THE NEW ZEALAND HYDROGEN OPPORTUNITY

A perspective on New Zealand's potential role in the emerging global hydrogen economy

July 2021

In December 2020 Contact and Meridian announced a joint study to investigate the potential of a large scale, renewable hydrogen production facility in the lower South Island. The initiative was prompted by New Zealand Aluminium Smelter's (NZAS) termination of its electricity supply agreement for its Tīwai Point smelter, which currently consumes 12% of New Zealand's largely renewable electricity.

The NZAS electricity supply agreement was subsequently extended on 14 January 2021 to 31 December 2024.

This joint study considers the prospect of repurposing the significant volume of lower South Island based renewable electricity that is expected to become available from 1 January 2025 into the emerging green hydrogen industry.

This report is the first part of this joint study and provides a perspective on New Zealand's potential role in the emerging global hydrogen economy. It draws on research carried out by Meridian Energy (Meridian), Contact Energy (Contact) and McKinsey & Company.

Contact and Meridian are working together on this study due to the anticipated nature, scale, investment requirements and risk profiles of potential hydrogen projects. Neither is likely to be able to progress a project of significant scale independently.

At this stage there has been no commitment to proceed jointly or exclusively with any opportunities identified in the study. Any formal arrangements for a joint project will be subject to legal advice and/or approval from the New Zealand Commerce Commission (if necessary).

KEY CONCLUSIONS

1. **International markets for green hydrogen are imminent**
   Global demand forecasts for green hydrogen are high. Hydrogen is quite possibly the only decarbonisation solution for countries with scarce renewable energy resources and for sectors that have no other renewable energy alternatives.

2. **New Zealand could become the world's first large-scale producer of green hydrogen**
   New Zealand has a key competitive advantage, as the renewable electricity available from 1 January 2025 could produce green hydrogen at an internationally competitive price point. This could enable New Zealand to be a world-leading exporter of green hydrogen. In addition, New Zealand's abundance of low-cost renewable development options may support long-term growth.

3. **Liquid green hydrogen or green ammonia?**
   Green hydrogen can be delivered in different forms, with liquid hydrogen and ammonia the most likely. Both have advantages and disadvantages. While a New Zealand project could deliver either, the ultimate choice will be determined by end customers' specific use case applications.

4. **Focus required to support a hydrogen future**
   There are a range of uncertainties that will influence the viability and timing of a green hydrogen opportunity in New Zealand. These include international government support, the certification of green hydrogen, technology developments, alternative fuels and consumer preferences. Given the extent to which growth is forecast, there is confidence that these issues will be overcome. The key issue will be timing.

5. **Bridging the economic gap will require government support**
   Hydrogen is projected to remain more expensive than conventional fossil fuel energy sources in the medium term. Bridging this cost differential will require significant government support through carbon pricing or other measures.

6. **A hydrogen production facility can support a dry-year solution**
   A green hydrogen plant can be designed to vary its production to suit conditions within the New Zealand electricity system. During dry years, production can be reduced, therefore providing dry year reserve. During times of energy surplus, production can be increased to capture renewable spill. This flexibility could offer a substantial and valuable contribution to support New Zealand's decarbonisation goals. Given its importance, a complementary piece of detailed analysis is being undertaken to quantify this opportunity.

7. **The potential for transformational economic change**
   New Zealand's competitive advantage provides an opportunity to create an entirely new industry with long-term economic value. This industry could help decarbonise both international and domestic markets.

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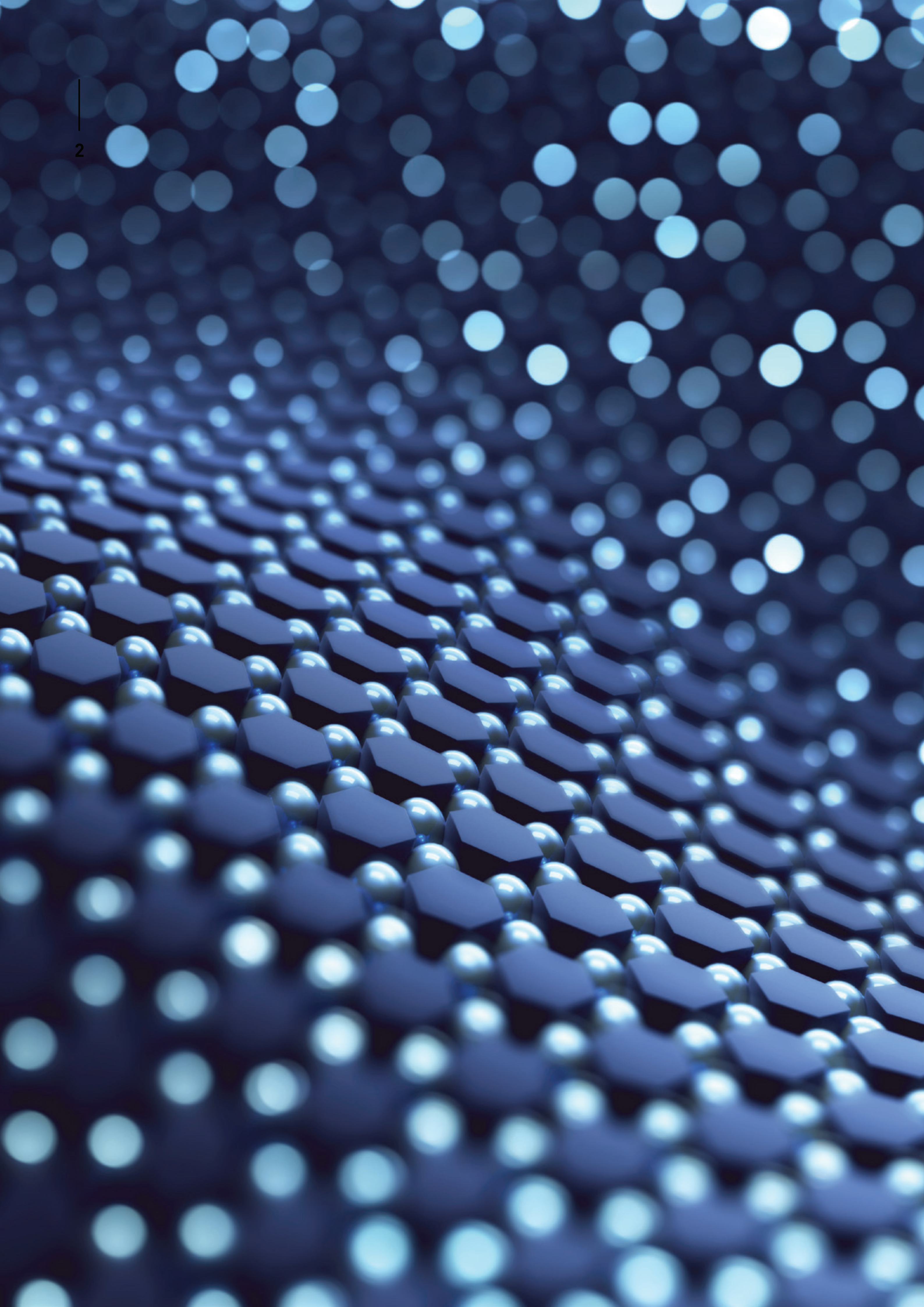


EXECUTIVE SUMMARY

The market for green hydrogen[1] is gathering strong momentum globally. For New Zealand, the renewable electricity available from January 2025 presents an early opportunity to take a position in this market. New Zealand has the potential to become the world's first large-scale producer of green hydrogen. The country's existing renewable generation is likely to underpin a long-term cost advantage.

Spurred by an increasing mandate from regulators, investors and consumers to decarbonise, green hydrogen and green hydrogen-derived chemicals (for simplicity referred to simply as 'green hydrogen' throughout this document) are being increasingly recognised as key enablers of the transition from fossil fuel-based to zero-carbon energy. This is particularly true for countries with few domestic renewable generation options and for sectors that have few or no feasible low-carbon alternatives. These 'hard-to-abate' sectors include chemical manufacturing, petroleum refining, steel manufacturing, heavy transport, shipping, air travel, high-temperature industrial heat, and heat for buildings.

Interest in hydrogen is accelerating. In March 2021 there were 50 gigawatts (GW) of announced green hydrogen electrolyser projects[2] through to 2030, up from 3GW in June 2019 for the same period. Various players are positioning for shares in this developing market.

Green hydrogen is a highly versatile, transportable solution to decarbonisation. It could become a global commodity that links renewable rich countries like New Zealand to countries that currently depend on fossil fuels.

As a highly versatile, transportable solution to decarbonisation[3], green hydrogen has the potential to become a global commodity that links renewable rich countries like New Zealand to countries currently dependent on fossil fuels. Governments around the world have sent strong signals of their confidence in hydrogen. More than 30 countries have developed hydrogen roadmaps and NZ$100 billion has been committed in financial support to date. Green hydrogen is expected to break even with conventional fossil fuels over time, but decarbonisation will continue to be the key driver, with buyers willing (or incentivised) to pay a premium.

1 *Green hydrogen* refers to hydrogen gas that is generated via electrolysis powered by renewable energy such as hydro, solar or wind energy; see sidebar: *Hydrogen production pathways*.

2 An electrolyser is a technology that uses electricity to split water into hydrogen and oxygen in a process called electrolysis.

3 *Decarbonisation* refers to the process of removing or reducing the amount of greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4) emitted into the atmosphere. This is usually done by replacing fossil fuels with renewable energy.

The global demand for low-carbon-intensity hydrogen could be as high as 553 million tonnes by 2050 (with demand growing by 7% per annum from 2020), creating significant opportunities for exports to Asia before 2030.

As global trade increases, major net importers (e.g. Japan and South Korea), net exporters (e.g. New Zealand, Australia, the Middle East, Canada and Chile) and self-sufficient markets (e.g. China) are likely to emerge. These markets will be propelled by a combination of decarbonisation commitments, a concentration of hard-to-abate sectors, and access to renewable energy resources. Asia, specifically Japan and Korea, is expected to be a key demand centre for green hydrogen, with more than 13 million tonnes of potential demand by 2030.

Japan and Korea have committed to targets of net-zero greenhouse-gas emissions by 2050. They have strong incentives to diversify their energy supply and have demonstrated a desire to build hydrogen economies. These countries will need to import green hydrogen, and projected net exporters like New Zealand will be well placed to leverage this opportunity[4].

Supply is ramping up to meet demand, but there are challenges to achieving a large-scale hydrogen economy.

Both green hydrogen and blue hydrogen[5] are expected to have roles in phasing out grey hydrogen[6] in the next 20 years. Their production potential varies by country based on the availability and cost of inputs such as renewable electricity and low-cost gas and CO_2 storage solutions. Over time, global green hydrogen costs are expected to decrease as more low-cost renewable energy comes online, making green hydrogen competitive with blue and grey. Under an accelerated transition scenario, the global demand for green hydrogen is expected to reach significant scale by 2040 and could be as high as 553 million tonnes by 2050.

Reflecting this demand increase, supply projects are ramping up around the globe, with more than NZ$462 billion[7] of hydrogen-related investments (equivalent to 50 GW of electrolyser projects) already announced through to 2030. For a large-scale hydrogen economy to eventuate by 2040, there will need to be a continued fall in costs such as:

- **Production costs** – Expected to decrease by over 60% by 2030 as the cost of renewable energy and electrolyser technology reduce, and the efficiency of conversion improves. However, this cost reduction will require rapid progress and large-scale uptake. For example, 65 GW of electrolysis may be required to reduce green hydrogen costs to break even with grey hydrogen.
- **Distribution costs** – Expected to fall by as much as 60% as the scale of deployment increases and trucking and pipeline transportation technology improves.
- **Shipping and reconversion costs** – Expected to fall by more than 80% by 2050. As technology improves and more capacity comes online, the cost of liquefying and shipping liquid hydrogen is expected to reduce substantially. This expectation is consistent with the cost decline observed in the development of the LNG (liquefied natural gas) industry.

For downstream use cases of green hydrogen to be viable, we will also need to see technological improvements in hydrogen end-use applications. This will require substantial investments in infrastructure such as refuelling stations, as well as more government measures to meet decarbonisation commitments.

4 In 2018 New Zealand and Japan signed a Memorandum of Cooperation on hydrogen.
5 *Blue hydrogen* refers to hydrogen produced using natural gas or coal and involves CO_2 capture and storage.
6 *Grey hydrogen* refers to hydrogen produced using fossil fuels such as natural gas or coal.
7 Of which US$80 billion can currently be considered 'mature', meaning that the investment is at the planning stage, has passed a final investment decision or is associated with a project under construction, already commissioned or operational.

THE NEW ZEALAND HYDROGEN OPPORTUNITY

New Zealand has a unique opportunity to enter export markets and kick-start domestic demand, with potential to supply competitively priced baseload green hydrogen at scale from the mid-2020s.

New Zealand's position is fundamentally different from those of other countries that are looking to produce hydrogen from yet-to-be-constructed, low capacity factor renewables from wind or solar generation. New Zealand's renewable generation available from 1 January 2025, alongside existing transmission assets, provides it with a valuable head start. With immediate access to cost-competitive, high capacity factor[8] renewable electricity, New Zealand could produce green hydrogen that has a significant competitive advantage in both export and domestic markets.

An abundance of renewable generation and transmission assets give New Zealand a valuable head start.

Modelling has estimated that exports of New Zealand's green hydrogen to a country such as Japan will be worth US$4.30-5.60/kg of hydrogen (NZ$6.60-8.60/kg) by 2025. This would be competitive even against the expected cost of competition from the likes of blue hydrogen from the Middle East through to 2030 or potentially longer if carbon capture and storage is uneconomic. Longer term, green hydrogen being produced in the Middle East, Chile and Australia from large scale solar and wind facilities is expected to be internationally competitive. As global competition intensifies, New Zealand will need to reduce the cost of its own renewable developments if it is to remain cost competitive as an exporter.

Domestically, green hydrogen presents an opportunity to accelerate the transition of hard-to-abate sectors away from fossil fuels. Even assuming low carbon prices, some transport and chemical production use cases are expected to be competitive with fossil fuel technologies by 2030. With the higher forecast cost of carbon and/or greater industry commitment, use cases like heavy duty transport could become commercially competitive by 2030. Locally produced green hydrogen for the domestic market produced from existing hydro assets in the lower South Island is expected to remain competitive in the long run, even against potential low-cost imports derived from large-scale solar/wind based facilities.

For other use cases, hydrogen is not expected to be competitive with fossil fuels until beyond 2030. However, growing customer sentiment suggests an increasing appetite from the private sector (with support from governments) to make initial investments in funding the gap to support the transition to hydrogen.

Investment in a green hydrogen economy may have significant decarbonisation, energy security and economic benefits for New Zealand. It may present unique opportunities to:

- **Help New Zealand deliver on its decarbonisation promise** to reduce greenhouse gas emissions to 30% below 2005 levels by 2030, and to be net-zero by 2050. Hydrogen has the potential to mitigate 23-53% of New Zealand's gross long-lived greenhouse gas emissions at 8.6-20.0 million tonnes CO_2e. Abatement potential is the highest in the chemical manufacturing, petroleum refining, steel manufacturing, heavy transport, shipping, air travel, high-temperature industrial heat, and heat for buildings sectors.

8 Capacity factor is the ratio between a generation unit's actual generation output over a period of time versus what the unit is capable of generating at maximum output.

- **Support New Zealand's energy transition** by providing flexible demand response to suit the needs of the New Zealand electricity system. During dry years, production can be reduced, therefore providing dry year reserve. During times of energy surplus, production can be increased to capture renewable spill. Flexible hydrogen production offers a cost-effective method to mitigate the risks of dry years when hydro inflows are low.
- **Attract new large-industrial manufacturers to New Zealand.** Rather than import renewable energy as hydrogen or ammonia from New Zealand, large-industrial companies may have a compelling reason to relocate their hydrogen and energy-intensive activities to New Zealand.
- **Continue to attract environmental, social and governance (ESG) focused investors to New Zealand.** Major fund managers such as the world's largest asset manager, BlackRock, have shifted their attention to sustainable investments and are likely to continue investing in New Zealand's economy.
- **Contribute to New Zealand's innovation agenda.** Hydrogen could attract high-tech jobs to New Zealand and contribute to the broader goal of being the leading innovator in the Asia-Pacific region.

The next few years will be critical for the creation of New Zealand's green hydrogen economy. Several decisions will be needed to facilitate it.

New Zealand's access to existing high-capacity-factor renewable electricity provides it with a significant advantage over global competitors in the early-stage of large-scale green hydrogen production. As this report details, New Zealand has an opportunity to support fuel-transition and carbon-abatement strategies in selected global energy markets, while also providing a platform for decarbonising the domestic transport and industrial sectors.

To capitalise on this early advantage effectively, four strategic considerations need to be assessed:

- **How can New Zealand capitalise effectively on potential global export opportunities to build a platform for the domestic hydrogen economy?** New Zealand's immediately available production capacity may be highly attractive to early off-takers[9] overseas. Securing an early export off-take agreement to support an initial investment in a hydrogen production facility, provides a future pathway for domestic hydrogen supply. This early facility could effectively cross-subsidise the establishment of a domestic market. At the same time, it will be important to balance the allocation of hydrogen export and domestic applications.
- **As the hydrogen market develops, how will regulatory mechanisms be monitored and deployed?** Domestic regulations will need to be carefully selected to stimulate demand and investment where they are most needed. They might include subsidies to fund the development of hydrogen technologies, or carbon levies on imports from countries with weaker emission rules (the latter was recently put forward by the European Union). Monitoring the regulatory environments in potential export markets will be critical to understanding how demand may evolve, and where New Zealand can potentially focus its supply.
- **Which green hydrogen products should be prioritised and produced at scale, now and in the long term?** Each hydrogen product examined in this report has distinct opportunities and risks. Ultimately customer demand will determine the commercial path. For New Zealand, the nearer-term, high-potential opportunities are likely to be in ammonia. Ammonia production technologies and transport mechanisms have already been proven, and markets such as Japan have material demand growth prospects. Domestic supply for applications such as transport and steel production will be important in the longer term if New Zealand is to fully decarbonise. Taking a long-term perspective and continually monitoring the evolution of hydrogen demand

9 An *off-taker* is a purchaser of renewable energy.

will support more efficient allocations of capital investments to the use cases with the greatest potential for New Zealand.

- **How do we leverage the benefits of green hydrogen production for the power system?** The New Zealand electricity system is a hydro-dominated power system where dry years represent the greatest security of supply challenge. While thermal generation is used to support electricity demand during dry years, there is clear Government interest in replacing this with a renewable alternative such as pumped hydro generation. A green hydrogen facility has the potential to reduce production during dry years and to increase production during periods of surplus. This represents a significant opportunity to solve a large portion of New Zealand's dry year problem. A complementary piece of analysis is being undertaken to quantify the costs and benefits of this demand response.

Several immediate next steps are critical to realise the opportunity.

For New Zealand to realise the full benefits of a green hydrogen economy, industry players, investors and government need to work together to:

- **Investigate the feasibility** of large-scale renewable energy hydrogen production in New Zealand while considering the commercial, technical, societal, economic and environmental impacts.
- **Determine the benefits to the New Zealand electricity system** in terms of energy flexibility and dry-year risk management.
- **Firm up the commercial potential internationally and domestically, and investigate potential business models** with participants in the hydrogen value chain.
- **Explore appropriate incentive mechanisms to kick-start** the hydrogen economy.
- **Develop appropriate certification schemes** for green hydrogen production and exports to demonstrate product authenticity.

HYDROGEN PRODUCTION PATHWAYS – AN INTRODUCTION

There are various ways to produce hydrogen. Today, around 99% of hydrogen comes from fossil fuels, primarily by reforming natural gas into hydrogen and CO_2. This hydrogen is often referred to as 'grey hydrogen' if the CO_2 is emitted into the atmosphere.

There are two main alternatives that have lower carbon intensity (Exhibit 1):

- **'Blue hydrogen'** is hydrogen gas produced by combusting non-renewable energy sources (such as natural gas reforming or coal gasification). Unlike grey hydrogen, the CO_2 that is released in the process is sequestered and stored permanently.
- **'Green hydrogen'** refers to hydrogen gas that is generated via electrolysis powered by renewable energy such as hydro, solar or wind energy. CO_2 sequestration is not required to avoid greenhouse gas emissions.

For reference, in this report we examine hydrogen in terms of:

- **Weight** – The standard unit of measure is expressed in kg, t, kt or Mt
- **Cost** – The cost of producing hydrogen is expressed in $/kg H_2.

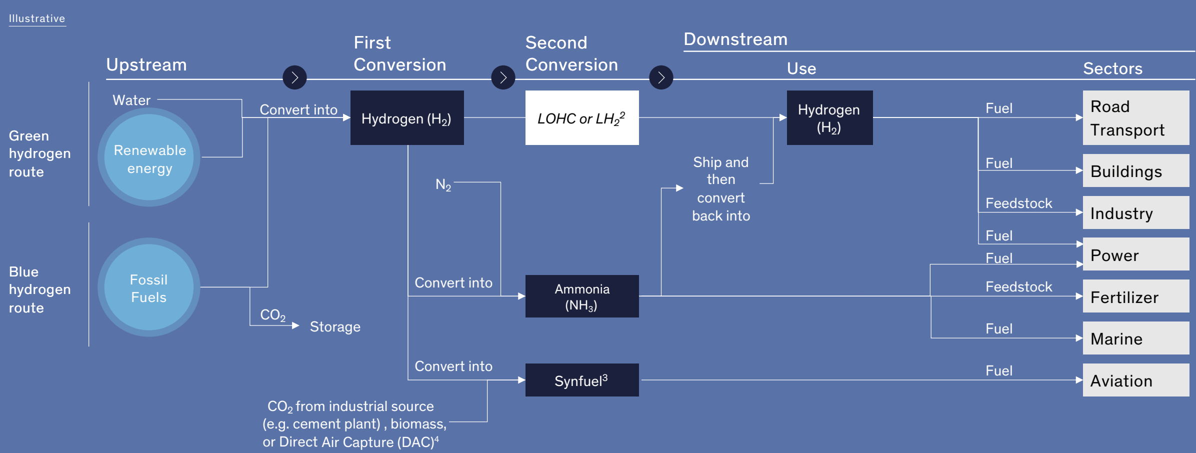
For ease of comparison, the following conversion factors have been applied:

- **Energy contained in hydrogen** – 33.33 kWh/kg or 120 MJ/kg H_2 (the lower heating value has been applied throughout the report).
- **Electricity required to produce hydrogen** – 49.8 kWh/kg H_2 (2030 example, assuming 67% lower heating value electrolyser conversion efficiency).
- **Cost of producing hydrogen** – $1/kg H2 equals $20.1/MWh or $5.58/GJ (2030 example, assuming 67% LHV electrolyser conversion efficiency).

Exhibit 1

Green fuels include hydrogen, ammonia, and synthetic fuels produced in a low-carbon manner

Hydrogen from renewable energy or fossil fuels (+CCS[1]) is transformed into fuel and feedstock which can be used to decarbonize multiple end sectors



1. Carbon Capture and Storage
2. Liquid organic hydrogen compounds or liquified hydrogen; both are mediums used for transporting hydrogen to end-markets
3. Synfuel can technically be used in other sectors to replace fossil fuels, but most likely in aviation
4. CO is another potential source of carbon and is more efficient than CO_2

LIQUID HYDROGEN VS AMMONIA VS METHANOL

The first step in the production of green hydrogen involves using renewable electricity to 'split' water (H_2O) into oxygen and hydrogen using an electrolyser. The resulting hydrogen can be converted from a gas to one of three main products:

- **Liquid hydrogen** – Produced by reducing the temperature of gaseous hydrogen to -253°C in a process called liquefaction. Gaseous hydrogen has a low volumetric density, so liquid hydrogen allows for a higher level of hydrogen to be transported and stored for a given size of tank.
- **Green ammonia (NH_3)** – Produced by adding nitrogen to gaseous green hydrogen. The ammonia production process is a mature technology.
- **Green methanol** – Produced by combining a carbon-neutral source of carbon with oxygen and green hydrogen. A carbon-neutral source of carbon can be sourced from biomass or potentially directly from the air.

The characteristics and possible applications of each product differ:

Liquid green hydrogen

- Widest range of potential applications; however, markets will take time to develop
- High energy content on a unit of mass basis (120 MJ/kg H_2) but low energy content on a volumetric basis (8 MJ/litre for liquid hydrogen)
- Liquefaction currently very expensive — costs are expected to fall
- Large-scale transport not yet proven
- Fewer energy losses to produce compared with green ammonia and methanol
- Potentially the highest-value product

Green ammonia

- 80% of ammonia currently used to produce fertilisers
- Proven production technology
- Established global logistics and supply chain
- Smaller range of potential energy applications than hydrogen
- Higher volumetric density than either compressed or liquefied hydrogen

Green methanol

- Existing market with established global logistics and supply chain
- Derivatives can be used in transport markets (including potentially aviation)
- Requires the addition of carbon (e.g. biomass). Direct air capture technology still being developed

It is not yet clear whether green liquid hydrogen or green ammonia will emerge as the preferred energy carrier to decarbonise. Green methanol appears problematic in the near term given the difficulties of sourcing a renewable source of carbon at the scale and cost required to meet the world's decarbonisation objectives.

The principal trade-off between green hydrogen and green ammonia appears to be time versus potential value. Markets for ammonia exist now, while the markets for liquid hydrogen are still developing and depend on technology improvements and cost reductions. The future value of each product is unclear. Given liquid green hydrogen's wider range of potential end uses, it is possible that buyers will be more willing to pay more for hydrogen than for green ammonia.

Given these market uncertainties, it is important to have options. It is possible to start producing green ammonia then to focus on liquid hydrogen.

1. THE GLOBAL OUTLOOK FOR HYDROGEN

INTRODUCTION

Hydrogen will have a critical role in decarbonising countries that do not have adequate renewable generation options of their own and in hard-to-abate sectors (which currently have no green fuel alternatives).

The 2015 Paris Agreement signalled world leaders' commitment to act on climate change, with governments agreeing to hold the increase in global average temperature to well below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C.

Around 65% of global carbon emissions are energy related (electricity, heat and transport), and renewable electrification is widely accepted as the key method for reducing them.

However, for around 30% of these energy-related CO_2 emissions, hydrogen is the fuel with the greatest potential. This is because there are limited, or no green alternatives available, and direct electricity-based solutions come with high costs or technical drawbacks (such as the requirement to integrate the variability of renewable electricity output from solar and wind). The affected sectors (called the hard-to-abate sectors) include chemical manufacturing, petroleum refining, steel manufacturing, heavy transport, shipping, air travel, high-temperature industrial heat, and heat for buildings (Exhibit 2).

Hydrogen and hydrogen-based chemicals like ammonia are expected to have a central role in these sectors given their functions as highly versatile and transportable stores of energy that can be reserved for 'peak' times or 'dry seasons' and exported to countries that do not have enough access to renewables.

Globally, the demand for hydrogen is expected to reach significant scale by 2040 and hydrogen projects across the value chain are accelerating, with projections for 200x growth until 2030. The momentum for hydrogen has already accelerated in the past 12 to 18 months, with 50 GW of electrolyser projects announced as of March 2021 for the period through to 2030, compared to just 3 GW in June 2019 for the same period (Exhibit 3).

This interest is coming from a broad set of players in the value chain who are looking to capitalise on the emerging economy. However, while NZ$462 billion of electrolyser investments have been announced globally out to 2030, only NZ$123 billion can be considered 'mature', having either entered a formal planning stage, passed a final investment decision, or are associated with a project under construction, already commissioned or operational.

Governments are also signalling their interest in hydrogen projects, pledging more than NZ$108 billion in financial support. Of the 75 countries with net-zero carbon ambitions, 30 have already developed national hydrogen roadmaps and set capacity targets and other regulations to encourage the development of their hydrogen economies. For example, several US states have implemented targets to achieve zero emissions in passenger cars and trucks by 2035, and China has allocated NZ$8 billion to developing its fuel-cell value chain, including vehicle and infrastructure subsidies.

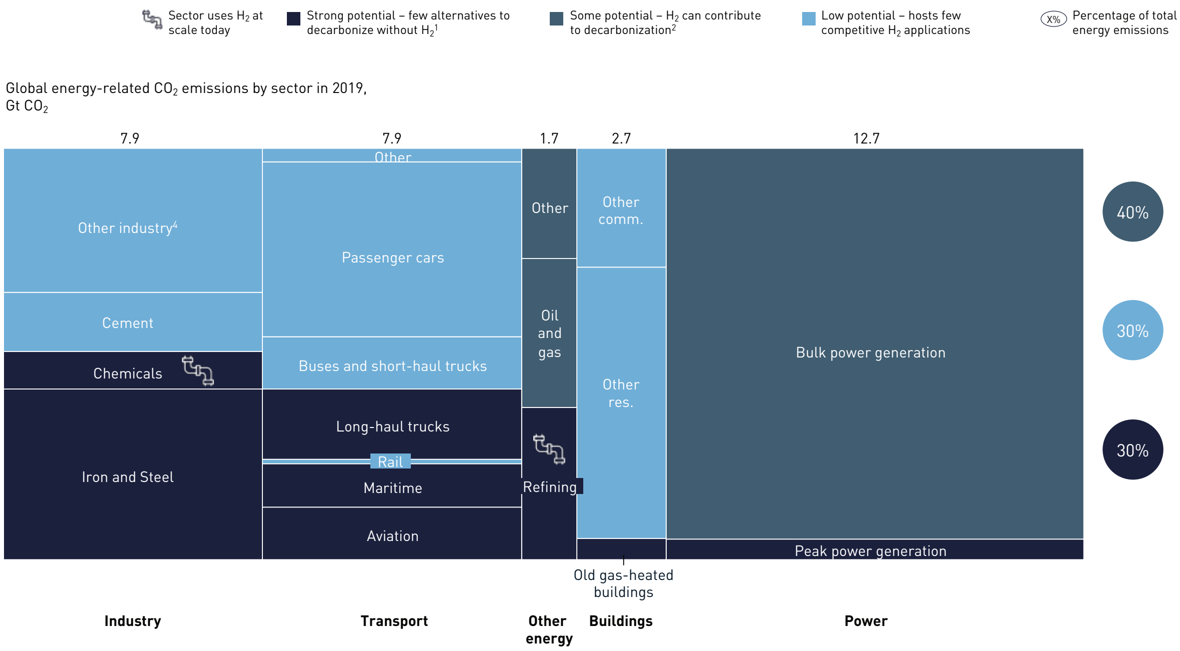
This is not the first time we've seen an interest in hydrogen. However, we believe structural shifts are making hydrogen uptake increasingly credible on a global scale:

- There is a growing and deep commitment to decarbonising government and industry, underpinned by increasing social expectations. Leaders in the automotive, chemicals, oil and gas and heating industries are looking to low-carbon hydrogen as a serious alternative to reach increasingly challenging sustainability

Exhibit 2

Hydrogen uptake can help to decarbonize hard-to-abate sectors

30 percent of energy-related CO_2 emissions are hard to abate with electricity only



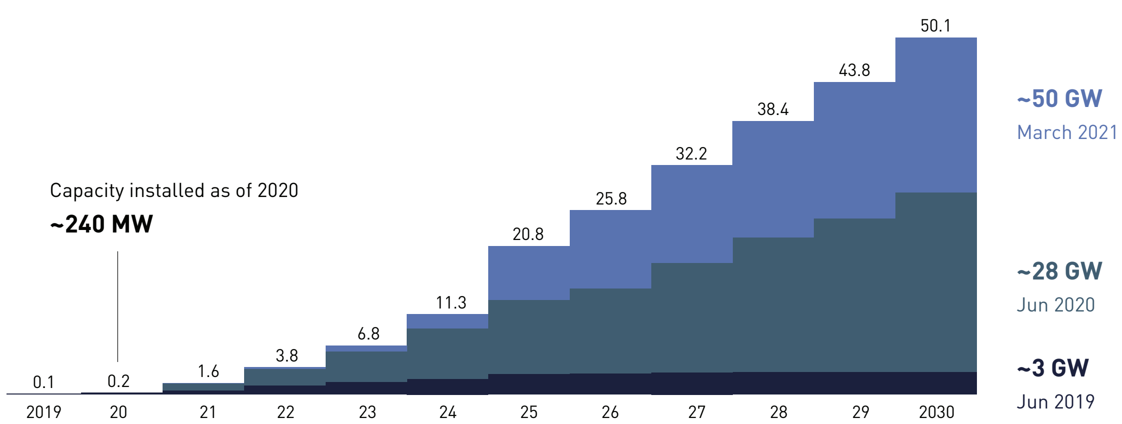
1. Hydrogen is one of few decarbonization options and is likely to be adopted on a large scale if decarbonization is pursued
2. Hydrogen is one of several decarbonization options and adoption will likely be on a limited scale
3. Contains agriculture/forestry, construction, fishing, food, manufacturing, mining, nonenergy use, nonferrous metals, and other materials
4. Contains transformation processes

Source: McKinsey Energy Insights Global Energy Perspective 2021, December 2020

Exhibit 3

Hydrogen projects are accelerating globally, with >200x growth until 2030

Global electrolyzer projects (announced)[1]
GW



1. For projects without known deployment timeline capacity additions were interpolated between known milestones

Source: McKinsey Hydrogen Project Database objectives. Even without specific directives from governments, many players are announcing bold hydrogen moves to get ahead of accelerating shareholder and customer pressure. For example, Japan's largest power generator, JERA, has already announced its intention to shift its fossil-fuel fleet progressively to 100% ammonia and hydrogen by the 2040s, starting with co-firing ammonia in its coal-fired power plants by 2030[10].

- Hydrogen is being recognised as a complement to renewable electricity in managing the variability of hydro, solar, and wind power (in addition to other alternatives such as batteries), thus unlocking the 'next horizon' of energy security.
- There are opportunities for hydrogen to build on the positive momentum of renewable energy (which required significant government investment prior to becoming cost competitive).
- There is a growing understanding that economic development benefits are especially important, and that hydrogen developments are expected to have substantial downstream impacts on economic activities.

Hydrogen is perhaps the only realistic decarbonisation option for hard-to-abate sectors, as they do not appear to have any realistic alternatives to address their carbon emissions. **This is particularly so for green hydrogen, which beyond being a fuel or method of transporting renewable energy is viewed as a viable and economically attractive option for addressing decarbonisation globally.**

GLOBAL DEMAND OUTLOOK

The global demand for low-carbon hydrogen could be as high as 553 Mt by 2050 – creating significant opportunities for export to Asia.

As Exhibit 5 shows, the demand for low-carbon hydrogen could increase by 2x to 4.5x in the next 20 years, reaching as high as 553 Mt by 2050. The 'reference case' assumes no major decarbonisation policies and that no premium is paid for low-carbon hydrogen. In contrast, Exhibit 5 also shows more likely high-decarbonisation scenarios, which are also more consistent with net-zero targets.

As of February 2021, a mix of 188 grey, blue and green downstream hydrogen projects had been announced globally, relating primarily to large-scale industrial usage in areas such as petroleum refining, ammonia production, fertiliser production, power generation, methanol production, steel production and industry feedstock (raw material), and to transport including trains, ships, trucks and cars. A further 23 midstream hydrogen projects in distribution, transportation, conversion and storage had also been announced.

As global trade of low-carbon hydrogen develops, major net importers, net exporters, and self-sufficient markets will emerge. This is being driven by decarbonisation commitments, the need to abate selected sectors and by countries with limited renewable energy resources.

Major net importers of low-carbon hydrogen will be those countries with insufficient renewable energy resources to support domestic production of green hydrogen to meet their strong demand forecasts. Indicators of strong demand include specific decarbonisation targets, tangible policies and investments in low-carbon hydrogen, and encouraging regulatory policies (e.g. carbon taxes). For example, Japan and Korea have both committed to net-zero targets by 2050, with published hydrogen strategies and substantial government funding confirmed for hydrogen developments.

10 *JERA Zero CO_2 Emissions 2020* strategy, available at: https://www.jera.co.jp/english/corporate/zeroemission.

HYDROGEN 101

The key attributes of hydrogen are that it is light, storable, reactive, has high energy content per unit mass, and can be readily produced at industrial scale. Today's growing interest in the widespread use of hydrogen for clean energy systems rests largely on two additional attributes:

1. Hydrogen can be used without direct emissions of air pollutants or greenhouse gases; and
2. It can be made from a diverse range of low-carbon energy sources. Its potential supply includes production from renewable electricity, biomass and nuclear. Low carbon production from fossil fuels is also possible, if combined with carbon capture, use and storage (CCUS) and emissions during fossil fuel extraction and supply are mitigated.

Broadly speaking, hydrogen can contribute to a resilient, sustainable energy future in two ways:

1. Existing applications of hydrogen can use hydrogen produced using alternative, cleaner production methods, and from a more diverse set of energy sources.
2. Hydrogen can be used in a wide range of new applications as an alternative to current fuels and inputs, or as a complement to the greater use of electricity in these applications. In these cases – for example in transport, heating, steel production and electricity – hydrogen can be used in its pure form, or converted to hydrogen-based fuels, including synthetic methane, synthetic liquid fuels, ammonia and methanol.

In both ways, hydrogen has the potential to reinforce and connect different parts of the energy system. By producing hydrogen, renewable electricity can be used in applications that are better served by chemical fuels. Low-carbon energy can also be supplied over very long distances, and electricity can be stored to meet weekly or monthly imbalances in supply and demand.

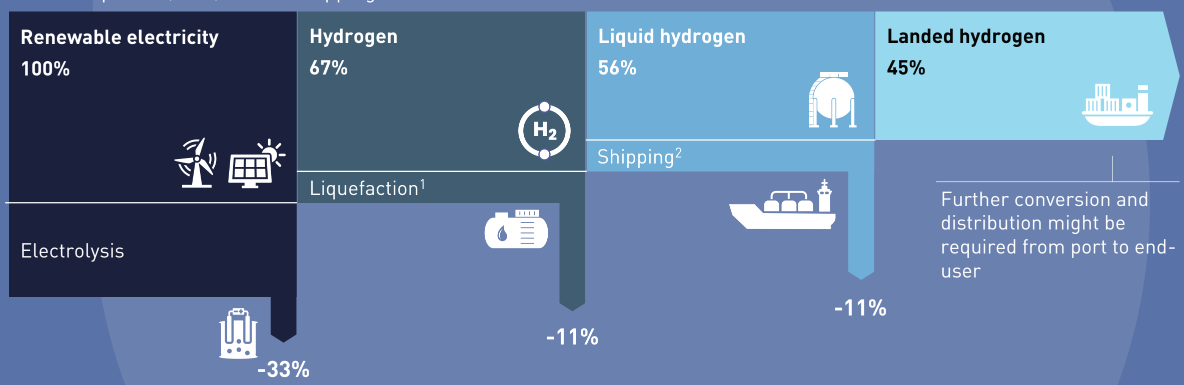
Source: IEA *The Future of Hydrogen: Seizing today's opportunities*

Exhibit 4

Liquid hydrogen shipping process flow and efficiencies

LHV efficiencies

2030 Perspective, ~10,000 km Shipping Distance



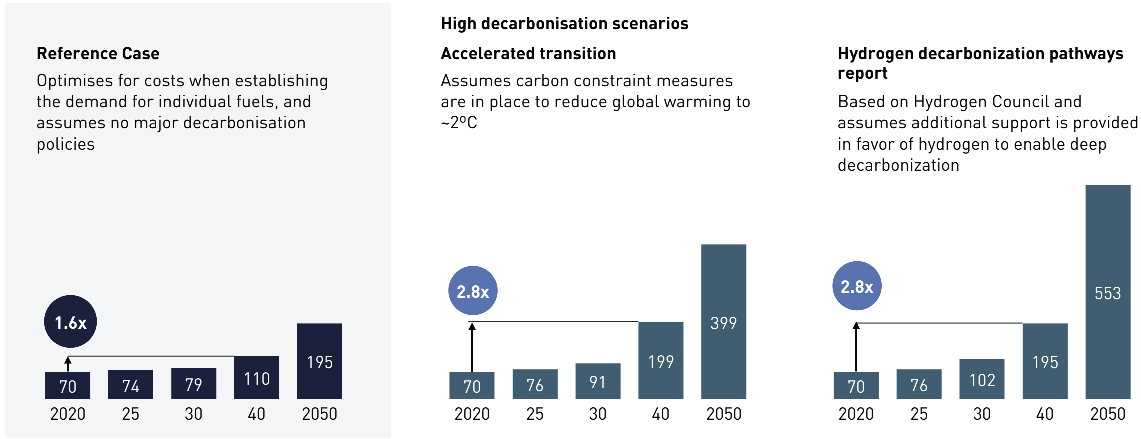
1. Power consumption for liquefaction as well as re-liquefaction for boil-offs during the process and storage
2. Includes loading and unloading losses as well as boil-off during shipping
3. Assuming hydrogen efficiency of 67%

Source: McKinsey Hydrogen Cost Model (2021)

Exhibit 5

Global hydrogen demand is expected to reach significant scale by 2040

Annual hydrogen consumption, Million tonnes



Source: McKinsey Energy Insights, Global Energy Perspective 2020 Post-Covid; Hydrogen Council – Hydrogen decarbonization pathways

Globally, Europe and Asia are expected to be key net importers due to a combination of strong decarbonisation commitments and negative expected demand/supply hydrogen balances. Given its geographical distance, Asia – specifically Japan and Korea – represents the most significant opportunity for future green hydrogen exports from New Zealand.

In its new hydrogen strategy (due for release in mid-2021), Japan is expected to announce increased 2030 demand targets of 10 Mt hydrogen[11] and 3 Mt ammonia[12]. This will follow its 'Basic Hydrogen Strategy'[13], released in 2017, in which Japan described several prominent use cases and objectives , including power generation, vehicles (200,000 fuel-cell vehicles by 2025 from ~3,800 in 2020; 320 refuelling stations by 2025 from ~140 in 2020; and 1,200 fuel-cell buses by 2030 from ~40 in 2020), ships, forklifts, industrial processes and heating.

Both Japan and South Korea have expressed their intentions to import hydrogen from abroad. In 2019 South Korea signed a letter of intent with the Australian government to commence imports of hydrogen[14], and Japan has targeted the technical feasibility of storing and transporting hydrogen from abroad by 2022 (Exhibit 6).

In addition, governments and the private sector in Japan and South Korea are making large investments in hydrogen projects:

- In December 2020 the Japanese government outlined a 2 trillion yen (NZ$29 billion) fund to support cooperating companies to achieve zero emissions by 2050, including hydrogen applications[15]. This was in addition to NZ$1 billion

11 Japan to make hydrogen major power source by 2030: Nikkei, Reuters, December 8, 2020, available at: www.reuters.com.

12 Japan sees 3 mil mt/year fuel ammonia demand in 2050 after commercial use in 2020s, S&P Global, February 8, 2021, available at: www.spglobal.com.

13 Basic Hydrogen Strategy, Ministerial Council on Renewable Energy, December 26, 2017, available at: www.meti.go.jp.

14 New report puts hydrogen production on the map, Australian Government, September 21, 2019, available at: www.minister.industry.gov.au.

15 Japan creates $19bn green fund to push hydrogen planes and carbon recycling, Nikkei Asia, December 4, 2020, available at: asia.nikkei.com.

Exhibit 6

Asia represents the greatest opportunity for NZ green hydrogen exports

✓ Existing in most countries (✓) Existing in several countries ⊗ Existing in very few countries or non-existent ▢ Greatest export opportunity Worst – Best

	Region	Projected regional demand by 2030, Mt H_2	Decarbonisation commitment: Carbon tax/ETS	Decarbonisation commitment: Targets	Endowment (supply)	Distance from NZ	Local H_2 cost in 2030
Net importers	Europe	9	✓	Net-zero by 2050	Expected scarcity of RES supply	Red	Yellow
	Asia (ex-Mainland China)	13	(✓)	Japan and Korea with targets for net-zero by 2050	Expected scarcity of RES supply in developed economies	Green	Red
Potentially self-sufficient	China	35	(✓)	Net-zero by 2060	Big locational variation, unclear if supply can keep up with demand	Green	Yellow
	North America	13	✓	Canada and selected US states with net-zero by 2050 targets	Big locational variation, unclear if supply can keep up with demand	Yellow	Yellow
Net exporters	Eurasia	7	⊗	Russia aims to reduce emissions by 30% vs 1990 by 2030	Very strong in blue	Red	Green
	Northern Africa	2	⊗	Several countries with 2030 reduction targets	Strong in green	Red	Green
	Middle East	9	⊗	Several countries with 2030 reduction targets	Very strong in green and blue	Yellow	Green
	Southern Africa	0	⊗	South Africa with net-zero by 2050 target	Potentially strong in green	Yellow	Green
	Australia & New Zealand	2	✓	NZ with net-zero target, no clear net-zero ambition in Australia	Very strong in green	Green	Green
	Latin America	6	(✓)	Several countries with near-term targets but no net-zero ambitions	Very strong in green	Yellow	Green

Source: McKinsey Energy Insights, World Bank, government publications

of announced subsidies for the hydrogen supply chain for mobility, household fuel cells and refuelling stations. The South Korean government has committed NZ$769 million to support the development of its country's hydrogen-fuel-cell vehicle industry.

- In the private sector South Korea's SK Group announced in March 2021 that it will invest KRW18 trillion won (NZ$25 billion) in the next five years on developing the domestic hydrogen value chain[16]. This followed Hyundai's 2018 announcement of plans for a KRW7.6 trillion won (NZ$10.3 billion) project extending to 2030 to boost the production capacity of fuel-cell systems[17].
- In Japan, a series of small-scale hydrogen investments is being made across the value chain. In 2020 the country started importing blue ammonia from Saudi Aramco for co-firing in fossil-fuel power stations. Initial projects to demonstrate the carbon footprint of low-carbon ammonia are now underway.
- In December 2020 Japan and Brunei partnered to build the world's first international hydrogen supply project to pilot the supply of hydrogen globally (in the form of methylcyclohexane, from which hydrogen can be extracted). The Brunei-supplied hydrogen will be extracted for end use in gas-turbine-power generators.
- In terms of domestic production, in 2020 Japan built what it claims to be the world's largest facility for green hydrogen production (10 MW)[18].

16 Korea's SK to build the world's largest liquefied hydrogen plant, H2Bulletin, March 2, 2021, available at: www.h2bulletin.com.

17 Hyundai Plans $6.7 billion investment to boost fuel-cell output, IndustryWeek, Dec 11, 2018, available at: www.industryweek.com.

18 The world´s largest-class hydrogen production, Fukushima Hydrogen Energy Research Field (FH2R) now is completed at Namie town in Fukushima, available at: https://www.toshiba-energy.com/en/index.htm.

While not all these investments are commercially viable, they represent a significant and tangible focus on hydrogen as a solution for decarbonisation. Given the increasing mandate from regulators, investors and consumers to decarbonise, interest and investment in such projects across the region can be expected to ramp up.

Major net exporters of low-carbon hydrogen will be those with access to the resources required for low-cost hydrogen production at scale, such as Australia, New Zealand, Canada, the Middle East and Chile.

Self-sufficient markets will likely emerge in China and North America, driven by high projected demand and high endowments to match.

GLOBAL SUPPLY OUTLOOK

Supply is ramping up to meet demand, but there are challenges to achieving an at-scale green hydrogen economy.

Today, around 99% of hydrogen comes from fossil fuels known as 'grey hydrogen'.

The suitability and potential of green and blue hydrogen production vary by country and depend on the availability and economics of resources.

- Blue hydrogen production has its own significant challenges as companies require access to low-cost natural gas or coal and large-scale CO_2 storage, which might be depleted gas fields or suitable rock formations. However, the sequestration and storage of CO_2 are still untested at scale.
- The critical factor for green hydrogen is access to low-cost renewables and fresh water. As detailed in Exhibit 7, countries such as Japan and Korea, central Europe and large parts of the US have limited resources to produce green hydrogen, while the Middle East is in the privileged position of having optimal resources for both green and blue hydrogen production. New Zealand's access to hydro, wind, fresh water and solar power makes it optimal for green hydrogen production.

18 giga-scale hydrogen production projects (i.e. more than 1 GW electrolysis) have already been announced, with the largest in Australia, Europe, the Middle East and Chile (a full list of these projects is provided in the Appendix). Supply projects are expected to ramp up rapidly to meet the growing demand for hydrogen (Exhibit 3). However, there are several big challenges to achieving an at-scale hydrogen economy.

1. **Green hydrogen production costs** must continue decreasing to become truly competitive with incumbent technologies. Production costs are expected to decrease by more than 60% by 2030, to US$1.3/kg (NZ$40/MWh) in an optimal location and US$2.2/kg (NZ$69/MWh) in a less optimal region as renewable energy and electrolyser costs fall and improved efficiency of conversion is achieved (Exhibit 8).
   - **Electrolyser capex costs** are expected to decline by 70% between 2020 and 2030, to about NZ$313-391/kW at the system level (including electrolyser stacks, voltage supplies and rectifiers). Forecasts in the Hydrogen Council's latest 2021 report[19] are 30-50% lower than anticipated in its 2020 report[20], with the reason cited as accelerated cost roadmaps and a faster scale-up of electrolyser supply chains. Estimates suggest that roughly 65 GW of electrolysis will be required to reduce costs to break even with grey hydrogen under ideal conditions; this implies a funding gap of about NZ$77 billion for these assets. Investors will have a critical role in realising early projects, to ensure this magnitude of scale eventuates.
   - **Variable renewable energy costs** are forecast to fall by 50% by 2030, to NZ$19-56/MWh. The Hydrogen Council's latest

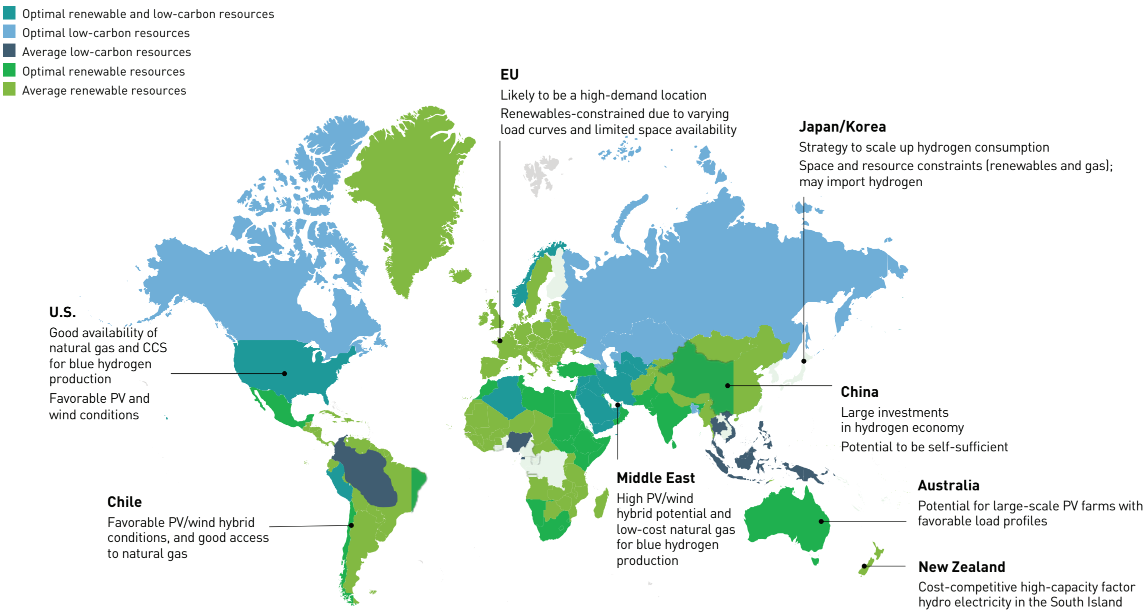
19 Hydrogen Insights: A perspective on hydrogen investment, market developments and cost competitiveness, Hydrogen Council, February 2021, available at: hydrogencouncil.com.

20 Path to hydrogen competitiveness: A cost perspective, Hydrogen Council, January 20, 2020, available at: hydrogencouncil.com.

Exhibit 7

Supply: Hydrogen from different types of resources can be an attractive option in several regions by 2030

Best source of low-carbon hydrogen in different regions

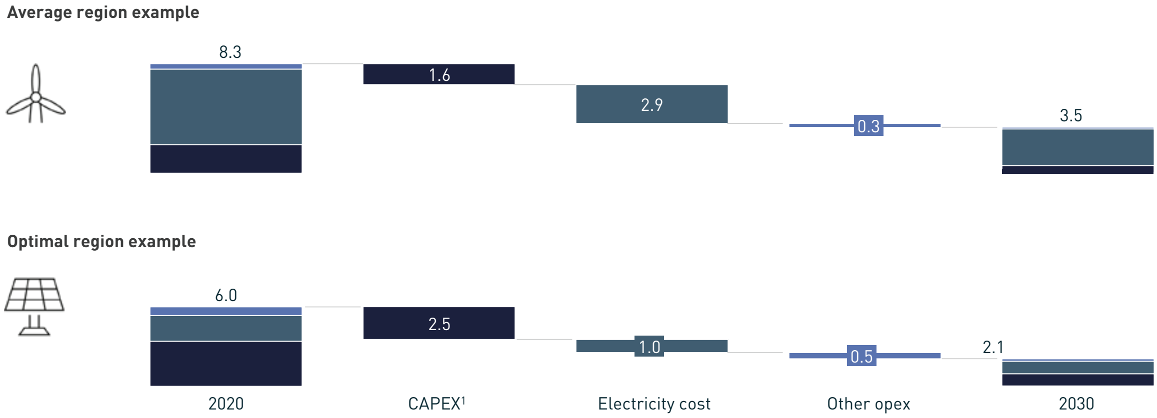


SOURCE: IEA, IGU, Global CCS Institute, McKinsey

Exhibit 8

The cost-down from 2020 towards 2030 is mostly driven by CAPEX and electricity cost

Production cost of hydrogen, NZ$/kg



1. Includes learning rate on CAPEX and impact of larger electrolyzer size class (from ~2 MW to ~80 MW)

Source: McKinsey Hydrogen Cost Model (2021), Hydrogen Council estimate of the reduction in the levelised cost of energy[21] (LCOE) is 15% lower than estimated in January 2020, due to the increased global forecast of renewables. The cost of energy is the largest single cost item in the production of hydrogen.

- **Electrolyser utilisation rates** are expected to rise as scale is achieved, as an optimal mix of renewables (e.g. an overbuild of wind and solar) becomes widely available, and with the potential use of batteries.

- **Electrolyser conversion efficiency** (i.e. the energy content of the hydrogen produced divided by the amount of electricity consumed) is expected to improve from 65% in 2020 to 67% in 2030 and 69% in 2050 as technology advances and catalyst materials improve.

If these forecasts eventuate, low-carbon hydrogen costs could become cost competitive with grey hydrogen by 2030, with carbon costs of NZ$74/kg H_2 (Exhibit 9). However, pure cost considerations may be the wrong benchmark, as green hydrogen is emerging as the preferred product due to government carbon policies and ESG demands.

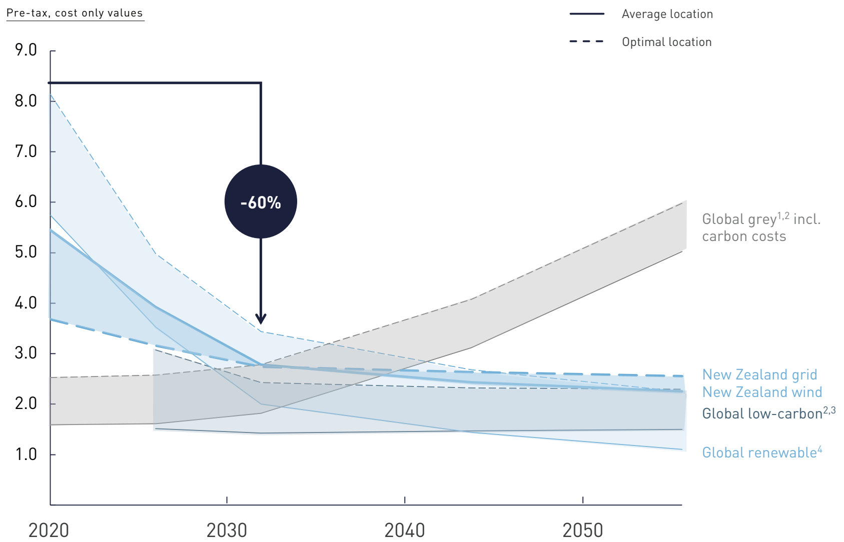
2. **Low-carbon midstream costs** are forecast to fall by as much as 60% for local distribution and 85% for shipping by 2030 as transportation technology improves and capacity is unlocked.

   - **Local distribution costs** are expected to fall by as much as 60% by 2030. Specifically, they are expected to fall for the following activities (using an example based on a distance of 300km):

Exhibit 9

Green hydrogen costs are expected to continue decreasing such that they can become competitive with blue and grey

Production cost of hydrogen, NZ$/kg (incl. carbon costs)



Key NZ assumptions 2020-2050

-70%	capex decline (2020 vs 2030)
95%	utilization for NZ grid
55-37	NZ$/MWh trajectory for NZ wind case
45-52%	utilization trajectory for NZ wind case

1. SMR without CCS 2. Gas price of flat 4.0-10.5 NZ$/Mmbtu; based on 43 NZ$/ton CO_2 (2020), 74 NZ$/ton CO_2 (2030), 230 NZ$/ton CO_2 (2040) and 459 NZ$/ton CO_2 (2050) 3. Assumes ATR with CCS and 98% CO_2 capture rate. Based on carbon transport and storage cost of 32-100 NZ$/ton CO_2 (2025), 18-26 NZ$/ton CO_2 (2030) and 18-22 NZ$/ton CO_2 (2050) 4. Based on alkaline with size classes of 2 MW (2020), 20 MW (2025) and 80 MW (from 2030); based on LCOE of 38-112 NZ$/MWh (2020), 19-56 NZ$/MWh (2030) and 10-39 USD/MWh (2050) 5. Analysis includes grid connection to shore for offshore windparks

Source: McKinsey Hydrogen Cost Model, Hydrogen Council

21 The LCOE is a measurement used to assess and compare alternative methods of energy production. The LCOE of an energy-generating asset can be thought of as the average total cost of building and operating the asset per unit of total electricity generated over an assumed lifetime.

SHIPPING HYDROGEN

There are four possible carbon-neutral forms of hydrogen for shipping – as liquid hydrogen, ammonia, compressed hydrogen, and in liquid organic carriers. However, with the exception of ammonia, for which there is already a mature seaborne market, advancements will be needed for each method to become economic.

The shipping method for green ammonia end uses is already mature, and costs are expected to decline further through technology improvements and scale-ups.

Where hydrogen is the end use, liquefaction technologies need further development and scale to enable liquid hydrogen to be shipped economically. The cost of international shipping is expected to decrease to ~US$1.6/kg H_2 (including liquefaction, shipping and import costs) by 2030 as more capacity comes online to meet demand.

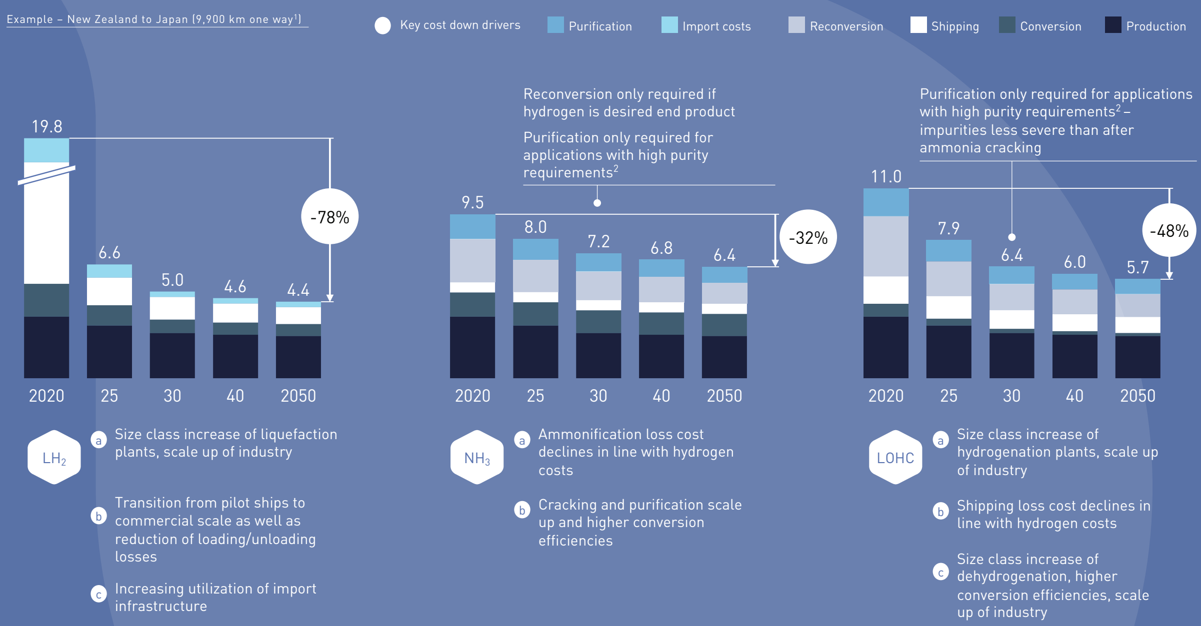
On a volumetric basis, far more ammonia than hydrogen can be transported for a given size of ship. While hydrogen may be favoured in end-use applications in future, ammonia is likely to always have substantially lower shipping costs when it is the end use at its export destination (rather than being reconverted to hydrogen).

Exhibit 10 compares shipping costs for liquid hydrogen, ammonia and liquid organic carriers.

Exhibit 10

Ammonia (end-use) shipping already cost-effective; liquefaction to improve by 2025-30

Landed cost (excl. further transport to end users), NZ$/kg



1. Lower South Island to Tokyo
2. Fuel cells require high hydrogen purity to avoid catalyst degradation

Source: McKinsey Hydrogen Cost Model

- Gaseous trucking to US$4.5/kg H_2 (NZ$207/MWh[22]) from US$11.2/kg H_2 in 2020 (NZ$516/MWh)
- Liquid trucking to US$4.3/kg H_2 (NZ$ 198/MWh) from US$10.4/kg H_2 ($479/MWh) in 2020
- Pipeline transport of hydrogen to US$4.4/kg H_2 (NZ$ 203/MWh) from US$11.8/kg H_2 (NZ$544/MWh) in 2020.

– **Shipping costs** are also projected to fall. Shipping ammonia (with ammonia as the end use) is already mature. We expect technology improvements and an increase in capacity to increase the viability of, and drive cost reductions in, shipping liquid hydrogen internationally (which includes the cost of liquefaction, shipping and import terminals). Costs are expected to decline by over 85% by 2030 to US$1.6/kg H_2 (NZ$2.4/kg H_2) for a single trip from the lower South Island, New Zealand to Japan. However, key uncertainties relate to overcoming the engineering challenges of liquefying hydrogen to sufficiently low temperatures, managing boil-off, and scaling up today's pilot projects to full-scale shipping operations.

3. **Investments in essential infrastructure and technology advancements are crucial.** Infrastructure investments and technological improvements in hydrogen end-use applications will be required for hydrogen to be competitive with incumbent and other decarbonisation alternatives. For example, transport will require a comprehensive hydrogen refuelling network, although we note that the rate of investment in this infrastructure will depend on the scale and mass uptake of vehicles refuelling.

   As an industry feedstock, hydrogen supply could come from dedicated production facilities, but in the long term a connection to a reticulated hydrogen network would most likely be the preferred option. Further examples are illustrated in Exhibit 11.

4. **Mandates by government and industry to meet decarbonisation commitments** will also be necessary for cost competitiveness. These mandates are quite possibly the easiest way to bridge the gap between the cost of hydrogen and the cost of fossil fuels.

   Governments' commitment to decarbonisation, backed by financial support, regulation and clear hydrogen strategies and targets, have activated momentum in the hydrogen industry. Seventy-five countries (representing over half the world's GDP) have net-zero targets by 2050; however, deep decarbonisation will require an increase in government intervention and support to address the limitations of direct electrification and batteries for some applications, and the persistent cost differences between hydrogen and fossil fuels.

   Under Japan's 'Basic Hydrogen Strategy', the Japanese government is forecasting that even with further cost reductions, the cost of hydrogen in 2030 will remain 126% higher than the equivalent LNG price, reducing to a 50% premium over LNG in the long term[23]. Bridging this cost differential will likely require government support and interventions, including higher carbon taxes, subsidies, risk sharing (e.g. backing off-take agreements), compliance legislation (e.g. fuel standards or outright bans of polluting fuels) and market facilitation (e.g. hydrogen auctions).

   Governments, with input from businesses and investors, will also need to set sector-level strategies (e.g. for steel decarbonisation) with long-term targets, short-term milestones and the necessary regulatory frameworks to enable the transitions. The industry must set up value chains for equipment, scale up manufacturing, attract talent, build capabilities and accelerate product and solution development. This scale-up will require capital, and investors will have an outsized role in developing and pushing at-scale operations. All this will require new

22 Conversions from US$ per kg to NZ$ per MWh for all local distribution costs have been done on a straight calorific basis with no losses from electrolysis, storage or distribution accounted for.

23 www.meti.go.jp.

Exhibit 11

Infrastructure availability and technology improvements in end-use applications will be required to unlock demand by 2030

Low / High

	Technology readiness	Main hurdles	Infrastructure availability	Examples
Transport	Varies by transport sector with road transport showing highest readiness[1]	Requires technology demonstration to move from prototypes to commercial products as well as cost decline and efficiency improvements	Requires comprehensive retail refuelling station network incl. distribution to stations	Delivered 7 heavy duty trucks to Switzerland in 2020 with plans to put 1,600 vehicles on Swiss roads by 2025 Targets 310 refuelling stations by 2022 up from <30 in 2020
Industry heat	Industrial scale, hydrogen-ready boilers do not exist today	For technology to emerge, requires cost parity prospect from a fuel perspective	Supply could come from captive production but connection to dedicated hydrogen grid most likely preferred option in the long term	n/a
Building heat and power	Building scale, hydrogen-ready boilers offered commercially with room for cost improvements	Commercial products exist with room for cost improvements	Requires conversion or installation of dedicated hydrogen grid – blending as near term option	Offers hydrogen-ready boilers as part of commercial product offering Pilots and tests heating with 20% hydrogen blended into natural gas grid
Industry feedstock	Processes like ammonia, methanol and petroleum refining require limited adjustment Hydrogen based steel production at pilot level[2]	Limited hurdles beyond feedstock cost, ease of converting natural gas based process to hydrogen to be tested	Supply could come from captive production but connection to dedicated hydrogen grid most likely preferred option in the long term	Will supply hydrogen from 20 MW electrolyzer to ammonia producer Fertibieria from late 2021 Installed 10 MW electrolyzer for supply of own refinery in 2019
Power generation	Limited real life experience with hydrogen-ready gas turbines	Requires technology demonstration and testing	Supply could come from captive production but connection to dedicated hydrogen grid most likely preferred option in the long term	Demonstrated successful operation of hydrogen fuelled turbine in H_2 2020 Plans to partially convert gas turbine in the Netherlands to run on 100% hydrogen by 2023

1. Aviation, maritime and off-highway solutions (e.g., mining trucks) show lowest maturity 2. Hydrogen based steel through DRI-EAF route (direct reduced iron electric arc furnace) requires conversion of existing natural gas based processes to hydrogen

Source: Expert interview, company and government publications

partnerships and ecosystem-building, with both businesses and governments having important roles.

As a starting point, government strategies could target the most critical enablers, such as by reducing the cost of hydrogen production and distribution. As noted earlier, roughly 65 GW of electrolysis may be required to reduce costs to a breakeven with grey hydrogen under ideal conditions. This implies a global funding gap of about NZ$77 billion for these assets.

Financial incentives such as subsidies can help to encourage these investments, and support is also required to scale up carbon capture and storage, hydrogen shipping, distribution and retail infrastructure, and the take-up of end-use applications.

Consumer and investor pressure for companies to meet their ESG requirements will lead to an increase in private investment in the hydrogen sector through financing mechanisms and partnerships. This is discussed in the next section of this report.

Encouragingly, there are already many examples of the private sector backing green hydrogen projects, despite their not yet reaching commercial break-even with incumbent non-renewable technologies.

LINKING SUPPLY AND DEMAND

Participants in the hydrogen value chain are partnering to progress early pilot projects, de-risk capital investments and solve technological and logistical challenges.

Financing for infrastructure projects is a major topic in the development of the hydrogen economy, with the transition requiring substantial investments along the value chain.

Similarly to the emergence of the renewable energy sector in the late 1990s to early 2000s, the availability and cost of capital will be critical for a successful transition. To limit risk exposure and raise sufficient capital, collaborations and partnerships between companies are likely to be required. 'Ecosystems' of partnerships are already forming with players along the value chain to optimise and share costs, tap in to multiple revenue streams and maximise the utilisation of shared assets.

The players and institutions in these ecosystems include:

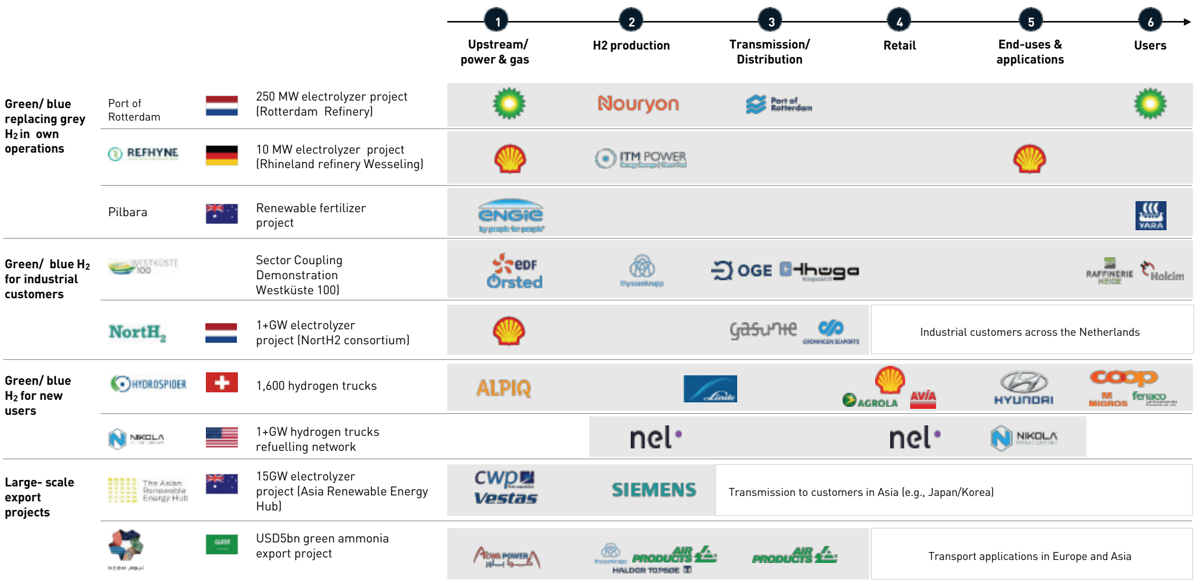
- **Upstream players** such as oil and gas companies, electricity companies, electrolyser original equipment manufacturers (OEMs), and engineering, procurement and construction providers (EPCs) who could supply the feedstock of energy (e.g. renewables for green hydrogen and natural gas for blue hydrogen) and/or operate the electrolyser plants.
- **Midstream players** such as logistics providers (shipping, road and rail), infrastructure providers (refuelling stations) and utility providers with existing pipeline assets.
- **End-use buyers** of hydrogen or hydrogen-derived chemicals.
- **Financial institutions** actively involved in funding hydrogen projects, looking to secure long-term returns from this rapidly emerging sector.

Examples are highlighted in Exhibit 12.

Exhibit 12

'Ecosystems' of partnerships are forming along the value chain

Example projects, not exhaustive



Agreements among these hydrogen ecosystem participants typically take three forms:

- **Joint ventures and co-investments,** which primarily aim to limit risk exposure, enhance scale and jointly develop capabilities along the value chain. For example, Halcyon Power – a joint venture between New Zealand's Tuaropaki Trust and Japan's Obayashi Corporation – has announced plans to develop a 1.5 MW production plant in New Zealand's North Island, utilising geothermal energy.

- **Bilateral long-term offtake contracts,** which are agreements with long-term supply periods and take-or-pay arrangements, used to underwrite capital risks and enable project funding to be secured.

- **Research and development partnerships,** which are agreements between technology providers and hydrogen end users that allow for a sustainable contribution of resources and capital to research and development, particularly in relation to still-developing end uses such as marine and aviation. For example, in 2019 BP partnered with Nouryon as its 'OEM partner' in installing an electrolyser add-on to its Rotterdam refinery that would enable it to use hydrogen as a feedstock.

These approaches de-risk capital investment by linking producers with end users to secure long-term baseload hydrogen demand. They can also help address the technological and logistical challenges of moving hydrogen between markets. In future these ecosystems will be critical to continued reductions in technology costs in the production, transport and end use of low-carbon hydrogen. They will also encourage demand growth, drive investments in the required infrastructure and attract the capital needed to make the hydrogen economy a reality.

It is expected that the hydrogen market will eventually evolve, similar to the evolutions seen in other globally traded commodities such as LNG, in a series of phases that aim to de-risk capital investments and overcome logistical and technological challenges. These phases could include:

- **Phase 1: Local hydrogen pilots,** where most hydrogen produced will be close to its end use. The pilots could be enabled through direct contracts and comprise mainly subsidised demonstration projects and two-party partnerships (e.g. energy and fertiliser players or electrolyser OEMs/EPCs and refineries). Owners of local low-cost resources, and players with early customer access to 'lock in' demand are likely to capture early value.

- **Phase 2: Regional hydrogen networks,** where one party sells hydrogen via shared infrastructure to another party and there are ecosystem partnerships along the value chain (e.g. energy players, off-takers and grid and pipeline operators). Orchestrators of regional hydrogen networks across the value chain will begin to capture value in this phase.

- **Phase 3: Global hydrogen markets,** which provide ubiquitous production and trade of hydrogen between countries via global shipping and pipeline networks. These markets will be enabled by transmission and distribution pipelines and new technologies for shipping and trucking liquid hydrogen. Global owners of low-cost resources (e.g. renewable-rich locations in Australia and the Middle East) and critical midstream assets (port access, shipping routes and technology) will capture the value in this phase.

HYDROGEN WILL PLAY A CRITICAL ROLE IN DECARBONISING HARD-TO-ABATE SECTORS, WITH MARKETS FOR GREEN HYDROGEN GATHERING STRONG MOMENTUM GLOBALLY.

2. NEW ZEALAND'S HYDROGEN OPPORTUNITY

New Zealand's access to global trade routes and ability to produce cost-competitive green hydrogen in 2025 put it in a privileged position that provides options for entering export markets and kick-starting domestic demand.

New Zealand's position is fundamentally different from those of other countries that are looking to produce hydrogen from yet-to-be constructed, low-capacity-factor renewables. In addition to having access to global trade routes, it will have an abundance of available baseload renewable generation and transmission assets from 1 January 2025 that will give it a valuable head start, particularly in export markets, as other exporters globally are still overcoming challenges in scaling up green or blue hydrogen production.

EXPORT OPPORTUNITY

Japan and South Korea offer the most significant export opportunities for future New Zealand green hydrogen or green ammonia, and their scale could help to underwrite domestic hydrogen and ammonia opportunities in the medium term.

Modelling of landed costs in Japan shows that, by 2025, New Zealand could achieve NZ$6.60-8.60/kg for green hydrogen (Exhibit 13) and NZ$880-1,050/tonne for green ammonia (Exhibit 14). At these prices New Zealand's exports could be competitive with locally produced green hydrogen and imported green and blue ammonia from Australia and Saudi Arabia respectively. In 2030, New Zealand could achieve landed costs of NZ$5.00-6.60/kg for green hydrogen and NZ$800-830/tonne for green ammonia.

At this stage it is not clear whether ammonia or liquid hydrogen will be the preferred energy carrier for the decarbonisation of hard-to-abate sectors. Ammonia's chief advantages over hydrogen are its volumetric density (a litre of ammonia carries 50% more energy than a litre of liquid hydrogen, or 2.8 times that of compressed hydrogen), its ease of storage and its transportability. The main attraction of hydrogen over ammonia is that it offers more versatility in its range of end-use applications.

For Japan, transport, industry feedstocks and power generation will be priority uses for green hydrogen. Significant investments in green hydrogen applications are already underway, even in use cases where green hydrogen is not yet cost competitive with the incumbent technology. For example:

- **Transport:** There are currently 3,800 fuel-cell vehicles in Japan, with a goal of 200,000 vehicles by 2025.
- **Power generation:** Co-firing of green ammonia in power plants is set to commence within the decade, with JERA publicly announcing a hydrogen strategy to reduce its emissions from fossil fuels.[24]

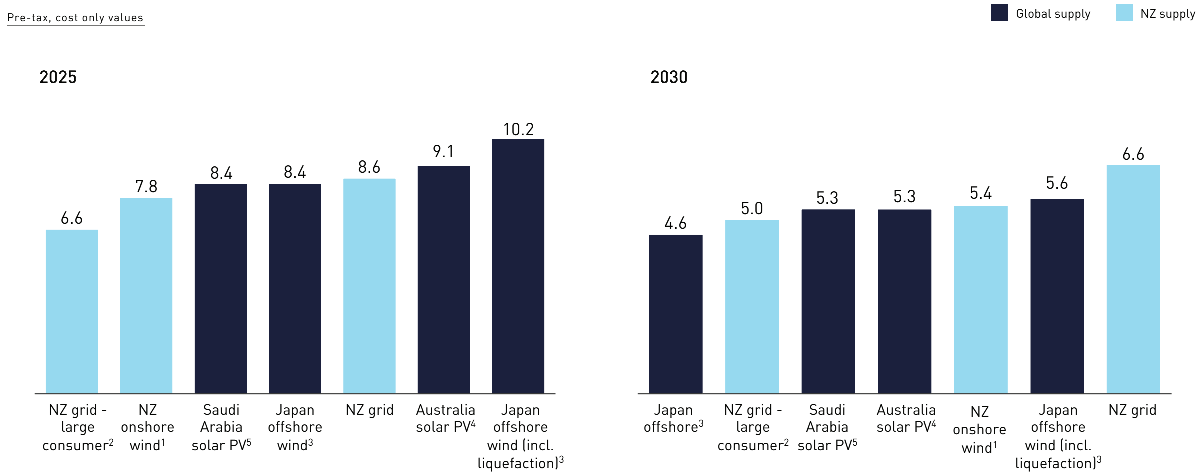
Based on an assumed landed cost of NZ$5.0/kg H_2 in Japan, seven use cases would break even with their conventional alternatives between 2030 and 2040. Government intervention (e.g. in the form of increased carbon prices or mandates) will have a significant role in the adoption of green hydrogen in the short to medium term, as hydrogen will not be able to compete on cost versus conventional technologies for quite some time (Exhibit 15).

24 *JERA Zero CO_2 Emissions 2050 roadmap*, available at: www.jera.co.jp.

Exhibit 13

NZ supply of hydrogen is highly competitive to green hydrogen from other export countries up to ~2030

Green hydrogen landed cost, NZ$/kg (all-in cost)

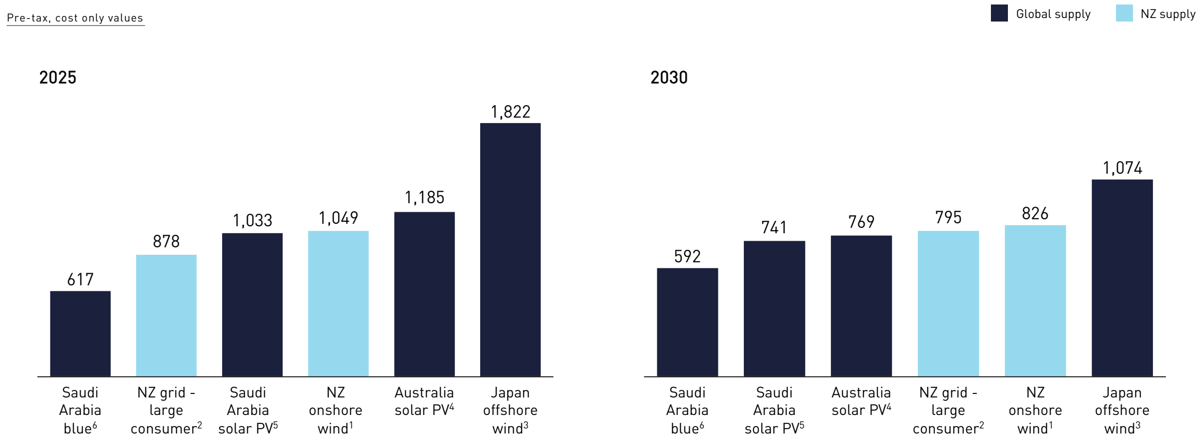


1. 48 NZ$/MWh, 49% utilization (2025) and 42 NZ$/MWh, 52% utilization (2030)
2. Assuming large consumers receive discounted electricity pricing
3. 136 NZ$/MWh, 48% utilization (2025) and 78 NZ$/MWh, 53% utilization (2030)
4. 38 NZ$/MWh, 26% utilization (2025) and 25 NZ$/MWh, 28% utilization (2030)
5. 32 NZ$/MWh, 34% utilization (2025) and 25 NZ$/MWh, 35% utilization (2030)

Exhibit 14

NZ supply of ammonia is highly competitive to green ammonia from other export countries up until ~2030

Ammonia landed cost, NZ$/t NH_3 (all-in cost)

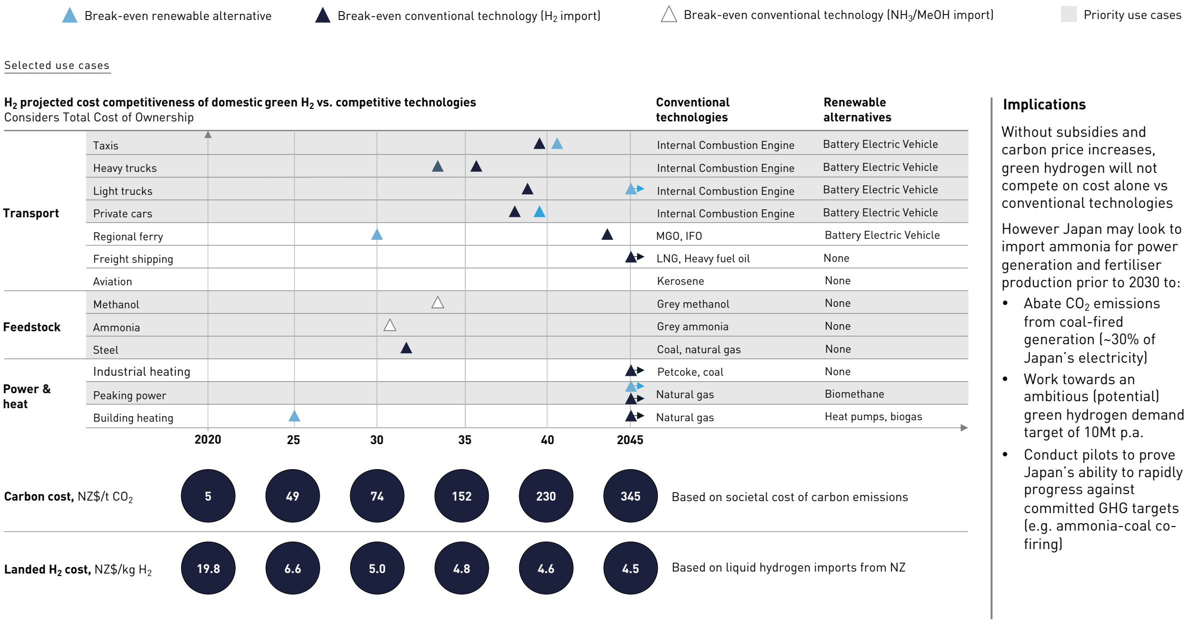


1. 48 NZ$/MWh, 49% utilization (2025) and 42 NZ$/MWh, 52% utilization (2030)
2. Assuming large consumers receive discounted electricity pricing
3. 136 NZ$/MWh, 48% utilization (2025) and 78 NZ$/MWh, 53% utilization (2030)
4. 38 NZ$/MWh, 26% utilization (2025) and 25 NZ$/MWh, 28% utilization (2030)
5. 32 NZ$/MWh, 34% utilization (2025) and 25 NZ$/MWh, 35% utilization (2030)
6. 5 NZ$/Mmbtu natural gas, transport and storage cost of 32 NZ$/t CO2 (2025) and 18 NZ$/t CO2 (2030). Capture cost of 8 NZ$/t CO2 throughout. Assumes 98% capture rate based on ATR process

Note: Green ammonia is referring to green hydrogen based production. Blue ammonia is referring to conventional production with Carbon Capture Storage

Exhibit 15

In Japan, transport, feedstocks and power will be priorities for green H_2, but subsidies and carbon price increases will be needed



Source: McKinsey Hydrogen Cost Models; Japan Strategic Roadmap for Hydrogen and Fuel Cells 2019

New Zealand has an initial competitive advantage in the supply of green hydrogen and green ammonia based on the large tranche of existing baseload renewable generation available from 1 January 2025. Potential competitors in the Middle East, Australia and Chile cannot boast any of these key attributes. However, in the long-term New Zealand's ongoing export competitiveness will hinge on its ability and willingness to match the LCOE of new renewable generation overseas.

DOMESTIC OPPORTUNITY

New Zealand has an ambitious target to reduce its greenhouse gas emissions to 30% below 2005 levels by 2030, and to be net-zero by 2050.[25]

Hydrogen has the potential to mitigate 23-53% of New Zealand's gross long-lived greenhouse gas emissions (8.6-20.0Mt CO_2e), especially in hard-to-abate sectors New Zealand's abundance of renewable development options could support growth in hydrogen demand.

Investments in pilot use cases of green hydrogen are already ramping up in New Zealand, with the most progress being made in the North Island. Transport-related pilot use cases in heavy trucks and buses are beginning in Auckland, while in Taranaki the recent ban on offshore oil and gas exploration has led industries (such as the fertiliser sector) and the owner of the national gas-transmission pipeline to explore alternative feedstocks to natural gas.

In the South Island, hydrogen use cases could also accelerate adoption due to relatively lower electricity prices than in the North Island and high-capacity-factor hydro generation. Under the current carbon cost of NZ$36/t CO_2 and an estimated hydrogen production cost of ~NZ$2.7/kg in the South Island, selected transport and industry feedstock use cases are expected to

25 New Zealand Climate Change Commission Report 2021, available at: ccc-production-media.s3.ap-southeast-2.amazonaws.com.

become competitive with conventional fossil fuels by 2030. Exhibit 16 models the competitiveness of hydrogen with the current technology.

More applications would become competitive if New Zealand increased its carbon cost (i.e. NZU price) to NZ$140/t CO_2 (as per the Climate Change Commission's 2030 forecast). Assuming the new renewable energy capacity is in the North Island, transport, chemicals, steel and refinery use cases could deliver deep decarbonisation across New Zealand (Exhibit 16).

Leveraging this high-capacity-factor hydro generation energy source to kick-start New Zealand's hydrogen economy could help in extending hydrogen use to the rest of the country, possibly fuelled further by new wind and solar developments.

By 2030 New Zealand could see ~140kt per annum of hydrogen demand in transport and chemicals use cases centred on the South Island, requiring an electrolyser capacity of ~850MW. In the case of chemicals, green hydrogen would replace grey feedstock for the production of urea, and for transport it would enable the decarbonisation of long-range trucking, train and bus routes. This demand modelling assumes:

- **Heavy duty transport**, a 50% adoption rate for new sales of heavy trucks (with a 10-year average life per truck) and buses in the South Island, and a 100% adoption rate for diesel-powered trains in the South Island. The latter may not be cost competitive, but it could be worth considering for environment-conscious consumers and tourists.
- **For ammonia**, that fertiliser production is sufficient to meet New Zealand's nitrogen fertiliser needs.

Other use cases that are expected to break even (steel and refinery) have been excluded because they are unlikely to shift from the North Island to the South Island in the near future (if ever). In the long run, if for example import tariffs are placed on goods produced with low or no carbon taxes imposed in the source country (a policy recently announced in Europe), importation of steel could transition to local production (Exhibit 17).

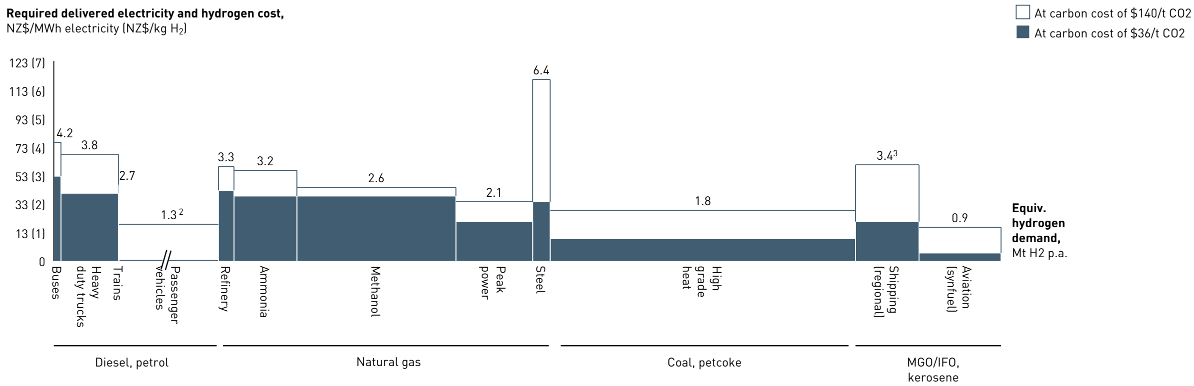
Exhibit 16

Selected transport and feedstock applications show highest willingness to pay compared to conventional alternatives by 2030

Estimated hydrogen costs required to be competitive with incumbent technology (TCO[1]) per application in 2030

Equiv. Hydrogen demand refers to amount of hydrogen required to fully replace current alternative

NZ carbon costs of NZ$36/t CO_2 and NZ$140/t CO_2 (based on Climate Change Commission 2030 forecast[4])



1. Total cost of ownership including all capex and opex elements to own and operate equipment related to respective end use
2. Equiv. hydrogen demand much larger than shown here but width reduced for better readability. Break even price varies between segments with larger vehicles (e.g., SUVs) showing highest willingness to pay
3. Dependent on shipping fuel used
4. Based on the marginal cost of abatement of carbon as set out in the Climate Change Commission's draft advice

Source: McKinsey Hydrogen Cost Model (2021); Ministry of Transport – Annual fleet statistics 2019; Ministry of Business, Innovation & Employment - Annual Oil and Oil Products Updates 2020; company publications; Climate Change Commission – 2021 Draft Advice for Consultation; team analysis

Exhibit 17

NZ could see ~140 kt demand of H_2 from priority use cases on South Island in 2030, requiring an electrolysis capacity of ~0.9 GW

ASSUMED 'FULL POTENTIAL' FOR 2030 USE CASES IN SOUTH ISLAND

		Potential demand for green hydrogen in NZ in 2030, kt	Hydro-based electrolyser capacity required[1], MW	Assumptions
Transport	Bus	2	10	South Island approx. share of bus transport (>12 t weight class) assuming 50% adoption rate of current vehicle park by 2030; 10 year life time
	Train	1	4	Includes conversion of diesel powered trains in South Island (669,000 km p.a.); 20 year life
	Truck	14	83	South Island approx. share of heavy duty trucks (>25 t weight class) assuming 50% adoption rate of current vehicle park by 2030; 10 year life time
Chemicals	Ammonia	126	756	Assumes current NZ demand for ammonia of ~640 kt NH3 p.a. to switch to green hydrogen and to supply NZ's domestic demand through production on the South Island
TOTAL		143	853	

1. Assumes 67% electrolyser efficiency as well as 95% hydro/electrolyzer capacity factor

Source: McKinsey Hydrogen Cost Model (2021), Ministry of Transport – Annual fleet statistics 2019, team analysis

While hydrogen's decarbonisation benefits and competitiveness are apparent in these use cases, creating the New Zealand hydrogen ecosystem and enabling the use cases' take-up would require an estimated capital investment of NZ$2.7 billion in the upstream (hydrogen production), midstream (hydrogen distribution infrastructure) and downstream (end-use-specific equipment) components of the hydrogen value chain (Exhibit 18).

For New Zealand domestic applications, even with the higher expected input costs of hydrogen over time, it is likely that locally produced green hydrogen will remain cost competitive compared to low-cost imports of Australian-produced hydrogen using scalable solar (including shipping and transport costs).

BENEFITS FOR NEW ZEALAND

Investment in a green hydrogen economy could have significant decarbonisation, energy security and economic benefits for New Zealand.

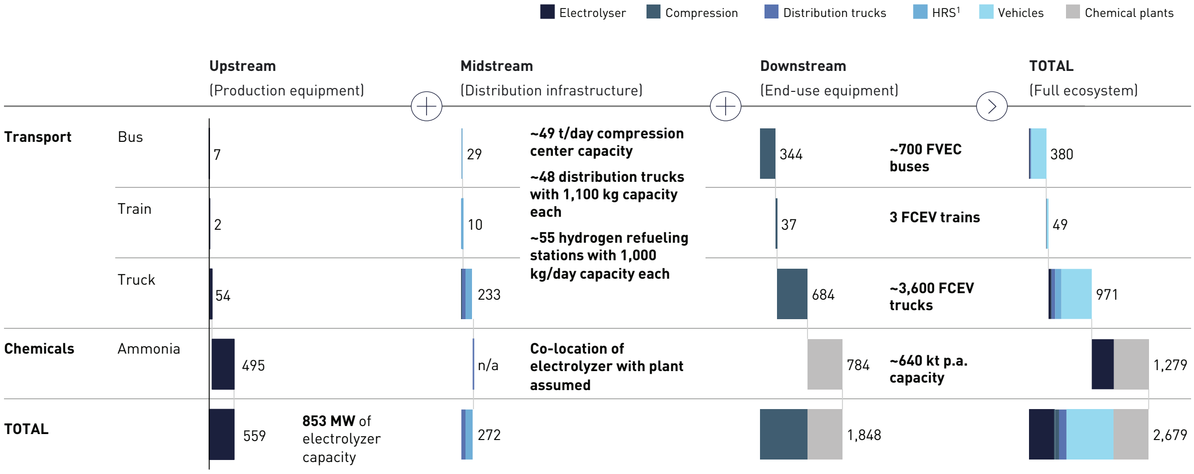
Most importantly, green hydrogen can help New Zealand to deliver on its ambitious decarbonisation commitments.

Hydrogen is expected to have a key role in the hard-to-abate sectors. By kick-starting the hydrogen economy in the South Island, ~2% of New Zealand's carbon emissions could be abated in the near term. This could provide the foundation for abatement of between 23% (base case) and 53% (full potential) of New Zealand's carbon emissions as hydrogen demand develops through to the North Island. Early adoption in the South Island could serve as a blueprint for the nationwide adoption of hydrogen for decarbonising the hard-to-abate sectors (Exhibit 19).

Exhibit 18

These use cases could require ~NZ$2.7b of capex investment to build the required ecosystem by 2030

Capex investment required, NZ$m

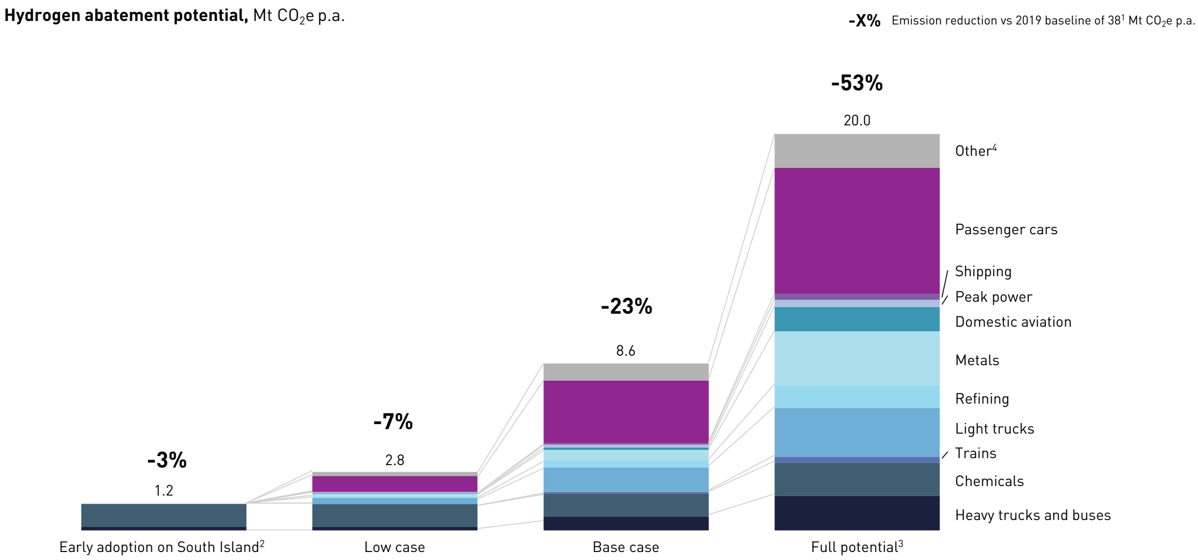


1. Hydrogen refueling station

Source: McKinsey Hydrogen Cost Model (2021), team analysis

Exhibit 19

Leveraging the South Island opportunity would create the foundation for a ~53% annual emission reduction across NZ



1. Includes emissions from energy and industrial processes and product use
2. Includes heavy trucks, buses and trains as well as ammonia production
3. Top-down estimation based on New Zealand's current emission profile for sectors where hydrogen shows high potential and is the likely or only decarbonization option
4. Includes base load power, minerals industry, paper production, building heat and power and off-highway transportation

Source: McKinsey Hydrogen Cost Model (2021), International Energy Agency, NZ Ministry for the Environment 2018/19 (latest data available)

Secondly, green hydrogen could help to secure New Zealand's energy transition and promote increased renewable generation within the electricity system. For example, a large-scale green hydrogen production plant could reduce production levels and free up electricity to support the country during dry-years (when hydro inflows are low), and export green hydrogen in other periods.

Thirdly, the creation of a hydrogen economy could deliver significant economic benefits to New Zealand. The South Island green hydrogen opportunity described in Exhibit 17 could generate (Exhibit 20):

- **One-time benefits** of an additional NZ$1.1-1.6 billion of GDP ($0.5-0.7 billion initial and direct, $0.2-0.3 billion indirect and $0.4-0.6 billion induced) and 17,500-22,500 job years (9,600-12,300 initial and direct, 2,900-3,800 indirect and 5,000-6,400 induced) for constructing the upstream, midstream and downstream components of the hydrogen value chain.

- **Ongoing benefits** of NZ$400-600 million added to GDP per annum ($200-300 million initial and direct, $70-110 million indirect and $130-190 million induced) and 4,100-7,200 new jobs (2,200-4,000 initial and direct, 700-1,200 indirect and 1,200-2,000 induced) to operate and maintain the upstream, midstream and downstream components of the hydrogen value chain.

These economic benefits are modelled on 853 MW of electrolyser capacity. Any additional generation infrastructure required to meet this hydrogen demand has not been modelled as we assume that electricity generation will always be built to meet future demand. However, if the electrolyser capacity was only 600 MW, the economic benefits under an export scenario would equate to:

- **One-time benefits** of an additional NZ$0.6-0.8 billion of GDP and 9,000-13,000 job years for constructing the upstream, midstream and downstream components of the hydrogen value chain.

- **Ongoing benefits** of NZ$350-450 million added to GDP per annum and 4,000-6,000 new jobs to operate and maintain the upstream, midstream and downstream components of the hydrogen value chain.

Exhibit 20

Kick-starting South Island's Green Hydrogen economy could generate NZ$400-600mn in ongoing GDP and 4-7k ongoing jobs by 2030

Potential economic benefits from supply of green hydrogen in the South Island by 2030 or exports of equivalent volume of green ammonia

INCLUDES INITIAL, DIRECT, INDIRECT AND INDUCED EFFECTS

Assumes hydrogen supply of ~850 MW in both scenarios

Upstream | Midstream | Downstream

		Capex required, NZ$b	One-time benefits for NZ[1]: GDP output, NZ$b	One-time benefits for NZ[1]: Job years, 000s	Ongoing benefits for NZ[1]: GDP output[2], NZ$b	Ongoing benefits for NZ[1]: Jobs[2], 000s	Notes
Domestic supply scenario	Transport	1.4	0.1-0.2	1.5-2.5	0.1-0.2	0.6-1.2	Excludes econ. activity from downstream manufacturing of vehicles (import assumed)
	Ammonia	1.3	1.0-1.4	16.0-20.0	0.3-0.4	3.5-6.0	Assumes import substitution (rather than replacing current domestic production)
	TOTAL	2.7	1.1-1.6	17.5-22.5	0.4-0.6	4.1-7.2	
Export scenario	Green ammonia exports	1.6	0.8-1.0	14.0-16.0	0.5-0.6	6.0-8.0	Benefits concentrated in upstream (includes electrolyser and ammonia plant)

1. Based on input-output multiplier analysis, including initial, direct, indirect and induced effects and only considers incremental jobs and GDP (i.e., excludes jobs that are replaced)
2. Assumes H_2 price of NZ$2.62/kg H_2

Source: McKinsey Global Institute (multipliers); McKinsey Hydrogen Cost Model, 2021

The economic benefits would also potentially extend to:

- **Attract new large manufacturing companies to New Zealand.** Rather than importing renewable energy (as hydrogen) from New Zealand, overseas companies may decide to relocate to New Zealand.
- **Attract Environmental, Social and Governance (ESG)-focused investors to New Zealand.** Large fund managers (such as the world's largest asset manager, BlackRock) are shifting their attention to sustainable investments, and could be encouraged to enter New Zealand's economy.
- **Address the innovation agenda in New Zealand** by attracting high-tech jobs to the country.

The next few years will be decisive for the development of the hydrogen ecosystem, achieving New Zealand's decarbonisation objectives and securing the energy transition. As this report has shown, momentum is already gaining pace and the country is well positioned to benefit from this rapidly developing global economy.

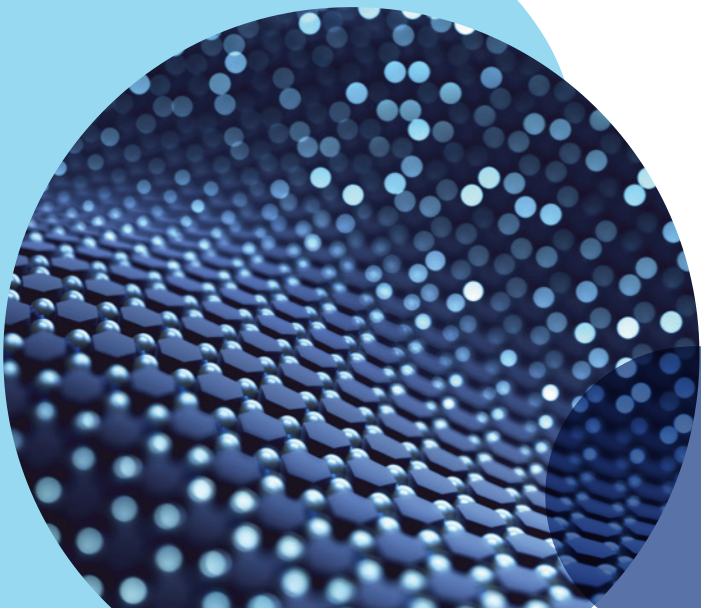
STRATEGIC CONSIDERATIONS

Several strategic decisions are critical to realise the opportunities offered by a green hydrogen ecosystem.

Global government commitments to decarbonisation have triggered unprecedented momentum for the creation of a global hydrogen industry. Financial support, regulation and clear hydrogen strategies and targets to support the hydrogen transition are increasing, which are driving down costs and attracting new investment in the sector.

Given today's relatively high cost of electrolysers, New Zealand's access to high-capacity-factor renewable electricity provides a competitive advantage in the early development stages of the green hydrogen market. Capitalising on this starting position will require the consideration and assessment of four strategic choices:

- **How can New Zealand capitalise effectively on potential global export opportunities to build a platform for the domestic hydrogen economy?** The abundance of renewable generation assets that will be available in New Zealand from 1 January 2025 provide the country with an early competitive advantage



for the export of hydrogen products. This is expected to last until at least 2030, when Middle East and Australian hydrogen production is expected to scale up significantly.

As the global hydrogen market continues to develop from now to 2030, the size of New Zealand's opportunity and its immediately available production capacity (from 1 January 2025) may be highly attractive to early off-takers overseas. These off-takers are likely to be interested in smaller-scale agreements initially, aimed at building their capabilities in targeted hydrogen applications. Given this, securing an export off-take agreement in the near term is one way to de-risk the capital investment required to kick-start New Zealand's green hydrogen economy for the longer term – and may even cross-subsidise the costs of establishing the domestic market. At the same time, it will be important to get the balance right between allocating New Zealand's high-capacity-factor renewables to hydrogen export and allocating domestic hydrogen to facilitate the development of the local hydrogen economy.

- **As the hydrogen market develops, how will regulatory mechanisms be monitored and deployed?** While selected green hydrogen use cases both locally and in overseas markets are already cost competitive against alternative technologies, others will require regulatory support to overcome initial investment hurdles and achieve cost parity with incumbent technologies.

  Domestically, regulatory mechanisms will need to be carefully selected to incentivise demand and investment where they are most needed to enable decarbonisation and the sustainable development of New Zealand's hydrogen economy. These mechanisms might include a significantly higher cost of carbon (i.e. NZU price), subsidies to fund the development of hydrogen technologies, or carbon levies on imports from countries with weaker emission rules (the latter was recently put forward by the European Union). Globally, a continued monitoring of the regulatory environments in potential export markets will be critical to understanding how demand may evolve, and where New Zealand can potentially pivot supply.

- **Which green hydrogen products should be prioritised and produced at scale, now and in the long term?** Given the wide range of potential applications for green hydrogen, it will be important to consider how the global hydrogen market will develop over time, and how New Zealand's positioning in this market will evolve. Each hydrogen product examined in this report will have distinct opportunities and risks.

  Ultimately, customer demand will determine the commercial path forward. In the early stages hydrogen is likely to be traded via direct contracts and partnerships between suppliers and off-takers. This would likely involve applications and sectors where green hydrogen is already 'in the money' or where projects have been subsidised to improve their commercial viability.

  For New Zealand, the nearer-term, high-potential opportunities are likely to be in ammonia, either for export to Japan to be used in power generation or for domestic fertiliser production. As the hydrogen market matures beyond 2030, a liquid, global market for hydrogen would allow for trade between many suppliers, traders and off-takers.

  At this stage the relatively small scale of New Zealand's hydrogen capacity means it may not remain competitively viable against larger global suppliers. This may result in a necessary shift towards primarily supplying to domestic applications. Alternatively, higher-value hydrogen export opportunities may develop if market conditions allow. Taking a long-term perspective and continually monitoring the evolution of the hydrogen economy will support more efficient allocations of capital investments to the highest potential use cases for New Zealand.

- **How do we leverage the benefits of green hydrogen production for the power system?** The New Zealand electricity system comprises a hydro-dominated power system with a large additional renewable energy contribution from geothermal and wind. Today, renewable energy contributes 80-85% of the total electricity supply and the current government aims to increase this further.

  New Zealand's largest challenge to security of supply is a dry year. Currently the power system solves this problem with thermal (fossil-fuel) generation to support electricity demand. As the country reduces its reliance on thermal generation, an alternative solution to the dry-year problem will be required.

  A green hydrogen production facility could be designed to flex beyond or below nominal production levels, providing electricity demand response back to the power system. In dry years the facility would reduce production for a period, and in times of renewable surplus (wet, windy and/or sunny) production would be increased. This presents a unique (and potentially low-cost) opportunity to solve a significant portion (possibly up to 40%) of the dry-year problem to the benefit of the New Zealand electricity system. Given the importance of this opportunity, Meridian and Contact are investigating it in detail via a specific work stream in the overall joint feasibility study.

NEXT STEPS TO CAPTURE THE HYDROGEN OPPORTUNITY

Given the significant decarbonisation and economic benefits that the hydrogen opportunity could present for New Zealand – in particular the lower South Island economy – there is a great incentive to get moving.

As a next step, industry players, investors and government need to work together to:

- **Investigate the feasibility** of large-scale, renewable energy hydrogen production in New Zealand – particularly introducing a new industry in the lower South Island that will capitalise on the availability of competitive, renewable energy resources – with considerations of the commercial, societal, economic and environmental impacts.

- **Explore appropriate incentive mechanisms** to kick-start the hydrogen economy (such as government policies) and accelerate the realisation of New Zealand's decarbonisation commitments.

- **Firm up the commercial potential** both internationally and domestically, and **investigate potential business models** by engaging with potential ecosystem participants along the value chain.

- **Determine the cost and benefit that a flexible hydrogen facility could provide back to the electricity system during dry-years.** The could provide New Zealand a significant (low-cost) contribution to mitigating dry year risk.

As this report shows, progress in the global hydrogen sector has been impressive in the past year – but much lies ahead. The next few years will be decisive for New Zealand's development of the hydrogen ecosystem as a key enabler of the country's decarbonisation objectives, and for its unlocking of the potential economic benefits. Continued commitment and efforts will be needed among players in the sector to realise this opportunity.

NEW ZEALAND'S ACCESS TO GLOBAL TRADE ROUTES AND ABILITY TO PRODUCE COST-COMPETITIVE GREEN HYDROGEN PROVIDE OPTIONALITY TO ENTER EXPORT MARKETS AND/ OR KICK-START DOMESTIC DEMAND.

ECONOMIC IMPACT METHODOLOGY

To measure the impacts of the hydrogen economy on GDP and jobs, we used input-output-based multipliers. These multipliers capture not only the direct contribution of an activity to a sector itself, but also the indirect effects on the suppliers to that sector, from tier 1 to sub-tier suppliers.

- **Initial impacts** – The sector's contribution through its direct operations, such as the maintenance and operator jobs required to run the electrolyser plant.
- **Direct impacts** – The industry's direct contribution through its one-off or ongoing operations, such as the impacts on its direct (tier 1) suppliers.
- **Indirect impacts** – The impacts across the company's or industry's supply chain, including the employment and economic output (GDP) (e.g. the impacts on tier 2, tier 3 and other tier suppliers).
- **Induced impacts** – The spending from wages of those employed directly by the company/ industry or its supply chain (e.g. on food, consumer goods), which supports economic activity in diverse industries.

The starting point for estimating multipliers is the input-output 'use' table, which describes the buying and selling relationships between industries and their links to GDP. Every industry is entered twice – as a row and a column. Looking across the rows we see how much an industry sells to other industries as well as to categories of GDP (i.e. final demands), and looking down the columns we see how much an industry buys from other industries as well as labour and capital.

- The sum of the columns for each industry and the rows is the gross output for the industry, which is equivalent to revenue.
- The sum of labour and capital is the value add or GDP for the industry.
- Thus, the gross output = value add + the value of the goods and service inputs. Note the column sum is actually total expenditure on inputs, but this is equivalent to the output values.

To calculate the multipliers, we translate the purchases an industry makes from its direct suppliers into shares of its total revenue, and apply some matrix algebra to arrive at the 'output multipliers' for each of the column industries. Output multipliers indicate how much total gross output or revenue changes in the economy for every $1 change in output in the column industry, both directly and indirectly.

From these output multipliers we then generate GDP multipliers by applying industry value-add to gross output ratios, which then indicate for every $1 change in output of the column industry how much GDP changes in the whole economy, directly and indirectly. Similarly, we translate the output multipliers to jobs multipliers, applying the ratio of jobs to output ratios to the output multiplier table. The jobs multipliers then tell us how many jobs are created directly and indirectly for every $1 million change in output.

The economic benefits for the domestic supply scenario have been calculated by assuming a capped supply of electricity in the short term of 850 MW in the South Island.

These economic impacts take account of the impacts on industries that are negatively affected. For example, there is no assumed incremental ongoing benefit for the South Island methanol use case as it would hypothetically be replacing the jobs of existing 'grey' methanol production (as well as the upstream production of natural gas). Additionally, the methodology used assumes that the economy has the capacity and skills required to support the sector in terms of domestic inputs required and labour. Likewise, the economic impact excludes activities that are likely to occur offshore, such as the manufacturing of electrolysers and hydrogen-fuelled vehicles.

Caveats

It is important to note the assumptions of Input Output tables and their implications for multipliers:

- **Fixed-purchase patterns** – Industries do not change the relative mix of inputs used to produce outputs. This assumes that an industry must double inputs to double output. Multipliers reflect this accordingly.
- **No supply constraints** – Input Output tables assume no price adjustments in response to supply constraints. When applying multipliers, this means the impacts calculated from an expansion in an industry may not be fully possible if, for example, the economy is at full capacity.
- **Static in nature** – Input Output tables capture one point in time, so do not take into account technology and other changes.

3. NEW ZEALAND'S HYDROGEN USE CASES

Hydrogen can be applied in a wide range of ways, and they are all relevant and promising for New Zealand's green hydrogen economy.

1. AMMONIA-BASED FERTILISER

There is an existing, mature market for hydrogen as a feedstock in the production of ammonia. Over 40% of total global hydrogen production is currently used to produce 187 million tonnes of ammonia per annum. Approximately 80% of this ammonia is used as a feedstock to produce nitrogen-based fertilisers such as urea, ammonium sulphate and diammonium phosphate (DAP). The remaining ~20% of the global demand for ammonia is used as feedstock for a range of industrial chemicals.

The global production of 'green ammonia' remains at the pilot stage, with 99% of global ammonia produced from fossil fuels. While the global ammonia supply will remain dominated by fossil fuels for the foreseeable future, the supply of green ammonia is projected to grow strongly, driven by a combination of customer demands to reduce their Scope 1, 2 and 3 GHG emissions and regulatory pressure to decarbonise. Europe is at the forefront of regulation on the decarbonisation of feedstock. In 2020 the EU announced a Farm to Fork Strategy that aims to reduce fertiliser usage by 20% and increase the share of organic farming from 5% to 25% by 2030[26].

New Zealand's potential export opportunity relies on either (Exhibit 21):

- A cost of carbon applying to the rest of the world, or
- Customer demand for green ammonia. New Zealand's supply of ammonia based on hydro generation in the lower South Island is highly competitive with green ammonia from other countries.

The cost of freight means the opportunity to supply ammonia-based fertilisers domestically is likely to be stronger than a potential export opportunity. New Zealand is currently a major net importer of ammonia-based fertilisers like urea, ammonium sulphate and DAP. These imports are typically produced from natural gas or coal and are primarily sourced from countries that do not place any cost on carbon (e.g. Saudi Arabia for urea, China for DAP).

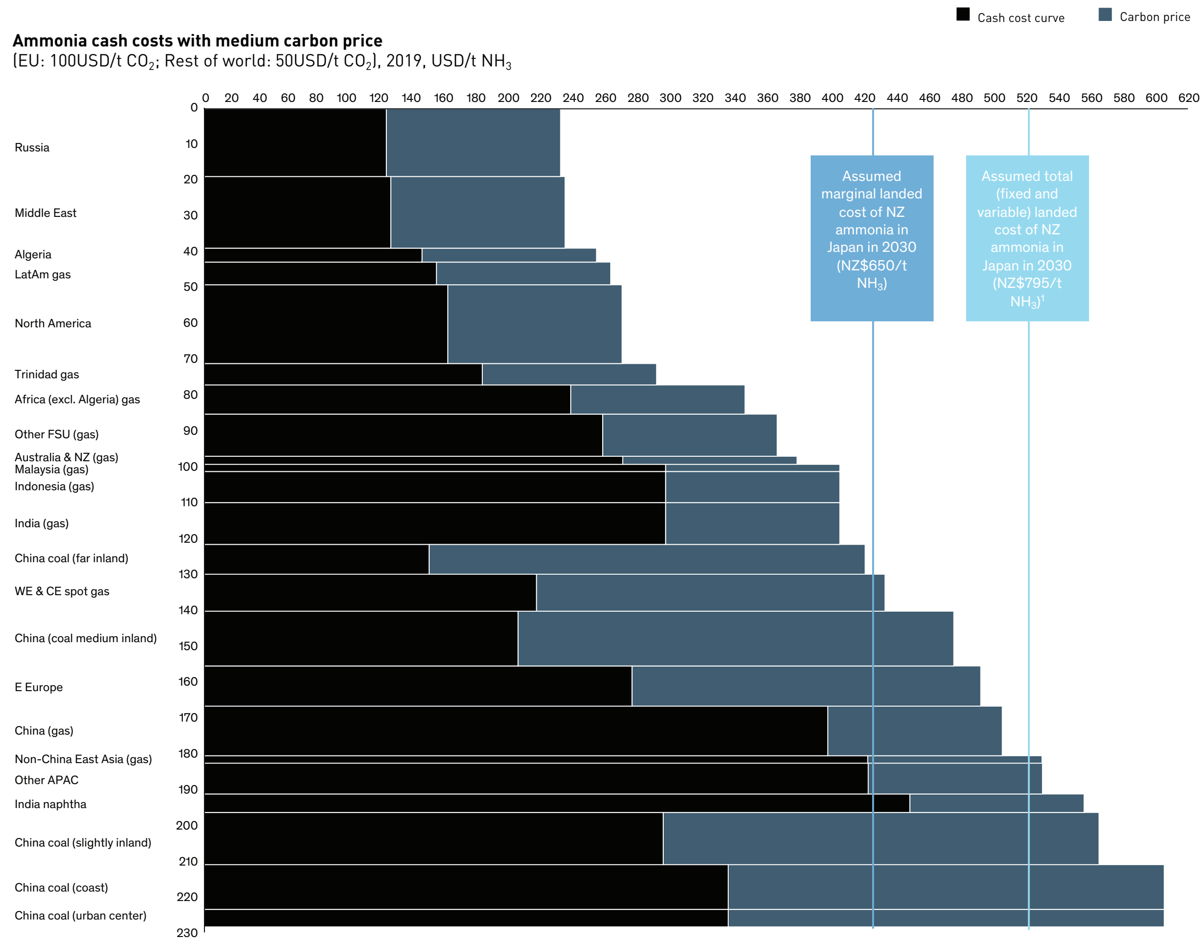
In theory, New Zealand could displace the bulk of these imports with ammonia-based fertilisers produced from domestic renewable electricity. If this could be achieved, it would have a number of broader NZ Inc co-benefits, notably around the country's branding for agricultural exports.

26 ec.europa.eu.

Exhibit 21

New Zealand exports of ammonia would likely sit in the third quartile of global production facilities

Cash cost curve for medium and high carbon prices



1. Total cost of ownership including all capex and opex elements except the fully depreciated cost of NZ hydro plant; based on NZ$2.1/kg H2 cost and 0.71 USD/NZD exchange rate

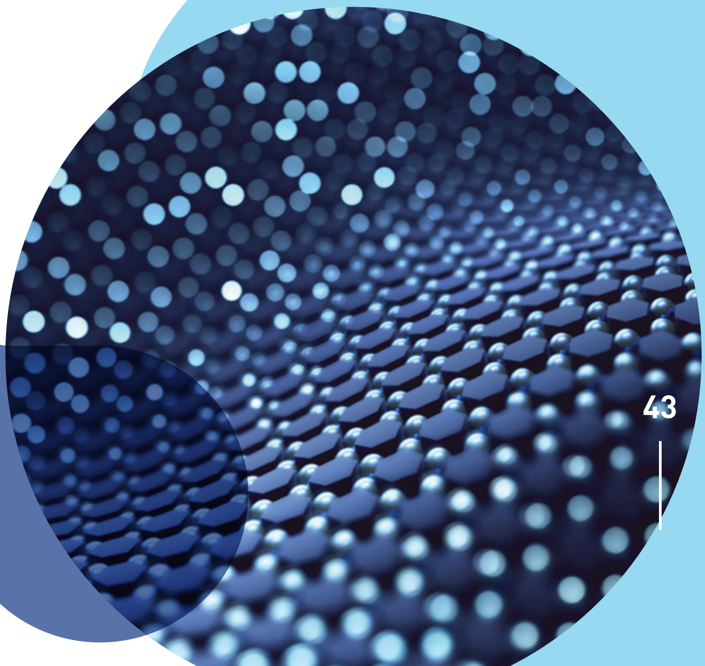
Source: Fertecon Ammonia Outlook 2019-10, McKinsey Margin Model

2. AMMONIA BLENDING WITH COAL FOR ELECTRICITY GENERATION IN JAPAN

In October 2020 the Japanese government announced its ambition to cut greenhouse gases to zero by 2050. To achieve this goal, the co-firing of ammonia and coal, combined with carbon capture and underground storage/carbon recycling has been identified as a means of reducing emissions from the country's fleet of coal-fired power stations.

The idea forms part of the country's 'Green Growth Strategy', which was released in January 2021[27] and was followed by a roadmap in February 2021[28]. According to the roadmap Japan is looking to expand ammonia fuel use to 3 million tonnes per annum by 2030, with a 20% ammonia co-firing rate at the country's coal-fired power plants. The Japanese demand for ammonia (of which most is for fertiliser and industrial applications) currently stands at 1 million tonnes per annum, of which 200,000 tonnes per annum are imported. The aim is to lift the ammonia-to-coal blending ratio to 50:50 after 2030, before establishing ammonia-fired power-generation technology in the run-up to 2050. This could lift ammonia fuel demand to 30 million tonnes per annum by 2050.

These government announcements have been complemented by announcements from many of Japan's largest electric power companies. For example, JERA, the country's largest power company, intends to move from pilot-scale to full-scale operations by 2030, moving up to a 20:80 ammonia/coal blend in the first half of the 2030s then shifting its thermal power plants to use 100% ammonia as a fuel in the 2040s[29]. The company's first test of burning 20% ammonia will be at its 4.1 GW Hekinan coal-fired power plant in central Japan, from the financial year 2021-22.



27 www.meti.go.jp.
28 www.argusmedia.com.
29 www.jera.co.jp.

3. EFUEL

Electrofuels (eFuels) are carbon-based liquid fuels manufactured using captured carbon dioxide or carbon monoxide together with low-carbon hydrogen. They are named as such because the hydrogen is obtained from a sustainable electricity source.

The key advantage of eFuels is that they are 'drop-in' replacements for existing transport fuels like petrol and jet fuel, and can therefore use existing infrastructure for distribution, storage and delivery to vehicles. The main disadvantage is the energy loss across the value chain, which adds to the overall costs – as shown in Exhibit 22.

Methanol synthesis and the Fischer-Tropsch process are the two methods used for producing synthetic fuels (synfuels). Methanol synthesis is well known in New Zealand, as between 1986 and 1999 the country produced synthetic petrol at Motunui using natural gas as a feedstock. A similar process could be envisaged for the lower South Island, with hydrogen produced from electrolysis and carbon monoxide sourced from biomass used to produce methanol. Subsequent processing would then convert the methanol to petrol, as shown in Exhibit 23.

Fischer Tropsch is a synthesis method for manufacturing transport fuels, waxes and other hydrocarbons (generally longer-chain molecules). The technology is founded on the conversion of synthesis gas (a mixture of H_2 and CO) to the desired product and is well established for transport fuels. Its primary shortcoming is that the method is characterised by a set of reactions making a range of products, so the liquid yield for a specific chemical may be suboptimal. However, the technology does produce sustainable aviation fuels.

The principal constraint on producing methanol and synfuels is the availability of sufficient biomass (or other sources of carbon-neutral carbon) in the lower South Island. Under preliminary modelling, only one-quarter of the potential available electricity in the lower South Island could be converted to methanol due to the constraints around biomass availability. This makes the economics of methanol and synfuel manufacture particularly challenging.

Exhibit 22

Efficiency and costs along the eFuels value chain

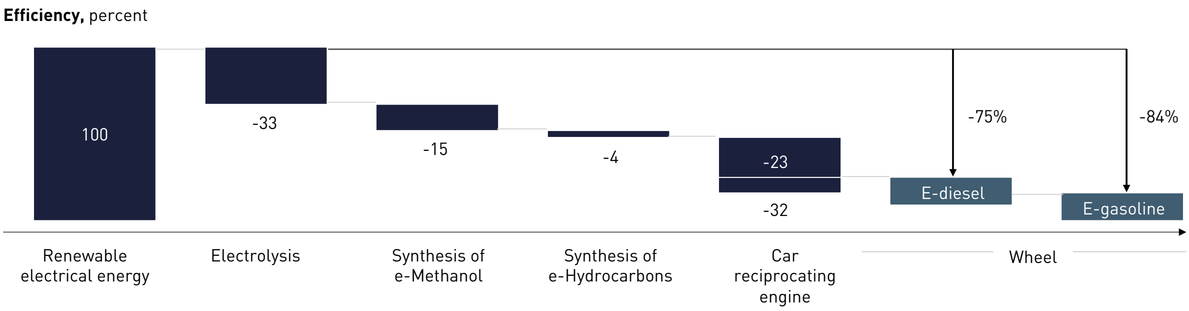
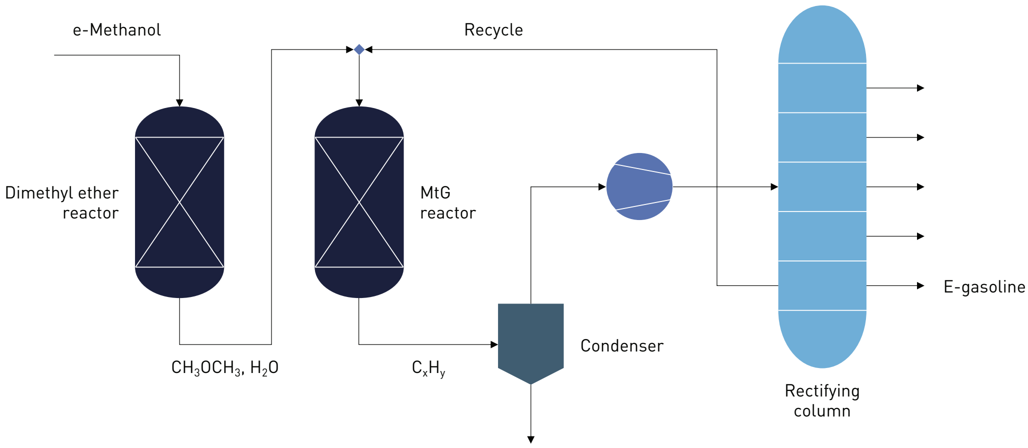


Exhibit 23

Methanol synthesis method for eFuel production



4. HYDROGEN FOR ELECTRICITY GENERATION IN NEW ZEALAND

Hydrogen can be used for electricity generation, although the economics of doing so are always likely to be challenging given the overall energy losses. The end-to-end efficiency ranges from 17% when blending green ammonia with coal to 25% when using hydrogen in a fuel cell. In comparison, a grid-scale battery has an end-to-end efficiency of 88%. So, if a battery has stored 1 MWh of renewable generation, 0.88 MWh will be available as generation.

In theory, hydrogen could also be used to generate electricity in dry years if large volumes of hydrogen could be stored at a low cost. However, the economics of doing this are always likely to be challenging.

It is possible that using hydrogen for electricity generation will work in markets aiming to fully decarbonise and with few domestic renewable-generation options of their own (e.g. Japan). This is not the case for New Zealand, which is starting from a very high level of renewable generation, has significant potential to increase the proportion of renewable generation, and can use options such as demand-side flexibility (i.e. interrupting a large volume of industrial demand) to address dry-year shortfalls.

	Blending green ammonia with coal	Blending green hydrogen with natural gas	Using hydrogen in a fuel cell
Initial renewable energy	1 MWh	1 MWh	1 MWh
Renewable hydrogen post electrolysis	0.65 MWh (=65% efficiency)*	0.65 MWh (=65% efficiency)	0.65 MWh (=65% efficiency)
Renewable ammonia post ammonia converter	0.50	n/a	n/a
Renewable hydrogen post liquefaction and storage	n/a	0.49	0.49
Renewable electricity post generation	0.17 MWh	0.20 MWh	0.25 MWh
Overall efficiency	17%	20%	25%

* Electrolyser efficiency applied relates to a 2020 assumption

5. GREEN STEEL

New Zealand currently produces ~600,000 tonnes of steel per annum and imports an additional ~380,000 tonnes to meet the country's total demand.

The sector is very carbon intensive and accounts for approximately 2% of New Zealand's gross emissions (approximately 1.7 million tonnes of CO_2e per annum). Globally, steel accounts for ~8% of CO_2 emissions.

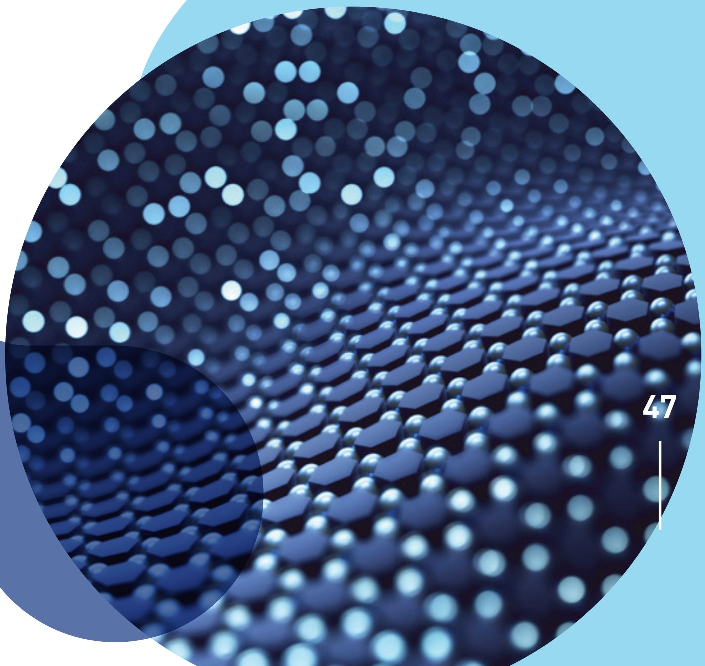
The sector is one of the country's strategic assets, offering resilience and independence, but it is facing headwinds from rising raw-material costs and carbon prices, and low-cost imports. There is also increasing uncertainty about the long-term availability of natural gas.

The high level of emissions has led to considerable global research into the production of green steel from hydrogen. One possible avenue to completely decarbonise the steel-making process is using renewable electricity to fire an electric arc furnace, with green hydrogen used as a reductant to produce the direct reduced iron.

Around the globe, several large-scale facilities and memoranda of understanding have been recently announced. For example:

1. Swedish steel maker SSAB began a pilot plant of its HYBRIT technology in August 2020 and has now committed to building a demonstration plant by 2025. The company is aiming to produce emission-free steel at commercial scale by 2026 and to be fossil-free at all its steel-making sites by 2045[30].
2. H2 Green Steel[31], another Sweden-based company, is looking to produce 5 million tonnes of carbon-free steel by 2030 using 800 MW of renewable electricity.
3. Origin Energy has signed a memorandum of understanding with South Korean steel maker POSCO to investigate future exports of zero-emission hydrogen made from renewable energy in Tasmania and Queensland. POSCO would use the hydrogen to make emission-free steel[32].

Alongside the technology challenges, significant logistical challenges need to be worked through before green steel can be a viable option for New Zealand. These include the fact that the least-cost renewable electricity generation is in the lower South Island, while the existing iron-sand-extraction and steel-making facilities are in the North Island.



30 www.ssab.com.
31 static1.squarespace.com.
32 www.smh.com.au.

APPENDIX

APPENDIX 1 – HYDROGEN PRODUCTION PROJECTS ANNOUNCED GLOBALLY AS OF MARCH 2020.

18 giga-scale hydrogen production projects have been announced

Name	Location	Companies	Electrolysis capacity [MW]	Estimated investment [MUSD]	H_2 production [kton p.a.]	COD[1]
Asia Renewable Energy Hub	Australia	CWP, Vestas	12,000	8,424	1,104	2035
NorthH2	Netherlands	gasunie, equinor, RWE	10,000	5,210	1,000	2040
AquaVentus and AquaDuctus	Germany	Helgoland, RWE	10,000	5,715	920	2035
Murchison Renewable Hydrogen Project	Australia	HRA, CIP	5,000	5,557	460	2028
Beijing Clean Energy & Storage Plant	China		5,000	3,259	450	2025
Base One	Brazil	enegix	3,400	5,400	615	2025
H2 Hub Australia	Australia		3,000	3,105	361	2025
Helios (Neom)	Saudi Arabia	Air Products	2,000	5,190	237	2025
HyEx	Chile	ENGIE, Enaex	1,600	1,491	124	2030
Lightsource BP Western Australia project	Australia	lightsourcebp, bp	1,500	1,240	198	n/a
Sustainable fuel production in Copenhagen area	Denmark	Ørsted, DSV, Maersk, DFDS, SAS, CIP	1,300	812	120	2030
Nel-Nikola framework agreement	United States	NIKOLA	1,000	1,851	175	2028
H2 Sines green hydrogen project	Portugal	galp, REN, Vestas, Martifer	1,000	904	92	2030
Pacific Solar Hydrogen	Australia	austrom	1,000	573	200	n/a
LIBERTY steel	France	LIBERTY, PAUL WURTH, SHS	1,000	941	175	2030
Esbjerg ammonia	Denmark	CIP, DFDS	1,000	1,200	92	2026
Aker Chile	Chile	AKER HORIZONS	1,000	353	92	n/a
SeaH2land	Netherlands	Ørsted, DOW	1,000	670	92	2030

1. Commercial operation data. Many projects announced to start partial operation before full COD

Source: McKinsey Hydrogen Project Database