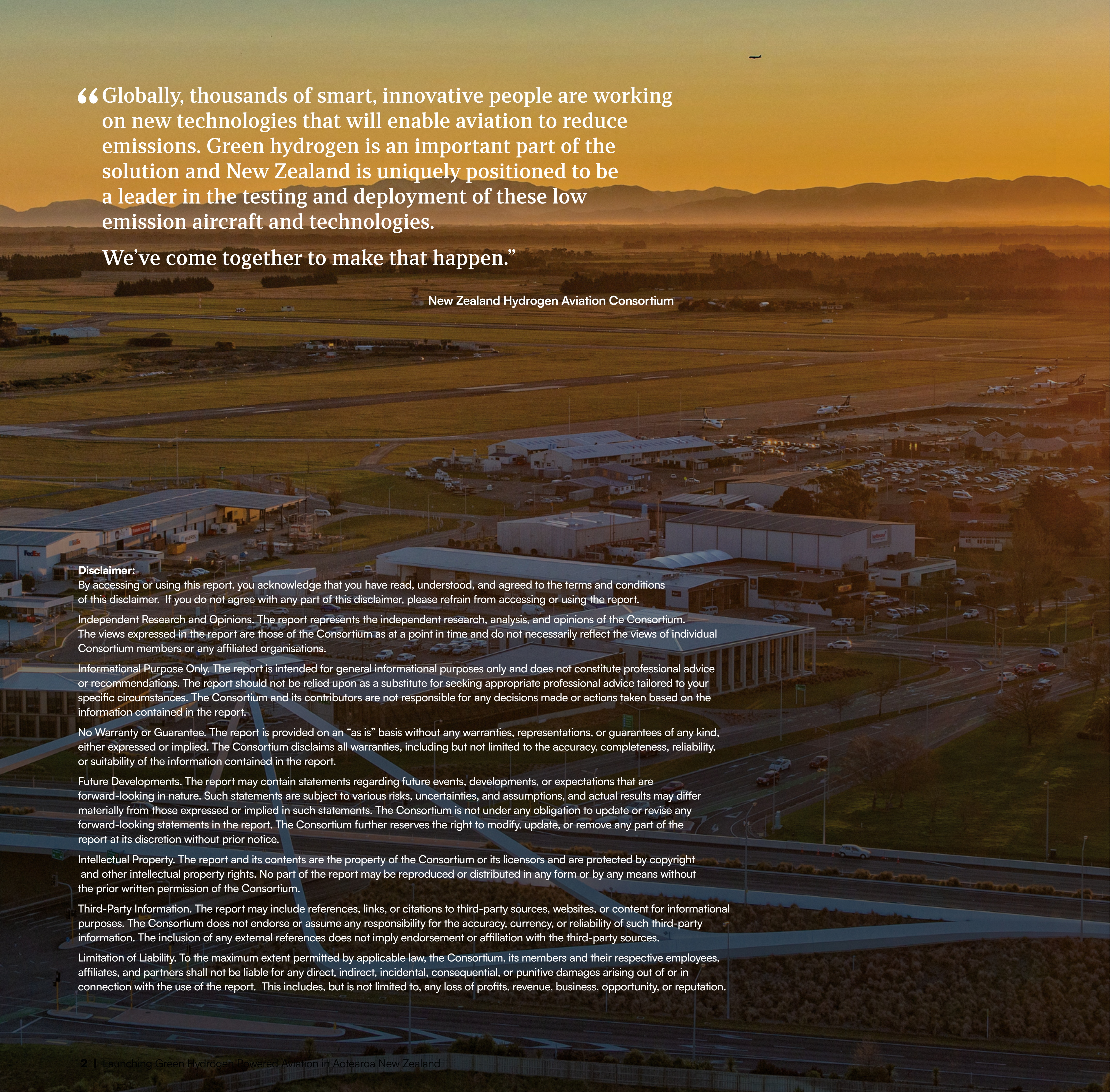
Launching Green Hydrogen Powered Aviation in Aotearoa New Zealand

Prepared by the New Zealand Hydrogen Aviation Consortium | September 2023 | www.h2aviationconsortium.co.nz

AIRBUS AIR NEW ZEALAND CHRISTCHURCH AIRPORT FABRUM. Fortescue HIRINGA



“Globally, thousands of smart, innovative people are working on new technologies that will enable aviation to reduce emissions. Green hydrogen is an important part of the solution and New Zealand is uniquely positioned to be a leader in the testing and deployment of these low emission aircraft and technologies.

We’ve come together to make that happen.”

New Zealand Hydrogen Aviation Consortium

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“The Consortium brings together a number of pioneering partners with a common interest: to make hydrogen-powered aviation in New Zealand a reality.”

AIRBUS
Karine Guenan
VP of the ZEROe Ecosystem
Airbus

“This consortium will ensure Aotearoa is ready to deploy green hydrogen aircraft once they’re available for commercial use. This is pioneering innovation.”

CHRISTCHURCH AIRPORT
Justin Watson
Chief Executive
Christchurch Airport

“Together we’ll make a big difference in taking zero emission aviation forward which is good news to anyone who wants to fly sustainably in the future.”

FABRUM.
Christopher Boyle
Co-Founder and Chair
Fabrum

“We are on a mission to eliminate fossil fuels, including from the aviation industry, and green hydrogen is a key to achieving this.”

Fortescue
Mark Hutchinson
CEO
Fortescue Energy

“Decarbonising aviation is our most significant challenge. And working collaboratively will be the most effective way our industry will progress the changes we need. Air NZ is very pleased to be part of this Consortium and we look forward to seeing how we can collectively build out green hydrogen infrastructure for aviation in Aotearoa.”

AIR NEW ZEALAND
Kiri Hannifin
Chief Sustainability Officer
Air New Zealand

“Our team is highly motivated to leverage our hands-on experience bringing green hydrogen to market to enable low emission aviation.”

HIRINGA
Andrew Clennett
Chief Executive
Hiringa Energy

Foreword

It is with great enthusiasm that I accepted the invitation to provide this foreword, having for some years now advocated for New Zealand to lead the world in being the first to move to 100% low emission (hydrogen and battery-electric) powered domestic aviation, and having been in regular discussions with many of these companies, encouraging them in this direction, for a similar period.

This report on hydrogen-powered domestic aviation in New Zealand is another key step forward towards these ambitious goals, and I congratulate these six companies on working together to make this a reality.

To summarise why New Zealand is ideally suited to this transition to hydrogen powered aviation:

1. We do not have a network of fast intercity trains, and our roads are modest due to our geography and low population density.
2. So we fly, with New Zealander's ranking number 15 in the world for the number of flights per capita.
3. Domestic flight distances around New Zealand, and perhaps to the east coast of Australia, are right for a mix of electric and hydrogen, both zero-carbon fuels, to be employed.
4. We already have a high percentage (about 85%) of renewable electricity generation, and more importantly we have massive, largely untapped to date, wind (on and offshore) and solar resources, so can readily double or preferably treble our current renewable electricity generation to enable this transition to a suite of future fuels (carbon-zero and carbon-neutral).
5. We have a relatively flat structure with good access to Government, a highly innovative and skilled workforce, and we are known for being able to move fast when we want to (for example when creating a space agency, fibre rollout and foiling a hydrogen fuel cell electric vehicle (HFCEV) chase boat).

It is also critical to note that New Zealand is remote from the rest of the world. So, we are uniquely dependent on aviation, for high value trade in particular.

Rapidly reducing the emissions associated with the transport of our exports must also be a top priority if we are to remain competitive in the global marketplace. For long-haul international flights this will require a mix of bioSAF and eSAF ('drop in' carbon neutral fuels).

In conclusion, shifting from fossil fuels to a suite of zero to low emission future fuels is a transformative economic opportunity for New Zealand. Furthermore, failing to do so would be a serious economic risk, especially regarding trade. Together this carrot and stick should encourage New Zealand to be bold and invest in adopting these future fuels with urgency. To do so will enable us to live up to our '100% Pure' image, contribute to mitigating the increasingly severe effects of climate change, and transform our economy into a high wage one.

C'mon New Zealand, we CAN do this!

Professor Sally Brooker
MNZM FRSNZ FNZIC FRSC
He Honoka Hauwai — German-NZ
Green Hydrogen Centre[1]
University of Otago, Dunedin, New Zealand

1. https://blogs.otago.ac.nz/honoka-hauwai/

Contents

Key messages for stakeholders and partners

Renewable Electricity Generation, Transmission and Distribution

- Green hydrogen has the potential to be an important part of New Zealand's transition to a lower emissions economy. It can help reduce aviation's emissions but also those from heavy transport, industrial production and energy storage.
- New Zealand's electricity supply sector needs to grow quickly to have sufficient generation and transmission capacity to meet the demand coming from aviation.
- New generation and transmission requirements will be greater than what is currently forecast by Government agencies.
- Green hydrogen production for aviation will require a significant increase in New Zealand's supply of renewable electricity.
- Indicatively up to 6.7 TWh pa of renewable energy will be needed to meet the Consortium's 2050 hydrogen demand modelling of up to 100,000 tonnes per annum for domestic aviation.
- There may be further hydrogen demand from short haul international flights and/or for production of sustainable aviation fuels.
- Electricity cost has the largest impact on the levelised cost of supplied hydrogen. Lowering that cost is a key lever for enabling green hydrogen aviation.
- A combination of onsite (at airports) and offsite electricity generation (grid) will likely be needed for hydrogen production at/near airports.
- This is additional to the electricity supply required for battery-electric aviation.
- Ensuring New Zealand has the transmission network needed to enable hydrogen production for aviation will be challenging and action is needed for hydrogen production at/near airports.

Green Hydrogen Production, Storage and Liquefaction

- Green hydrogen production is a new industry for New Zealand and currently small-scale.
- Green hydrogen production is more cost effective at scale, yet initial demand will be low.
- Support mechanisms from Government will reduce the risk to participants and help close the commercialisation gap as production increases.
- While hydrogen aircraft technology is still being developed and deployed, additional demand for green hydrogen across the economy will help to kickstart the scale of production aviation needs for hydrogen to become cost effective.
- It is essential effort is focused on green hydrogen production from renewable energy and sustainable water sources (including wastewater options).
- Hydrogen production will likely be required at several key locations — on-airport or in proximity to key airports.
- Efficiency in plant, infrastructure and supply chain/logistics helps lower the cost of supplied hydrogen.

Hydrogen Distribution and Refuelling

- Infrastructure and processes for delivery of hydrogen to airports from the production site require careful planning. Options include delivery by road and/or pipeline.
- The aviation industry needs to consider onsite refuelling infrastructure and operational requirements early in the master planning phases.
- The operational and refuelling technology exists, and is being developed further to meet aviation scale-up requirements
- The regulations around refuelling with liquid hydrogen are not yet developed in New Zealand.
- Aviation is a global industry. This means New Zealand will be able to develop regulations utilising international regulations and standards.

Aviation End Use

- New Zealand's geography and scale of domestic aviation (both size of aircraft and length of journeys) means it is an ideal location for hydrogen powered aircraft.
- Liquid Hydrogen (LH_2) has the potential to be the fuel powering most commercial flights within New Zealand by 2050.
- H_2 fuelled planes are currently being developed and trialled internationally. Airbus is targeting H_2 commercial entry to service by 2035.
- Hydrogen modelling for Air New Zealand's domestic fleet suggest demand could be up to 100,000 tonnes by 2050. This could remove up to 900,000 tonnes of GHG emissions per annum by 2050.
- There will be additional emissions reductions opportunities from green hydrogen being used by other domestic airlines, for short-haul international flights and for the production of sustainable aviation fuels.

Executive Summary

Aviation is critical to New Zealand's present and future prosperity
Aviation sits across our entire economy, providing access to domestic and global markets for primary industry, tourism, healthcare, business and education.

Globally, the sector recognises it emits greenhouse gases and is investing in the development of new technology to reduce these. This is technically and economically challenging, making aviation one of the 'hard to abate' sectors.

New Zealand's geographical remoteness from international markets necessitates a heavy reliance on carbon intensive, long-haul aviation at present. International consumers are increasingly scrutinising the emissions impact of the products and services they use. For New Zealand to retain confidence in vital export industries like tourism, proactive measures must be taken to reduce their overall greenhouse gas emissions.

The aviation sector is taking on these challenges and this report is one of many steps underway to ensure that it supports New Zealand to achieve its net zero by 2050 target. It will not be easy and will take time, investment and unprecedented collaboration.

Green hydrogen is a key future fuel to reduce New Zealand's aviation emissions
The New Zealand Hydrogen Aviation Consortium has come together to lay the groundwork for the effective deployment of green hydrogen powered aviation and to support transition of New Zealand's airports into hydrogen hubs serving both aviation and non-aviation users.

The Consortium has a specific focus on using locally produced green hydrogen made by using renewable electricity to electrolyse water.

By 2050, the Consortium envisages liquid green hydrogen fuelling most commercial flights within New Zealand and possibly for some short-haul international routes to Australia and the Pacific Islands.

There is increasing global consensus that three complementary fuel options will underpin the reduction of the aviation sector's emissions; green hydrogen, battery-electric technology, and sustainable aviation fuel. All three fuel options are likely to be needed and used to reduce emissions from New Zealand's commercial aviation.

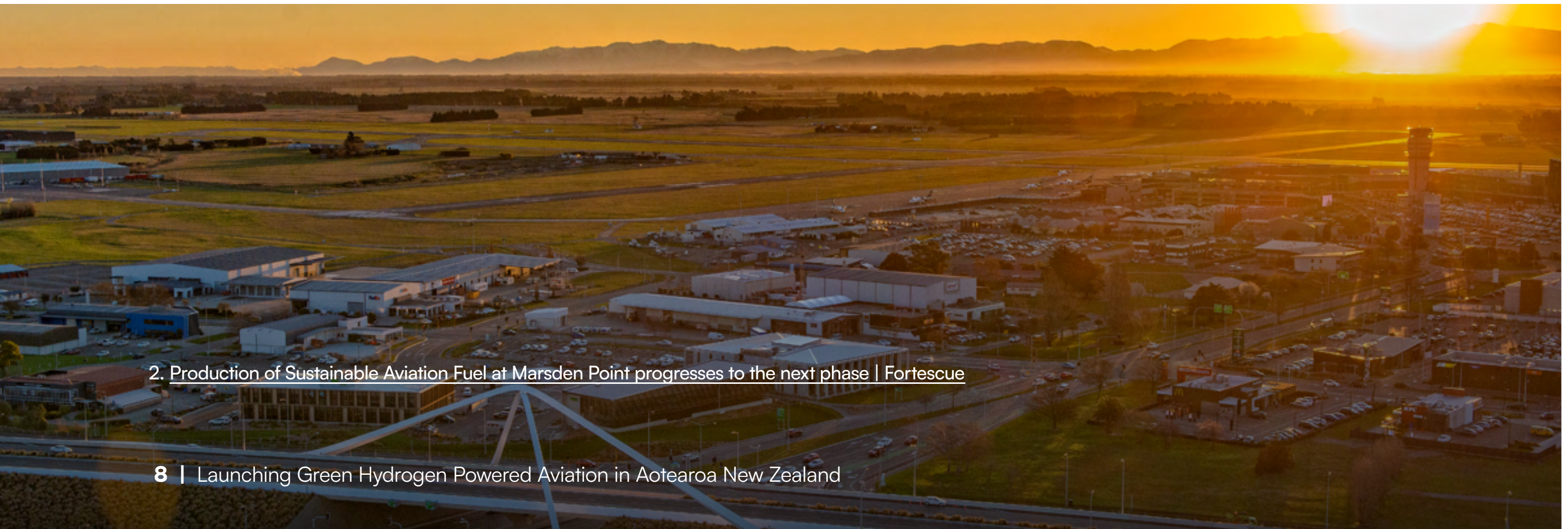
Green hydrogen powered aircraft may complement the use of small battery-electric aircraft flying short distances while sustainable aviation fuel will power larger aircraft flying longer distances.

In addition to its direct use as a fuel, green hydrogen can also be used as a feedstock for producing sustainable aviation fuel. Please note this report focuses solely on the direct use of green hydrogen in aviation and excludes potential demand for hydrogen created for the production of SAF. This use case is being explored[2] and adds weight to the need for New Zealand to create a green hydrogen ecosystem.

The Consortium will lead the introduction of green hydrogen for aviation in New Zealand
In publishing this report the Consortium members are:

- Presenting the rationale for the use of green hydrogen as an aviation fuel,
- Describing the challenges and the opportunities for its use in aviation,
- Outlining a pathway to launch and grow the use of green hydrogen in aviation,
- Sharing the key enablers for the transition with regulators, iwi and policy makers in New Zealand, and
- Providing confidence to the aviation sector, airports, investors and the wider community that there is an achievable low emissions future for aviation in New Zealand and beyond.

New Zealand is ideally suited to lead the development of green hydrogen as an aviation fuel. The country's large renewable electricity and water resources are key advantages while the size of aircraft used in the country and the length of routes flown match the capabilities of hydrogen-powered aircraft.



2. Production of Sustainable Aviation Fuel at Marsden Point progresses to the next phase | Fortescue

While the Consortium is leading the process of developing green hydrogen as a low emissions aviation fuel, the members will need support from many other stakeholders and partners to achieve success. This includes both public and private sectors, regulators, iwi (and hapū); some of whom are developing expertise and/or already involved with current or proposed hydrogen projects.

Technical and commercial challenges will need to be addressed
There are technical challenges surrounding the introduction of green hydrogen in aviation, but the core technologies are under development from both traditional and start-up manufacturers. It is anticipated these aircraft will be available for trial flights in New Zealand during the 2020s, with the potential for a full rollout of commercial service fleets in the 2030s.

Green hydrogen will need to become more cost-effective to produce and supply if it is to become commercially viable for aviation. Lowering production costs will be difficult when initial demand is low as economies of scale only develop with greater demand. Closing this commercialisation gap is a significant challenge for the successful introduction of green hydrogen in aviation, which will require focus from all stakeholders.

Potential demand for green hydrogen has been modelled
The Consortium has modelled the potential demand for green hydrogen as an aviation fuel in New Zealand through until 2050 plus the resource requirements to produce it. This modelling suggests up to 100,000 tonnes of green hydrogen could be required annually by 2050.

The renewable electricity generation capacity required to produce this volume of green hydrogen in New Zealand is large (up to 6.7 TWh p.a. using current technology). Developing new generation capacity at the rate and scale required, supported with new transmission infrastructure, and hydrogen production plants, will be challenging but is considered achievable.

Production of hydrogen for aviation can support wider electricity market benefits
Production of green hydrogen via electrolysis can be turned off or on at short notice. This demand response capability can enable renewable electricity to be released to the wider market. The development of green hydrogen production for aviation can benefit the wider electricity market and support the country's transition to a 100% renewable electricity system.

Coordination with Government is essential
The members of the Consortium are committed to accelerating the introduction of green hydrogen for aviation but share a concern that its introduction will be delayed if the industry acts in isolation.

The Consortium recommends the New Zealand Government considers and enables the use of hydrogen in aviation while developing green hydrogen within other areas of transport and industry. This means taking important actions to help position New Zealand as a global leader in reducing aviation emissions such as:

- Actioning a long-term cross-party approach to reducing greenhouse gas emissions from aviation and establishing a green hydrogen industry in New Zealand,
- Including the green hydrogen pathway for aviation as a key action for the sector in the Emissions Reduction Plan for the period 2026 to 2030,
- Developing a regulatory and policy environment that enables the development of renewable electricity generation and green hydrogen production to underpin the use of green hydrogen in aviation,
- Continuing to use the Emissions Trading Scheme to incentivise cleaner fuel options such as green hydrogen,
- Creating an enabling environment for investment through policies that de-risk and incentivise green hydrogen production and related renewable electricity generation. For example, concessionary finance, power purchase agreements, green hydrogen production credits or rebates. These initiatives could be supported from the Climate Emergency Response Fund or one of the programmes it supports (such as the Low Emissions Transport Fund or the Government Investment in Decarbonising Industry Fund), and
- Ensuring New Zealand's electricity sector grows quickly enough and has sufficient generation and transmission capacity to meet the significant increase in demand that will come from emissions reductions in multiple industries, including aviation. New generation and transmission requirements will be greater than current forecasts by Government agencies due to aviation demand for green hydrogen not being included in current modelling.

New Zealand's net zero legislation was developed with a cross-party approach. The Consortium encourages political leaders to continue that approach when implementing the key actions, such as reducing aviation emissions, that will be required to reach the target of net zero by 2050.

Key Levers

Required to Launch Green Hydrogen Aviation in Aotearoa New Zealand

Industry levers and Government support
The following key levers diagram highlights the industry levers and Government support that can be applied to launching and then developing the use of green hydrogen in aviation.

Collaboration is the key to success
Collaboration between the Consortium, Government and other stakeholders is key to developing a green hydrogen ecosystem and achieving the roadmap outlined at the end of this report.

It requires collaboration of private and public sectors to encourage investment in the renewable energy and hydrogen production industries. Government strategies will be key to creating scale and commercial viability by aligning transport and heavy industry emissions reduction through the use of green hydrogen.

If Government and businesses work together, aviation emissions can be reduced while managing the cost of sustainability on New Zealand's economy and New Zealanders.

Renewable Electricity Generation, Transmission and Distribution

Certainty of supply of renewable energy for hydrogen production (at scale, at right time)

Hydrogen Aviation Consortium Actions / Levers

- Green hydrogen production is electricity intensive and will require a significant increase in New Zealand's supply of renewable electricity.
- Indicatively need 6.7 TWh p.a. of renewable electricity to meet the Consortium's modelled green hydrogen demand for 2050.
- Electricity cost has the largest impact on the levelised cost of supplied hydrogen — key lever for lowering cost.
- A combination of onsite (airport) and offsite generation (grid) will likely be needed.
- Hydrogen demand for renewable electricity is in addition to demand for powering battery-electric aircraft.
- Ensuring generation/transmission investment programme meets H_2 demands will be challenging, and action is needed now.
- New Zealand's electricity supply sector needs to grow quickly enough and have sufficient generation and transmission capacity to meet the wall of demand that will come from aviation.
- New generation and transmission requirements will be greater than current forecasts by Government agencies.

Government Actions / Levers

- Setting regulations and policies that enable the timely development of renewable electricity generation and transmission infrastructure.
- Ensuring the electricity requirements for green hydrogen production (and e-SAF) are recognised in Government forecasts (such as the Electricity Demand and Generation Scenarios).
- Providing initiatives to de-risk and encourage investment in renewable energy generation (i.e Contracts for Difference mechanism and/or Government sector Power Purchase Agreements).
- Transmission charges pricing relief/incentives for green hydrogen production purposes.
- Reviewing the regulatory frameworks to enable major investment in electricity transmission and distribution infrastructure to be planned and developed ahead of demand.
- Ensuring that resource management legislation enables projects to be consented and developed promptly.

Industry Actions / Levers

- Opportunity for electricity generation developers to engage with hydrogen developers.

Green hydrogen production, storage and liquefaction

Development of commercial supply chain for hydrogen at scale (de-risking ramp-up)

Hydrogen Aviation Consortium Actions / Levers

- Risk for participants establishing a new industry needs support mechanisms from Government
- Hydrogen production is more cost effective at scale, yet initial demand will be low.
- The technology exists, and is being developed further to meet aviation scale-up requirements
- Industry is committed to green hydrogen production from renewable energy and sustainable water sources (including waste water options).
- Hydrogen production will likely be required at several key locations — on-airport or in proximity to key airports
- Efficiency in plant, infrastructure & supply chain logistics will help lower the cost of supplied hydrogen.

Industry Actions / Levers

- Collaborating on hydrogen hubs and demand / coordinated investments and projects.

Government Actions / Levers

- Developing a National Policy Statement on Hydrogen
- The development of a Hydrogen Taskforce and/or the appointment of a Hydrogen Champion to oversee the delivery of actions included in the Hydrogen Roadmap and provide ongoing independent advice to Government to activate and develop the hydrogen sector.
- Providing policy initiatives to de-risk and encourage investment in green hydrogen (ie. Contracts for Difference, production credits, cross-funding to subsidise green hydrogen).
- Capital support for early/sub-scale plants prior to achieving minimum viable commercial scale.
- Developing and funding national green hydrogen demand (in addition to demand from aviation industry) to improve economies of scale, infrastructure and production costs, and support the efficient ramp-up in demand over time.
- Adoption of international hydrogen standards as part of regulatory environment, to ensure the industry operates consistently, safely and cleanly.

Hydrogen distribution and refuelling

Operational and infrastructure requirements to deliver/refuel hydrogen aircraft

Hydrogen Aviation Consortium Actions / Levers

- Aviation industry needs to consider onsite refuelling infrastructure and operational requirements early in the master planning phases
- The technology exists, and is being developed further to meet aviation scale-up requirements
- The regulations around refuelling with liquid hydrogen are not yet developed in New Zealand.
- As aviation is a global industry the development of the required New Zealand regulations will likely be able to utilise international regulations and standards.

Government Actions / Levers

- Adoption of international hydrogen standards as part of regulatory environment, to ensure the industry operates consistently, safely and cleanly.
- Coordination across multiple government organisations including Airways, CAA, Worksafe, MBIE, Ministry of Transport.
- Capital support for early/sub-scale plants prior to achieving minimum viable commercial scale.

Industry Actions / Levers

- Airports — include hydrogen powered aircraft and infrastructure requirements into master-planning.
- Airports advocating for hydrogen uses in non-aviation purposes (emergency vehicles, buses, emergency generators)
- Airports — collaborate on learnings/opportunities for H_2 (locally and globally)

Aviation end use

Establishing aviation market for hydrogen aircraft

Hydrogen Aviation Consortium Actions / Levers

- NZ is an ideal location for hydrogen powered aircraft.
- Liquid Hydrogen (LH_2) is the likely fuel for most commercial flights within NZ, by 2050.
- H_2 fuelled planes are currently being developed and trialled internationally. Airbus targeting H_2 commercial flight by 2035
- The Consortium's modelled green hydrogen demand for aviation is 100,000 tonnes per annum by 2050. This would remove up to 900,000 CO_2-e per annum.
- Additional emissions reductions opportunity from international flight and other airlines.
- Additional H_2 demand if used in short-haul international (Eastern Australia, Pacific Islands) and for eSAF production.

Government Actions / Levers

- Develop a Net Zero Aviation Strategy, which delivers on the COP26 commitment of promoting development and deployment of new low and zero-carbon aircraft technologies that can reduce aviation CO_2 emissions.
- Including the green hydrogen pathway for aviation as a key action for the sector in the Government's Emissions Reduction Plan (including for the period 2026 to 2030).
- Using the Emissions Trading Scheme to incentivise cleaner fuel options such as green hydrogen. This may include concessionary finance, green hydrogen production credits, or landing tax rebates for low emissions flights.
- Including aviation as a key sector of focus in NZ Hydrogen Roadmap.
- Introducing mandates for low emission fuel use.
- Supporting development of trans-Tasman green lanes (routes).
- Implement regulations and certification of hydrogen aircraft in NZ, ie CAA.
- Hydrogen aircraft regulations and international Standards adoption.

Industry Actions / Levers

- Airlines — include hydrogen powered planes in future planning / routes etc...
- Work with airports/green hydrogen developers on supply chain.
- Adopt the EASA eco-labelling system for informing passengers.

Section A: The opportunity for green hydrogen to power aviation in Aotearoa New Zealand

Why Green Hydrogen is so important for aviation in New Zealand
As an isolated country, aviation plays a vital role in connecting New Zealanders to the world and in enabling trade and tourism.

In other countries air travel is being replaced by lower carbon alternatives; high-speed train services, long distance and high-speed dual carriageway roads, or by marine transport. However, New Zealand is an isolated country comprising of long thin islands with multiple mountain ranges. Therefore, aviation plays a vital role not only internationally but domestically.

Aviation connects New Zealanders to the world, to family and friends, and it enables trade and tourism. New Zealand's geography means the country will remain reliant upon air travel for domestic and short-haul international journeys.

For this reason, the Consortium is confident that strong demand for air services will continue in New Zealand, provided it can reduce emissions.

The New Zealand Government committed to the International Aviation Climate Ambition Coalition set up at COP26 in Glasgow in 2021[3]. This included commitments to:

- Advance ambitious actions to reduce aviation CO_2 emissions at a rate consistent with efforts to limit the global average temperature increase to 1.5°C.
- Promote the development and deployment, through international and national measures, of innovative new low- and zero-carbon aircraft technologies that can reduce aviation CO_2 emissions.

In 2022 the Government also adopted the International Civil Aviation Organization's collective goal of net zero carbon emissions from aviation by 2050[4].

The country's first Emissions Reduction Plan (2022) subsequently contained aviation related actions in its transport initiatives[5]. These included the establishment of Sustainable Aviation Aotearoa, a public private leadership body focused on decarbonising aviation[6], and specific targets for decarbonising domestic aviation and implementing a sustainable aviation fuel (SAF) mandate.

These Government-mandated actions are complemented by strong commitment from sector leaders and growing consumer demand for businesses to reduce emissions. Aviation is one of many sectors of the New Zealand economy that will need to make significant changes to meet these targets and expectations.

New Zealand's current aviation emissions
According to the Ministry for the Environment's Emissions Tracker[7] domestic flights within New Zealand emitted 1,024,890 tonnes of CO_2-e[8] in 2019[9]. This was 1.26% of New Zealand's total reported gross domestic greenhouse gas emissions of 81,617,000 tonnes of CO_2-e[10].

However, most emissions from aviation are a result of international aviation. In 2019 it accounted for around 80% of total aviation emissions (3,893,600 tonnes of CO2-e), bringing aviation's total impact to 4.9 million tonnes of CO2-e, or 6% of New Zealand's total gross GHG emissions.

3. International Aviation Climate Ambition Coalition: UN Climate Change Conference (COP26) at the SEC — Glasgow 2021
4. States adopt net-zero 2050 global aspirational goal for international flight operations | International Civil Aviation Organization (ICAO)
5. Transport | Ministry for the Environment
6. Sustainable Aviation Aotearoa was established in 2022
7. New Zealand's interactive emissions tracker | Ministry for the Environment

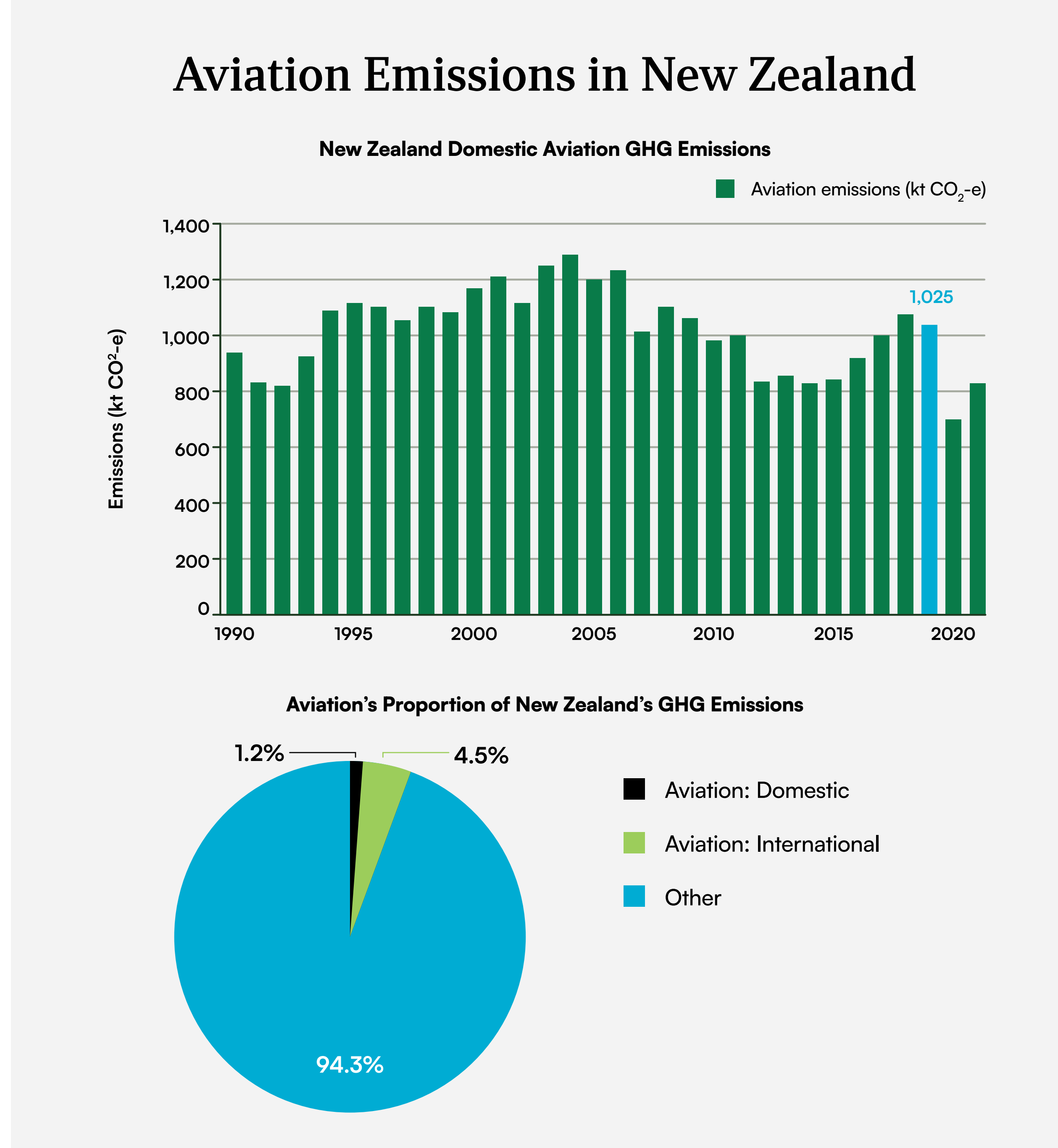


Figure 1. Aviation Emissions In New Zealand, Source Ministry for the Environment

8. Greenhouse gas emissions are made up of a mixture of gases — each of which have differing impacts and differing periods during which they remain active as greenhouse gases in the atmosphere. For example methane (CH4) has an initially bigger impact than CO_2 but does not stay active for as long. CO_2-e is a measure that combines the impact of these various gases into an equivalent volume of only CO_2 emitted.
9. 2019 is the last full pre-Covid normal year
10. New Zealand's greenhouse gas emissions | Stats NZ

To date, the aviation sector's actions to reduce emissions have largely focused on fleet renewal and reducing fuel use by improving route and operational efficiency. There are limits to how far aviation emissions can be reduced while aircraft continue to be powered by fossil fuels. For aviation to meet its 2050 commitments and expectations, the use of fossil fuels will need to be phased out and replaced by low emission alternatives.

The new aviation fuels
Finding alternative fuels for aviation that provide comparable performance to fossil fuels while reducing, or ideally eliminating, the associated GHG emissions is challenging. This is why aviation is viewed as a hard to abate sector. There is growing international consensus there will be a mix of low emissions options required for aviation to meet its net zero 2050 goals, depending on the length of journey and size of aircraft required:

- Battery-electric technology will likely be best suited for small aircraft (less than ~20 passengers) flying short distances (less than ~400km)
- Hydrogen-powered technology will likely be best suited for medium sized aircraft (~20-200 passengers) flying distances up to ~2,000km and potentially up to ~3,500km.
- Sustainable Aviation Fuel (eSAF or bioSAF[11]) has the potential to power aircraft for all distances. However, due to supply constraints, the use of SAF should be focused on larger aircraft (more than ~150 passengers) flying longer routes (more than ~2,000km) for which emissions remain hardest to abate.

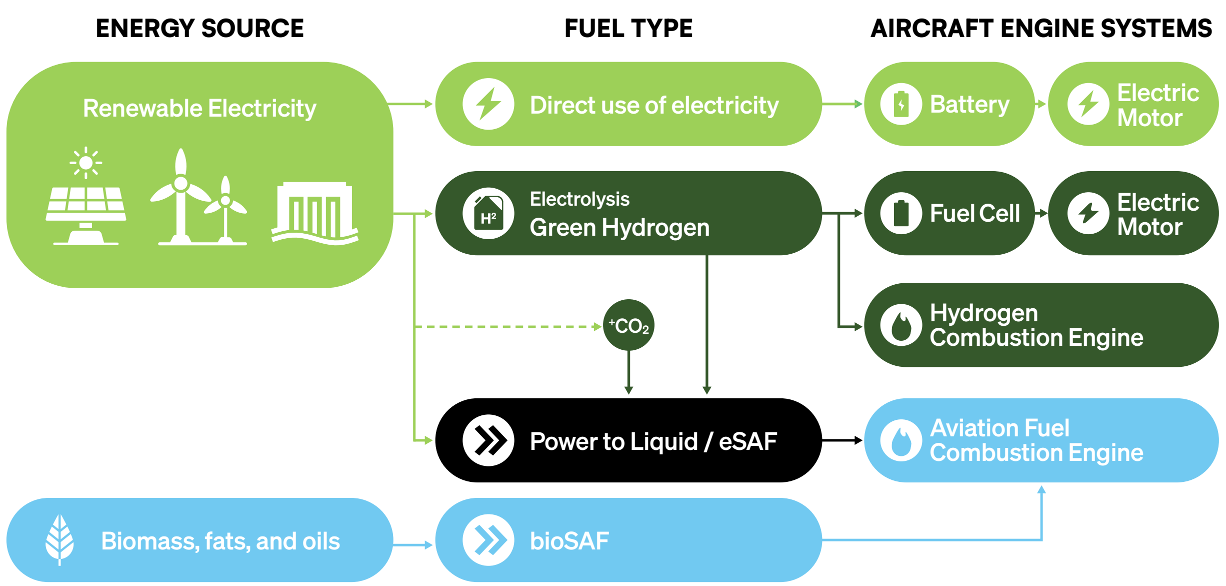


Figure 2. The new aviation fuels

The use of hybrid-electric aircraft could complement the use of pure battery powered aircraft. These aircraft could offer longer ranges and greater payload opportunities than pure battery-electric aircraft but will come with the added complexity of also using combustion engines.

Green hydrogen as an aviation fuel
All hydrogen that is produced and used industrially is chemically identical. The difference between green hydrogen and other 'colours' is that green hydrogen is produced using renewable electricity. The electricity is used to electrolyse (or split) water (H_2O) into H_2 and O_2.

Three different pathways are being explored for how green hydrogen can be utilised directly[12] as an aviation fuel:

- It can be burnt in a combustion engine similarly to how aviation fuel is currently used[13].
- It can be chemically combined with oxygen in a fuel cell. This chemical reaction produces electricity and water. The electricity is then used to power an electric motor while the water is a waste product[14].
- Aircraft can also be powered by a hybrid system combining both combustion and fuel cell technology.

Green hydrogen is also a key feedstock for the production of eSAF, and can play a significant role in reducing the carbon intensity and increasing yields from bioSAF production.

While using green hydrogen as an aircraft fuel greatly reduces GHG emissions, it does not eliminate them.

The production of green hydrogen from renewable electricity is a zero or very low emission[15] process.

While hydrogen produces no CO_2 emissions during its combustion or usage in a fuel cell, there are some non-CO_2 GHG effects linked to hydrogen for aviation — namely production of nitrous oxides (NOx) that occur during combustion and/or contrails from the release of water vapour.

11. Sustainable Aviation Fuel can be produced via two main pathways — as eSAF produced by combining green hydrogen with carbon dioxide and bioSAF produced from biomass.

12. As noted above green hydrogen can also be used indirectly as one of the raw materials for making SAF.
13. Hydrogen combustion, explained | Airbus
14. Could hydrogen fuel-cell systems be the solution for emission-free aviation? | Airbus
15. While hydro, wind and solar generation are zero emissions processes, geothermal electricity generation does release some greenhouse gas emissions albeit much lower than fossil fuel based thermal electricity generation.

New Zealand's opportunity to be a global leader in green hydrogen powered aviation
New Zealand has several key advantages that support the opportunity to develop green hydrogen-powered aviation.

Plentiful renewable electricity resources
Renewable electricity is the key resource that underpins green hydrogen production. New Zealand is rich in renewable resources and already generates most of its electricity from renewable sources — averaging over 87% renewable generation in 2022[16]. This is higher than most other developed countries. Based on known resources[17] New Zealand has the physical capacity to produce the volume[18] of renewable electricity needed to replace the use of fossil fuels and reduce emissions from its energy system, including for aviation.

Strong commercial support to grow renewable energy generation
There is rapidly growing commercial interest in developing new renewable electricity generation projects in New Zealand.

Over the decade preceding 2019, Transpower typically received a handful of new generation connection enquiries per year. This number of enquiries has expanded rapidly since 2020 and over 100 generation connection enquiries were made in the year to 30 June 2022 with a further 60 in the nine months to March 2023. As other New Zealand industries reduce emissions, this demand and opportunity is expected to continue.

New Zealand has a range of sustainable water sources
The second key resource needed for green hydrogen production is a consistent and sustainable supply of water. Water sources can include a mixture of freshwater, groundwater, and treated wastewater. Saltwater may also be an option for future use.

While parts of New Zealand have constraints on water supply, the country as a whole is water rich compared to most developed countries.

It is important, however, to recognise this valuable resource is precious. Wai (water) is a taonga for tāngata whenua. It sustains life and is a core part of Māori cultural identity — without it, people, animals, plants or fish cannot survive. That means the health of the waterways, oceans and freshwater of Aotearoa must be protected and organisations involved in green hydrogen production must do so in the spirit of kaitiakitanga and partnership with iwi and hapū.

The green hydrogen ecosystem also supports the concept of the circular economy, Ōhanga Āmiomio, where renewable energy is the foundation and resources such as water are recovered and regenerated where possible. Due to the more sustainable production methodology, all the new hydrogen projects currently being considered for development in New Zealand involve green hydrogen.

New Zealand Government support
To achieve the country's emissions reduction targets, the Government is co-investing with industry. Recent examples include supporting the transition from fossil fuels to renewable energy by companies such as NZ Steel and Fonterra and the development of the Hiringa/Ballance Agri-Nutrients green hydrogen project at Kapuni[19].

In its 2023 Budget, the New Zealand Government announced the Regional Hydrogen Transition initiative[20]. From 2024 this $100m programme will provide a rebate mechanism to bridge the price gap between green hydrogen and fossil fuel alternatives.

In August 2023 the Government released an Interim Hydrogen Roadmap for New Zealand. This will inform the New Zealand Energy Strategy which is due for completion by the end of 2024.

The Government is also considering regulatory changes to enable hydrogen's use. This clarity on the Government's commitment to the hydrogen sector will reduce risk for investors.

Energy independence
The development of New Zealand-based fuel supply lines reduces risks from relying on other countries for fuel. This provides increased security of supply for a critical industry while also reducing exchange rate risks. The returns from successfully doing so will provide long term environmental, economic, and social benefits to New Zealand.

16. As reported in MBIE's "Energy in New Zealand 2023" report.
17. New Zealand generation stack updates | Ministry of Business, Innovation & Employment (mbie.govt.nz)
18. There are different scenarios and varying forecasts about just how much electricity will be needed to decarbonise the energy system. Some scenarios suggest New Zealand needs 1.5x as much electricity by 2050, others suggest 2x as much electricity while others suggest 3x. New Zealand has the physical capacity to achieve the requirements of all these scenarios though achieving 3x is more challenging than 1.5x. Fully decarbonising current levels of domestic, regional and international aviation with green hydrogen is expected to require new renewable generation perhaps greater than New Zealand's current total generation. This suggests that New Zealand will need considerably more than 1.5x current generation.

19. As discussed later in this report the Governments of several other countries are providing even more support for hydrogen developments. A range of additional steps the New Zealand Government could take to encourage and enable the use of hydrogen in aviation are suggested.
20. Regional Hydrogen Transition | Ministry of Business, Innovation & Employment

Section B: Aotearoa New Zealand's green hydrogen aviation requirements

Hydrogen Demand
Prior to Covid-19, Air New Zealand flew 3,500 flights per week, and within Aotearoa, over 360 domestic flights a day to 20 destinations. Operations are split into three markets:

- The domestic network - which is most suited to the first hydrogen fuelled aircraft similar to that proposed by Airbus.
- The short-haul international network (Australia and the South Pacific) - which is expected to be more suitable for hydrogen once technology improves. This could be as soon as the 2040s.
- The international long-haul network (currently Asia, Hawaii and North America) - which is expected to transition to be fuelled by SAF.

To give a sense of scale, In the pre-pandemic baseline year of 2019, approximately 1.7 million tonnes of aviation fuel[21] was used for refuelling international, domestic and regional aviation in New Zealand. If all this fuel was converted to hydrogen, aviation would require ~590,000 tonnes of green hydrogen per annum[22].

In order to understand more tangible future hydrogen needs, the Consortium completed a modelling exercise to understand the demand created by transitioning the domestic fleet to green hydrogen powered aircraft through to 2050.

It should be noted that this modelled demand for green hydrogen does not include:

- Potential demand from other airlines operating in New Zealand.
- Potential demand for use on short-haul international routes (to and from Australia and the Pacific Islands).
- Air New Zealand's domestic fleet (turboprop and domestic jets) fully transitioning to hydrogen by 2050.
- Production of SAF.

The potential volume of green hydrogen needed for SAF production is significant and likely much greater than for its direct use as an aviation fuel. Demand modelling for SAF production was outside the scope of this report.

Greenhouse gas emissions removed by Air New Zealand's transition to green hydrogen
The modelling completed by the Consortium suggests that a transition of Air New Zealand's domestic fleet to green hydrogen powered aircraft could remove up to 900,000T CO_2 by 2050. This is equivalent to the CO_2 emissions of 621,000 new vehicles driving an average of 10,000km per year.[23]

The potential reduction in New Zealand's aviation emissions will be even greater if:

- Other airlines begin to use green hydrogen.
- Hydrogen aircraft technology is available and utilised for short-haul international flights.
- Aircraft fleet replacement timelines can be accelerated.

Potential Hydrogen Demand and Impact

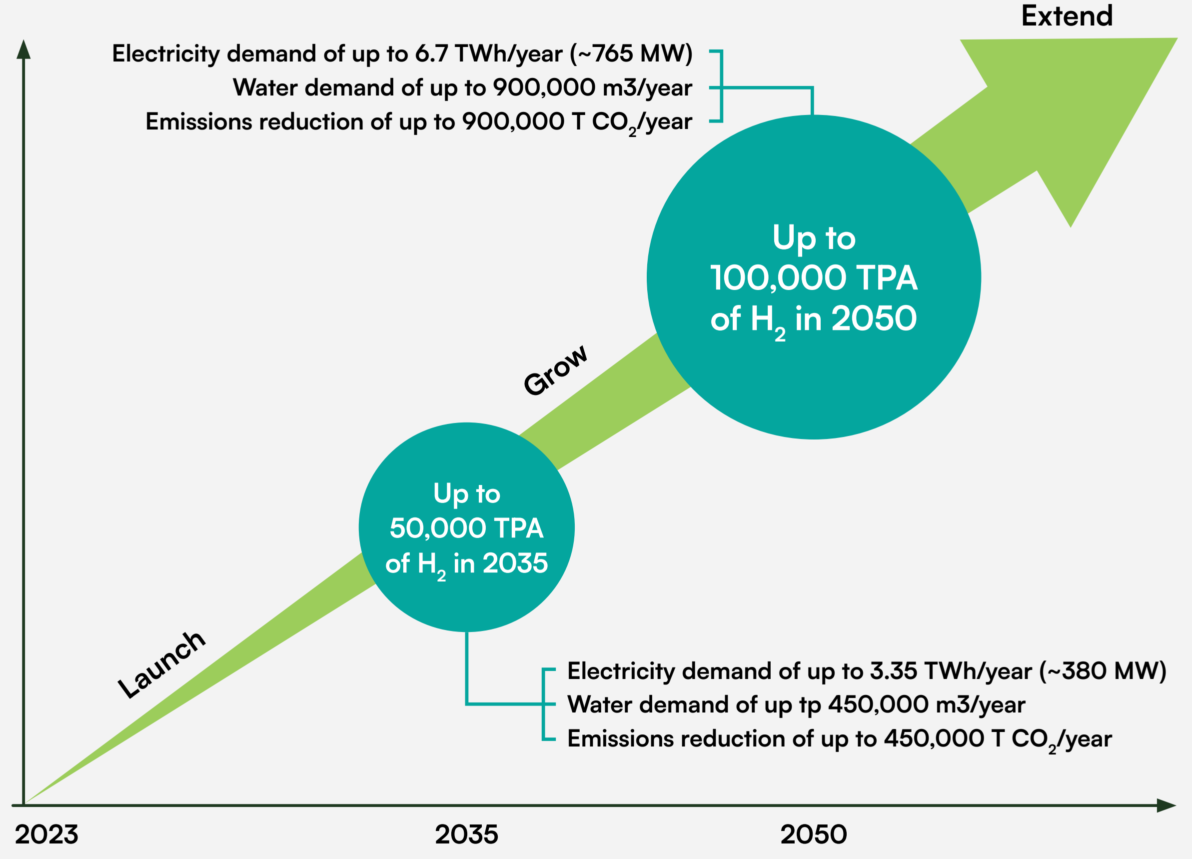


Figure 3. Potential Hydrogen Demand and Impact

21. Estimated by Arup in Pilot Hydrogen Hubs for Trialling Advanced Aviation in New Zealand (mbie.govt.nz)
22. The reduction in tonnage is because hydrogen has abo three times the energy density by weight than aviation fuel.
23. Assumes new vehicles meet the Ministry of Transport's 2023 clean car standard for passenger cars of 145 grams of CO_2 per km.

Section C: Establishing Aotearoa New Zealand's green hydrogen ecosystem

A significant transition from the existing aviation ecosystem needs to occur to support green hydrogen as an aviation fuel.

The aviation hydrogen ecosystem is expected to comprise a series of interlinked components.

Airports will be at the hub of the ecosystem with many components based at airport campuses. Some components such as electricity generation and green hydrogen production may occur onsite or at a distance from an airport. The Consortium has broken down the hydrogen aviation ecosystem into the following simplified structure:

1. Renewable electricity generation, transmission and distribution.
2. Green hydrogen production, liquefaction and storage.
3. Hydrogen distribution and refuelling.
4. Aviation end use.

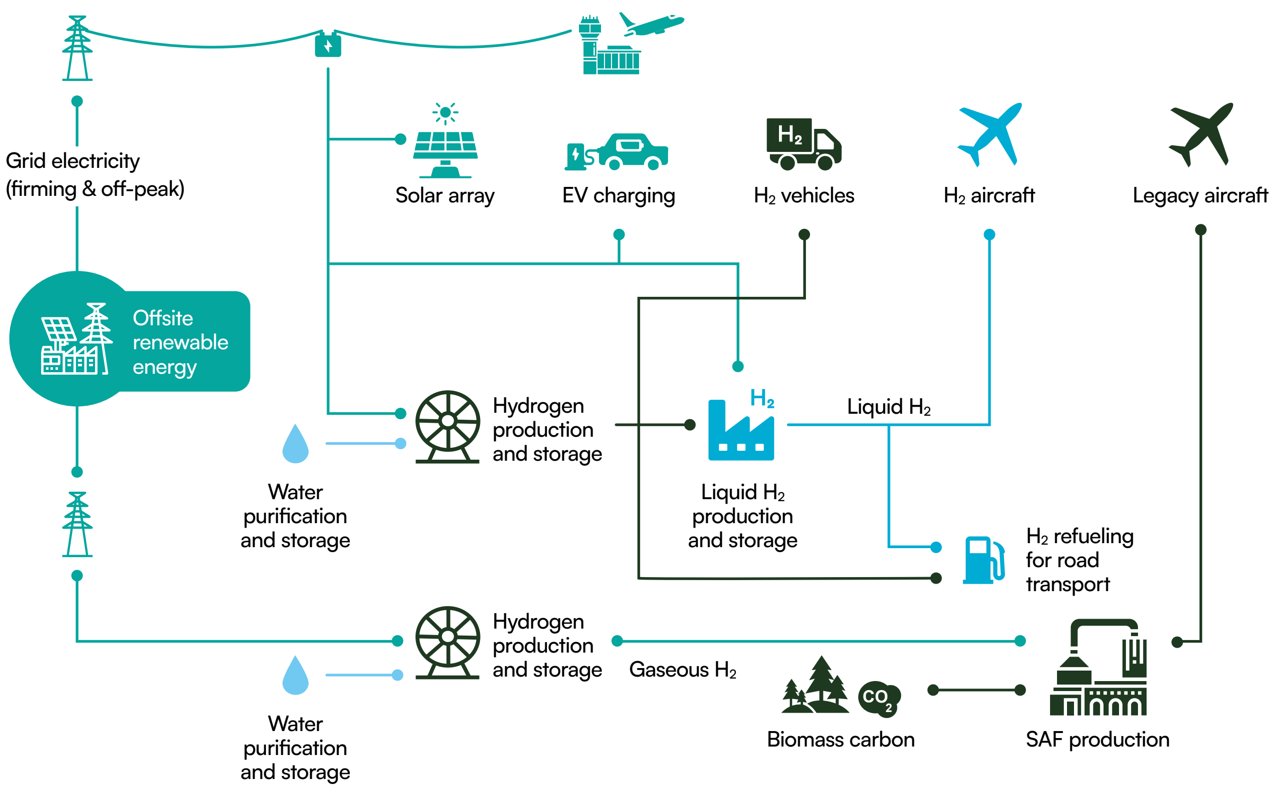


Figure 4. Green Hydrogen Ecosystem

Renewable Electricity Generation, Transmission and Distribution

The provision of large-scale renewable electricity is a critical factor in the development of the hydrogen aviation ecosystem.

Green hydrogen production via electrolysis is an energy intensive process and, as noted earlier, will require a significant increase in New Zealand's renewable electricity supply.

This green hydrogen is likely to be produced at several sites across New Zealand with production levels varying from site to site. The greatest volumes will be required for supply to Auckland with lower volumes required at other major airports such as Wellington and Christchurch.

Producing up to 100,000 tonnes of green hydrogen per annum (as modelled for 2050) would require up to 6.7 TWh of renewable electricity. This is comparable to the electricity demand of the country's single largest point user of electricity - the Tiwai Point Aluminium Smelter.

This additional electricity demand would be significant, and require development of new renewable generation and associated transmission infrastructure.

6.7 TWh per annum is the equivalent of the annual electricity production from around 1,900 MW of onshore wind generation or 3,825 MW of solar generation[24].

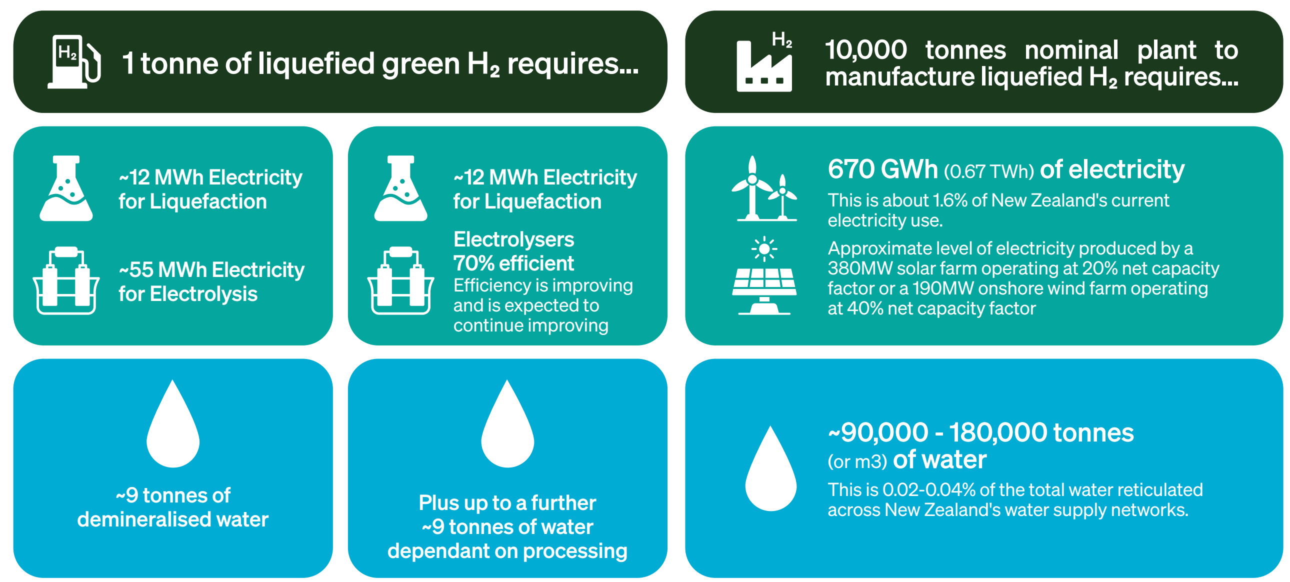


Figure 5. Requirements for Green Hydrogen production

24. Assuming net capacity factors of 40% for onshore wind, and 20% for solar generation.

In recent years there have been many forecasts of total future electricity demand through to 2050 and the potential supply from various generation types. These forecasts have been prepared by Government agencies including MBIE, Transpower and the Climate Change Commission. While useful, these forecasts have not included large-scale electricity requirements for green hydrogen from the aviation sector. The Consortium suggests these forecasts should be revised to include the potential level of demand from aviation.

It is critical New Zealand takes an integrated approach to solving the significant electrification challenge facing the country as it transitions away from fossil fuels. There is no escaping the additional energy demands aviation will put on this transition. The Consortium is committed to supporting the energy sectors grow sufficient generation and transmision capacity to meet the increase in demand and encourages government policy to assist in accelerating this process.

Christchurch Airport: Kōwhai Park - a new concept in renewable energy

The development of a renewable energy ecosystem at Christchurch Airport provides a great example of what can be developed at New Zealand airports.

Christchurch Airport is New Zealand's second largest airport by passenger numbers and freight volumes. It operates on 1,445 hectares of land on the western side of the city, of which an initial 400 ha has been set aside for the purpose of renewable energy generation.

The Airport has decarbonised its own airport operations by 94% against its 2015 baseline and is recognised as world leading in this space. The Airport's priority now is to support the wider aviation sector with the transition to a decarbonised future. This means ensuring the Airport is ready with the infrastructure required to support green hydrogen, sustainable aviation fuel and decarbonised aviation as soon as it is needed.

Trends impacting infrastructure at Christchurch Airport
Christchurch Airport is accustomed to intergenerational infrastructure planning and recognises the opportunities that exist with respect to future decarbonised fuel generation, scalability, peak energy management and resilience.

Given the nature of decentralised renewable energy production, this opens the possibility of generating future aircraft fuels on site, rather than being reliant on international supply chains.

In addition, businesses across the airport campus are searching for energy resilience. This includes physical resilience, price resilience and climate change resilience.

Transpower estimates that following a decade or more of flat or declining electricity demand, New Zealand is entering a phase of 70% growth over the next 27 years. As discussed above, the scale of electricity growth expected from the aviation industry is likely to increase demand above Transpower's forecasts.

The electricity demand study for Christchurch Airport outlines the growth in the electricity supply needs of its campus. The initial deployment of battery-electric aircraft, production of hydrogen for land and air transport, and expansion of the property portfolio is expected to triple the peak load from approximately 10 MW currently to 30 MW by the late 2020s. The transition to low emission aviation over the next twenty-five years could raise the electricity supply requirement to 400 MW.

	Terminal	Commercial load	EV charging	Electric aviation charging	Hydrogen production	Industrial load	Data centre	Vertical farming
Today	~3 MW	5-10 MW						
Near term (this decade)	Not electrically intensive		5-10 MW	5-10MW	5-10 MW (land transport)	10-20 MW near term prospects		
Long term (2050)			10-20 MW	15-30 MW	150 MW+ (land & aviation)	Opportunities too diverse to quantify		

Figure 6. Christchurch Airport - Potential Electricity Demand

Electricity demand projection at Christchurch Airport
The total throughput from the Christchurch Airport fuelling facility in 2019 was 203 million litres. This fuel was consumed by domestic (36%), trans-Tasman (38%) and other international (30%) aircraft. If the total domestic and trans-Tasman flight jet fuel was displaced with a zero emission alternative, that could equate to an annual reduction in emissions of up to 400,000 tCO_2e.

The possibilities of emissions reduction resulting from the establishment of aviation hydrogen facilities at Christchurch Airport could be larger than this if the facilities were a supply hub for domestic aviation across the South Island. When considering the role of green hydrogen within aviation more broadly, this presents a nationally significant decarbonisation opportunity.

Christchurch Airport is a land transport hub across both passenger transport and freight transport, and a major property precinct. The decarbonisation of land transport through electric vehicle charging and green hydrogen, and the electrification of industrial property further increases the supply chain emissions reductions opportunities.

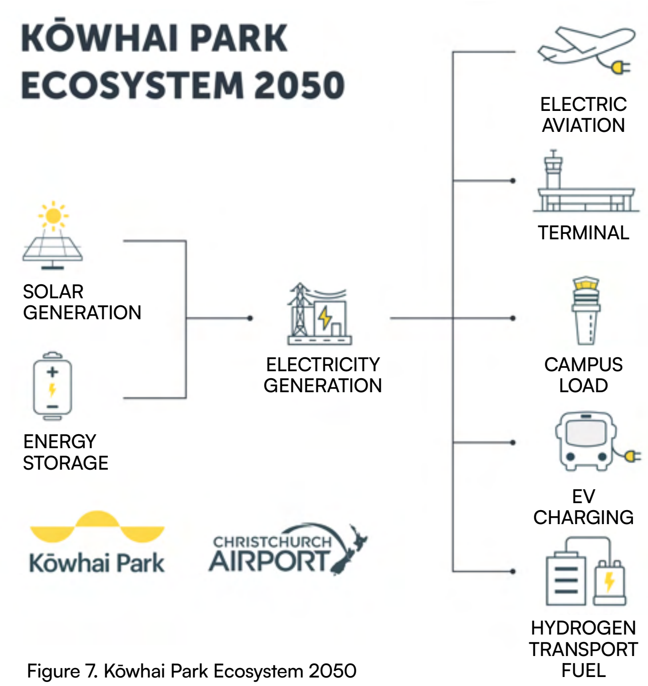


Figure 7. Kōwhai Park Ecosystem 2050

Activating the opportunity at Christchurch Airport
Christchurch Airport aspires to make the energy transition an opportunity, by adopting a proactive and innovative energy strategy, rather than a passive strategy that risks energy becoming a constraint. A holistic view of energy demands across the campus is encapsulated by the Kōwhai Park ecosystem concept.

Christchurch Airport announced in 2021 that it would develop a renewable energy precinct, known as Kōwhai Park. This recognises the need to decarbonise aviation and land transport activities based at the airport. Other features of Kōwhai Park include its proximity to New Zealand's second largest city, being adjacent to Transpower's national grid, and close to Orion's lines network that supplies electricity to Christchurch. The figure below left outlines the Kōwhai Park ecosystem currently under development at Christchurch Airport.

Christchurch Airport Kōwhai Park partnerships
Christchurch Airport has selected Contact Energy and international solar developer Lightsource bp to develop the first stage of the precinct — a solar farm that will span around 300 hectares on land just behind the Airport's runways. The solar farm will have a generating capacity of 150 megawatts (or 170 MWp) and is expected to generate approximately 290 GWh per year.

Phase one is the equivalent of the energy required by around half of Christchurch's domestic flights if they are converted to low-emission technologies or the equivalent electricity consumption of around 36,000 homes. Construction of phase one is expected to begin in 2024.

For Christchurch Airport, one of the core objectives of Kōwhai Park phase one, in addition to generating the additional energy, is to obtain a grid connection sufficiently scaled for long term transition needs. Electricity network capacity will play a major role in determining where electrification and decarbonisation of aviation and land transport can occur. However, development of traditional regulated network infrastructure is at risk of lagging behind demand and constraining electrification. Working with Orion (Christchurch Airport's electricity distribution provider) and Transpower (New Zealand's electricity transmission infrastructure owner), Christchurch Airport is taking a proactive approach to developing network access in advance, rather than just in time. A sub-transmission upgrade is planned that will bring 50-150 MW of capacity to the campus boundary.

Green hydrogen production, storage and liquefaction

Sustainable water supply
The production of green hydrogen requires water (along with renewable energy) as a key feedstock. It is often assumed that producing green hydrogen at commercial scale will require a large volume of fresh water. The reality is that the quantities of water required is a very small percentage increase in total demand on New Zealand's current water supplies. Additionally, treated wastewater can be an excellent option for hydrogen production.

The Consortium recognises that water is a life sustaining resource that must be cared for. For Māori, water holds particular cultural significance — it is considered the life blood of Papatūānuku (the 'earth mother') and a taonga (a treasure). It is recommended that any organisations involved in green hydrogen production embrace kaitiakitanga (guardianship) and work together with iwi and hapū to establish frameworks to protect water resources.

As illustrated above in Figure 5, to produce the national modelled demand of up to 100,000 tonnes per annum of hydrogen in 2050, this would require approximately:

- 900,000 tonnes (or m^3) of water for electrolysis per annum, or ~0.17% of the water currently reticulated in New Zealand. An equivalent volume of additional water may be required for processing.

Treated wastewater can be utilised in hydrogen production facilities where available, supporting sustainable water practices.

Electrolysis
There are several existing types of electrolyser technology that can be used to produce green hydrogen, each having advantages or disadvantages.[25]

The operational requirements, efficiency and performance varies between electrolyser technologies. Current technologies typically require around 55 MWh of electricity to produce one tonne of hydrogen. This energy requirement is expected to continue reducing over time.

Hydrogen storage
There are several different options for storing hydrogen, each of which have advantages and disadvantages depending on factors such as the quantity, storage duration, and distance it needs to be transported.

Liquid hydrogen is the delivery and final storage option required at airports for its use in aviation. However, gaseous storage (or storage using a carrier substance) may also be required for longer term storage of green hydrogen. Long-term storage of hydrogen may be necessary as:

- There are seasonal variations in renewable energy production.
- There are peaks and troughs in demand for aviation fuel.
- There will be a need to ensure there is a strategic reserve of fuel available in case electricity generation or hydrogen production is interrupted.

Hydrogen liquefaction
Hydrogen liquefaction (the process of liquifying gaseous hydrogen) is an energy intensive process. It necessitates hydrogen be cooled to -253°C which requires around 12 MWh/tonne of energy. This is about 35% of the energy contained in a tonne of hydrogen (33.33 MWh).

Processes for liquefying hydrogen are commercially available at reasonable scale. Current plants can liquefy up to 32 tonnes of hydrogen per day[26] (or just under 12,000 tonnes per year). This is sufficient for the indicative 10,000 tonnes per year green hydrogen plant considered in this report.

25. See p41 of the Arup report: Pilot Hydrogen Hubs for Trialling Advanced Aviation in New Zealand | Ministry of Business, Innovation & Employment
26. As discussed in this 2022 article by Al Ghafri et al which provides a detailed technical overview of hydrogen liquefaction: Hydrogen liquefaction: a review of the fundamental physics, engineering practice and future opportunities | Royal Society of Chemistry

Hydrogen distribution and refuelling

Hydrogen distribution
Hydrogen can be distributed in several ways from its point of production to its point of storage and end use. Green hydrogen may be distributed by pipeline, truck, rail or even partly by ship from the point of production to an airport. The best option for distribution of hydrogen will depend on the distance between the points of production and demand, and the available infrastructure.

Moving large quantities of hydrogen short distances from production to airports is expected to be cheapest through pipelines. However, barriers such as consenting and high capital costs mean it is likely that delivery by truck will be the most cost-effective option initially when small volumes of hydrogen are being moved.

Hydrogen refuelling systems
Current refuelling systems for aviation fuel involve aircraft being refuelled on the tarmac at areas adjacent to the airport terminal. Fuel is delivered via pipe or truck to fuel dispensers.

New infrastructure and processes will be required for refuelling aircraft with liquid hydrogen. The infrastructure required is under development while the refuelling processes and safety procedures will need to be developed and standardised.

Three broad processes are possible:

- Delivery via pipe to dispensers at the airport apron.
- Delivery via refuelling truck to aircraft at the airport apron.
- Removal of hydrogen tanks from aircraft and delivery of full tanks via a ground service vehicle.

Whichever process is developed, it will require strict regulation and protocols for storage and transfer of liquid hydrogen — just as regulations and protocols exist around the handling of aviation fuels today.

Aviation end use

Aircraft
Several global organisations and partnerships are already investing in the development of hydrogen-fuelled engine technologies — both combustion engines, fuel cell/electric motors and hybrid-electrics.

Most are focused on the use of liquid hydrogen, but some continue to explore the use of gaseous hydrogen.

Airbus has the ambition to develop a hydrogen-powered aircraft (ZEROe) and bring it to the market by 2035. It is currently evaluating various concepts and maturing the technologies they will require.

Aircraft maintenance
Airlines will need to introduce new systems for the maintenance of hydrogen-fuelled aircraft.

This will require teams with new training and qualifications operating under new sets of procedures.

In addition, there is a range of procedures that have not been fully scoped yet but that will be impacted by a change in aviation fuel:

- Fire emergency training and response.
- Ground handling.
- Aircraft storage and hangarage.
- Fuel Storage.
- Ground service equipment requirements.

27. The ZEROe demonstrator has arrived | Airbus

Airbus: working towards the world's first hydrogen-powered commercial aircraft

Through a research and development project known as ZEROe, the global aerospace pioneer is exploring a variety of configurations and technology options that will shape the development of its future hydrogen aircraft.

Airbus has developed three ZEROe concepts. They are either powered by hydrogen combustion through modified gas turbine engines, fuel cell or hybrid configuration. Liquid hydrogen is used as fuel for combustion with oxygen from ambient air.

In 2022, Airbus launched its ZEROe demonstrator[27] activities with the aim of testing hydrogen combustion and fuel cell technology on an A380 multimodal platform.

Airbus concept designs for hydrogen fuelled aircraft:

1. Turbofan
Capacity: up to 200 passengers
Range: 3,700+ km (2,000+ NM)

Capable of operating transcontinentally and powered by a modified gas-turbine engine running on hydrogen, through combustion.

The liquid hydrogen will be stored and distributed via tanks located behind the rear pressure bulkhead.

2. Turboprop
Capacity: 100 passengers
Range: 1,800+ km (1,000+ NM)

A turboprop engine powered by hydrogen combustion in modified gas-turbine engines and/or an electric motor fed by a fuel cell, making it an option for short-haul trips.

3. Blended-Wing Body
Capacity: up to 200 passengers
Range: 3,700+ km (2,000+ NM).

This is a concept in which the wings merge with the main body of the aircraft with a range similar to that of the turbofan concept. The exceptionally wide fuselage opens up multiple options for hydrogen storage and distribution, and for cabin layout.

Airbus is currently assessing these various concepts and expects to make the final decision on development options in the 2024-2025 timeframe and to launch the corresponding programme by 2026-2028.

Technology demonstrators will be required over the next five to six years and a full-scale aircraft prototype in the late 2020s timeframe.

Airbus ZEROe Ecosystem
In parallel to the ZEROe aircraft concepts developments, Airbus is also working on the development of the liquid hydrogen infrastructure and ecosystem that will be needed to refuel the future hydrogen powered ZEROe aircraft.

New Zealand is the perfect location to start on these opportunities and pave the way for the green hydrogen aviation ecosystem.

The Airbus ZEROe Ecosystem team is working on strategies and development of infrastructure with various partners including airports and hydrogen specialists from across the globe, to develop a large network of hydrogen hubs.

Section D: Actions required to launch green hydrogen aviation

The challenge of the commercialisation gap for launching and developing the use of green hydrogen in aviation needs to be addressed. Closing this gap will require considerable private investment. The Consortium suggests that targeted public investment will also be required.

The New Zealand Government also has key policy and regulatory levers that it can apply to support and encourage the development of green hydrogen in aviation.

Improving green hydrogen's commercial viability
If liquid green hydrogen was being produced for aviation today, it would be more expensive than existing fossil fuels on both a per unit of energy and a per passenger basis.

The pathway to achieving commercial viability of hydrogen for aviation is heavily dependent on six key factors:

- Policy support and lowering costs for renewable electricity generation and transmission to green hydrogen plants.
- Costs and policy settings for fossil-based aviation fuel — including the pricing of carbon units under the Emissions Trading Scheme.
- Continued improvements in the efficiency and cost of processes for producing, storing, distributing and using liquid green hydrogen.
- Developing and funding national green hydrogen demand to increase economies of scale, decrease infrastructure and production costs, and meet the step-up in demand over time.
- Continued development in the performance and efficiency of hydrogen-fuelled aircraft technology.
- Developing a regulatory environment that enables the use of green hydrogen for aviation.

Cost is however, only one of many factors that affect this commercial viability. Other factors include:

- Relative power train efficiency.
- Capital cost of aircraft.
- Size of aircraft and potential passenger numbers.
- Turnaround time between flights.
- Flight range.
- Maintenance regimes.
- The pricing elasticity[29] of passengers and freight customers.

Modelling future costs
The Consortium has carried out modelling of production costs to create a 2030 reference case. The case assumes 10,000 tonnes per annum of liquid hydrogen demand and a supply chain configuration of a liquid hydrogen plant located at the airport to avoid transporting liquid hydrogen via trucks on public roads.

This potential cost for liquid hydrogen has been estimated using publicly available reports[30], with production scale and local factors applied. The costs presented in this report reflect realistic potential outcomes in different scenarios and are included to provide insights into the areas with the most impact. The values do not represent expected costs or indicate commercial pricing.

Fossil-based aviation fuel currently fluctuates around NZ$1.25 per litre delivered to the aircraft. As hydrogen is more energy dense than aviation fuel, this equates to a liquid green hydrogen cost of around $4.40 per kilogram[28] on a per unit of energy basis.

The cost for liquid green hydrogen delivered to the aircraft in the 2030 reference case is estimated at >NZ$10/kg which is around 2.5 times the current price for the equivalent quantity of energy from aviation fuel.

The following pie charts show the factors that contribute to the cost of green liquid hydrogen — by cost and by supply chain category for the 2030 reference case.

28. 1 kg of hydrogen replaces ~3.45 L of Jet A-1 fuel based on lower heating values and assumption of no change in energy efficiency.
29. Elasticity refers to how demand from consumers responds to lower or higher prices.
30. For example: H2-powered aviation at airports — Design and economics of LH2 refueling systems | Energy Conversion and Management

Breakdown of liquid green hydrogen costs

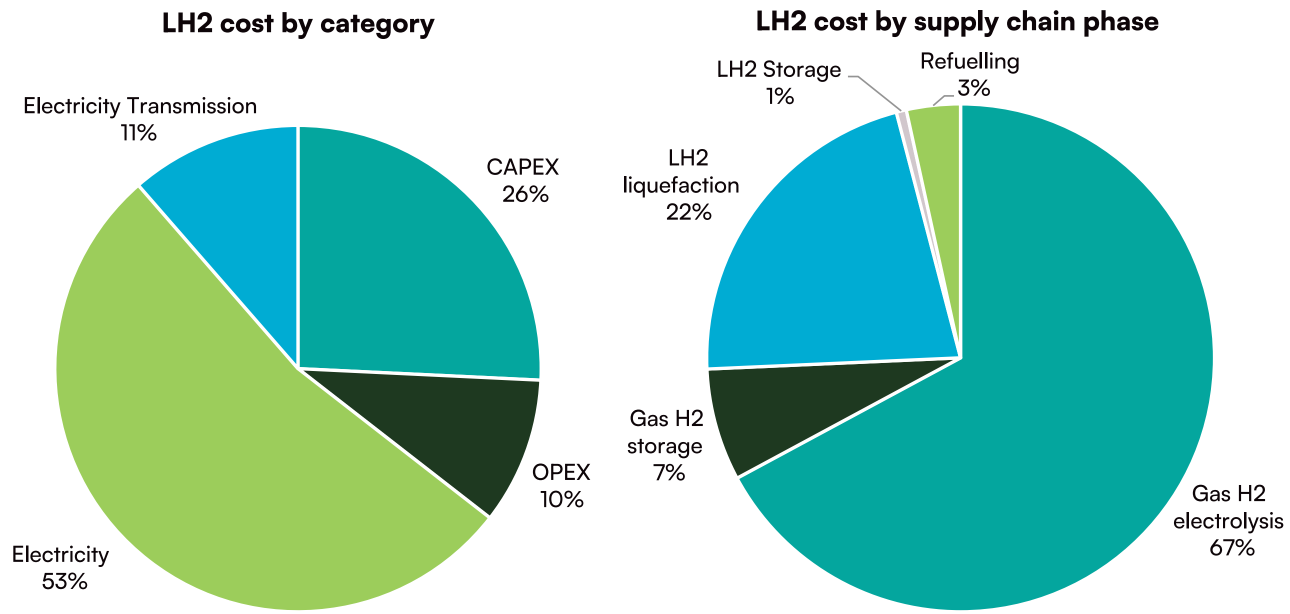


Figure 8. Breakdown of liquid green hydrogen costs

The production of gaseous hydrogen is the most significant cost in the supply chain primarily due to requirements for large amounts of renewable electricity for electrolysis.

Policies supporting adoption of green hydrogen in other New Zealand sectors will lead to lower costs for aviation in areas such as the development of labour market capability, supplier support and supply chain efficiencies for spare parts.

It is important to note that hydrogen technology for commercial aviation is on a steep development curve, with no firm cost predictions. Hydrogen technology for other sectors is however rapidly maturing. This will benefit the cost of transferring technologies to aviation.

To gain better insight into the areas that impact commercial viability, sensitivity analysis around the reference case assumptions is shown in Figure 9.[31] This chart shows the impact on the reference case cost of hydrogen by varying a range of factors — lower in a tail wind scenario and higher in a head wind scenario.

Figure 10 shows an example of the impact on the cost of liquid green hydrogen from combining reasonable reductions in costs for the key factors in a 2050 scenario. Using these assumptions, the cost of liquid green hydrogen has reduced from >$10 in 2030 to $5-$6 per kilogram in 2050.

31. Sensitivity analysis based on a mix of potential ranges and publicly available targets. For example, U.S Department of Energy technical targets for PEM electrolysis

Future Costs of Liquid Green Hydrogen

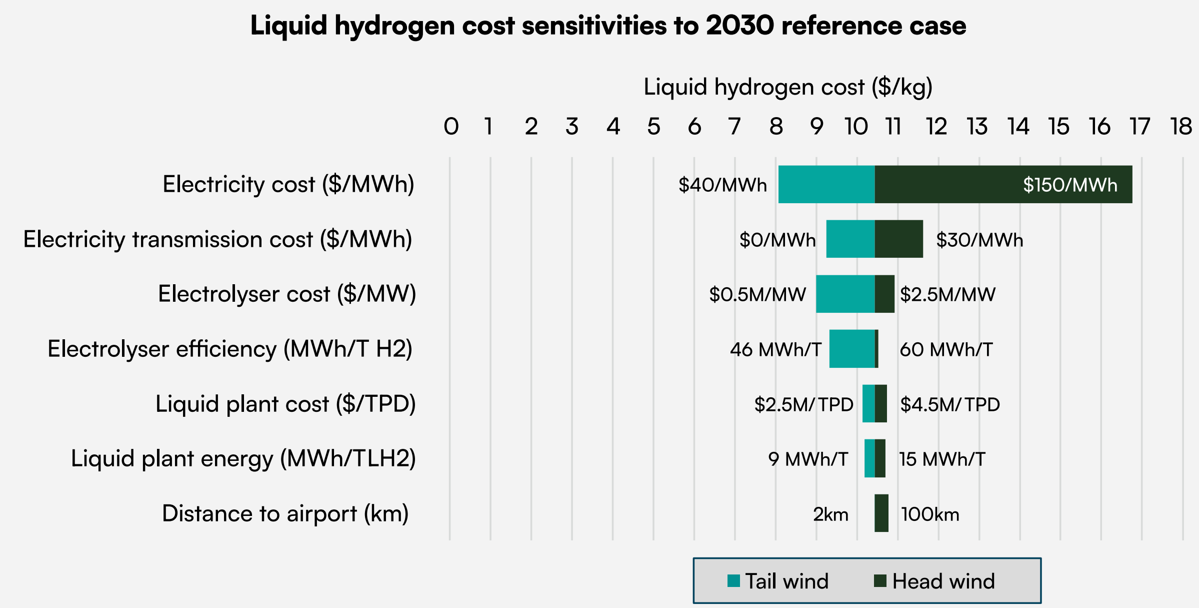


Figure 9. Hydrogen cost sensitivities to 2030 reference case

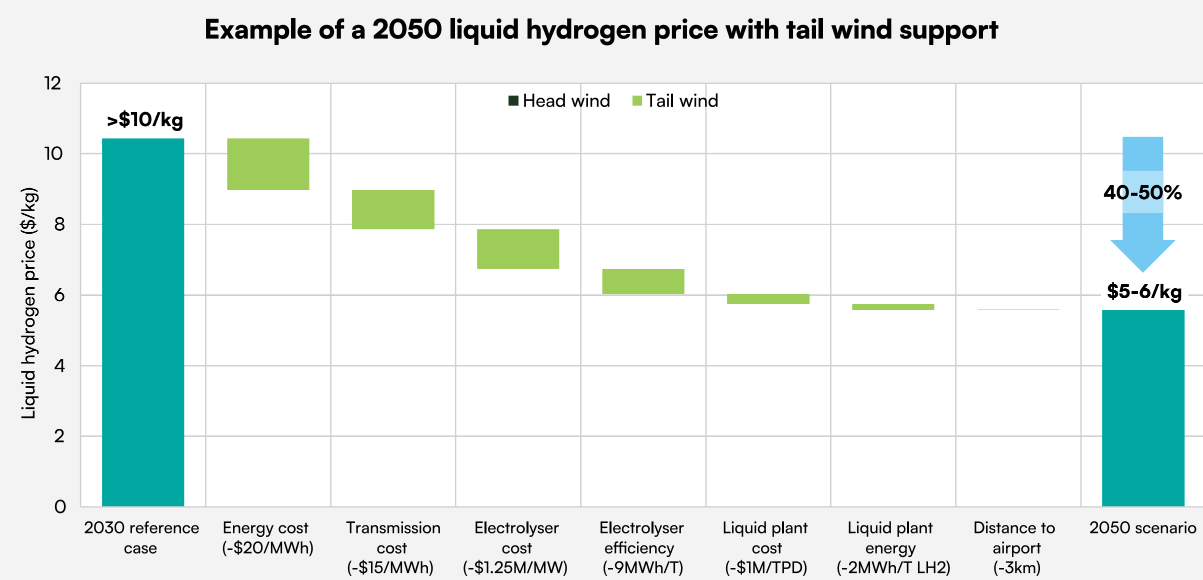


Figure 10. Hydrogen cost reductions to 2050

The main observations from the sensitivity analysis are:

- Electricity costs are significant in the production cost of hydrogen. The Consortium suggests that this is the cost factor that has the most ability to benefit from policy support, infrastructure planning and commercial coordination.
- As trucking distance does not have much impact, reducing the electricity transmission costs between energy sources to liquid hydrogen plants is essential to avoid negative outcomes such as increased movement of liquid hydrogen via trucks on public roads.
- Electrolyser cost reductions and efficiency improvements from market adoption in other applications will improve liquid hydrogen costs for aviation.

Two important aspects not considered in the above analysis are the effects of liquid hydrogen plant scale and legacy investments in infrastructure required to meet growth in demand over time.

The Consortium has not modelled the potential impact on ticket prices in New Zealand, but modelling completed by McKinsey & Co for the European market suggests that the impact on pricing for commuter and regional aircraft in those markets could be limited to a 10% increase.

The Consortium notes this assessment but stresses considerably more analysis is required before conclusions can be reached about the impact on New Zealand ticket prices. Nevertheless, the Consortium believes that there is a pathway for affordable hydrogen-fuelled flights to operate in New Zealand.

Ultimately there is a range of cost factors (or levers) that will impact upon the commercial viability of hydrogen-fuelled aviation.

To meet demand as it grows, investments in supply assets must be made with the cost and efficiency factors available at the time. Policy support during early adoption has a role to play in reducing the legacy impacts and increasing the ability to achieve the targeted low hydrogen prices in the future.

Policies to enable and encourage the use of green hydrogen in aviation

The development of a hydrogen ecosystem as described in this report requires consenting, regulatory and policy support from local and central government.

The development of the hydrogen aviation ecosystem requires an appropriate:

- Policy environment that enables the industry to achieve commercial success while also meeting emissions reduction targets.
- Regulatory environment (including associated standards) to ensure the industry operates consistently, safely and cleanly.

The New Zealand policy environment

The New Zealand Government has already implemented policies and agreed to international obligations to reduce GHG emissions. There are two major policies enacted by the New Zealand Government to incentivise emissions reduction. The first is the Emissions Trading Scheme (ETS); incentivising industries through increasing costs for carbon emissions. The second is the Climate Emergency Response Fund (CERF)[32], which utilises the proceeds of the ETS to fund decarbonisation and emission reductions initiatives. The CERF could provide a mechanism for substantial Government support for developing the use of green hydrogen in aviation[33].

Projects funded from the CERF in the 2022 Government Budget[34] that are relevant to the use of green hydrogen in aviation were:

- The New Zealand Hydrogen Roadmap (an Interim Roadmap was released in August 2023).
- The New Zealand Energy Strategy (currently under development by MBIE).
- The Target True Zero: Government Policy Toolkit to Accelerate Uptake of Electric and Hydrogen Aircraft provides a global reference of policy and regulatory needs[35].

32. The Climate Emergency Response Fund | The Treasury New Zealand
33. The largest single emissions reduction project using support from the CERF was announced in May 2023: Government announces emissions reduction partnership with New Zealand Steel | Ministry of Business, Innovation & Employment. This project is forecast to reduce emissions by 800,000 tonnes per year, slightly less than the Consortium's modelled 2050 demand for utilising green hydrogen on Air New Zealand's domestic routes.
34. Summary of key Climate Emergency Response Fund initiatives - Budget 2022 - 19 May 2022.
35. Target True Zero: Government Policy Toolkit to Accelerate Uptake of Electric and Hydrogen Aircraft

The 2023 Budget extended these initiatives with its announcement of the Regional Hydrogen Transition initiative[36]. From 2024 this $100m programme will provide a rebate mechanism to bridge the price gap between green hydrogen and fossil fuel alternatives.

The New Zealand Hydrogen Aviation Consortium wishes to work closely with MBIE on development and implementation of both the New Zealand Hydrogen Roadmap and the New Zealand Energy Strategy.

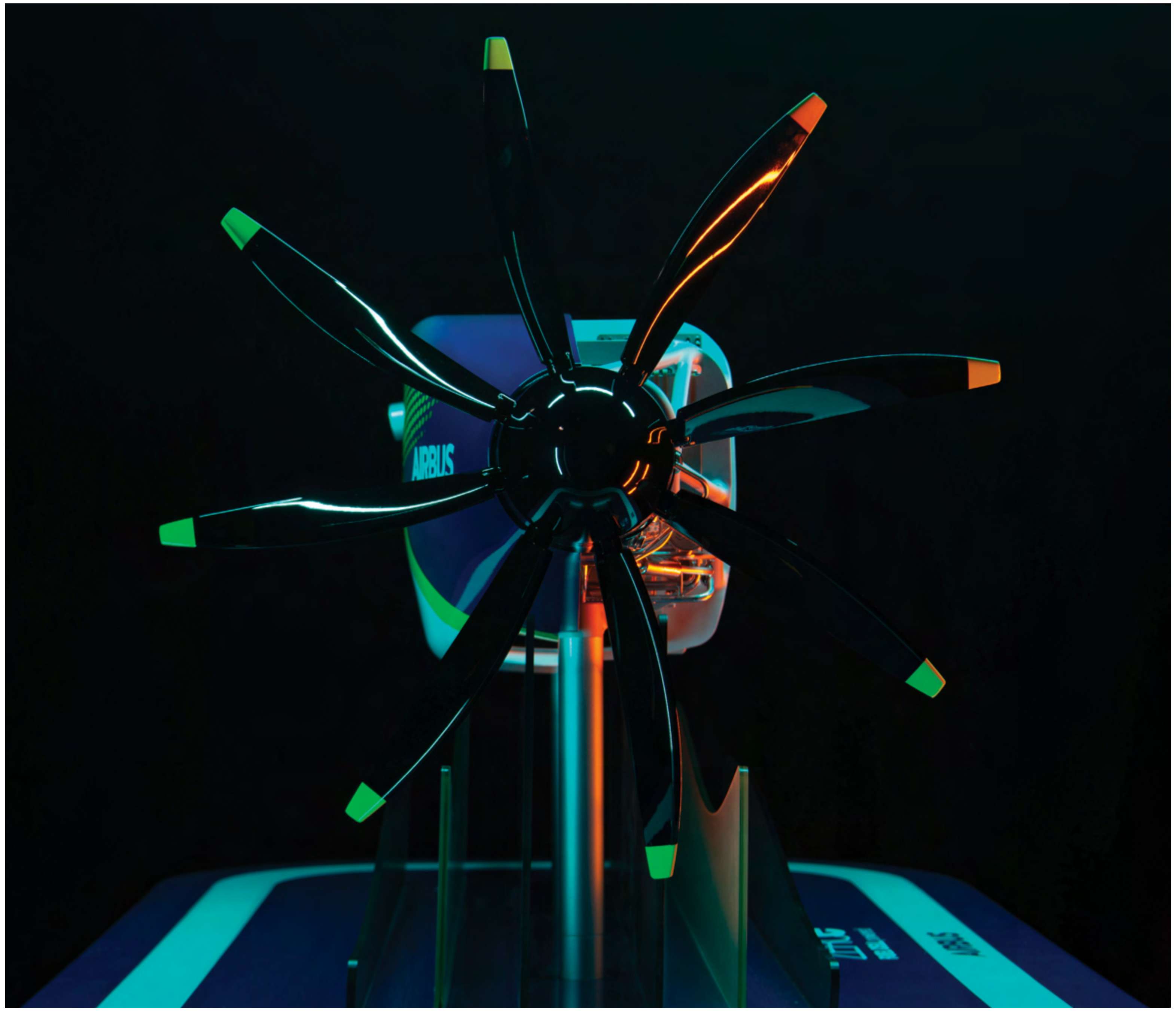
The Consortium has given thought to policies and actions that should be considered in the New Zealand Hydrogen Roadmap as it is further developed and these are listed below. The Consortium was pleased to see many of these covered to some extent in the recently released Interim Hydrogen Roadmap, and looks forward to working with MBIE to round out the aviation-focused elements of the roadmap.

- Recognition of the core role that green hydrogen will play in reducing aviation emissions — both as a direct fuel and as a feedstock in the production of SAF.
- Recognition that the use of hydrogen for aviation will complement and help develop its use in other sectors.
- The development of a National Policy Statement for Hydrogen to guide developers of projects and consenting agencies on best practice.
- The implementation of Green Hydrogen Certification standards to provide certainty to the aviation sector and its customers as to the quality of the hydrogen being used. These standards are likely to be aligned internationally.
- Review of all regulations and standards relevant to the use of hydrogen in aviation and the development of appropriate regulations and standards before they are needed.
- The development of a Hydrogen Taskforce and/or the appointment of a Hydrogen Champion to oversee the delivery of actions included in the Hydrogen Roadmap and to provide ongoing independent advice to Government to activate and develop the hydrogen sector.
- The implementation of a Hydrogen Production Credit Scheme to underwrite the revenue stream for green hydrogen producers.
- Recognition of the strategic reserve requirements for hydrogen as an aviation fuel[37] and an assessment of the scale required.
- Recognition of hydrogen workforce development and training initiatives.
- Recognition of green hydrogen production in Just Transition activities in regions specifically affected by the changing energy system.
- Recognition of the role that iwi and hapū can play in New Zealand's green hydrogen economy.

36. Regional Hydrogen Transition | Ministry of Business, Innovation & Employment.
37. Similar to the requirements in the Fuel Industry (Improving Fuel Resilience) Amendment Bill introduced to Parliament in June 2023.

In addition to these policies, which are also relevant to the New Zealand Energy Strategy, the Consortium suggests the Energy Strategy should consider:

- Recognition of the scale of demand for renewable electricity generation from production of green hydrogen for aviation.
- Updating the existing National Policy Statement on Renewable Electricity Generation and the National Policy Statement on Electricity Transmission to enable;
  — Development of renewable electricity generation
  — Associated transmission infrastructure to meet the required energy needs[38].
- Implementation of policies and mechanisms to enable faster, more certain development of renewable electricity generation and associated transmission services. The length of time that it takes to plan and develop new generation projects and associated transmission upgrades in New Zealand means that developers require certainty ahead of green hydrogen production being confirmed. Methods could include;
  — Contracts for Difference — which will provide certainty of cashflow to developers of new projects. This is a strategy used by Governments in other countries to encourage new renewable generation, notably the UK[39].
  — Power purchase agreements supplying the New Zealand Government, which will provide certainty of cashflow to new projects[40].
  — The implementation of Renewable Energy Zones[41] that can enable efficient and coordinated investment in generation and transmission.
  — Development of new funding model(s) for Transpower to plan, invest and deliver strategic transmission infrastructure that better enables rapid emissions reductions by supporting demand growth and renewable generation development more efficiently. The current structure limits the speed of transmission infrastructure development, constraining the development rate of new generation.
  — A review of the electricity industry structure to encourage development of new generation at the pace that will be required. The current structure benefits generators where supply constraints keep wholesale market prices at relatively high levels.
- Recognition of the value provided from using hydrogen in multiple sectors including aviation. These multiple use cases will enable the most efficient use of generation and green hydrogen production assets while also providing opportunities for synergies in energy storage.



In 2022 it was announced that the Climate Emergency Response Fund would support industry specific initiatives such as "Decarbonising Freight Transport — Resourcing and Seed Funding", Decarbonising the Public Transport Bus Fleet" and "Funding Further Decarbonisation of Process Heat and Implementation of Supporting Policies".

An initiative such as the use of green hydrogen in aviation is eligible for support from the CERF if it is included in the Emissions Reduction Plan, or directly supports emissions reductions[42].

As well as the policy initiatives outlined above, the New Zealand Hydrogen Aviation Consortium suggests using CERF to support initiatives that de-risk and enable the development of the hydrogen aviation ecosystem. This could include testing and development of hydrogen aircraft suitable for New Zealand, and development of the required infrastructure.

The Consortium suggests that Government investment via CERF also targets the development of hydrogen infrastructure to bridge the commercialisation gap outlined in this report. This investment could be structured similarly to the model that has worked effectively with the roll-out of ultrafast broadband.

The Consortium wishes to partner with the Government on these initiatives working in collaboration with agencies such as the:

- Ministry of Business Innovation and Employment.
- Ministry of Transport.
- Energy Efficiency and Conservation Authority (EECA).

During 2022 the Climate Change Commission released New Zealand's first Emissions Reduction Plan (ERP).

The 2022 ERP noted that green hydrogen will help decarbonise New Zealand's transport system potentially including aviation. The ERP included three key initiatives for aviation including implementing a SAF mandate and establishing Sustainable Aviation Aotearoa. However, there was no mention of green hydrogen as a future aviation fuel.

The 2022 ERP also included the recommendation "Ensure hydrogen regulatory settings are fit for purpose" and a recommendation to prepare the New Zealand Hydrogen Roadmap.

When the next ERP is prepared[43] the Consortium recommends that it includes actions to encourage the use of green hydrogen to reduce aviation emissions. This will ensure the use of green hydrogen in aviation is eligible for support from the Climate Emergency Response Fund.

38. It is noted that a review of these NPS is underway: Consenting improvements for renewable electricity generation and transmission | Ministry of Business, Innovation & Employment
39. Contracts for Difference | Department for Business, Energy & Industrial Strategy, and Department for Energy Security & Net Zero (UK)
40. This is included as an initiative in the New Zealand Emissions Reduction Plan.
41. Also an initiative in the New Zealand Emissions Reduction Plan.

42. There are other criteria which projects can meet: The Climate Emergency Response Fund | The Treasury. Being included in the ERP is the most directly relevant criteria to the use of green hydrogen in aviation.
43. The Climate Change Commission's advice for the second Emissions Reduction Plan is due to be delivered to the Government by 31 December 2023.

The 2022 ERP also recognised the core importance of New Zealand's renewable electricity sector. However, as noted earlier, it significantly underestimates the volume of additional renewable generation that will be required by 2050 by not including the requirements of the aviation sector.

The Consortium recommends that when the next ERP is prepared it includes updated forecasts on the requirements for renewable electricity generation.

The 2022 ERP also noted that New Zealand needs to:

- Accelerate development of new renewable electricity generation.
- Ensure that the electricity system and the market can support high levels of renewables.
- Support development and efficient use of transmission and distribution infrastructure to further electrify the economy.

The Consortium supports these goals and suggest that the next ERP[44] also include the policy suggestions made above for the New Zealand Energy Strategy.

In addition to the potential for specific support for development of the use of hydrogen in aviation to be provided directly via the CERF there are other support mechanisms that could be applied via existing channels:

- The Low Emissions Transport Fund managed by EECA.
- The Government Investment in Decarbonising Industry Fund managing by EECA[45].
- The Innovation Programme for Tourism Recovery managed by MBIE.
- Regional Strategic Partnership Fund managed by MBIE.
- Callaghan Innovation's R&D programmes.
- MBIE's Public Science funding programmes.

As noted above, the Consortium recommends the Climate Change Commission update its electricity demand forecasts. Similarly, the Consortium recommends that the demand for electricity from the aviation sector is fully included in the next Electricity Demand and Generation Scenarios (EDGS) prepared for MBIE. The current EDGS forecasts do not take into account the volume of electricity required for aviation.

Transpower is required to use the EDGS for planning purposes. Not including the full volume of electricity required for aviation has had a flow on impact on Transpower's planning which the Consortium suggests underestimates the requirements for new transmission capacity in New Zealand. Transpower has however, recently acknowledged the aviation sector's potential future requirements for renewable electricity in its March 2023 Whakamana I Te Mauri Hiko Monitoring Report[46]. Until the EDGS are updated Transpower remains constrained in the planning it can undertake.

44. Consultation on the Climate Change Commission's draft advice to Government for the next ERP was carried out from April to June 2023 - Reducing emissions in Aotearoa New Zealand: 2026-2030 | He Pou a Rangi Climate Change Commission
45. These two EECA programmes are funded from the Climate Emergency Response Fund.
46. Page four of Monitoring Report - March 2023 | Transpower.

What other countries are doing

Several other Governments are providing much stronger support for the development of renewable infrastructure and green hydrogen production than is currently the case in New Zealand.

United States

The United States Government has implemented a support programme worth an estimated US$391 billion for energy and climate programmes through what is known as the Inflation Reduction Act. Under its provisions renewable energy producers can receive a tax credit of 2.6 cents per kWh and up to $3 per kg of hydrogen, respectively, for the first 10 years of operation.

These support mechanisms provide a major incentive for companies exploring hydrogen production to focus on the US market in preference to countries such as New Zealand.

Europe

The European Union (EU) has a Green Deal Industrial Plan that is offering a fixed premium per kg to green hydrogen producers, with a first auction starting in 2023 with an indicative budget of €800 million[47].

In 2022 two Important Projects of Common European Interest in the field of hydrogen were introduced. They will provide up to €10.6 billion in funding, which is expected to unlock an additional €15.8 billion in private investment. In addition, various Member States are developing competitive schemes to enable renewable hydrogen projects to be developed at least cost[48].

In 2022, following Russia's invasion of Ukraine, the EU established 'RePOWER EU'. This plan has an objective to boost hydrogen production and import up to 20 million tonnes by 2030[49]. This has been followed by the creation of a 'Hydrogen Bank' while the Emission Trading Scheme Innovation Fund will ensure an additional €3 billion to support hydrogen production.

Australia

In 2023 the Australian Government announced AU$2 billion in funding for a new Hydrogen Headstart programme to support the scale-up of the country's green hydrogen sector[50].

While final details are still being confirmed this programme is expected to largely be implemented as a credit per kilogram on the price of production. Hydrogen Headstart is also expected to provide support for development of infrastructure.

The Australian Government also announced funding of:

- AU$38.2 million for development of a Guarantee of Origin scheme for green energy products - "in particular hydrogen".
- AU$2.0 million to support First Nations people and businesses "to engage with hydrogen project proponents, planning processes and program design."

The Budget announcement noted the new investment was about making Australia a global leader in green hydrogen, as competition for clean energy accelerates around the world.

47. A Green Deal Industrial Plan for the Net-Zero Age | European Commission
48. Questions and Answers on the EU Delegated Acts on Renewable Hydrogen | European Commission
59. RePowerEU: Joint European Action for more affordable, secure and sustainable energy | European Commission
50. Hydrogen Headstart to power new jobs & industry | Treasury (AU)

Improved regulations and standards
MBIE has already begun a process intended to lead to improved regulations for the hydrogen sector while Standards New Zealand is also reviewing standards for the hydrogen sector.

New Zealand Hydrogen Regulatory Pathway Report
PwC was contracted by MBIE to prepare a report on hydrogen related regulations. The report titled "New Zealand Hydrogen Regulatory Pathway" was released in November 2022.

PwC worked with a Hydrogen Regulators Working Group set up by MBIE in April 2022. The Working Group did not include any representatives from the aviation sector. PwC also consulted a range of parties when preparing their report including Hiringa Energy and Fortescue but neither airlines, airports nor the Civil Aviation Authority were interviewed. Despite this lack of input from the aviation sector, the report provides useful information on hydrogen-related regulatory matters.

PwC identified 44 Acts and 93 Regulations and Rules that may be relevant to hydrogen. Of specific relevance to aviation this list included the Civil Aviation Act (1990), which amongst other responsibilities determines rules relating to aircraft fuel.

PwC made four key overarching recommendations in their report. These were supported by more detailed recommendations.

1. Set national hydrogen strategy
"We recommend that Government develops a clear and specific national strategy for how Aotearoa will navigate the hydrogen opportunity. This needs to identify and prioritise several core strategic policy objectives."

2. Remove regulatory friction
"Improving the flexibility of the regulatory system can be addressed relatively easily and quickly. Aligning incentives and policy support for hydrogen with those provided to other decarbonising options would also level the playing field."

3. Monitor and respond
"We recommend that a monitoring regime is set up to keep abreast of hydrogen market developments and coordinate regulatory responses to 'trigger events' as they arise."

4. The Working Group
"We see the need for ongoing monitoring of regulatory issues across the future hydrogen value chain. The Hydrogen Regulators Working Group is the right forum to coordinate this activity."

These recommendations are supported by the Consortium with the proviso that the aviation sector is represented on the Working Group. To ensure country-wide involvement, airports or the NZ Airport Association, and airlines should have representation, along with subject matter experts from within the hydrogen production industry. The Consortium suggests Māori should also be represented on the Working Group.

Treaty of Waitangi
PwC noted that hydrogen regulatory reform will:

"need to confirm with the constitutional principles of the Treaty of Waitangi".

They noted that the Treaty is explicitly considered in current environmental legislation but not in some key energy and transport laws.

The Consortium supports and encourages Māori involvement with the development of hydrogen, electricity and aviation sector policies and plans at a national level. With respect to specific projects, the Consortium members view iwi and hapū as key partners to be engaged with early and meaningfully as projects are developed. Within the Consortium, some companies have their own specific relationships through which Māori perspectives are incorporated with relevant mana whenua.

The Standards New Zealand Review
In 2019 Worksafe commissioned Standards New Zealand[51] to investigate what they could do to enable the integration of hydrogen as a fuel and industrial feedstock.

Standards New Zealand has formed a technical advisory group (and sub-working groups) to review standards across this framework. This process is not expected to be finalised until 2025.

51. Reviewing standards for the future integration of hydrogen | Standards New Zealand

The Consortium's review of standards and regulations
The members of the New Zealand Hydrogen Aviation Consortium carried out a brief review of key regulations and standards that are likely to affect the production and use of hydrogen as an aviation fuel.

While carrying out this review the Consortium noted that it supports full reviews of:

- Hydrogen regulations in partnership with MBIE.
- Hydrogen standards in partnership with Standards New Zealand.
- Relevant aviation rules in partnership with the Ministry of Transport and the Civil Aviation Authority[52]

As aviation is a global industry there are several components of the ecosystem where New Zealand chooses to adopt and apply international standards rather than developing and applying local standards.

The key agencies that administer regulations and standards that affect New Zealand aviation are:

- The New Zealand Civil Aviation Authority (CAA)[53] which administers the Civil Aviation Rules (CAR).
- Standards New Zealand[54] which publishes and administers specific New Zealand Standards (NZS).
- The US Federal Aviation Administration (FAA)[55] which administers the Federal Aviation Regulations (FAR).
- The European Union Aviation Safety Agency[56] (EASA) which administers the European Union (EU) regulations.
- International Organization for Standardization (ISO)[57] which publishes and administers international standards.

The important role of the International Air Transport Association is also noted. The IATA is the trade association for the global airline industry representing some 300 airlines, including Air New Zealand. While its policies and guidelines do not have regulatory status in New Zealand, they do influence some critical aviation issues[58]. For example, contracts for refuelling are operated in accordance with the IATA Standard Ground Handling Agreement.

The Consortium's review identified the following standards and regulations. The Consortium notes this list is not comprehensive. There are other relevant regulations and standards from national or regional bodies that may be relevant for application in New Zealand.

Area of operation	Rules and Standards
Aircraft certification	CAR Part 21 Certification of Products and Parts. This New Zealand rules specifies FAA design requirements, with ability to recognise other jurisdictions. There are various FAA and EASA rules covering design requirements for aircraft, engines and propellers. There are also mechanisms for when the regulations do not contain adequate or appropriate safety standards because of a novel or unusual design.
Aircraft operations	CAR Part 91/119/121/125/135 etc. These are various operating rules for general and commercial air transport operations.
Aircraft operations	CAR Part 139 covers Aerodrome Certification, Operation and Use. This rule may not adequately consider hydrogen fire suppression requirements. CAR Part 12 Accidents, Incidents and Statistics. This rule may need additional guidance to clarify hydrogen related incidents and near misses.
Hydrogen refuelling	CAR Part 91 General Operating and Flight Rules. 91.15 only considers Class 3.1A, 3.1C and 3.1D flammable liquids under the Hazardous Substances (Classification) Regulations 2001 — this definition does not include hydrogen. This rule also requires refuelling and defueling be done in line with the HSNO Act 1996. The Health and Safety at Work (Hazardous Substances) Regulations 2017 will apply to any onsite or transportable storage of hydrogen fuel. The Health and Safety in Employment (Pressure Equipment, Cranes, and Passenger Ropeways) Regulations 1999 will apply to any pressurised equipment. Several ISO standards are relevant to New Zealand for example: • ISO 13984:1999 Liquid hydrogen — land vehicle fuelling system interface • ISO 13985: 2006 Liquid hydrogen — land vehicle fuel tanks. • ISO 14687:2019 Hydrogen fuel quality — Product specification. • ISO 20421—1&2:2019 Cryogenic vessels — large transportable vacuum-insulated vessels. • ISO20454:39:00 Cryogenic vessels.
Distribution of hydrogen	CAR Part 19F Supply Organisation Approvals. This rule contains organisational requirements including the need for adequate supply control procedures. Land Transport Rule Dangerous Goods 2005 — is applicable to transportation of hydrogen. Gas (Safety and Measurement) Regulations 2010 — will be applicable if hydrogen is distributed via gas distribution network. UN Modal Regulations- Dangerous Goods. ADR: EU Dangerous Goods Regulations.[59, 60]
Production of hydrogen	Health and Safety in Employment (Pressure Equipment, Cranes, and Passenger Ropeways) Regulations 1999 will apply to any pressurised equipment as part of hydrogen production. ISO 22734:2019 Hydrogen generators using water electrolysis — industrial, commercial and residential applications.

52. The CAA has begun the process with an initial scan of rules that may need to be reviewed or created to support alternative propulsion systems: Regulatory policy | Aviation New Zealand
53. CAA and Avsec
54. Standards New Zealand
55. Federal Aviation Administration
56. European Union Aviation Safety Agency
57. International Organization for Standardization
58. Programs & Policy | International Air Transport Association (IATA)
59. About the Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) | United Nations Economic Commission for Europe
60. Mobility & Transport - Road Safety: Dangerous goods | European Commission.

The roadmap for green hydrogen aviation

The New Zealand Hydrogen Aviation Consortium has developed a roadmap outlining the 2023 to 2050 pathway for the introduction and expansion of the use of liquid green hydrogen as an aviation fuel in New Zealand.

This includes a range of key actions for Consortium members, for other organisations in New Zealand's aviation sector, and for the New Zealand Government and its ministries and agencies.

	Today	2025	2030	2040+
Renewable Electricity Generation, Transmission and Distribution Certainty of supply of renewable energy for hydrogen production (at scale, at right time)	• Aviation energy demand included in planning for new renewable generation and transmission capacity.	• Kōwhai Park solar farm begins operation at Christchurch Airport • Electricity supply confirmed for initial green hydrogen production sites • Large scale infrastructure development co-ordination for generation and transmission underpinned by green hydrogen production demand	• New renewable generation operating and further renewable generation under development • Electricity supply contracts supplying large scale green hydrogen production facilities • Electricity transmission and distribution infrastructure connecting to new generation	• Ongoing development and scale up to meet green hydrogen demand
Green hydrogen production, storage and liquefaction Development of commercial supply chain for hydrogen at scale (de-risking ramp-up)	• Master planning for a hydrogen hub at Christchurch Airport • Second hydrogen hub initial planning	• Development of hydrogen hub at Christchurch Airport • NZ Airports Association involvement • Hydrogen network and logistics planning • Planning for hubs at other airports	• Additional airport hydrogen hub(s) established • Increased hydrogen production to meet increased demand and reserve requirements at main hubs • Storage increase at established hubs and development of regional hydrogen hubs	• Increasing demand for liquid hydrogen for aviation, potentially including short-haul international flights • Increasing demand for green hydrogen through eSAF production • Further hydrogen hubs established • Full hydrogen supply network operating
Hydrogen distribution and refuelling Operational and infrastructure requirements to deliver/refuel hydrogen aircraft	• Development of hydrogen distribution and fuelling technology, preparation for scaling up	• Gaseous hydrogen refuelling available at Christchurch Airport - for airport ground service vehicles or heavy transport • Planning, trialling, and setup of Liquid Hydrogen storage and refuelling at Christchurch Airport • Gaseous refuelling at secondary hydrogen hub location	• Liquid hydrogen refuelling at second hydrogen hub location • Gaseous and liquid refuelling be-comes available at other hydrogen hub locations • Refuelling technology continues to advance and mature	• Ongoing development and scale-up to meet increasing green hydrogen demand
Aviation end use Establishing aviation market for hydrogen aircraft	• Concept development of hydrogen powered aircraft technology	• Development of small and regional scale hydrogen powered aircraft under experimental certifications • Testing of small hydrogen powered aircraft in New Zealand • Development of maintenance facilities to support hydrogen powered aircraft	• Hydrogen powered trucks and buses deployed for servicing airport precinct • Hydrogen powered-ground services vehicles deployed at airports • Commercial hydrogen powered flights for turboprop routes available • Ongoing maintenance facility development • Deployment of hydrogen powered aircraft on domestic routes	• Increasing deployment of commercial hydrogen powered aircraft on domestic routes • Potential testing / introduction of hydrogen powered aircraft on short-haul international routes
Government	• Inclusion of aviation demand into Electricity, Distribution and Generation Scenarios (EDGS). • Inclusion of aviation demand into Government strategies, including NZ Hydrogen roadmap and NZ Energy strategy • Engagement with iwi/hapu around green hydrogen opportunities	• Introduction of support schemes for green hydrogen • Enabling development of renewable energy • Aviation regulation development • Green Hydrogen certification • CAANZ acceptance of international type certifications and adoption of standards • Training standard development	**Ongoing activities** Enabling establishment of green hydrogen powered aviation • Emissions Reduction Plan drives ongoing emissions improvements • Engagement with iwi/hapu for training and scale opportunities • Implementation of support programmes enabling large-scale generation and investment for green hydrogen • Ongoing monitoring and continuous improvement to hydrogen sector (and associated aviation) standards • Upskilling of hydrogen production and aviation workforce • CAANZ ongoing development and support of novel propulsion aircraft	

Concluding comments

Aviation is key to New Zealand's prosperity, providing access to domestic and global markets for primary industry, tourism, healthcare, business and education. However, aviation must reduce its emissions. The Consortium expects that liquid green hydrogen will have an important part to play in this.

The New Zealand Hydrogen Aviation Consortium has developed a pathway for introducing and then growing the use of liquid green hydrogen in aviation.

Key steps will be the development and deployment of:

- New and large-scale renewable electricity generation
- Green hydrogen production plants and storage systems
- Hydrogen refuelling systems
- Hydrogen powered aircraft

Collaboration between the Consortium, Government and other stakeholders is key to developing a green hydrogen ecosystem and achieving the roadmap outlined.

This hydrogen aviation ecosystem will be enabled by private sector vision and investment complemented by the development of policies and regulations by the New Zealand Government. The Consortium embraces the challenge and looks forward to working with all stakeholders on the journey ahead, to launch green hydrogen powered aviation in Aotearoa New Zealand.

The New Zealand Hydrogen Aviation Consortium

The vision
The New Zealand Hydrogen Aviation Consortium was launched in February 2023 and consists of six international businesses with a shared vision to support Aotearoa in pioneering the commercial deployment of hydrogen-powered aircraft.

The companies Airbus, Air New Zealand, Christchurch Airport, Fabrum, Fortescue and Hiringa Energy recognise this as a strategic opportunity for the aviation sector.

The first phase of the Consortium's work programme focused on this research.

In particular, the members committed to developing a vision for hydrogen aviation in New Zealand, examining the hydrogen supply chain and its challenges, assessing the local aviation market's projected hydrogen needs to 2050, and developing a pathway of policies, regulations and incentives to promote the development of hydrogen aviation.

Membership

Airbus
Airbus pioneers sustainable aerospace for a safe and united world. As a proven leader in the global aerospace sector, Airbus designs, produces and delivers innovative solutions with the aim of creating a better-connected, safer and more prosperous world. Currently, Airbus is developing the first hydrogen-powered commercial aircraft with the ambition to enter into service in 2035.

Airbus is a global leader in aeronautics, space and related services. In 2022 it generated revenues of €58.76 billion and employed a workforce of around 134,000. Airbus offers the most comprehensive range of passenger airliners. Airbus is also a European leader providing tanker, combat, transport and mission aircraft, as well as one of the world's leading space companies. In helicopters, Airbus provides the most efficient civil and military rotorcraft solutions worldwide.

Air New Zealand
Air New Zealand is a leading global airline with a goal to achieve net zero carbon emissions by 2050. Based on reported 2019 passenger numbers, Air New Zealand provided around 80% of domestic and regional services and just over 40% of international services to and from New Zealand. It is committed to reducing emissions from its fleet, and green hydrogen is emerging as a key technology for the industry. Air New Zealand is actively investigating the role of low emission aircraft technologies to support the decarbonisation of its network and aiming to have a commercial demonstrator flying in 2026.

Christchurch International Airport
Christchurch Airport is a leader in airport decarbonisation having reduced airport operational emissions by 94% since 2015, achieving net zero airport operations from 2021 onwards, and mentoring airports globally on how to decarbonise their operations. Christchurch Airport has taken a leadership position in aviation decarbonisation through launching the development of a 400-hectare renewable energy park, named Kōwhai Park, to actively encourage the uptake of low emission aircraft technologies.

Fabrum
Fabrum is a privately held New Zealand company and a global leader in the design and manufacture of full ground infrastructure for hydrogen production, liquefaction, storage, fuel transfer, on-board flight fuel systems and architecture, motors, and certification support. Fabrum has successfully deployed commercial solutions to clients for hydrogen (including liquid) for aviation applications including electric and superconducting aircraft motors. In addition, Fabrum has designed and built fuelling infrastructure and systems for decarbonising heavy freight vehicles and industrial equipment including mining and marine. Fabrum designed, modelled and specified the hydrogen propulsion systems for Emirates Team New Zealand Chase Zero Americas Cup boat as well as SailGP zero emission hydrogen chase craft.

Fortescue
Fortescue is a global metals and green energy company, recognised for its culture, innovation and industry-leading development of infrastructure, mining assets and green energy initiatives. It operates with two divisions — Metals and Energy. Fortescue Energy is comprised of Fortescue Future Industries (FFI) and WAE Technologies. FFI is committed to producing green hydrogen, containing zero carbon, from 100 per cent renewable sources. FFI is leading the green industrial revolution, developing technology solutions for hard-to-decarbonise industries, while building a global portfolio of renewable green hydrogen and green ammonia projects. FFI is also leading the global effort to help decarbonise hard-to-abate sectors and is developing and acquiring the technology and energy supply to help decarbonise the iron operations of one of the world's largest producers of iron ore, Fortescue Metals, by 2030 (Scope 1 and 2 terrestrial emissions).

Hiringa Energy Limited
Hiringa Energy is a privately held New Zealand energy company focused on the commercial and sustainable development and operation of hydrogen production, storage, distribution, and supply infrastructure. Hiringa designs, builds, owns and operates green hydrogen infrastructure for industrial feedstock, energy management, and the heavy transport sector. Specific projects include the development of New Zealand's first green hydrogen refuelling network, coming online from 2023 as well as the development of a number of large-scale wind and solar to green hydrogen projects across New Zealand and Australia.

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Glossary

Aviation fuel — fossil sourced hydrocarbon fuels used in aircraft including jet fuel (Jet A-1 in New Zealand) and Avgas (mostly used in small aircraft) and often called kerosene. For the purposes of this report the term aviation fuel is distinct from Sustainable Aviation Fuel (SAF).

Biofuels — these are liquid hydrocarbon fuels that are produced from a range of biological raw materials. Biofuels are one of two pathways for producing sustainable aviation fuel.

BioSAF — sustainable aviation fuel produced using a biofuel method.

CO_2-e — Carbon dioxide equivalent emissions. The different greenhouse gases have different effects and lengths of time they remain in the atmosphere. CO_2-e combines the impact of all gases into one measure.

Domestic — Through this report domestic flights refer to flights within New Zealand. Air New Zealand use 'domestic' to refer to internal jet fleet flights and "regional" to refer to internal turboprop flights.

Electrolysis — the process of using electricity to split water (H_2O) into its constituent components — hydrogen and oxygen.

eSAF — Sustainable Aviation Fuel produced when green hydrogen (made by electrolysis) is combined with CO_2 captured as part of a low or ideally no emissions cycle.

GHG — greenhouse gas emissions. While carbon dioxide is normally the largest contributor to GHG emissions the term GHG includes other gases such as methane, nitrous oxides and water vapour. Hydrogen is also a GHG.

Green hydrogen — hydrogen produced from using renewable electricity to electrolyse water.

Hydrogen (or H_2) — the smallest lightest and most abundant element, making up about 90% of the universe. It is colourless and odourless and readily combines with other substances (e.g. oxygen to form water) so it is rarely present on earth as pure hydrogen.

Jet A-1 — is a kerosene-based fuel that meets specific performance and quality standards set by international aviation authorities. Jet A-1 is the main grade of aviation fuel used in New Zealand for commercial purposes.

LH_2 — liquid hydrogen.

MW and GW — megawatt and gigawatt are units of power. 1 GW = 1,000MW.

MWh, GWh and TWh — megawatt hour, gigawatt hour and terrawatt hour are units of energy produced or used over an hour. 1 TWh = 1000 GWh. 1 GWh = 1,000 MWh.

Net capacity factor - is a measure of the proportion of time that a generation plant can produce electricity.

Renewable electricity — electricity that has been generated from sustainable sources. In New Zealand this includes hydro, solar, wind and geothermal generation.

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