydrogen generated and liquified off site and transported via tanker to airport**
   There are limited hydrogen production sites in New Zealand and no green liquid hydrogen production sites.



3. **Hydrogen generated and liquified at airport**
   Possible depending on the size and associated facilities of the airport.

Potential options for a pilot green hydrogen hub are options 2 and 3, hydrogen (either gas or liquid) generated offsite and hydrogen generated at an airport site, respectively. This report focuses on a pilot green hydrogen hub located at an airport due to the limited number of green hydrogen supply sites in New Zealand.

Commercial scale liquid hydrogen use at airports is not expected until the mid 2030's due to liquid hydrogen aircraft development timescales. Therefore, the initial hydrogen use cases will mainly be gaseous hydrogen. However, liquid hydrogen production at an airport could foster research and development opportunities for New Zealand through trials until liquid hydrogen aircraft are commercially available.

A pilot green hydrogen hub may include the system elements outlined in Table 10. Figure 6 illustrates a high-level process flow diagram for the pilot hub, showing how the system elements are likely to interface with each other. The system elements likely to be included in the pilot will include technologies that have previously been demonstrated and deployed with technology readiness levels of 9.

Table 10: Pilot Hydrogen Hub – Chosen System Element Summary

Electrical Source	Hydrogen Production	Hydrogen Compression	Hydrogen Storage	Hydrogen Transport	Airport uses
Renewable grid source	PEM Electrolyser	Gas Compressor	Low Pressure Tanks	Hydrogen Dispenser	Ground Service Equipment
	Membrane free electrolyser	Liquefier	Pressurised tanks		Airside vehicles
			Liquefaction – Cryogenic Tanks		Power Generation
					Landside vehicles

Additional, balance of plant and system element configurations should be considered in the design process of the pilot hydrogen hub. The rationale for including these key system elements is outlined below:

Ground Service Equipment and airside vehicles	Due to the existing commercial availability of hydrogen fuel cell electric vehicles compared to hydrogen air transport, the airport pilot hub uses will likely be for airport airside cars and ground service equipment. This may initially include cars, buses and later the substitution of vehicles like baggage tugs, belt loaders and forklift trucks for their hydrogen alternative. The deployment of a hydrogen hub will encourage transition of existing vehicles to hydrogen alternatives.
Power Generation	Power generation using hydrogen with either fuel cells or gas engines could replace typical diesel generators. With hydrogen readily available at airports, other stakeholders may opt for the new equipment.
Landside vehicles	Separate from the airport uses, external stakeholders stand to benefit from the availability of hydrogen. Local buses operators, hotel or business park shuttle buses, taxis could all consider the transition to fuel cell vehicles if a local supply becomes available. In addition, heavy vehicles and refuse trucks could be considered for potential hydrogen use.
Renewable grid source	This is required for the electrolysis process, auxiliary balance of plant, compression, liquification and storage. The electric source is required to be zero carbon so the hydrogen can be designated as 'green hydrogen'. As mentioned on p32, New Zealand's electricity grid is already on average 80% green, with aims to be 100% carbon free by 2030. Until 2030, commercial options should be considered such as power purchase agreements with renewable generation suppliers to ensure the electricity from grid is carbon free. Alternatively, a direct connection to a renewable generation can be considered however security of supply will be required to ensure hydrogen production capacity factors are high to maximise hub return of investment. It should be noted a connection to the New Zealand Electricity grid for hydrogen production before 2030 should not be treated as a hard barrier.
Electrolyser	The electrolyser selected will likely be a membrane free, PEM or Alkaline Electrolyser. Solid oxide electrolysers are still being developed for commercial use and will take some time before they are cost competitive with PEM and alkaline. Alkaline electrolysers are widely deployed, and PEM electrolysers are increasingly deployed as it's associated cost decreases. Depending when the pilot hydrogen hub is deployed alternative electrolysis technology options should be researched and determined as there is considerable investment in electrolysis technologies and what is considered the best solution today may not be the case at the time of the pilot green hydrogen hub design and deployment.
Hydrogen Compressor	The pressure output from the electrolyser will be in the range of 10 – 40 bar. Compression is required to increase the hydrogen pressure so it can be used in fuel cell electric vehicles. Buses and trucks typically require hydrogen at pressures of 350 bar and cars typically require hydrogen at pressures of 700 bar. This enables vehicle fill time to be similar to diesel alternatives at roughly 15 minutes.
Hydrogen Storage	Hydrogen storage will be required to enable a readily available supply of hydrogen for end users. Storage facilities will supply hydrogen at the correct pressure, temperature and flow rate. Hydrogen will need to be cooled to negative 40 DegC during refuelling. Depending on the scale and specific end use(s), the storage capacity, pressure, interconnections, and safety buffer zones will need to be considered in detail. Different storage technology will be required for both hydrogen gas and liquid hydrogen. Regardless of whether the hydrogen is produced on-site or off-site, safeguarding for significant storage facilities at an airport will need to be considered. A buffer supply is required to support continued or slightly reduced operations (aircraft and others uses). The amount of buffer will depend on the resilience of the hydrogen production network and availability specific to each region.
Hydrogen Dispenser	A hydrogen dispenser is required for transfer of hydrogen to the end user at the desired pressure, quality (purity 99.998% or as per ISO 14687-2 for PEM), temperature (-40°C) and includes a high accuracy flow measurement. The dispenser can be integrated with different payment system. Hydrogen tools has provided a list of design considerations for hydrogen dispensers.[64]
Hydrogen Liquefier	Liquification of hydrogen could be included to enable the hub to act as a research and development platform to develop less deployed or novel technologies such as hydrogen bowsers, liquid hydrogen fuel hydrant systems and aircraft with liquid hydrogen combustion engines. Liquid hydrogen system elements could be installed at a later stage but the availability of liquid hydrogen on site provides opportunities for novel aviation developments. Hydrogen liquification offers the benefit of storing hydrogen in a smaller space, suited to applications with limited space like aircraft. Hydrogen liquefaction is a cryogenic process and storage of liquid hydrogen requires cryogenic temperatures below -250 C.

64 H2 tools hydrogen dispenser design considerations Design Considerations | Hydrogen Tools (h2tools.org)

Pilot hydrogen hub should aim to produce both gaseous and liquid hydrogen to enable ground uses and liquid hydrogen technology trials and demonstrations

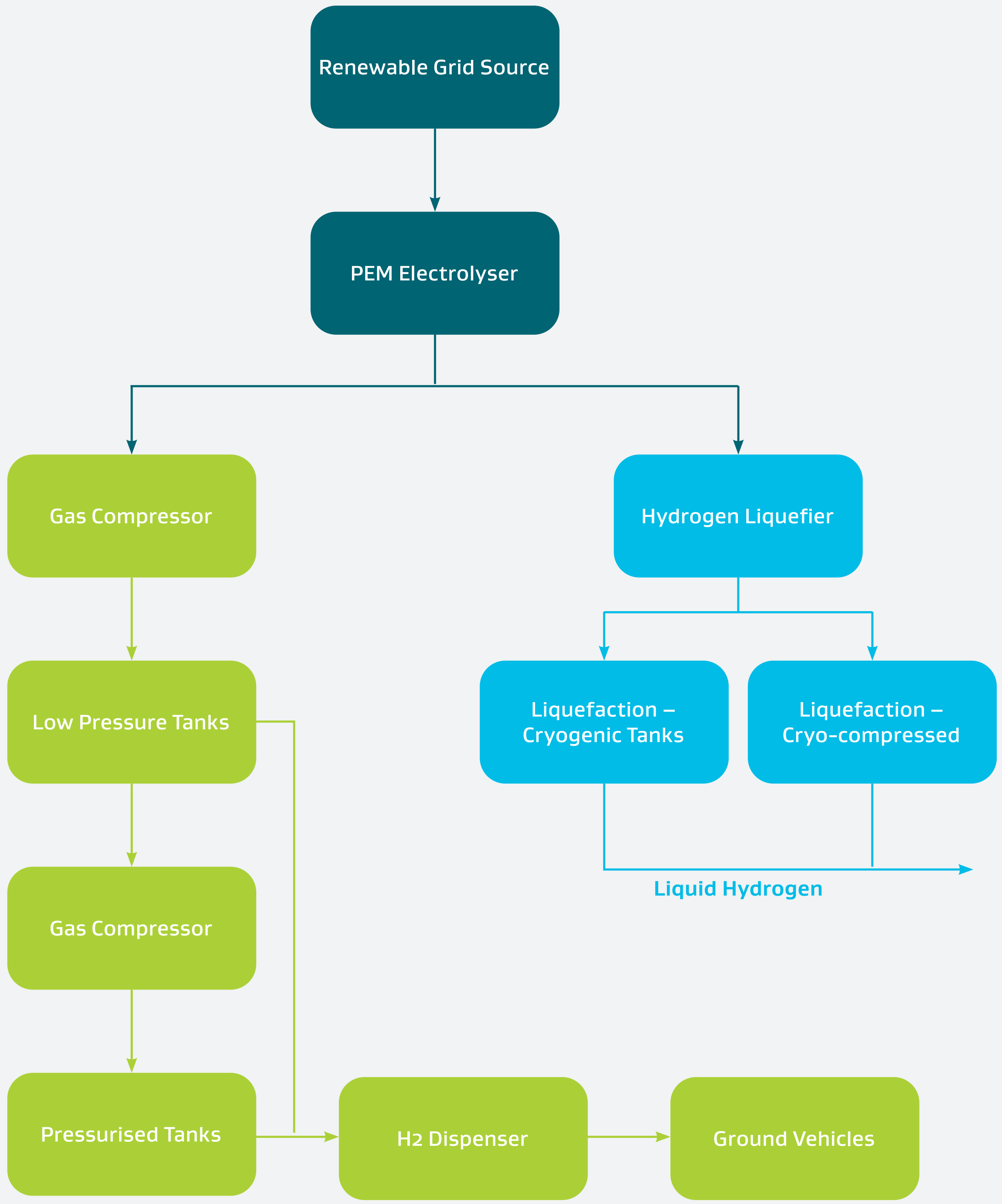


Figure 6: Pilot Hydrogen Hub High-level Process Flow Diagram

Considerations for Scale Up of a Hydrogen Hub at Airport(s)

This section details the likely steps required to scale up hydrogen production for commercial aviation uses from a pilot scale (0.25 – 1MW) to a scale in which it can support commercial aviation.

Significant investments would be required to attract the aviation industry leaders such as Airbus, Boeing or similar to establish research facilities in New Zealand. Not only in terms of financial support, but also to attract the skilled workforce associated with research.

A pilot hydrogen hub in New Zealand must clearly outline the intended goals and market interest of the investment.

The core goal of an airport-based pilot hub/s should be to provide the opportunity for the aviation related industries to prepare themselves for the eventual shift towards hydrogen, ranging from live on-airport operators to local research bodies.

With regards to market interest, thorough engagement with local stakeholders should identify the appetite for hydrogen and whether the influential businesses such as the airport operator or airlines have already committed to alternate power sources such as battery powered electric vehicles. This will significantly influence the baseline demand for the hydrogen production at the airport or the surrounding businesses.

As demand for hydrogen increases to cater for new commercial hydrogen aircraft, the location of the hydrogen production will need to be reviewed. An airport's direct access to international markets typically results in high rental rates for airport tenants and as such cost sensitive businesses will typically select sites that are close to but not directly on the airport site.

For a larger scale hydrogen production facility to achieve a competitive levelised cost, a cheaper location in the local vicinity of the airport may be preferred. However, this will be influenced by the commercial arrangement of production; whether it is owned and operated by the airport operator or a third party company. In the event that the airport owner controls the hydrogen production, the additional resilience and reduced transport requirements from onsite production may justify the allocation of premium airport land.

Whether on airport or in the local vicinity, the challenges mentioned in Table 3, need to be resolved to enable scaled deployment of green hydrogen hubs in New Zealand.

The opportunities to resolve these challenges has already been discussed. In summary, the following should be considered to achieve scaled green hydrogen hub deployment:

- ✓ **Attract investment** such as international Research & Development, private funding.
- ✓ **Enable** hydrogen deployment by setting out clear standards and regulations framework
- ✓ **Initiate pathways** to decarbonisation for surrounding infrastructure
- ✓ **Upskill workforce**
- ✓ Reduce risk of deployment by tapping into **lessons learnt from global community** and existing domestic projects.

Whilst the time horizons for hydrogen fuelled aircraft differ between researchers, there is a broad consensus on how the gradual transition will occur for the aviation sector.

In the near-term, and likely to benefit most from a pilot hydrogen hub, are the existing ground vehicles and power generators at the airport. Whilst these operations represent a very small percentage of overall emissions, they play an important role in establishing a hydrogen operation and the associated protocols within an airport environment.

The maturity of the hydrogen fuel cell technology within vehicles is well established and depending on the use case presents a strong competitor to battery vehicles, particularly those in constant use requiring rapid refuelling such as airport shuttles. Some specialised vehicles may require retrofitting to accommodate a fuel cell engine but broadly the technology is available. Hydrogen power generators also present an opportunity to replace diesel technology typically employed for back-up power resilience. This information is explored in further detail on page 44.

In the medium term, and with hydrogen well established at airports for ancillary uses, Boeing and Australia's research body CSIRO expect hydrogen to play a key role in the generation of drop-in electro fuels or synthetic Sustainable Aviation Fuels (SAF). These drop-in fuels provide a potential solution to bridge the transition period between existing kerosene jet engines and hydrogen only combustion engines under development. SAFs also have the potential to be utilised in the long term alongside hydrogen to decarbonise aviation.

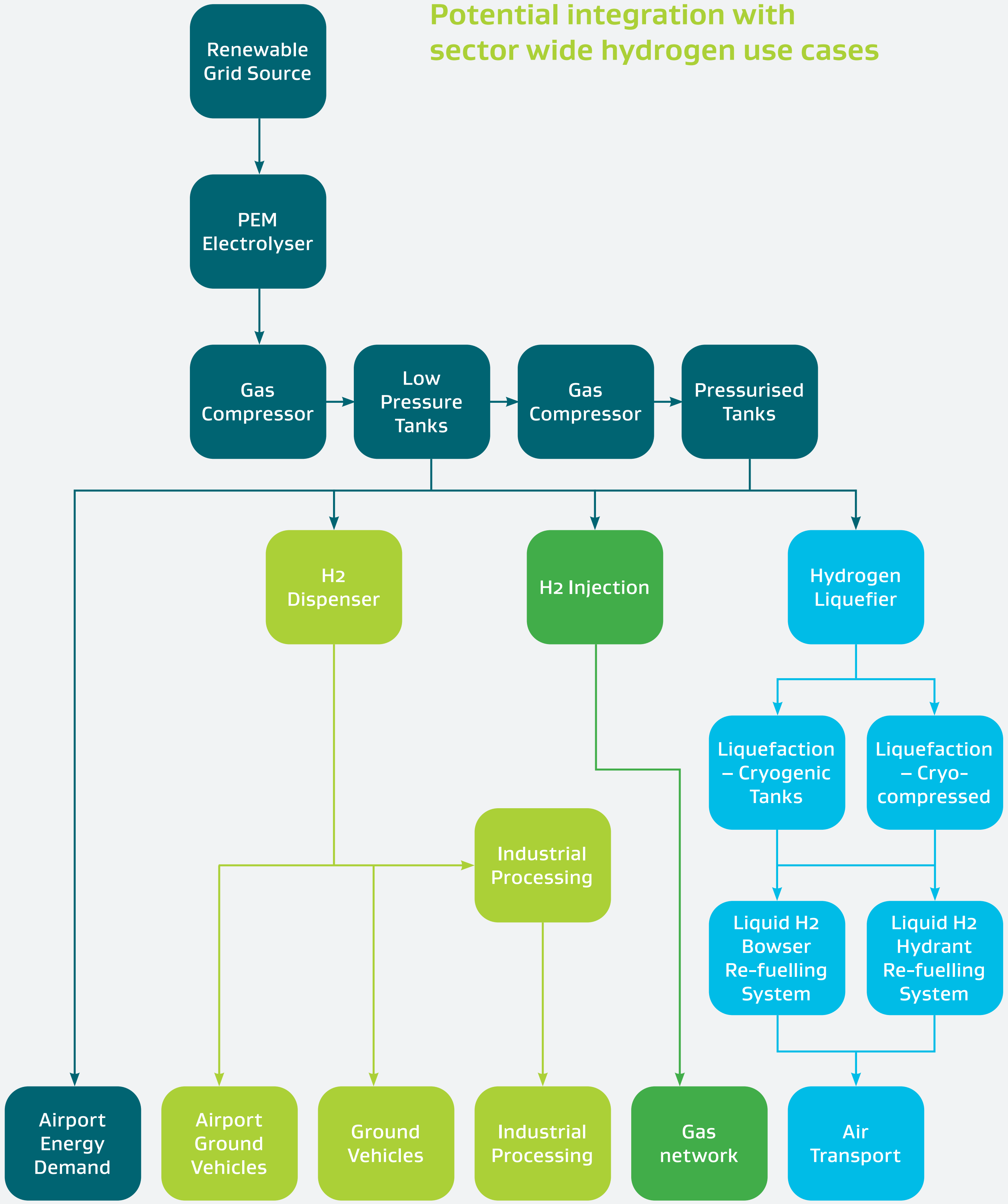


Figure 7: Future Hydrogen Hub High Level Process Flow Diagram

Somewhere between 2035 and 2050, hydrogen only combustion engines are expected to enter the commercial airline market by which point hydrogen on airport will gradually replace the existing fuel infrastructure. Depending on the size of the operation and the aircraft technologies in use at the airport, hydrogen will be transported to the aircraft by different methods. For smaller airports or those operating a mixture of power types (e.g. hydrogen, SAFs or battery), conventional tankers will likely be the most effective method of refuelling aircraft.

Larger airports with significant based airline operations may opt for in-ground pipe solutions at the aircraft stands, minimising the vehicle activity on apron and potentially reducing the turnaround time between arrival and departure. By this point the hydrogen hub, whether on airport or off airport, would serve a critical role in the operation of the airport. As with current fuel systems at airports, a storage capacity on or near the airport would be required to maintain daily operations during down periods of supply.

As hydrogen hubs around the world become operational and more commonplace, there will be a lot of learning to determine pathways to fully transform as well as potential to integrate across regional boundaries through hydrogen hub networks.

Additionally, for hydrogen hubs to be fully integrated with airports, future phases will need to include the addition of the below system elements:

- Liquid H2 Bowser Re-fuelling System
- Liquid H2 Hydrant Re-fuelling System
- Hydrogen air transport
- Hydrogen airport energy and water demand infrastructure.

Figure 7 illustrates what a developed scale hydrogen hub at an airport could look like.

Appendix

Stocktake of International Hydrogen Hubs at Airports

Table 16: Stocktake of Airport Hydrogen Hubs in Asia

Country	Airport	Hydrogen Hub Information
Japan	Kansai[65]	Kansai International Airport (KIX) plans to transform itself into a "hydrogen airport" The airport has begun development and trial of hydrogen-powered infrastructure and transport including forklifts and a bus. A commercial hydrogen station will be developed on the island for generating hydrogen, storage, and refuelling.
	Narita Airport[66]	A hydrogen fuelling station has been opened at Narita airport and provides commercial sale of hydrogen. The station has storage tanks and compressors with hydrogen trucked in from off-site.
South Korea	Incheon Airport[67]	Air Liquide, Airbus, Incheon Airport and Korean Air have partnered to prepare the use of hydrogen in the decarbonization of the aviation sector in Korea. The collaboration will study the development of Korean airport infrastructure to support the deployment of hydrogen-powered commercial aircrafts. The four partners will prepare a roadmap to first develop hydrogen usages at and around Incheon Airport and build scenarios to support the deployment of hydrogen ecosystems connected to other Korean airports. Future steps will focus on defining and developing the required liquid infrastructure to prepare for the arrival of hydrogen-powered aircraft. Two hydrogen stations currently exist onsite at Incheon airport which serve hydrogen-powered buses, cars and demonstration trucks.
China	Shanghai Airport[68]	Shanghai Airport Group and SAIC Group signed a strategic cooperation framework agreement to introduce hydrogen fuel cell vehicles.
	Beijing Daxing Airports[69]	BAIC Foton, Sinopec, Beijing Airport Bus and Yihuatong signed a cooperation intention to deepen research and development, production, operation and construction of hydrogen fuel cell vehicles and promote their use at Beijing Airport. BAIC Foton, Sinopec, Beijing Airport Bus and Yihuatong signed a cooperation intention to deepen research and development, production, operation and construction of hydrogen fuel cell vehicles and promote their use at Beijing Airport. Air Liquide Houpu Hydrogen Equipment Co., Ltd, a subsidiary of Air Liquide Group, supplied and installed 8 hydrogen dispenser units for the Daxing Airport station. With a capacity of 4.8 tonnes, this station can refuel 600 hydrogen fuel cell vehicles (cargo van, garbage truck and bus) per day, making it the largest in the world in terms of refuelling capacity.
India	Cochin Airport[70]	The Indian Oil Company plan to produce hydrogen at Cochin International Airport using a 40MW on-site solar array. This hydrogen will be used to fuel 10-20 buses which will be procured to connect the airport to the city of Thiruvananthapuram.

65 Kansai airport hydrogen transformation Kansai International Airport's cutting-edge hydrogen experiment | February 2015 | Highlighting Japan (gov-online.go.jp)

66 Narita airport hydrogen Chiba-Kita Hydrogen Station launches | News releases | Idemitsu Kosan Global

67 Incheon Airport hydrogen hub Air Liquide, Airbus, Incheon Airport and Korean Air Partner to Prepare The use of Hydrogen In The Decarbonization of The Aviation Sector in Korea - Hydrogen Central (hydrogen-central.com)

68 Shanghai Airport hydrogen use China: Foton, Yihuatong, SAIC And Others Push Forward The Era Of Hydrogen Transportation In Domestic Airports - FuelCellsWorks

69 Beijing Airport hydrogen use https://energies.airliquide.com/air-liquides-technology-chosen-worlds-largest-hydrogen-station-beijing-china

70 Accelerating a green drive for Kochi https://www.newindianexpress.com/cities/kochi/2021/nov/02/accelerating-a-greendrive-for-kochi-2378482.html

Stocktake of International Hydrogen Hubs at Airports

Table 17: Stocktake of Airport Hydrogen Hubs in Australasia

Country	Airport	Project Information
Australia	Brisbane[71]	BOC Gas received funding from the Australian Renewable Energy Agency to develop a green hydrogen facility at Bulwer Island, near Brisbane Airport. The facility will include a 220 kW electrolyser and a 100kW solar array.
Singapore	Changi Airport[72, 73]	Changi Airport Group (CAG) is set to carry out a feasibility study for establishing a hydrogen hub at Singapore Changi Airport (SIN), in partnership with industrial gas company Linde, Airbus and the Civil Aviation Authority of Singapore (CAAS). The study will focus on hydrogen production, storage and distribution in aircraft ground services, operational equipment and refuelling systems. CAG will also focus on the viability of hydrogen fuel cells in airport operations, as well as setting regulations and standards to enable hydrogen technologies to be adopted safely. Airbus will provide characteristics on aircraft configuration and fleet energy usage, insight on hydrogen-powered aircraft for ground operations, and data on the estimated hydrogen aircraft ramp-up at airports. Airbus has signed a Cooperation Agreement with Changi Airport Group, global industrial gases and engineering company Linde and the Civil Aviation Authority of Singapore (CAAS) to study the potential for a future hydrogen hub in the city state. Under the collaboration, the partners will look at how hydrogen can be transported, stored and delivered to aircraft at existing and new airports.

71 Brisbane airport hydrogen use https://spaceaustralia.com/news/hypersonix-use-locally-produced-green-hydrogen#:~:text=BOC%20received%20funding%20from%20the%20Australian%20Renewable%20Energy,proven%20versatility%20and%20performance%20compared%20to%20fossil%20fuels

72 Changi Airport Airbus Hydrogen Hub CAG, Airbus and others explore creation of hydrogen hub (airport-technology.com)

73 Airbus and Changi Airport agreement Airbus Signs Agreement to Study Hydrogen Hub in Singapore - Hydrogen Central (hydrogen-central.com)

Stocktake of International Hydrogen Hubs at Airports

Table 18: Stocktake of Airport Hydrogen Hubs in Europe

Country	Airport	Hydrogen Hub Information
Germany	Hamburg[74 75]	Hamburg airport have launched a new project that seeks to exploit aircraft maintenance processes and needed ground infrastructure for hydrogen aircraft operations. Over the next two years, the German Aerospace Center DLR, the Center for Applied Aeronautical Research ZAL, Hamburg Airport and Lufthansa Technik will design and test these solutions for hydrogen technologies. An A320 aircraft will be converted to a stationary laboratory with a goal of developing a pioneering demonstrator. Michael Eggenschwiler, Chief Executive Officer of Hamburg Airport, added: "At the airport, we also rely on hydrogen as the technology of the future for our ground transport. This project offers us the chance to identify and make the best possible use of synergy effects between gaseous hydrogen, such as that used for refuelling our baggage tractors, and liquid hydrogen for aircraft refuelling." Additionally, Shell have also opened a hydrogen fuelling station at Hamburg airport.
	Berlin[76]	H2 BER is a project which aims to determine the optimized technical layout and mode of operation of a hydrogen refuelling station. Project partners Total, Linde, McPhy and 2G added hydrogen as a fuel to the existing refuelling station at Berlin airport BER. Passenger cars with 700 bar hydrogen storage can be refuelled as well as 350 bar vehicles like buses.
UK	Kirkwall Airport[77]	This project will see a novel hydrogen combustion engine, provided by Doosan Babcock, installed and demonstrated at Kirkwall Airport in Orkney in 2021. The plant will use green hydrogen supplied by EMEC to generate electricity as well as recover and use by-product heat to deliver an efficient and comprehensive energy solution. Decarbonising airport groundside activities is an important step to enable the Scottish Government's target for the Highlands and Islands to be the world's first net zero aviation region by 2040.
France	Paris Airports[78]	Groupe ADP, Air France-KLM Group, Airbus, Paris Region, and Choose Paris Region have launched a challenge to invite corporations, start ups and research institutes to propose a product or solution that brings hydrogen into the airport environment. 11 projects were selected which includes trials of hydrogen solutions or research and development projects over the next five years.
	Lyon Airport[79]	Aircraft manufacturer Airbus, industrial gases company Air Liquide and airport owner Vinci Airports have joined forces to create a hydrogen distribution hub at Lyon-Saint Exupéry Airport.

74 Hamburg Airport Hydrogen Aircraft Operations Hamburg Airport prepares for hydrogen aircraft operations (avipeo.com)
75 Hamburg Airport Hydrogen fueling Fill up with hydrogen at Hamburg Airport - NOW GmbH (now-gmbh.de)
76 Berlin Airport hydrogen use H2BER - Reiner Lemoine Institut (reiner-lemoine-institut.de)
77 Kirkwall airport hydrogen use Green Hydrogen Will Decarbonize Kirkwall Airport in UK (powermag.com)
78 Paris Airports hydrogen hub H2 Hub Airport | Choose Paris Region
79 Lyon Airport Hydrogen Hub Lyon Airport to get hydrogen hub - Tank Storage Magazine

Stocktake of International Hydrogen Hubs at Airports

Table 18: Continued below

Country	Airport	Project Information
Italy	Milan Airport[80 81]	The operator of Milan Airports, SEA, and Airbus have signed an agreement whereby Milan airports will prepare to supply Airbus' first hydrogen powered aircraft. The agreement will focus on a series of feasibility studies aimed at developing a hydrogen refuelling hub for non-aviation use in the short term, as well as developing infrastructure for hydrogen use in aviation in the long term.
	Venice[82]	Snam, SAVE and Airbus will jointly develop hydrogen based innovative technologies and solutions. Aimed at both Venice airport and other potential users, also participating in grant programs and public tenders at both national and European level. The engineering and design studies envisaged by the agreement will include the technological infrastructure necessary for the refuelling of hydrogen to both aircraft and airport vehicles, with the possibility of evaluating effective solutions also for energy needs related to accessibility to the airport, making the entire airport system zero emissions.
Netherlands	Groningen Eelde Airport[83]	Companies from the northern Netherlands are joining forces to develop an electrolyser to produce green hydrogen for light aircraft, drones and ground equipment. The airport is home to, among other things, a 22 MW solar park, which the project will use to generate green hydrogen. The northern Netherlands is recognized by Europe as an important centre for the development of hydrogen technology, which has declared the region a Hydrogen Valley. The plant will be operational by 2023 and the green hydrogen produced in the project is intended for on-site use.
Denmark	Copenhagen[84]	The 'Green Fuels for Denmark' strategy by the Danish Government can potentially supply green fuels corresponding to Denmark's total domestic consumption of jet fuel by 2027, thus enabling the government's ambition of 100 % green domestic aviation by 2030, three years ahead of schedule. Stage 1 will include a 100 MW electrolyser that can produce more than 50,000 tonnes of sustainable fuels in 2025, mainly e-methanol for shipping, but prompted by the Danish Government's ambition to establish green aviation opportunities in Denmark as early as 2025. Future phases will ramp up production to have 1,300 MW of electrolyser capacity by 2030 and will provide 30% of the expected aircraft fuel consumption at Copenhagen Airport.

80 Milan Airport hydrogen aircraft Milan Airports Prepare to Serve Hydrogen Aircraft | Airport Industry-News
81 Milan Airport and Airbus first hydrogen aircraft SEA and Airbus Sign Agreement - Milan Airports Prepare to Supply Airbus First Hydrogen Powered Aircraft - Hydrogen Central (hydrogen-central.com)
82 Venice Airport Hydrogen Transport Airbus, Snam and SAVE - Venice Airport Sign an Agreement to Promote Hydrogen Applications in The Air Transport Sector - Hydrogen Central (hydrogen-central.com)
83 Dutch Eelde Airport large scale green hydrogen Electrolyzer at Dutch Eelde Airport will Produce Green Hydrogen for Large-Scale use - Hydrogen Central (hydrogen-central.com)
84 Copenhagen Airport green jet fuel agreement Hydrogen for Aviation - Partnership Behind 'Green Fuels for Denmark' Accelerates Project and Investigates Production of Green Jet Fuel by 2025 - Hydrogen Central (hydrogen-central.com)

Stocktake of International Hydrogen Hubs at Airports

Table 19: Stocktake of Airport Hydrogen Hubs in North America

Country	Airport	Hydrogen Hub Information
USA	California Airports[85]	ZeroAvia signed an MoU and announced a new partnership with the hydrogen fueling firm ZEV Station to develop green hydrogen refuelling infrastructure for airports in California. They are developing an initial regional airport project that represents sufficient scale to showcase how hydrogen-electric propulsion systems can deliver zero-emission commercial flights.
Canada	Edmonton International Airport[86]	Edmonton International Airport (EIA)and hydrogen trucking pioneer, Hydra Energy, announced signing a memorandum of understanding (MOU) to deliver North America's first airside hydrogen-diesel fleet. Under the terms of the MOU, Hydra will convert EIA's light, medium, and heavy-duty fleet vehicles and other specialized equipment in airside and restricted areas of the airport using its proprietary hydrogen-diesel, co-combustion system.

Central and South America Stocktake of Hydrogen Hubs

Table 20: Stocktake of Airport Hydrogen Hubs in North America

Country	Airport	Hydrogen Hub Information
Chile	Santiago -Arturo Merino Benitez International Airport[87]	The Chilean Ministry of Energy and Mining and Arturo Merino Benitez International Airport announced their plans to evaluate initiatives and projects that would promote the use of green hydrogen in aircraft operating in the country's capital.

85 California airports hydrogen refueling ZeroAvia and ZEV Station sign MoU to Develop Hydrogen Refueling Ecosystem at California Airports - Hydrogen Central (hydrogen-central.com)

86 Edmonton International Airport Hydrogen fleet Edmonton International Airport and Hydra Energy Sign MOU to Deliver North America's First Airside Hydrogen - Diesel Fleet - Hydrogen Central (hydrogen-central.com)

87 Santiago Airport Hydrogen fuel Chile: Santiago airport is set to be the first one in the region to use hydrogen as fuel - Aviacionline.com

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