New Zealand Government

Green Hydrogen Strategy

a vision for hydrogen in New Zealand

Green Paper

SEPTEMBER 2019

Contents

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MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

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Message from the Minister

Hon. Dr Megan Woods
Minister of Energy and Resources

I am a passionate believer in the idea of a well-managed transition: a clear, transparent and well-managed pathway to a new economy - a more sustainable economy that is better for the environment, creates jobs and improves New Zealanders' lives.

Our reliance on fossil fuels is compromising our climate and the wellbeing of future generations. The changing climate is affecting our economy, the environment and our way of life. New Zealand remains an active participant in the international response to the challenge of climate change (through the 2015 Paris Agreement), principally by making substantial reductions in our greenhouse gas emissions.

The Government has a goal to transform New Zealand into a more productive, sustainable and inclusive economy. This includes our goal to reach 100 per cent renewable electricity by 2035 and to transition to a clean, green and carbon neutral economy by 2050. The Government has committed to making this process a 'just transition'– one that is fair, equitable and inclusive. This is about making sure the Government carefully plans with iwi, communities, businesses and unions, regions and sectors to manage the impacts and maximise the opportunities of the changes brought about by the transition to a low emissions economy.

A major piece of work for the Government this year will be to develop policies that will facilitate a Renewable Energy Strategy for New Zealand. We are considering areas where Government action can make the biggest difference – identifying the incentives that may be needed, the roadblocks that need to be removed and how we can help new technologies come on stream. We also need to ensure our regulatory and policy settings are fit-for-purpose in order to make the most of our abundant renewable energy sources. Leadership from our local Governments, communities, businesses, universities and other organisations, and iwi is crucial as we build the architecture for the transition to a productive, sustainable and inclusive economy.

Green hydrogen is a tool that will help reduce global emissions

Hydrogen could become a major differentiator for New Zealand's energy, transport and industrial sectors with substantial export potential.

The establishment of a strong low emissions economy, to which hydrogen contributes, is a very real opportunity and within reaching distance. Private sector investment, facilitated by appropriate Government policies, will allow New Zealand to benefit from significant decarbonisation across the entire energy system.

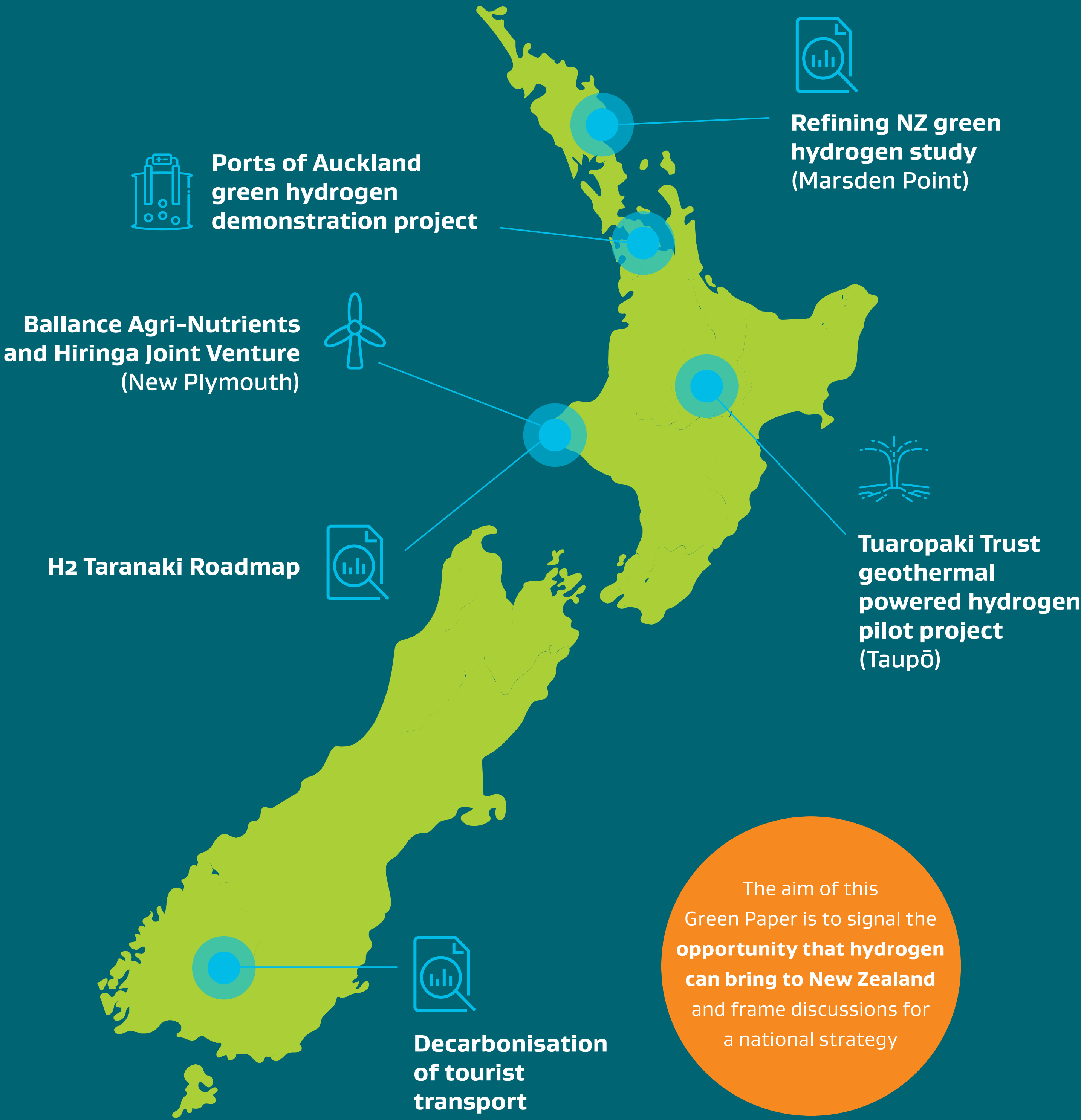
Green hydrogen is a platform that will help reduce global emissions. New Zealand has an abundance of renewable energy that could be used to produce hydrogen as a next generation fuel in a sustainable way. With green hydrogen we have opportunities to create new jobs, convert heavy transport away from fossil fuels, enhance our security of electricity supply and even create significant export revenue. In combination, electricity and hydrogen provide a robust energy system platform to decarbonise New Zealand. Their complementary characteristics can deliver benefits that neither can deliver in isolation.

We have seen large and growing international interest in hydrogen. Countries are investing heavily in hydrogen research, development and demonstration projects, and in some cases, national strategies. New Zealand signed a Memorandum of Cooperation with Japan in 2018 which signalled our interest in working in partnership with Japan to collaborate in the development of hydrogen for the benefit of both countries. New Zealand aims to transform its energy and transport sectors as we make the transition to a low emissions economy and this partnership will allow the exchange of knowledge to enhance hydrogen development.

Several firms in New Zealand are seeing the potential opportunities for hydrogen in our future economy and some are already investing in hydrogen projects and trials. Ports of Auckland has committed to building a green hydrogen production and refuelling facility. The company, along with its project partners Auckland Council, KiwiRail and Auckland Transport will invest in hydrogen fuel cell vehicles as part of the project.

Current Hydrogen Opportunities in New Zealand

These are the current known green hydrogen projects being explored by the private sector in New Zealand



The aim of this Green Paper is to signal the **opportunity that hydrogen can bring to New Zealand** and frame discussions for a national strategy

Figure 1: Current Hydrogen Opportunities in New Zealand

Similarly, in Taupō, the Tuaropaki Trust has partnered with Japanese multinational Obayashi Corporation to construct a pilot hydrogen production facility using geothermal electricity. Several other local hydrogen projects are being developed in Southland/Otago and Taranaki.

The Prime Minister, Rt. Hon Jacinda Ardern launched the *H2 Taranaki Roadmap* in March 2019. This Roadmap, which was developed by Venture Taranaki, New Plymouth District Council, Hiringa Energy and the Provincial Growth Fund, illustrates how the region can use its existing skills and infrastructure to become a leader in hydrogen production. Provincial Growth Fund support has also been secured to help develop hydrogen fuel infrastructure in Taranaki.

The Government is establishing a National New Energy Development Centre in Taranaki to help lead New Zealand's transition to a low carbon future. This Centre will help create new business and jobs while helping New Zealand move towards clean, affordable, renewable energy and away from fossil fuels. The Centre will look at the full range of available clean energy options such as offshore wind, solar systems, hydrogen and new forms of energy storage. The Government will also establish a new science research fund to facilitate early stage research into new green energy technologies.

A Vision for Hydrogen in New Zealand was developed by building on previous research globally and in New Zealand, including the 2018 Productivity Commission work, the Concept Consulting studies in 2017 and 2019, and incorporates the knowledge and expertise of key stakeholders.

Through this paper, the Government is seeking your feedback on the potential for hydrogen production, export and utilisation of hydrogen in New Zealand's economy.

The aim of this Green Paper is to signal the opportunity that hydrogen can bring to New Zealand and frame discussions for a national strategy.

While there are many detailed technical sources of information on hydrogen, this Green Paper is provided for wide discussion and feedback from all New Zealanders on the current and future economic opportunities for hydrogen.

Achieving a low emissions economy based around greater electrification and next generation fuels such as hydrogen is a formidable challenge. I believe that New Zealand is well positioned to tackle it by transitioning our energy system to renewable energy, and capitalising on the economic opportunities that present themselves along the way. This Government will continue to provide leadership and impetus so that we develop a local emission pathway to carbon neutrality.

Hon. Dr Megan Woods
Minister of Energy and Resources
September 2019

New Zealand policy context for hydrogen

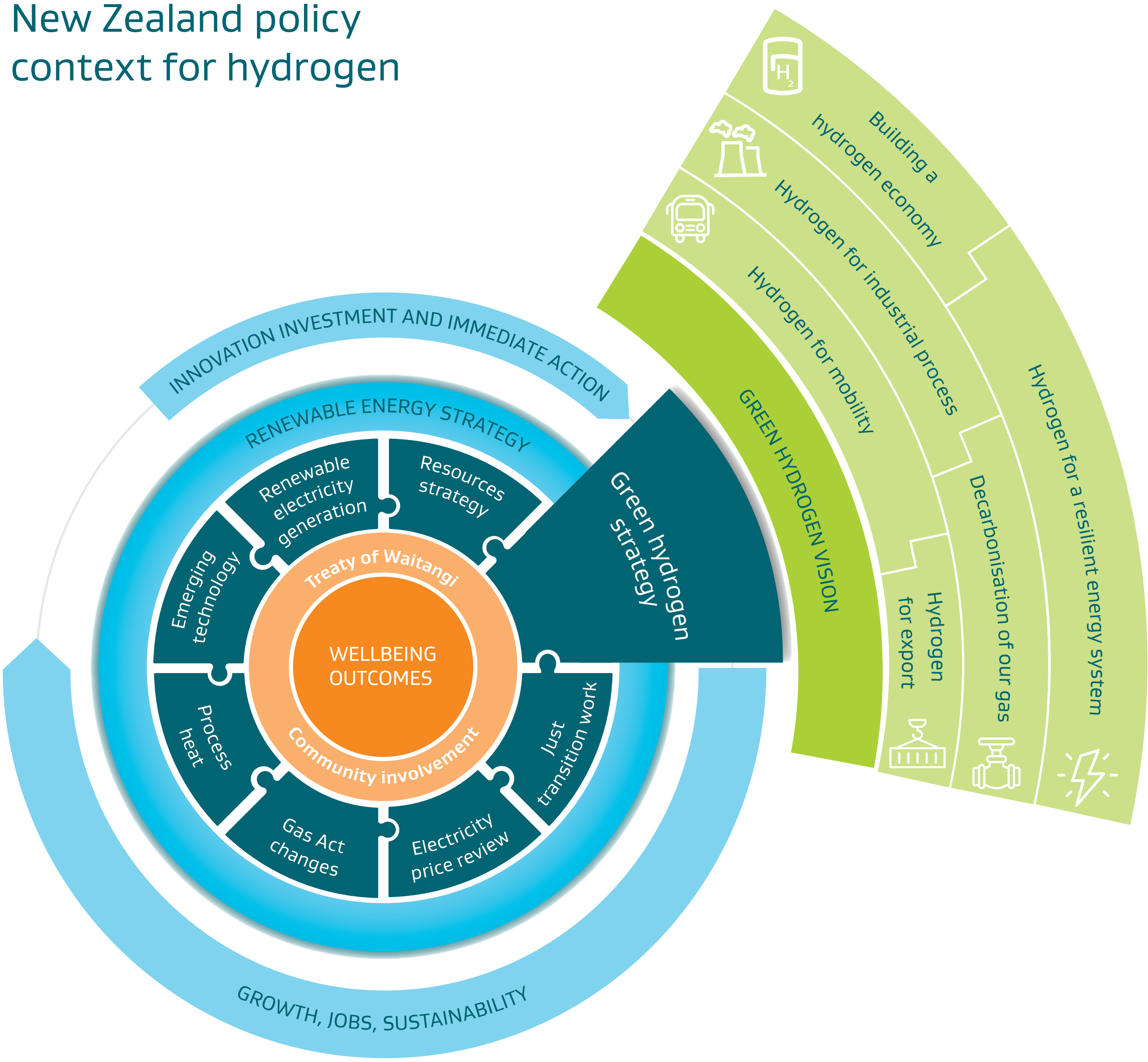


Figure 2: New Zealand policy context for hydrogen

New Zealand is fortunate to have an abundance of renewable energy potential

Auckland ©iStock

Executive Summary

The Government aims to achieve a net zero carbon economy by 2050. This ambitious goal requires the transition away from an energy system which relies heavily on hydrocarbons (oil, coal and gas) to one that is based on renewable energy sources.

Hydrogen is poised to fulfil it's potential as a clean alternative to hydrocarbons in the global pursuit of decarbonisation to address climate change.

New Zealand is one of several countries investigating the most appropriate applications and transition pathway for hydrogen within their energy system and economy, making best use of their existing natural, social, cultural, human and financial resources.

This document presents the New Zealand Government's vision to harness the hydrogen opportunity for a sustainable and resilient energy future for New Zealand.

It is envisaged that in combination, hydrogen and electricity could provide a robust energy system platform for the delivery of deep decarbonisation of our energy and transport.

There are many potential areas of application including seasonal electricity storage for winter peak demands in electricity generation, decentralised energy generation for remote and isolated users, decarbonised gas, intermediate and high temperature industrial process heat, green industrial chemical feedstocks, and transport and mobility applications such as for freight, materials handling, return to base fleet transport, shared mobility and public transport.

While hydrogen produced from fossil fuels and industrial processes (brown, blue and grey) may play a role in the transition of New Zealand's regions and existing industries, the Government considers there is greater opportunity for New Zealand in exploring the use of our renewable energy to produce green hydrogen as an alternative fuel for domestic use and for export.

Global momentum can be seen in the recent policy announcements by Governments in South Korea, China, Japan, France, Norway, California, Australia and others – as well as New Zealand – regarding green hydrogen's investigation and use in demonstration projects in energy, industrial and transport.

Demonstration projects are underway here, with others planned. They include collaborations and partnerships between iwi, public and private sectors with both local and international players. With the recent establishment of the New Zealand Hydrogen Association and Just Transitions work, and learnings from overseas, these ventures are advancing the emerging hydrogen industry and economy.

Hydrogen production, transportation and storage technologies are advancing rapidly and renewable energy systems are on the way to cost parity with fossil fuel-based systems. Today, green hydrogen production costs are challenging (electricity costs factor significantly in the economics of electrolysis) and higher than brown hydrogen produced from natural gas which is coupled with the release of the greenhouse gas CO_2.

Predictions vary over exactly when green hydrogen is expected to reach cost parity with fossil fuel based hydrogen. The IEA, in its 2019 report (20), predicts that the cost of producing hydrogen from renewable energy could fall by 30 per cent by 2030 as a result of the declining cost of renewables and scaling up of hydrogen production. Others predict green hydrogen costs will fall faster and NEL (35) noted recently that renewable hydrogen already beats fossil fuel options in terms of total cost of ownership.

Other challenges to developing hydrogen in the short to medium term could be overcome by technological advances and investment, enabled and supported by appropriate Government policy platforms.

These challenges include cost and technological maturity, safety, regulatory and policy uncertainty and gaps, infrastructure development, building the hydrogen economy, utilising additional natural resources such as water, developing new renewable energy, the perception of inefficient use of energy and lack of understanding of, the need for lifecycle assessments in investment decisions.

In a transport context, availability and access to suitable vehicles and the establishment of a sufficiently dense refuelling infrastructure are key. However, the greater range of hydrogen vehicles and their shorter refuelling times will reduce the magnitude of this problem somewhat compared with electric vehicles (49).

Hydrogen can also provide an economic export opportunity for the country. Thanks to our abundant renewable energy, New Zealand can produce some of the cleanest green hydrogen in the world, and potentially receive a premium for it in international markets. This is a strategic advantage our Government wishes to explore.

Through this Green Paper, the Government is seeking your feedback on the role of hydrogen in a more productive, more sustainable and a more inclusive economy for New Zealand's future wellbeing.

Hydrogen's potential role in the New Zealand economy

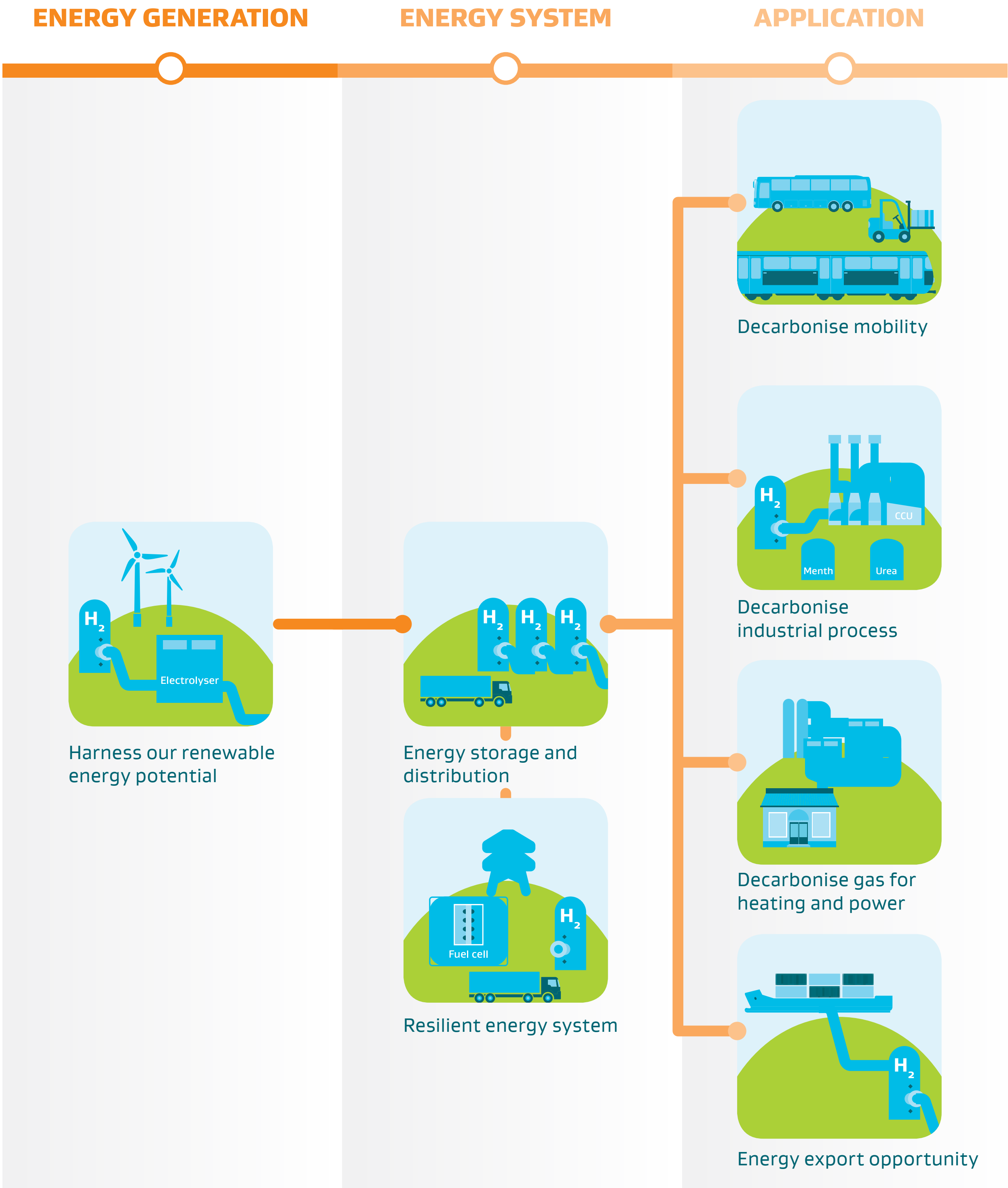


Figure 3: Hydrogen's role in the New Zealand economy

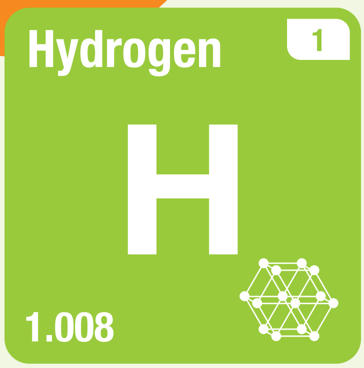
Our vision

To harness the hydrogen opportunity for a sustainable and resilient energy future for New Zealand

New Zealand has a significant opportunity to decarbonise electricity, heat and transport systems and demonstrate global leadership to other countries also looking at low carbon pathways.

The life cycle of green hydrogen is a journey from water and back to water. As illustrated in Figure 4, it is created from water using energy from the sun or the wind. When utilised, there is no pollution by-product, and the only output apart from energy is water.

What is hydrogen?



It is the simplest, lightest and most abundant element in the universe, making up more than 90% of all matter.

In its normal gaseous state, hydrogen is odourless, tasteless, colourless and non-toxic. It reacts readily with oxygen, releasing considerable amounts of energy as heat and producing only water as exhaust. It has a high energy content by weight – nearly three times that of gasoline.

Hydrogen is generally encountered as molecular hydrogen (H_2). It is an energy carrier that can transfer and store energy: it is not a primary energy source such as natural gas, coal, biomass or wind. (21).

Hydrogen is not naturally abundant and has to be produced. Hydrogen produced from natural gas or coal gasification and the associated release of the carbon dioxide produced into the atmosphere, is the common method of production termed brown hydrogen.

If the CO_2 emitted can be captured and sequestered (CCS), it becomes blue hydrogen. In addition, grey hydrogen is produced as a co-product during an industrial process.

Green hydrogen is the focus of this paper: it is produced by splitting water molecules into the constituent elements of hydrogen and oxygen, using renewable electricity to power an electrolyser.

Types of hydrogen?

- Low Carbon Derived (Green) Hydrogen
- Carbon Fuel Derived (Brown) Hydrogen
- Industrial Process Derived (Grey) Hydrogen
- Carbon Fuel Derived with CCS (Blue) Hydrogen

Seen in this perspective, green hydrogen is an energy vector that is in harmony with our vision of a clean renewable energy future and net zero carbon economy.

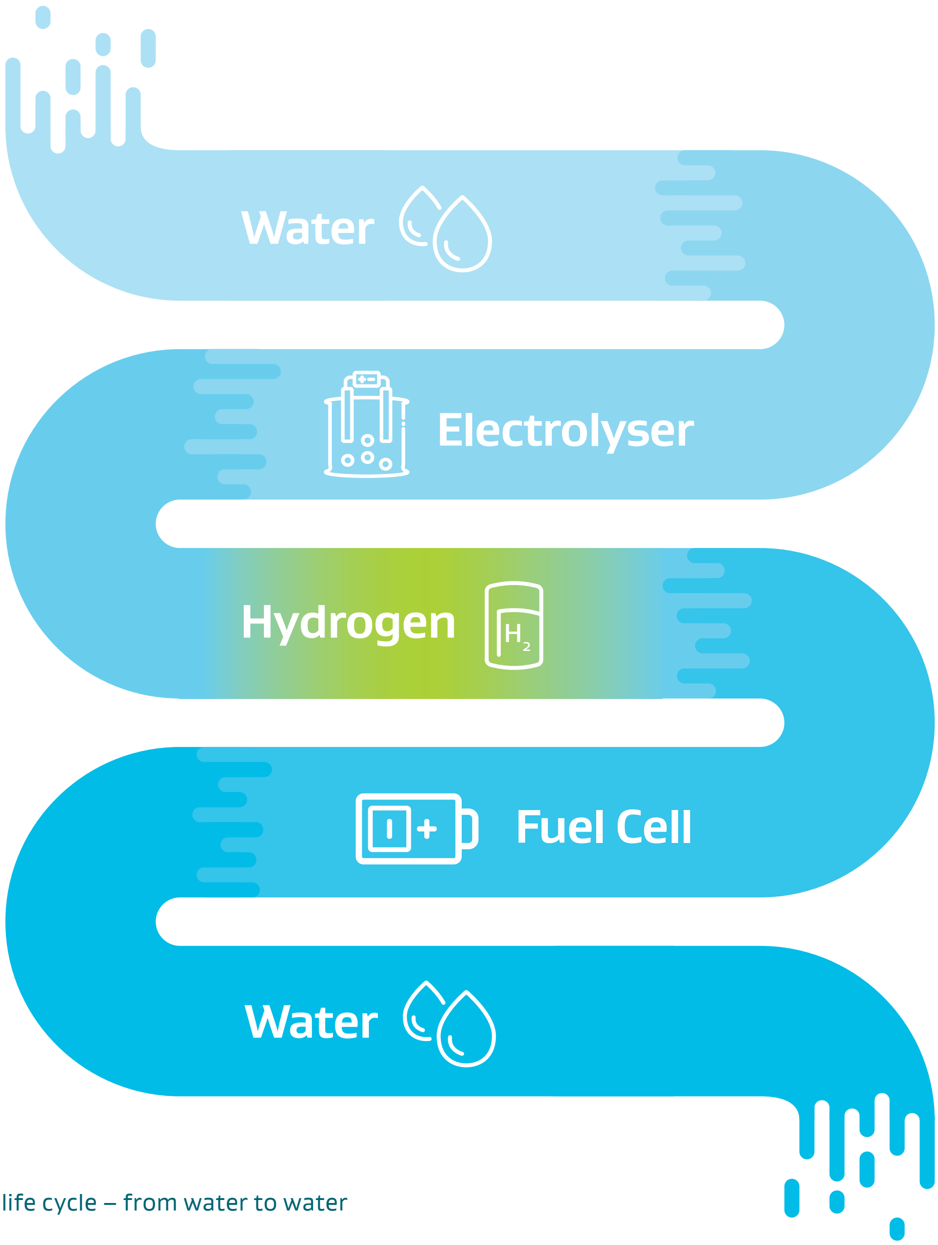


Figure 4: Hydrogen life cycle – from water to water

Tongariro alpine crossing ©iStock

Aim of the Green Paper

This Green Paper: *A Vision for Hydrogen in New Zealand*, discusses how hydrogen could fit into New Zealand's wider energy and transport system.

This paper builds on existing work, identifying the possible applications, benefits and barriers to uptake for hydrogen in our energy, transport and export sectors.

It continues the conversation on the role that hydrogen could play in pathways to decarbonisation, and discussions around energy resilience and frameworks for a national hydrogen strategy.

The insights captured in this vision are the result of collaborative work across Government agencies, consultation with industry, academics and other key stakeholders, and discussions at workshops in Auckland, New Plymouth, Wellington and Christchurch in March 2019.

The paper seeks feedback on our vision for hydrogen in New Zealand and how we can best take advantage of the opportunities presented by moving towards a low emissions economy.

Why Hydrogen?

Uses and Benefits

In a compressed gas or liquid form, hydrogen is a chemical carrier that is energy dense, transportable and flexible, (similar to natural gas) and is emerging as a clean and versatile fuel and chemical production feedstock – a viable transition and alternative to hydrocarbon use across many applications.

In an urban setting, using hydrogen is particularly beneficial because it contributes to air quality improvements.
The use of hydrogen in fuel cells emits only water, with no particulates, sulphur oxides (SO_x) or nitrogen oxides (NO_x).

Regardless of the process used to produce it, hydrogen can be either compressed or liquefied, (very similar to natural gas which is mainly methane) and can be used:

- to fuel vehicles or stationary plants which are fitted with fuel cells or internal combustion engines
- for heat by direct combustion or fuel cells
- to generate electricity in dedicated hydrogen gas turbines
- to replace carbon in industrial processes such as steel production, and
- for energy storage.

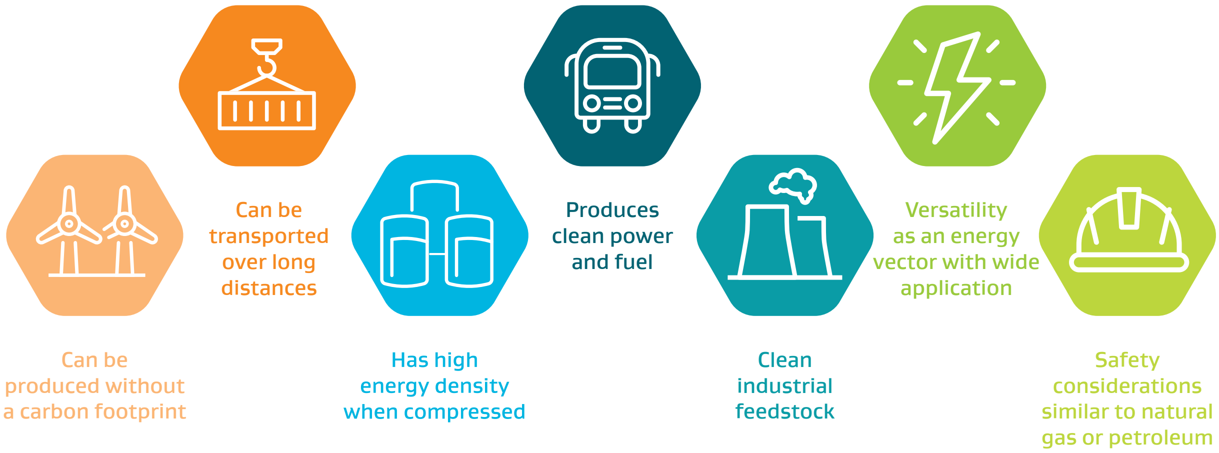


Figure 5: Why hydrogen?

Figure 5 summarises some of the features of hydrogen and why it may be attractive in New Zealand as a decarbonisation pathway. It complements electrification and can provide resilience to the energy system in specific aspects that are not economically or technically amenable to electrification. These applications include long distance heavy-duty road transport, shipping, aviation, iron and steel production, chemical manufacture and high-temperature industrial heat.

Hydrogen fuelled vehicles can be quieter than their fossil fuelled equivalent, helping to reduce noise pollution.

As a partial or complete replacement for natural gas, hydrogen fuel could provide a realistic route for decarbonisation of heavy industry by providing heat for industrial processes. Similarly, combustion of hydrogen could produce heat for district heating systems or replace natural gas as a source of domestic heating and cooking. In bottled or bulk form it could replace LPG (liquefied petroleum gas). Hydrogen is flexible and can be used in both combustion and fuel cells.

Significantly, hydrogen can also provide an energy storage medium. It can be produced by electrolysis using surplus renewable electricity when there is greater generation than demand. It can be stored and used to generate electricity during periods of low solar or wind generation and also during dry weather events that limit hydroelectric generation. Hydrogen can be stored for a much longer time and greater capacity than electricity. It can also respond to seasonal variations in solar irradiance, or wind resources or low precipitation in dry years.

Cost Trends

Governments around the world have embraced policies directly supporting hydrogen deployment by targeting applications for its use. The number of countries implementing some of these policies by type is depicted in Figure 6.

Global policies directly supporting hydrogen deployment by target application

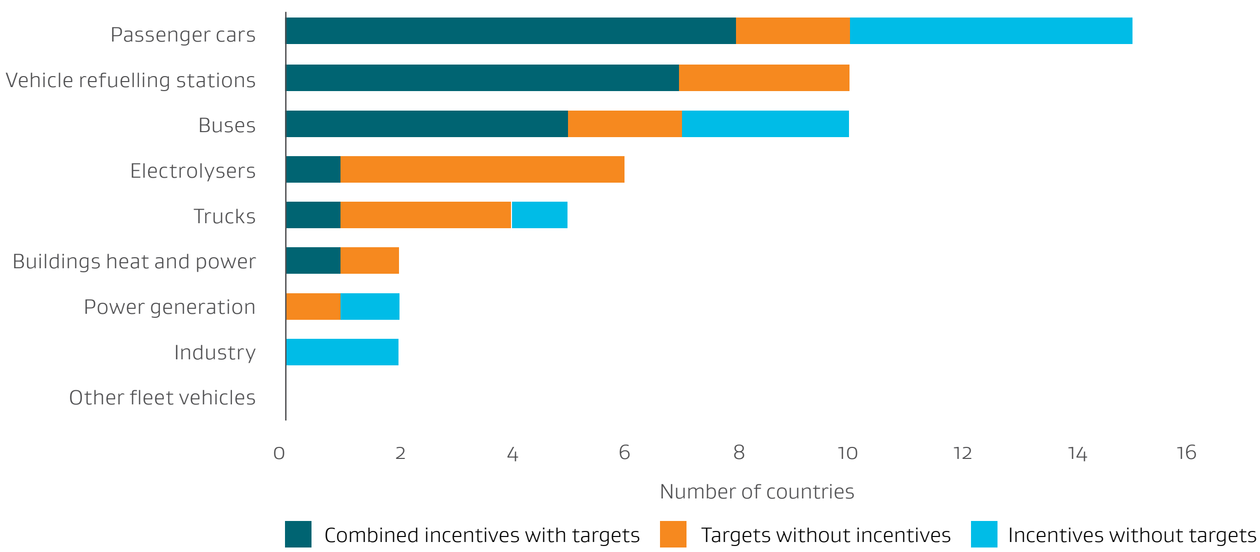


Figure 6: Policies directly supporting hydrogen deployment and application (20)

As the cost of renewable electricity becomes cheaper, the cost to produce green hydrogen will similarly reduce. Cost reductions may also result from increased scale-up of the hydrogen economy internationally. The global design of electrolysers is advancing and in the next few decades, technological developments will help to substantially reduce costs. World-wide development of the hydrogen market is expected to drive significant decreases in the cost of electrolysers, compressors and liquefaction equipment as well as end use application such as fuel cells.

Concept Consulting (5) modelled hydrogen costs for various applications in New Zealand (see Figure 7). These cost estimates provide useful insight into the challenges for hydrogen uptake across a wide variety of applications. The costs and benefits of hydrogen are only fully appreciated when the whole energy system, including lifecycle analysis from cradle to grave, is analysed. Further lifecycle analysis and cost benefit assessment are needed to better inform decision makers. It is also noted that hydrogen costs will vary across the world, depending on these variables, as shown in the IEA's 2019 report (21).

Modelled current hydrogen costs for various use-cases in New Zealand

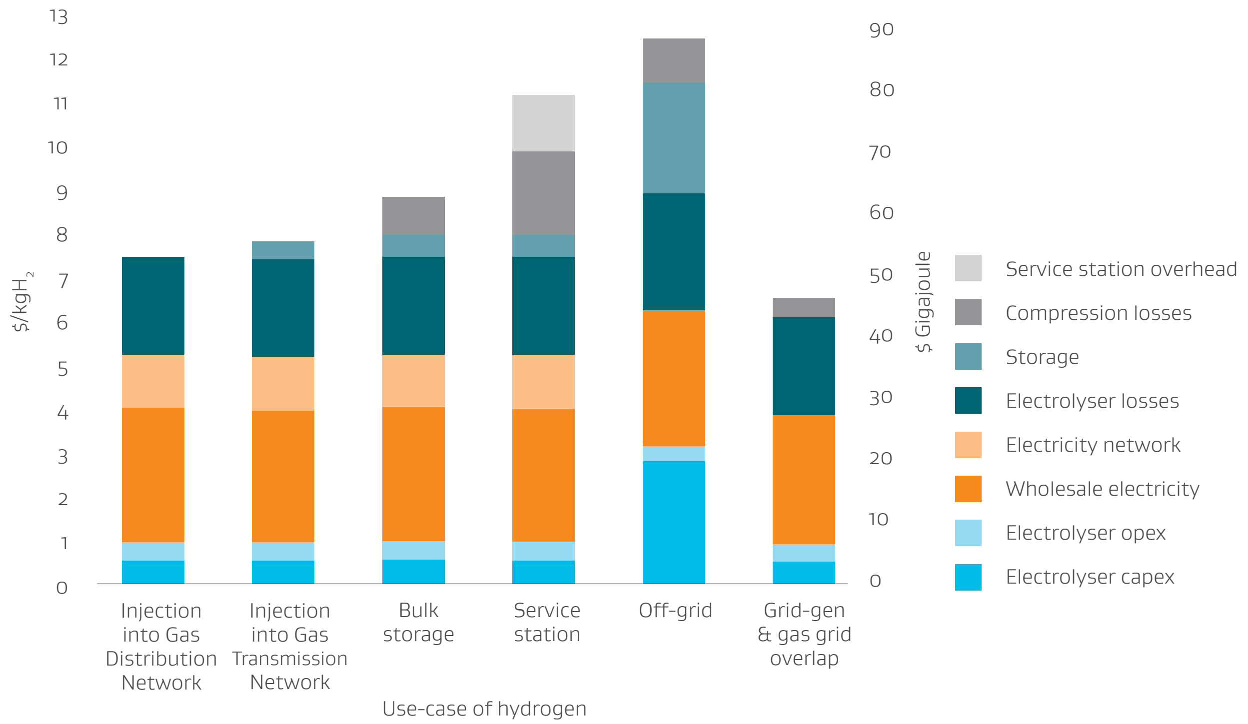


Figure 7: Modelled hydrogen costs for various use-cases in New Zealand (5)

Energy conversion – a lifecycle perspective

The production, transmission, distribution and use of heat or electricity inherently results in energy losses throughout the process. This makes hydrogen good for some uses and less efficient for others.

Lifecycle analysis of all energy system options, including hydrogen, is vital when making decisions between them. The goal of this analysis is to compare the full range of effects assignable to products and services along the supply chain by quantifying all the inputs and outputs of material flows and assessing how these affect the environment. This information is then used to improve processes, support policy and provide a sound basis for informed decisions.

Without such analysis, investment decisions can be made that address only part of the problem and ignore critical external factors such as, for example, the effect on local electricity distribution assets caused by widespread adoption of fast electric vehicle chargers, or the need for a robust process for battery disposal.

All energy carriers, including fossil fuels and electricity, encounter efficiency losses each time they are produced, converted or used. In the case of hydrogen, these losses can accumulate across each step in the value chain. After converting electricity to hydrogen, shipping and storing it, then converting it back to electricity in a fuel cell, the delivered energy can be less than 30% of the initial electricity input.

This makes hydrogen more 'expensive' than electricity or the natural gas used to produce it. It also makes a case for minimising the number of conversions between energy carriers in any value chain.

That said, in the absence of constraints to energy supply, and as long as CO_2 emissions are valued, efficiency can be largely a matter of economics, to be considered at the level of the whole value chain.

This is important as hydrogen can be used with much higher efficiency in certain applications and has the potential to be produced without greenhouse gas emissions.

For example, a hydrogen fuel cell in a vehicle is around 60% efficient, whereas a gasoline internal combustion engine is around 20% efficient and a modern coal-fired power plant is around 45% efficient. Electricity power line losses account for a further 10% or more. (20).

The future of hydrogen is here

Establishing a strong role for hydrogen in the economy is a very real opportunity and within reaching distance. Technology transformation and the global momentum to decarbonise, improve air quality and increase energy system resilience, have refocussed the attention of countries on alternatives to fossil fuels and nuclear power, and the potential of green hydrogen.

As the share of variable renewables such as wind and solar increases, so too does the need for storage to 'firm' the supply and facilitate diurnal and seasonal shifts in renewable electricity generation to give grid reliability. Hydrogen's characteristics mean it can be used as an intermediate energy vector and carrier to optimise energy systems and achieve energy sustainability and practical energy storage in every sector of the economy (21).

The capacity of new projects for low carbon hydrogen production is increasing substantially (see Figure 8), including investigation of electrolysis and CCS projects (20).

Current hydrogen technology already provides advantages over other energy vectors and many of its challenges are being actively addressed by

Capacity of new projects world wide for hydrogen production for energy and climate purposes

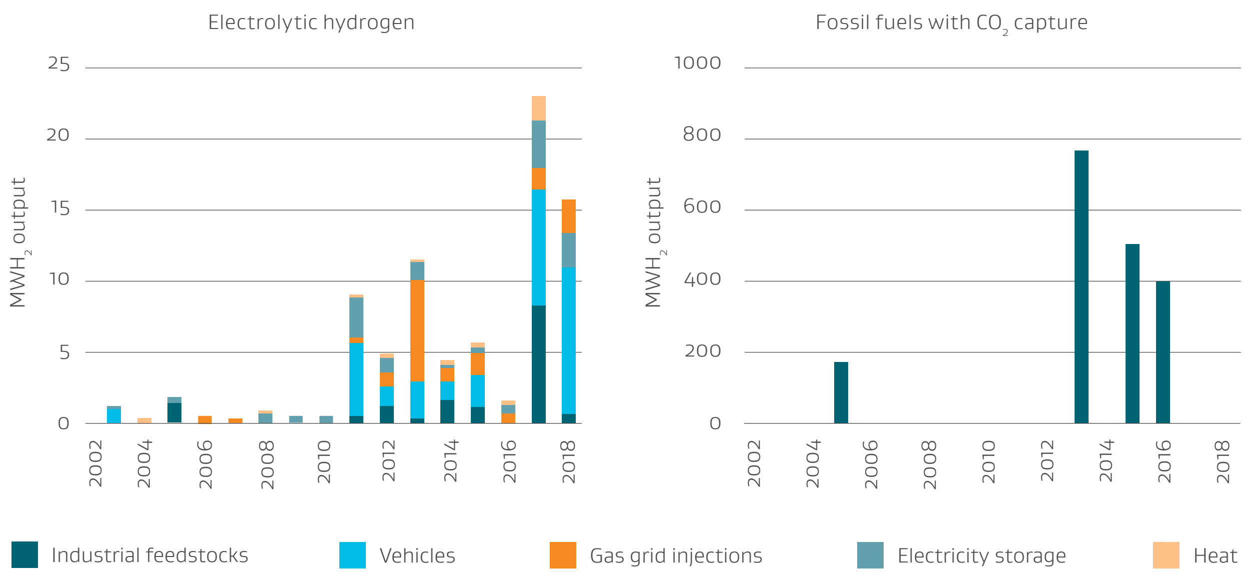


Figure 8: Capacity of new projects for hydrogen production for energy and climate purposes, by technology and start date (20)

research and development. Some aspects of the hydrogen supply chain are reasonably mature while others are still emerging and are not yet at cost parity with other low emission alternatives.

Production costs of green hydrogen are highly dependent on factors such as electricity costs and taxes, grid fees and the capacity utilisation rates of electrolysers.

The costs for fossil fuel based hydrogen also depend on natural gas prices and the availability and cost of carbon capture use and storage (CCS) services. The price of hydrogen currently varies widely between countries and end uses (different end uses require different volumes, pressures and purity levels of hydrogen). It also varies according to the way hydrogen is transported.

There is research and development activity internationally aimed at enhancing and extending hydrogen technologies and their real-world applications. In the medium term, if production costs fall and carbon prices rise, then hydrogen will become more cost-competitive with natural gas and liquid fuels.

Hydrogen currently appears less competitive than direct use of electricity for most applications but should become competitive in some applications, such as 24/7 on-site freight loading operations or meeting energy demands for remote, off-grid locations (7).

The potential development of a new global commodity market in hydrogen is now also accelerating interest and investment (38). This international commodity market in hydrogen is slowly emerging, allowing countries with abundant renewable energy to export to those with an energy deficit due to lack of domestic resources or a need to balance seasonal differences.

This could provide an opportunity for New Zealand to diversify its economy and create new jobs through exporting hydrogen to meet increasing global demand for secure, decarbonised renewable energy.

"There have been false starts for hydrogen in the past; this time could be different.

"The recent successes of solar PV, wind, batteries and electric vehicles have shown that policy and technology innovation have the power to build global clean energy industries. With a global energy sector in flux, the versatility of hydrogen is attracting stronger interest from a diverse group of Governments and companies.

"Support is coming from Governments that both import and export energy as well as renewable electricity suppliers, industrial gas producers, electricity and gas utilities, automakers, oil and gas companies, major engineering firms and cities. Investments in hydrogen can help foster new technological and industrial development in economies around the world, creating skilled jobs." (20)

Recent hydrogen project announcements

French Government has set a target of **10% green hydrogen** in industrial gas use by 2021 and 20-40% by 2027 (52).

China announced the **Yangtze River Hydrogen Corridor plan** connecting Shanghai and neighbouring cities via hydrogen highways with refuelling stations (3).

Japan is hosting the **2020 Olympics showcasing hydrogen** energy use and has set a target for 80 hydrogen refuelling stations by 2021 (20).

Australia exported the **first green hydrogen trial shipment** in April 2019 (34).

Significant **advances** in **transport** include:

The planned roll out of **20 hydrogen fuelled double decker buses** in London for 2020 (51).

27 Alstom hydrogen trains to replace diesel in Germany in 2022 (1).

Norled's world first hydrogen ferry, transporting cars and passengers in Norway in 2021 (12).

SkyNRG / KLM Royal Dutch Airlines to build Europe's first production facility of sustainable aviation fuel using green hydrogen and waste (48).

Hydrogen safety and public perception

As with hydrocarbon fuels like petroleum or natural gas, hydrogen needs to be carefully managed in appropriately designed infrastructure, facilities and products. Similar to natural gas, safety considerations are central and standards need to be developed to ensure wide-scale adoption of hydrogen can be achieved in a regulated and appropriate manner.

"The health and safety impacts of established energy products – gasoline, diesel, natural gas, electricity, coal – for consumers are familiar and rarely questioned, showing that risks – including flammability, presumed carcinogenicity and toxicity – can be managed to the satisfaction of users. Hydrogen is a non-toxic gas and there is no risk of carbon monoxide pollution associated with its use, but its high flame velocity, broad ignition range and low ignition energy make it highly flammable. This is partly mitigated by its high buoyancy and diffusivity, which causes it to dissipate quickly. It has a flame that is not visible to the naked eye and it is colourless and odourless, making it harder for people to detect fires and leaks." (20)

It is worth noting that "there are already many decades of experience of using hydrogen industrially, including in large dedicated distribution pipelines. Protocols for safe handling at these sites are already in place, and they also exist for hydrogen refuelling infrastructure in site-specific forms." (20)

Why New Zealand?

Hydrogen can play a complementary role to further renewable energy deployment and can help New Zealand transition to a more productive, sustainable and inclusive economy.

The Government has a goal to transform New Zealand's economy to become more productive, more sustainable and more inclusive. This includes the goal to reach 100 per cent renewable electricity by 2035 and to transition to a net zero emission economy by 2050.

To achieve this, we need to work together to unlock our energy productivity and renewable potential (25). As a small country we have the advantage of being able to discuss, decide and mobilise efficiently for robust outcomes with the appropriate policies and leadership.

New Zealand is acknowledged as one of the best places in the world for innovation, trials and demonstrations with minimal regulatory impediments. Working in partnership with international stakeholders to encourage the use and production of hydrogen will be critical in achieving our goals.

Our high renewable electricity level will greatly assist decarbonisation. Our electricity system currently meets approximately 40 per cent of our total end-use energy needs (27) and is expected to grow with further electrification of our transport and energy system. With renewable electricity currently at around 85 per cent and growing without direct Government intervention, we are well on our way to meeting the goal of 100 per cent renewable electricity by 2035.

New Zealand is also well placed to leverage our renewable energy potential to create green hydrogen. Further studies will help assess its possibility as an accelerator of domestic decarbonisation through the associated economy of scale which would result.

Our proximity to Japan and other potential hydrogen importing countries such as South Korea means we are in a strong position to develop a new commodity export of green hydrogen. Further studies should be undertaken to assess the extent to which hydrogen export has a role in New Zealand's future by providing a way to utilise our renewable advantages to provide a new source of export earnings and jobs.

Why New Zealand?

- ✓ *Existing industrial production and use of H_2 across NZ*
- ✓ Existing gas, process and industrial infrastructure that can be retrofitted
- ✓ Established energy generation and electricity and gas distribution

One of the best places in the world for innovation, trials and demonstrations

Significant existing and potential

water, wind and solar resources

85%

renewable electricity

Home to strong open export market and

trusted trade partner

Multiple

deep-water ports

Māori World view and Treaty of Waitangi

Te Tiriti o Waitangi/The Treaty of Waitangi forms the foundation for nationhood in Aotearoa-New Zealand. This affords hapū and iwi with the ability to participate and make decisions within the energy system according to their own cultural norms.

Leveraging off natural resources and investments, accessing technology, information and skills to grow capability and forming partnerships can assist whānau, hapū and iwi to thrive.

Māori view the energy system from a Te Ao Māori World view perspective, which is derived from the realm of Ngā Atua. Natural resources – land, sea, water and people-are descended from the spiritual realm. As descendants, Māori are the kaitiaki or stewards of these resources. This relationship between the land, the sea, the water and the people is depicted in Figure 9. Green hydrogen, as a fuel created from water using the sun or the wind, has a life cycle that begins and ends with water, and is thus a technology that is consistent with this perspective.

The outcomes of the potential convergence of views and technologies in a future New Zealand energy system are shown in Figure 10.

A woven approach

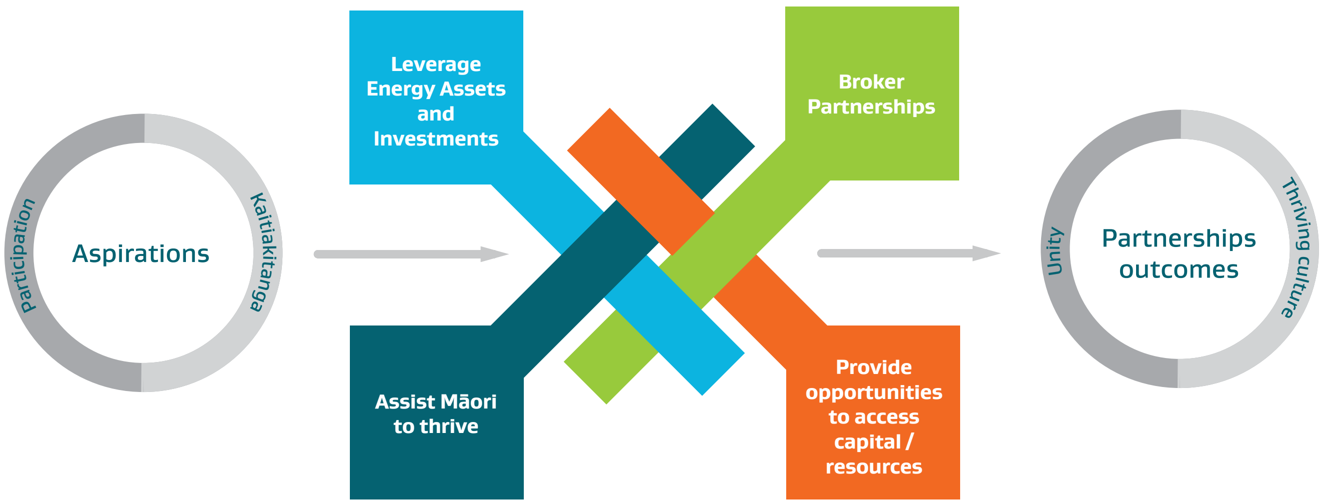


Figure 10: Convergence in the future New Zealand energy system

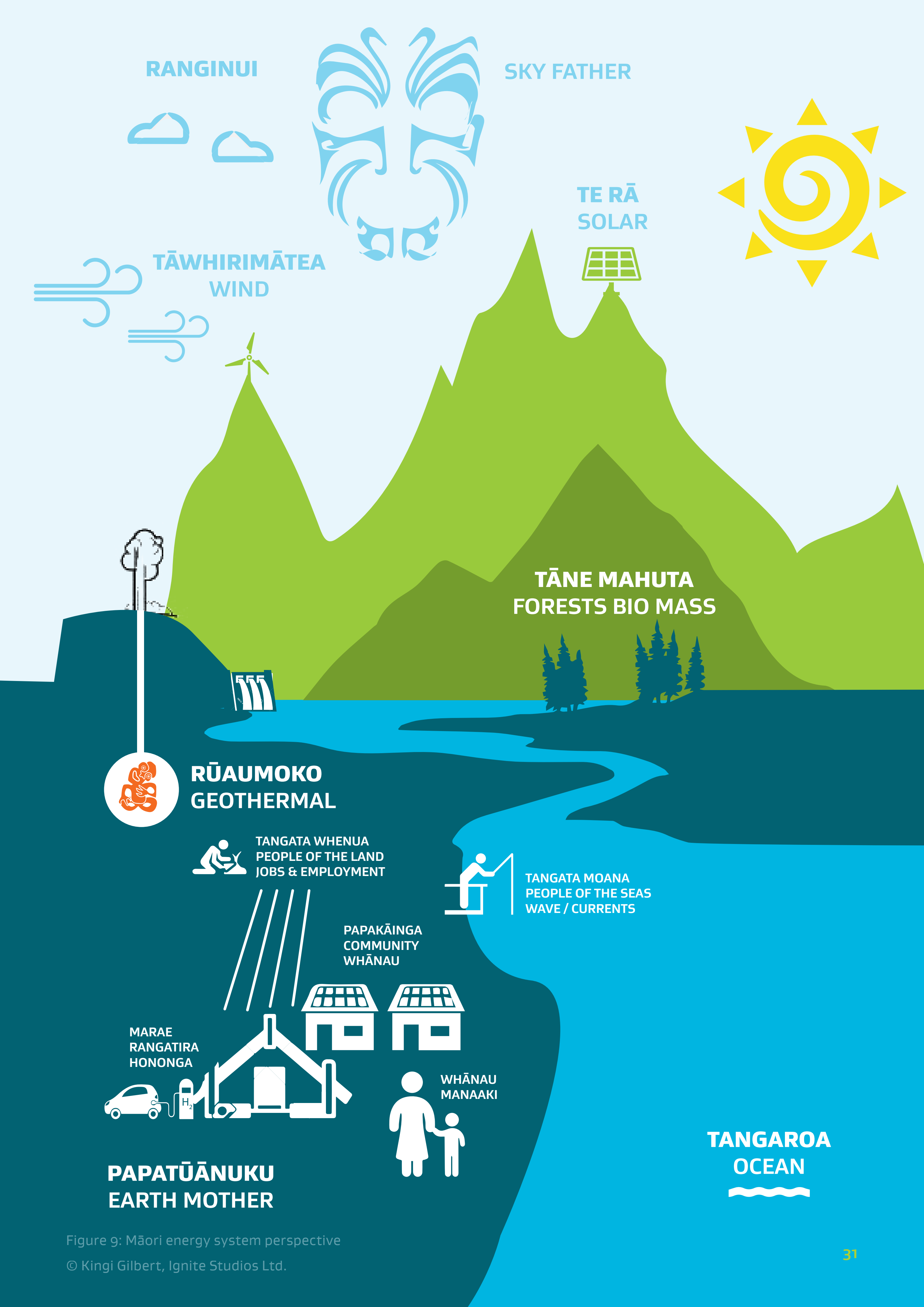


Figure 9: Māori energy system perspective

Potential Applications

The 2019 ICCC report (22,47) indicated that there will be significant challenges ahead if we are to achieve the last few percentage points in electricity decarbonisation.

However, the value which can be gained by embracing the complementary characteristics of hydrogen and electricity is one way to meet the challenge of reaching 100 per cent renewable electricity.

Like other countries, road transport will be a particularly significant sector to transition its energy mix. It comprises 40 per cent of our fossil fuel energy use (see Figure 11) and contributes 17.9 per cent of New Zealand's gross emissions (see Figure 12) (24). Decarbonising this sector will require a zero-carbon alternative to hydrocarbon fuel use where further electrification is not pragmatic.

For transport, hydrogen is well suited to the heavy-duty logistics, road, rail, marine and ultimately aviation applications, while electricity is a more suitable option for light duty vehicles.

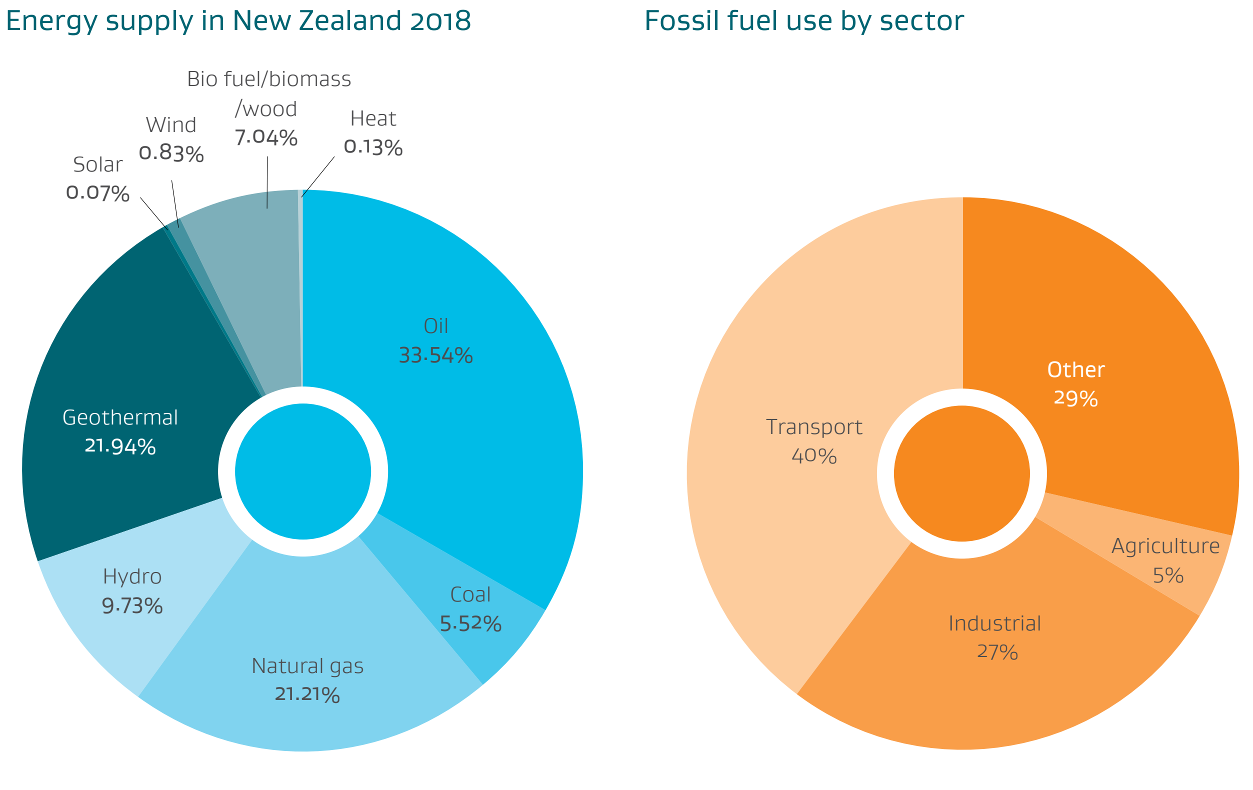


Figure 11: Total primary energy supply in New Zealand and source and fossil fuel use by sector (27)

As a proportion of total New Zealand gross emissions

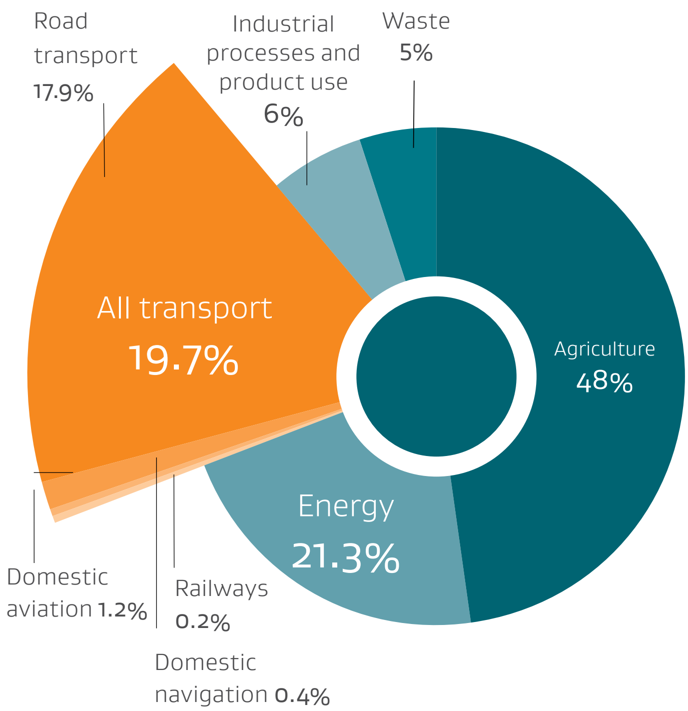


Figure 12: New Zealand gross emissions by sector 2017 (24)

Agriculture contributes 48 per cent of New Zealand's gross greenhouse gas (GHG) emissions including methane, mainly from livestock and nitrogenous fertiliser use (24).

There is the potential to reduce the fossil fuel demand of the food supply chain through fuel switching to hydrogen. Green hydrogen could be used as feedstock for fertiliser manufacture (via ammonia), for heat and power demand for food processing and refrigeration, heating of greenhouses and for the materials handling and transport supply chain.

For industrial, commercial and residential heating, hydrogen can be effective from a process, space and water heating perspective. It can also provide a low carbon chemical feedstock. Electricity plays its part where buildings or processes have suitable attributes or can be effectively retrofitted to accept hydrogen or reduce energy demand.

Addressing Challenges

The journey to a net zero economy will not be without its challenges for New Zealand and indeed globally. The necessary transformation of our energy, transport, agricultural and industrial sectors will require us to apply innovative systems-wide thinking to appreciate the whole-of-life costs and benefits or opportunities.

Hydrogen, alongside increased electrification, is but one of the tools that will enable us to reach our net zero economy goal. Direct use of electricity is currently a more logical and efficient choice in many situations, notably for grid balancing and for shorter distance travel. In the future, hydrogen may prove to be more suitable than electrical solutions, particularly where the total life cycle costs of a solution prove to be lower for hydrogen.

Challenges across the production, delivery and storage of hydrogen are being addressed by Governments and industry within New Zealand and around the world, through regulatory reform, technological R&D, demonstration projects and early adopter roll out plans.

These actions will help bridge the gap between hydrogen feasibility and community acceptance in the near future.

Building Hydrogen into a Low Emissions Economy

Discovering the potential role of hydrogen in New Zealand's low emissions economy requires all components along the supply chain to be developed, scaled and integrated in synchrony.

Many applications of hydrogen have the potential to play a variety of roles in an evolving low emissions economy, complementing electricity and other low emission options as they come to the fore.

Hydrogen is not new and there are global standards to manage the generation, transportation and storage of hydrogen. Like other energy carriers, hydrogen requires careful health and safety management when used on a large scale.

Safety considerations and incidents can slow, or even prevent, the deployment of a new energy technology if the risks are not well communicated and managed. Hydrogen is a non-toxic gas, but highly flammable in the right oxygen mix. This is partly mitigated by its high buoyancy and diffusivity, which causes it to dissipate quickly. It has a flame that is not visible to the naked eye and it is colourless and odourless, making it harder for people to detect fires and leaks. Less heat radiation and a vertical flame profile means hydrogen is less prone to igniting neighbouring materials or infrastructure.

There are decades of experience of using hydrogen industrially in New Zealand by organisations like BOC (hydrogen transporter pictured below) and Refining New Zealand. Protocols for safe handling are already in place and exist for hydrogen refuelling infrastructure in site-specific forms.

© BOC

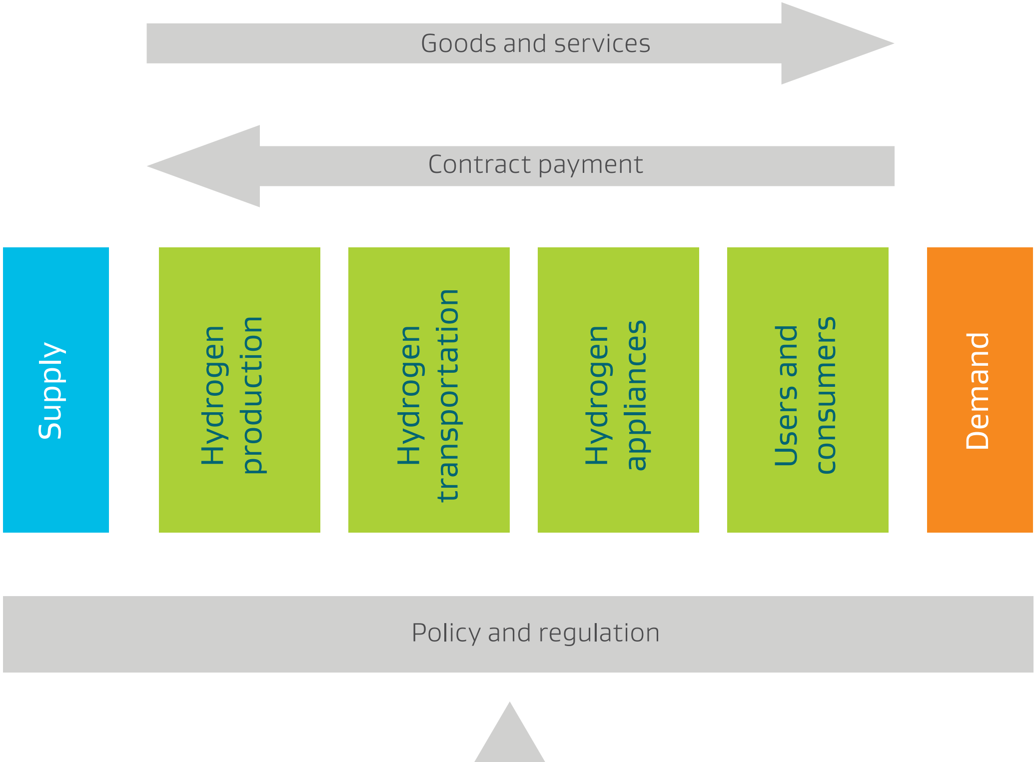


Figure 13: Balancing supply and demand

The health and safety impacts of established energy products – gasoline, diesel, natural gas, electricity, coal – show that risks, including flammability and toxicity, can be managed to the satisfaction of users.

To realise the potential of hydrogen, a coordinated and holistic approach is required in building the energy value chain, from supply to end-use. Enabling policy and regulation are vital components in building the hydrogen contribution to a low emissions economy and will facilitate in balancing supply and demand (see Figure 13).

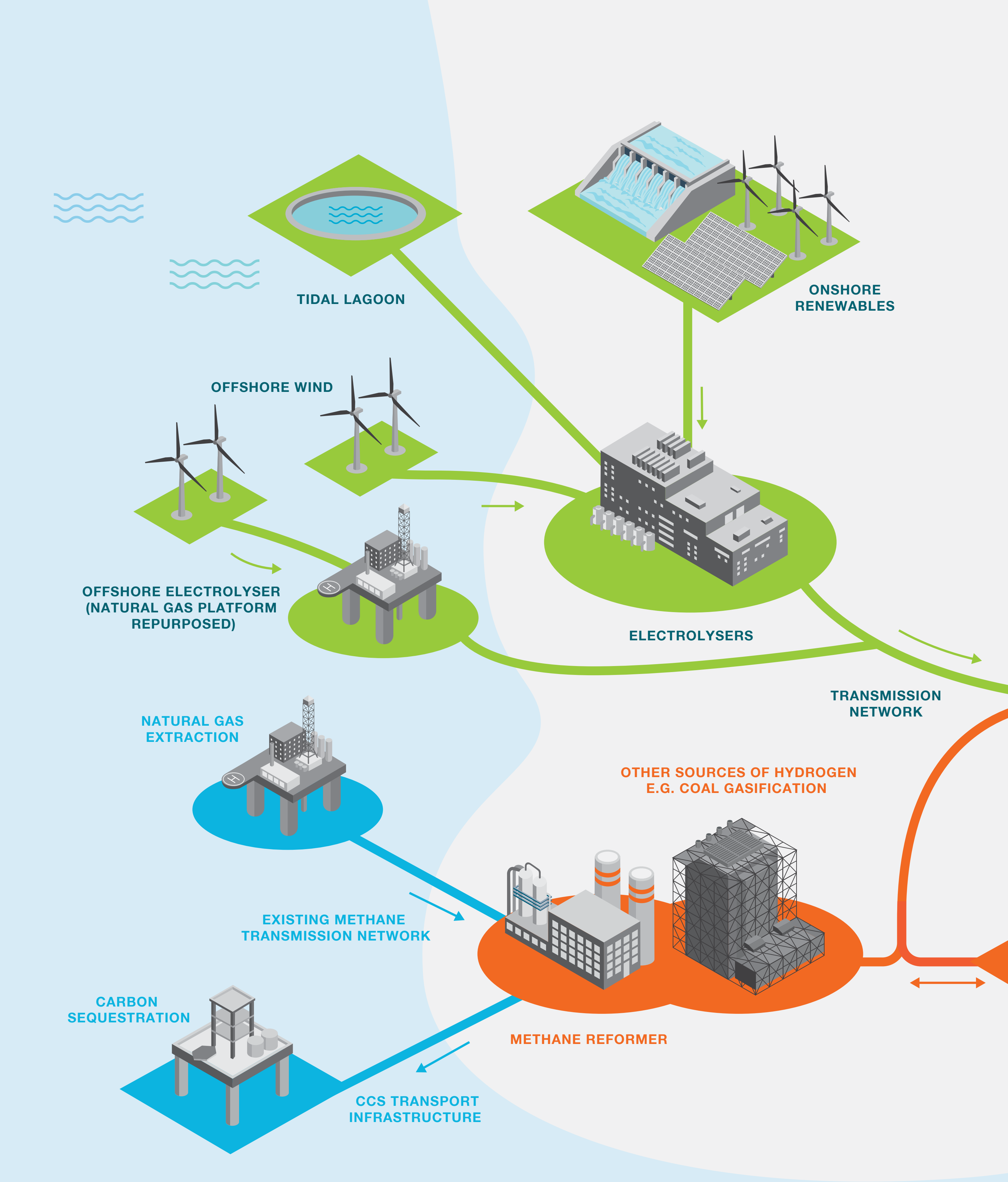
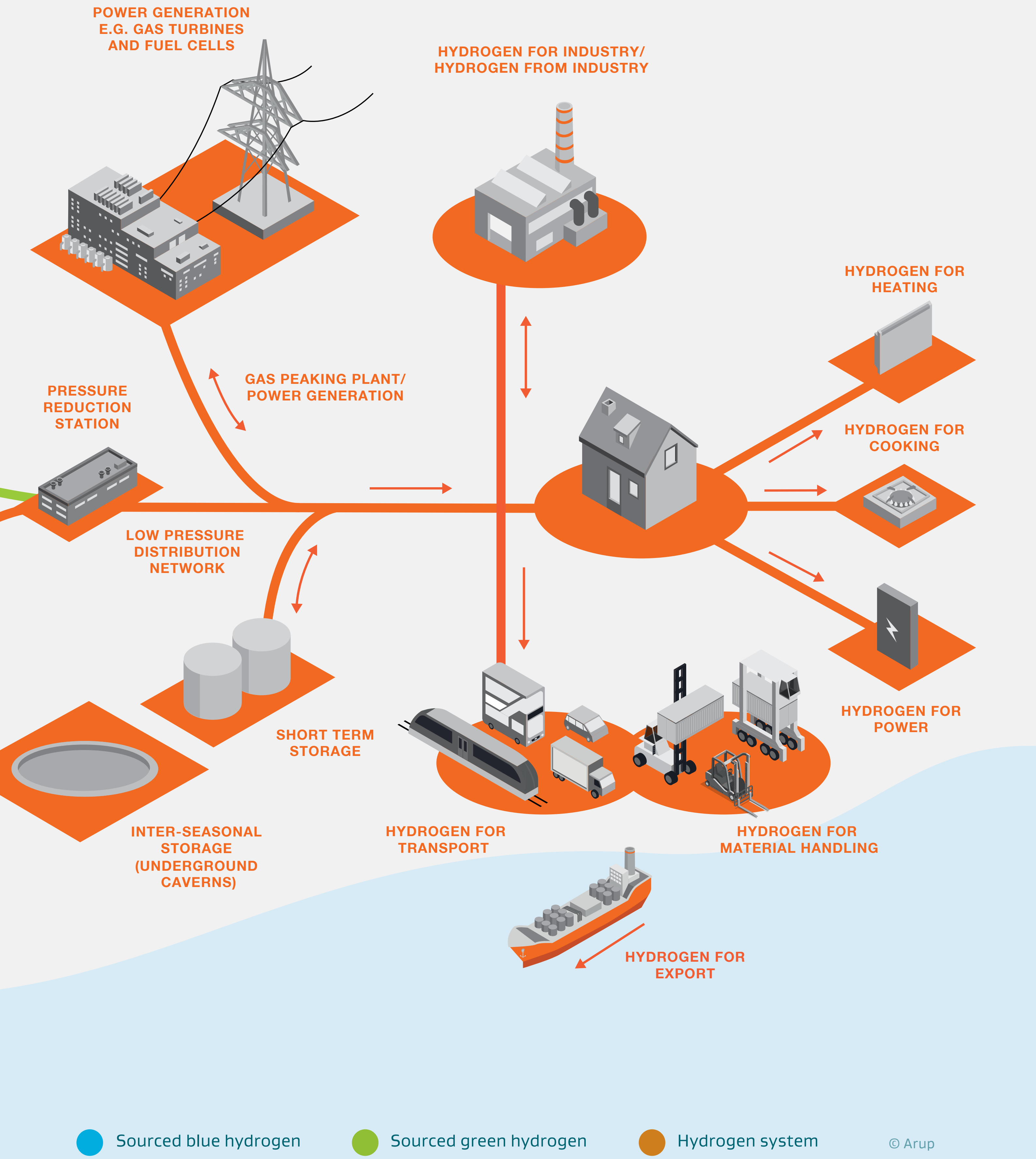


Figure 14: Hydrogen in an Integrated Energy System


POWER GENERATION
E.G. GAS TURBINES
AND FUEL CELLS
HYDROGEN FOR INDUSTRY/
HYDROGEN FROM INDUSTRY
HYDROGEN FOR
HEATING
PRESSURE
REDUCTION
STATION
GAS PEAKING PLANT/
POWER GENERATION
HYDROGEN FOR
COOKING
LOW PRESSURE
DISTRIBUTION
NETWORK
HYDROGEN FOR
POWER
SHORT TERM
STORAGE
INTER-SEASONAL
STORAGE
(UNDERGROUND
CAVERNS)
HYDROGEN FOR
TRANSPORT
HYDROGEN FOR
MATERIAL HANDLING
HYDROGEN FOR
EXPORT
Sourced blue hydrogen
Sourced green hydrogen
Hydrogen system

Our Renewable Potential

While New Zealand currently has the fourth highest renewable electricity percentage in the OECD (around 85 per cent per annum) (24) with a goal to extend this to 100 per cent by 2035, there is still significant untapped renewable potential, particularly in wind, solar and biomass (see Table 1).

For example, New Zealand currently has more than 2,500 MW of onshore wind generation consented but not built including the up to 286 turbine, 858 MW Castle Hill Wind Farm (37). This consented onshore wind potential is predominantly in the South Island. There is 10,000 MW of potential onshore wind. This does not include realising the potential for offshore wind.

Additional renewable energy supplies will be needed to meet the 100 per cent renewable electrical generation goal, in an average hydrological year, by 2035 given the predicted increase in demand in the future from further electrification of our energy and transport systems. Some estimates put additional electrification needs at 50 per cent increase by 2050 (36).

New Zealand's Potential Additional Renewable Capacity

GENERATION TYPE	Existing Capacity (MW)	Potential Capacity (MW)
Wind	700	10000
Geothermal	1000	1200
Hydro	5500	1000
Solar	50	2500

Table 1: New Zealand's potential additional renewable capacity (8)

To realise the potential of green hydrogen, sufficient renewable electricity is required to generate hydrogen by electrolysis. Electrolysers can range from small systems of 2-3 kW for mobile use to possible large scale facilities of 500-1000 MW in New Zealand by 2035 (49) which would likely be sufficient to meet our domestic requirements with some export potential. The current demand for fossil fuels is around 60 per cent of our total energy demand of around 675 PJ for heat, power and transport (27).

Further development of our renewables to replace retiring fossil fuels and meet our green energy demands will require us to strike the balance between economic, social, cultural and environmental considerations and future inter-generational wellbeing.

Hydrogen Production

Hydrogen can be produced, stored and converted through various processes and using different chemical feedstocks, each of which represents different levels of carbon intensity, efficiency and end use functionality.

As outlined in Figure 15, feedstocks include fossil fuels (oil, natural gas, coal) or industrial by-products or water. These substances must undergo one of a number of process technologies including chemical, biological, electrolytic, photolytic and thermo-chemical, or steam-reformation in order to produce hydrogen (40). More information about these processes can be found in the glossary at the end of this paper.

Globally 95 per cent of hydrogen is generated through methane-reformation of hydrocarbons, producing grey and brown hydrogen. The remainder is blue or green hydrogen, typically produced through electrolysis (20).

Currently, more than 99 per cent of hydrogen produced globally is carbon emitting and is responsible for total emissions worldwide of 830 $MtCO_2$/yr (20). There is potential for CCS to be used to capture most of the carbon dioxide produced during this reformation process, should it prove technically and financially viable.

Hydrogen Storage and Distribution

STORAGE

Hydrogen storage is predominately based on compression, liquefaction or chemically in materials such as metal hydrides. Most of the hydrogen produced today is stored as a compressed gas or liquid in tanks; as the hydrogen supply chain becomes more mature and more complex it is likely that other storage options will need to be considered. The most appropriate storage solutions will be determined by the volume of hydrogen, how long it needs to be stored for, the location and the end use application.

Hydrogen's low density in a gaseous or liquid form requires high pressure tanks. Research into optimising tank size and pressure for domestic and urban applications is ongoing (20). Gaseous hydrogen can also be stored underground, in salt caverns or in depleted natural gas or oil reservoirs, a technology which has been in use since the 1970s (20).

As a liquid, hydrogen has a boiling point at one atmosphere of pressure of -252.8°C, so must be stored at cryogenic temperatures in insulated tanks (20). Liquefaction results in a higher energy density in comparison to compressed hydrogen, but an energy input of around 10 per cent is required (18). The energy input for cooling is much higher (around 30 per cent of stored energy) (20).

The method of storage used depends on the end-use, and how the hydrogen will be transported for domestic or export markets. Line-pack storage in pressurised pipelines or underground storage is most appropriate for domestic applications. Storing hydrogen underground as a pressurised gas facilitates seasonal storage of energy, while storage in polyethylene pipelines may enable repurposing of the existing gas network.

The storage of hydrogen in liquid or organic materials is still in the early stages of development. One example is the Chiyoda Industries SPERA method which bonds hydrogen chemically to toluene to create methylcyclohexane. These technologies are currently too costly to be effective but are expected to become more viable in the near future. They also have the advantage of being able to reuse existing infrastructure.

Hydrogen can also be stored and exported as a cryogenic liquid. However, there is no technology currently mature enough to facilitate the low cost, low loss, high volume means that will be required by a hydrogen energy economy, as opposed to those which suffice for the comparatively modest quantities currently accommodated for industrial use.

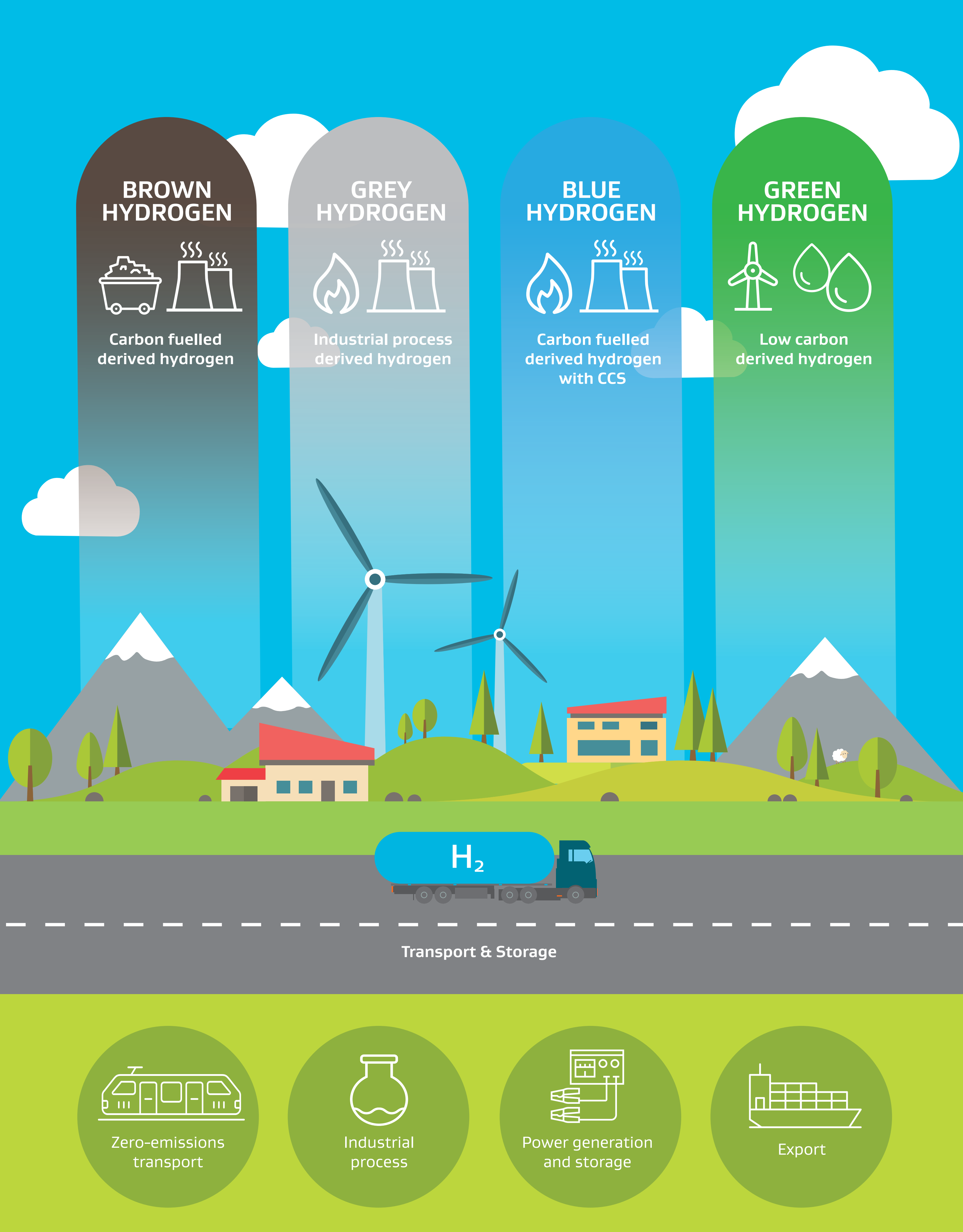


Figure 15: Types of hydrogen

TRANSMISSION AND DISTRIBUTION

While most hydrogen produced today is used at point of production (20), the transmission and distribution of hydrogen will need to be considered in regard to the requirements of domestic and export markets as the hydrogen economy develops.

Given the low energy density of hydrogen by volume, it can be expensive to transport. As with natural gas, this can be overcome by compression or liquefaction.

Another option is incorporation into larger molecules, such as ammonia, methanol or LOHCs (liquid organic hydrogen carriers) (20) that can more readily be transported as liquids. Each method has associated costs for transmission, distribution, storage and, if applicable, energy conversion and reconversion losses.

Locally, hydrogen has the potential to be distributed by trucks and high-pressure trailers or in new or existing polyethylene pipelines, through blending with natural gas or ultimately full replacement.

Hydrogen export is likely to be as a chemical compound or potentially as a cryogenic liquid as technologies mature. The most effective method for doing so will depend on geography, volume, distance and end use as well as the transition process, including potential repurposing of existing hydrocarbon infrastructure.

New Zealand currently exports approximately 95 per cent of the 2.4 Mt of methanol produced per annum to Asia, and as a result there are well established handling procedures, facilities and shipping routes for this substance (23). New Zealand's only ammonia-urea manufacturing plant is in Taranaki, converting atmospheric nitrogen and hydrogen to ammonia and then to urea using natural gas as its feedstock and power source (2).

While New Zealand does not export ammonia currently there is a large global market, predominantly as a fertiliser precursor chemical. This suggests a valuable potential export market for New Zealand, using established distribution and handling procedures.

Once the exported chemical reaches its destination, it is can be converted (hydrogenated) to the hydrogen form (liquid or gas) required for its end-use application (20).

Depending on the chemical used to transport the hydrogen, the conversion requires between 7-40 per cent of the energy contained in the hydrogen itself (20).

Have your say…

1a What is the role of Government in **developing hydrogen for storage and distribution**?

1b What are the **challenges** for using hydrogen for storage and distribution?

1c What are the **opportunities** for using hydrogen for storage and distribution?

Kaikoura Peninsula Walkway ©iStock

Hydrogen for a Resilient Energy System

Leveraging New Zealand's renewable energy advantage, further electrification together with energy saving and fuel switching from hydrocarbons, is a primary pathway for decarbonisation of the energy sector in New Zealand, enabling greater contribution of renewables to our energy system.

Energy demand in New Zealand is predicted to increase. Potential increases of around 50 per cent in electricity demand by 2050 have been predicted with the further electrification of our energy and transport systems (36).

As the share of variable renewable electricity, from wind and solar, increases towards 100 per cent renewable electricity, we will need to adopt the most cost-efficient way to match demand and supply, both daily and over longer durations. As electricity supply and demand must be balanced in real time, storage is needed to buffer the difference between the two.

This can be provided by various battery technologies, additional pumped hydro, and potentially other energy vectors such as hydrogen.

In recent years, New Zealand's electricity system has been increasingly challenged by the effects of dry winter seasons when hydropower generation is low, and generation is supplemented by natural gas peaker plants which have relatively low efficiency and therefore impact electricity pricing and drive up carbon emissions. This risk was highlighted by Genesis Energy and Transpower in the Electricity Price Review (28).

In providing this storage capacity, hydrogen is cheaper than lithium ion batteries or overbuilding capacity of other renewable sources and is less environmentally impactful than [large scale] pumped-hydro storage (46).

Opportunities

New Zealand experiences dry winters where output from existing hydro generation decreases during the winter months while demand for heating and lighting increases.

Energy storage systems need to be created to account for the variability of renewable outputs. Hydrogen is well-placed to take on this role. Excess electricity from summer outputs can be used to produce hydrogen which is stored and used in winter when renewable outputs drop below demand levels.

This provides a carbon-free alternative to current operations involving natural gas and coal fired plants to meet this peak demand.

Hydrogen can complement the electricity network to support the resilience of the New Zealand energy system by:

- Cost effective transition to decarbonisation through use of existing energy system assets and skills. Hydrogen can act as a versatile energy carrier to replace or displace fossil fuel. It can be used directly as a transport fuel or provide heat for domestic or industrial processes.

Some examples, based on international trends and developments, include:

  - Hydrogen transfer using the existing natural gas transmission and distribution pipeline network
  - Oil and gas rigs retrofitted with electrolysers using renewables such as offshore wind (56)
  - Flexible power generation gas turbines that can run on partial or full power on hydrogen or ammonia (20, 6)
  - Retention and expansion of existing skills and experience derived from the process-oriented hydrocarbon industry, including methanol production. The versatility of hydrogen could avoid stranded resource and assets for industrial processes. Delivery of energy system resilience, with fuel diversity, self-sufficiency and security in a highly developed renewable energy setting, including reducing dry year risk.

- Delivery of energy system resilience, with fuel diversity, self-sufficiency and security in a highly developed renewable energy setting, including reducing dry year risk.
- Buffering medium to long-term (seasonal) energy transfer through large scale storage. 'Time-shifting' to maximise renewable penetration and mitigate against dry year risk and for seasonal peak demand (e.g agriculture/ tourism) (20, 49).
- Remote area power solutions by delivering an efficient and effective distributed energy resource, including microgrids and local energy storage, including stationary applications such as construction sites and port facilities.

Challenges

While there are no insurmountable technical challenges to prevent deployment of hydrogen to improve the resilience of New Zealand's energy system, the rate of uptake of the opportunities will be determined by the economics of adapting the existing infrastructure, facilities and skills. Challenges include:

- Developing the policy and regulation framework to enable a pragmatic approach to the evolution of our energy system, deploying electricity and hydrogen to their best pragmatic use
- Variable maturity of technology and other barriers challenging the implementation of hydrogen
- The economics and preferred approach to large scale hydrogen storage, which have yet to be solved in a practical and efficient manner
- Public acceptance of fuel-switching to hydrogen.

Looking Ahead

New Zealand's ambitions for a clean, green, carbon neutral economy by 2050 require hydrogen and electricity to be deployed in tandem, deploying the most effective application to each circumstance, to maximise opportunity and positive energy outcomes.

With the right policy signals and support, and engagement, New Zealand can lead the way in growing a robust hydrogen industry, creating skilled jobs, utilising existing resources and decarbonising industry.

Aoraki Mount Cook ©iStock

Have your say...

2a What is the role of Government in developing the complementary **role of electricity and hydrogen**?

2b What are the **challenges** for achieving this complementary role of electricity and hydrogen?

2c What are the **opportunities** for this complementary role of electricity and hydrogen?

Hydrogen for Mobility

Internal combustion engines fuelled by petrol or diesel have dominated transport for more than a century. They are the major cause of transport emissions in New Zealand and worldwide.

Currently transport accounts for half of New Zealand's energy-related emissions: of these, road transport contributes 89 per cent of transport emissions and is also the fastest growing transport emitting sector (5).

The approach over the past decade has been to choose a single energy pathway to achieve a net zero emission transport sector. However, when using lifecycle analysis and looking at energy vectors from a resilient energy system perspective, there is increasing realisation that there is no one single energy pathway, but a combination of energy pathways, which will achieve net zero emissions in the transport sector.

Like battery electric vehicles (BEVs), vehicles hydrogen fuel cell electric vehicles (FCEV) can provide an opportunity for zero carbon emissions at the point of use. For green hydrogen, water is electrolysed to generate the hydrogen with oxygen as the by-product.

The technologies of FCEVs and BEVs are often portrayed as competing, but in reality they play complementary roles. For example:

- Battery electric vehicles exhibit higher overall fuel efficiency if they are not too heavy due to large battery sizes, making them ideal for short-distance and light vehicles (5).
- Hydrogen can store more energy in less weight, making fuel cells suitable for vehicles with heavy payloads and long ranges. Faster refuelling also benefits commercial fleets and other vehicles in near-continuous use like straddle carriers, forklifts, taxis and car sharing (20).

Similar to battery electric vehicles (BEVs), hydrogen fuel cell electric vehicles (FCEV) can provide an opportunity for zero carbon emissions at the point of use.

Comparing electric fuel cell vehicles – BEVs and FCEVs – and conventionally powered cars in terms of vehicle size, travel distance and fuel diversity shows how expected emissions vary over time for different technologies. FCEVs have a range advantage compared to BEVs for a similar emissions profile.

The complementary nature of these technologies enhances progress in BEVs, plug-in hybrid electric vehicles and FCEVs that benefit each other due to their many shared components and development options. How these technologies relate will depend mostly on how battery technology will evolve and how quickly cost reductions from scaling fuel-cell production can be realised.

Key attributes of the FCEV which make it an attractive transport mode in the transition to net-zero emission economy are:

- A highly efficient fuel cell that transforms the hydrogen directly into electricity to power the electric motor/s
- Produce zero harmful tailpipe emissions, with water vapour being the only exhaust
- A long-distance driving range, comparable to conventional petrol and diesel cars and vans while providing a smooth, quiet and responsive driving experience
- Refuelling time comparable to conventional petrol and diesel vehicles (three to five minutes)
- Vehicles are as safe, if not safer, than traditional gasoline vehicles or BEVs. The carbon-fibre compressed hydrogen storage tanks of the vehicles have withstood highly demanding crash, fire and ballistic testing. Vehicles already meet the strict safety and quality regulations of the countries where they are currently being deployed including Japan, South Korea, USA and throughout Europe.

> "From a global future perspective, the Hydrogen Council has estimated that by 2050, hydrogen-powered fuel-cell vehicles could constitute up to 20 per cent of the total vehicle fleet, some 400 million cars, 15 million to 20 million trucks, and around 5 million buses. In their scenario, hydrogen would play a larger role in heavier and long-range segments and hence contribute around 30 percent – higher than its share due to longer distances driven and lower fuel efficiency in these segments – to the total emission-abatement target for the road transport sector." (16)

Potential Applications in the Transport Sector

Green hydrogen could play a significant role in reducing vehicle emissions in New Zealand. Figure 16 shows the variety of different vehicles and the different fuel options that may be best suited to which vehicle type.

Maritime, long distance road-based freight, buses, coaches and aviation have limited available low-carbon fuel options and represent a significant opportunity for hydrogen-based fuels. Ports, warehousing facilities and freight handling operations using forklifts and straddle carriers that run continuously, could also benefit greatly from the ability to refuel with hydrogen as quickly as with diesel but without the associated transport emissions (20). The exact numbers are outlined below in Table 2.

Fuel electric cell vehicles

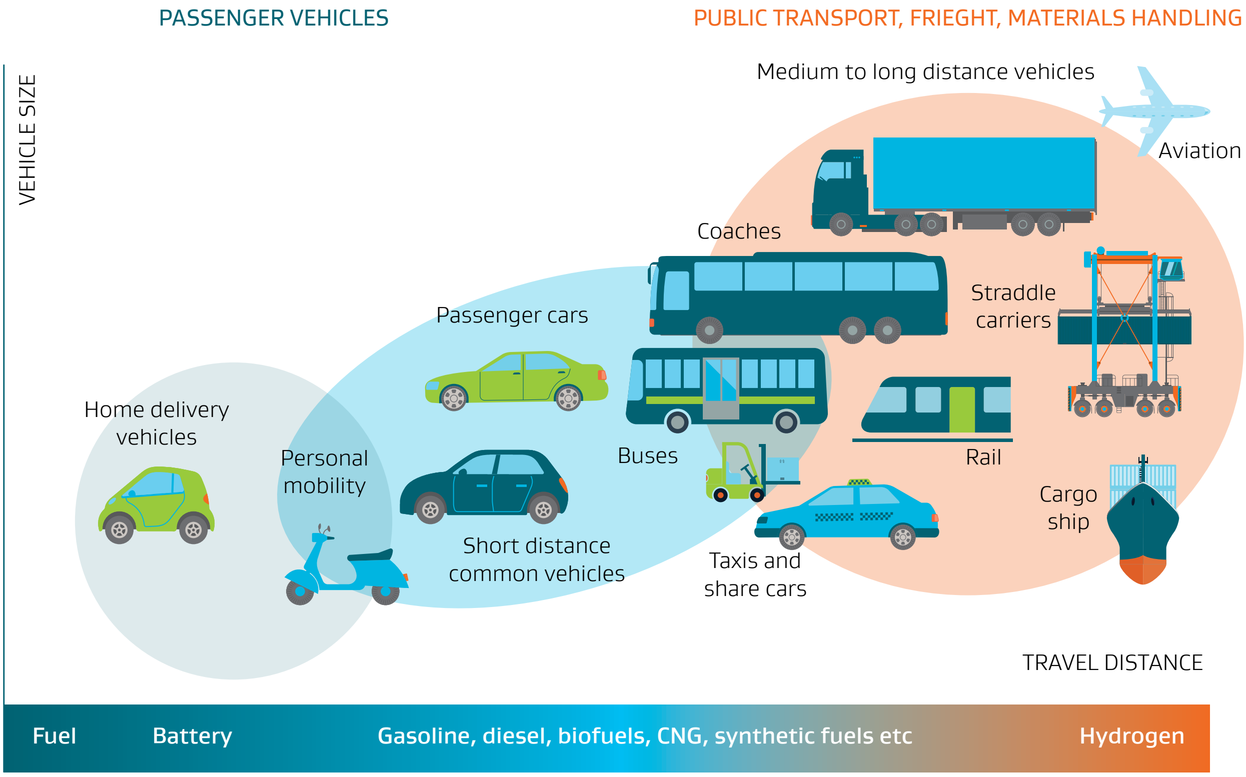


Figure 16: Vehicles that can be powered by hydrogen or electricity (17)

Hydrogen vehicles current and future demand, opportunities and challenges

	Current role	Demand perspectives	Future deployment: OPPORTUNITIES	Future deployment: CHALLENGES
Cars and vans light-duty vehicles	11,200 vehicles in operation, mostly in California, Europe and Japan	The global car stock is expected to continue to grow; hydrogen could capture a part of this market	Hydrogen: Short refuelling time, less weight added for energy stored and zero tailpipe emissions. Fuel cells could have a lower material footprint than lithium batteries Return-to-home fleets can help overcome challenges of low utilisation of refuelling stations; long-distance and heavy-duty are attractive options Hydrogen and ammonia are candidates for both national action on domestic shipping decarbonisation, and the IMO Greenhouse Gas Reduction Strategy, given limitations on the use of other fuels	Hydrogen: Initial low utilisation of refuelling stations raises fuel cost; reductions in fuel cell and storage costs needed; efficiency losses on a well-to-wheels basis Power-to-liquid: Large electricity consumption and high production costs Ammonia: Caustic and hazardous substance close to end users mean that use is likely to remain limited to professional operators Hydrogen: Storage cost higher than other fuels Hydrogen/ammonia: Cargo volume lost due to storage (lower density than current liquid fuels)
Trucks and buses heavy-duty vehicles	Demonstration and niche markets: • 25,000 forklifts • 500 buses • 400 trucks • 100 vans. Several thousand buses and trucks expected in China* by end-2019	Strong growth segment; long-haul and heavy-duty applications are attractive for hydrogen		
Maritime	Limited to demonstration projects for small ships and on-board power supply in larger vessels	Maritime freight activity set to grow by around 45% to 2030. 2020 air pollution targets and 2050 greenhouse gas targets could promote hydrogen based fuels		
Rail	Two hydrogen trains in Germany	Rail is a mainstay of transport in many countries	Hydrogen trains can be most competitive in rail freight (regional lines with low network utilisation and cross border freight)	Rail is the most electrified transport mode; hydrogen and battery electric trains with partial line electrification are both options to replace nonelectrified operations, which are substantial in many regions
Aviation	Limited to small demonstration projects and feasibility studies	Fastest-growing passenger transport mode. Large storage volume and redesign would be needed for pure hydrogen, making power-to-liquid and bio-fuels more attractive for this mode	Power-to-liquid: Limited changes to status quo in distribution, operations and facilities; also maximises biomass use by boosting yield Hydrogen: Together with batteries, can supply on-board energy supply at ports and during taxiing	Power-to-liquid: Currently 4 to 6 times more expensive than kerosene, decreasing to 1.5–2 times in the long-term, potentially increasing prices and decreasing demand

* China = People's Republic of China.

Table 2: Hydrogen vehicles current and future demand, opportunities and challenges (20)

Hydrogen vehicles are well suited to commercial fleets which travel long distances or do not have long periods of downtime in their duty cycle (e.g. forklifts operating in a 24hr warehouse, inter-city buses and coaches travelling more than 200 km per day) (20).

On-site production of hydrogen from sources of renewable distributed generation will be able to accommodate fluctuating power input or draw off-peak electricity from the grid. For trucks the priority is to reduce the delivered price of hydrogen. In early stages of deployment, building hydrogen stations that serve return-to-base fleets on hub-and-spoke missions could help to secure high refuelling station utilisation and thus could be a way to encourage infrastructure construction.

Being more suited to heavy-duty transport applications, there is an opportunity to begin early deployment of hydrogen infrastructure throughout New Zealand at key locations such as freight hubs and ports. At least three demonstration projects in New Zealand are actively investigating this opportunity including planned hydrogen bus trials in several locations.

MARITIME

Ports are nodal points in global supply chains and are embedded in local and regional communities. The World Ports Sustainability programme is responding to the UN Sustainable Development Goals and many international ports including Ports of Auckland, Long Beach and Rotterdam are investing in renewable energy systems including hydrogen. They are using existing industrial functions to create hubs for lower-cost, lower-carbon hydrogen. Port shore-side industrial transport like forklifts and straddle carriers, which require 24-hour operation, are being transitioned to hydrogen away from fossil fuels.

The Ports of Auckland hydrogen demonstration project is indicative of the willingness of the New Zealand maritime industry to consider the hydrogen opportunity (42). Hydrogen fuel has the potential to contribute to environmental targets in shipping, but the current cost of production is high relative to fuel-oil that is currently used.

While the Ports of Auckland demonstration project is initially focussed on onshore vehicles there is the potential that it, other Ports, or similar plants, could be scaled up to generate enough hydrogen to power other onshore port vehicles, maritime vessels and trains. This could be facilitated by using existing retrofitted infrastructure to help support and fuel these vessels.

On the water, fuel-cell powered ferries, tugs and small ships are being developed and demonstrated in other parts of the world, including in Norway, the Netherlands and the UK. The first hydrogen shipping routes are being established to kick-start the international hydrogen trade.

RAIL

The World Energy Council (56) stated that hydrogen-powered locomotives could replace 20 per cent of diesel locomotives globally by 2040 and hydrogen-based synthetic fuel could power a share of airplanes and freight ships. In all, the transportation sector could consume 20 million fewer barrels of oil per day if hydrogen was deployed as a substitute (56).

Japan, China and the UK are developing hydrogen trains, and small commercial trials are underway such as Alstom's two trains operating in North Saxony. The growing interest in hydrogen for rail is being driven by a number of factors, including the rising cost of diesel fuel, lessening public acceptance of diesel-based transport and the high cost of further electrification. New Zealand faces many of these issues and concerns with its geography and the unaffordability of electrifying all rail.

There is no single solution to going emission free; instead, both electrification and hydrogen will play a complementary role. Battery electric trains with smaller batteries can be used on partially electrified lines, enabling electrification costs to be sharply reduced by missing out those portions of track that are most difficult to electrify (such as bridges or tunnels).

Hydrogen fuel cell technology can complement this and is most competitive for services requiring long distance movement of large trains with low-frequency network utilisation, a common set of conditions in rail freight.

The use of hydrogen in rail could be combined in the ancillary infrastructure – for forklifts, trucks and other railyard and logistics hub machinery to decrease costs and improve flexibility (45).

New Zealand's national rail services are focussed on the moving bulk freight, such as logs or coal and the import/export of goods (33). Around 4,000 km of track carry containerised or palletised products, and the Ministry of Transport predicts rail freight volumes will increase to 23 million tonnes per year by 2031 (32). Converting or replacing existing rolling stock with hydrogen-powered trains, and ancillary hydrogen fuelled equipment like container handlers, would significantly reduce rail sector emissions and would not require future costly[1] electrification of the network. There is further benefit in transitioning to hydrogen trains in the South Island where none of the track is electrified.

AVIATION

On the air-side and land-side of airports there is the opportunity to supplement electrified operational vehicles with FCEVs for critical vehicles that need to operate 24/7. Liquid hydrogen fuel provides a potentially attractive option for aviation but at the expense of higher energy consumption and potentially higher costs. While hydrogen planes are still under development, there is long-term potential to contribute to greatly reducing international transport emissions using hydrogen as some form of decarbonised fuel.

1 Current electrification costs are estimated at 1.5 million euro/km (1). New Zealand costs are likely to be similar, if not higher.

Opportunity

In addition to strong Government policy direction, there is support from the New Zealand people to transition to a zero carbon environment in the longer term to achieve a cleaner and healthier environment. This high level of community acceptance of the need for change will help spur Government and private sector interest in demonstration projects and trials for hydrogen-fueled vehicles.

The key opportunities for hydrogen in the New Zealand context include:

- Learning from and building on the significant array of global experiences, investment, technological development and trials into hydrogen fueled-vehicles.
- Government taking a proactive approach to policy and regulation and encouraging hydrogen demonstration projects to ensure they are enabled, and informing policy and regulation development through active stakeholder and demonstration project engagement.
- Sharing hydrogen generation and refuelling points between heavy industries, such as ports and rail. Trains frequent the ports as part of their freight routes and there is opportunity for vehicles to be refuelled quickly in these locations as goods are unloaded and reloaded.
- Being able to generate and store hydrogen on-site. The speed of refueling and the greater range offered compared to a fully electric equivalent makes hydrogen ideally suited to rail, marine and 24/7 operations.
- Ports, warehousing facilities, and freight operations that run continuously will benefit greatly from the ability to refuel as quickly as a diesel vehicle but without the associated transport emissions.
- Applying the lessons from the local roll-out of EV charging sites on the state highway network and from hydrogen infrastructure built in the US, Japan, South Korea, the UK and Europe to enable New Zealand to be a fast follower.

Also noteworthy is that the technology to safely refuel and store hydrogen at high pressures in vehicles has been fully developed with alignment of international standards and a strong track record of safety in operating environments. The safety record for hydrogen globally in mobility is robust, as strong health and safety standards have been followed by professional experts.

Challenges

There are no significant technical challenges in New Zealand to deployment of hydrogen as a transport fuel today, but economics, and perceptions on safety and affordability will need to be addressed through an open and factual discussion.

Challenges will include policy and regulation, economics, infrastructure, hydrogen availability, vehicles, economics and safety.

Moving to low emissions vehicles will likely be dictated by external market forces and the share of available new and used petroleum-fueled vehicles will reduce as the global production of electric vehicles increases. However, this transition will happen more slowly than is needed, because of the average life of vehicles and the higher age of the New Zealand fleet as we import many used vehicles. New Zealand may need to consider incentivising and fostering uptake to avoid locking-in higher emissions for decades from newly imported diesel and petrol vehicles.

POLICY AND REGULATION

Hydrogen developers face hurdles where regulations and permit requirements are unclear, unfit for new purposes or inconsistent across sectors and countries. Sharing knowledge and harmonising standards is critical, including for equipment, safety and certifying emissions from different sources. Hydrogen's complex supply chains mean Governments, companies, communities and civil society need to consult regularly.

Policy options could be developed to promote the uptake of FCEVs including fuel economy standards, zero-emission vehicle mandates, feebates (which tax the worst performing vehicles and subsidise those that perform best in terms of CO_2 or air pollutant emissions) and purchase subsidies.

ECONOMICS

The primary challenge will be the economics of supply of hydrogen, infrastructure and vehicles while there is, at least, limited demand. Further research is needed into the economics of these factors.

The emerging FCEV market requires close value-chain synchronisation to overcome the first-mover risk of building hydrogen refuelling infrastructure. While the initial investment is relatively low, the risk is high and therefore greatly reduced if many companies invest, co-ordinated by Governments and supported by dedicated legislation and funding.

INFRASTRUCTURE

The slow global development of hydrogen infrastructure is holding back widespread adoption, mainly due to the economics and availability of vehicles and the hydrogen fuel. Hydrogen price depends on the number of refuelling stations, how often they are used and how much hydrogen can be delivered or locally produced per day. Tackling this is likely to require planning and coordination that brings together national, local and regional councils, industry and investors.

Technically, there needs to be improvements in the hydrogen supply chain (e.g. spare parts availability, number of suppliers). This is a particularly significant challenge as New Zealand is a small and less populated country and the demand for hydrogen infrastructure, vehicles and hydrogen will be less than Australia and other countries.

HYDROGEN AVAILABILITY

Today, most hydrogen in New Zealand is produced from the reforming of fossil fuels, which releases a large amount of CO_2. The main challenge is therefore to leverage New Zealand's renewable energy advantage and produce hydrogen using renewable energy sources like wind turbines and solar panels. However, compared with the production of hydrogen from natural gas, producing it through renewable energies is currently very expensive (20).

VEHICLES AND HYDROGEN APPLICATIONS

As discussed, there is currently a lack of global supply and availability of hydrogen vehicles and other applications such as trains, planes and ships. Most FCEVs are light duty vehicles and forklifts. There is limited availability of buses and heavy duty vehicles, with long lead times (one year to 18 months) for delivery to smaller and more distant markets such as New Zealand as larger orders may be prioritised over smaller orders. Moreover, huge investments in lithium-ion battery technology are rapidly driving down the price of electric vehicles. This has caused a decline in the prices of BEVs and PEVs compared to FCEVs.

Aviation, shipping and maritime applications are limited with some applications like ferries and ancillary vessels like tug boats being demonstrated in Europe and Asia.

SAFETY

Like other gases and liquid fuels in common use, hydrogen can be explosive in certain conditions. It can be safely stored and transported under pressure in containers. Hydrogen has a number of health and safety challenges for mobility. They are as follows:

- It has a wide explosive range, compared to other fuels, and it ignites more easily in the right oxygen mix.
- It burns with an invisible flame.
- It can be difficult to odourise as an aid for leak detection.
- Requires pressure relief devices and a safe shutdown programme to lock and isolate components.

However, these disadvantages are offset by the fact that hydrogens, buoyancy means that it disperses rapidly and is usually only able to achieve a flammable mixture with oxygen in a confined environment.

As hydrogen technology becomes more mainstream, further work and safety standards will need to be adopted.

Long term public acceptance of hydrogen as a safe and reliable energy vector relies on applying and adhering to established safety fundamentals and techniques to minimise the risk of harm.

Looking Ahead

Hydrogen holds long-term promise in transport if the costs of production and utilisation reduce to a point where they are competitive with alternatives. The complex processes involved in developing and deploying hydrogen, however, mean that carefully crafted policy support will be critical.

Lifecycle analysis is needed around all transport energy options including hydrogen to enable effective decision making. The goal of lifecycle analysis is to compare the full range of effects assignable to products and services along the supply chain by quantifying all inputs and outputs of material flows, use and disposal and assessing how these material flows affect the environment.

Initially the economics will favour converting daily 'return-to-base' fleets, public transport fleets or heavy-duty industrial precinct applications such as the current project at the Ports of Auckland. Looking ahead the IEA (20) predicts that FCEVs will break even in the longer-term with BEVs at a range of 400 km with respect to the total cost of ownership.

Public policy can also play a supportive role in the initial stages by (20):

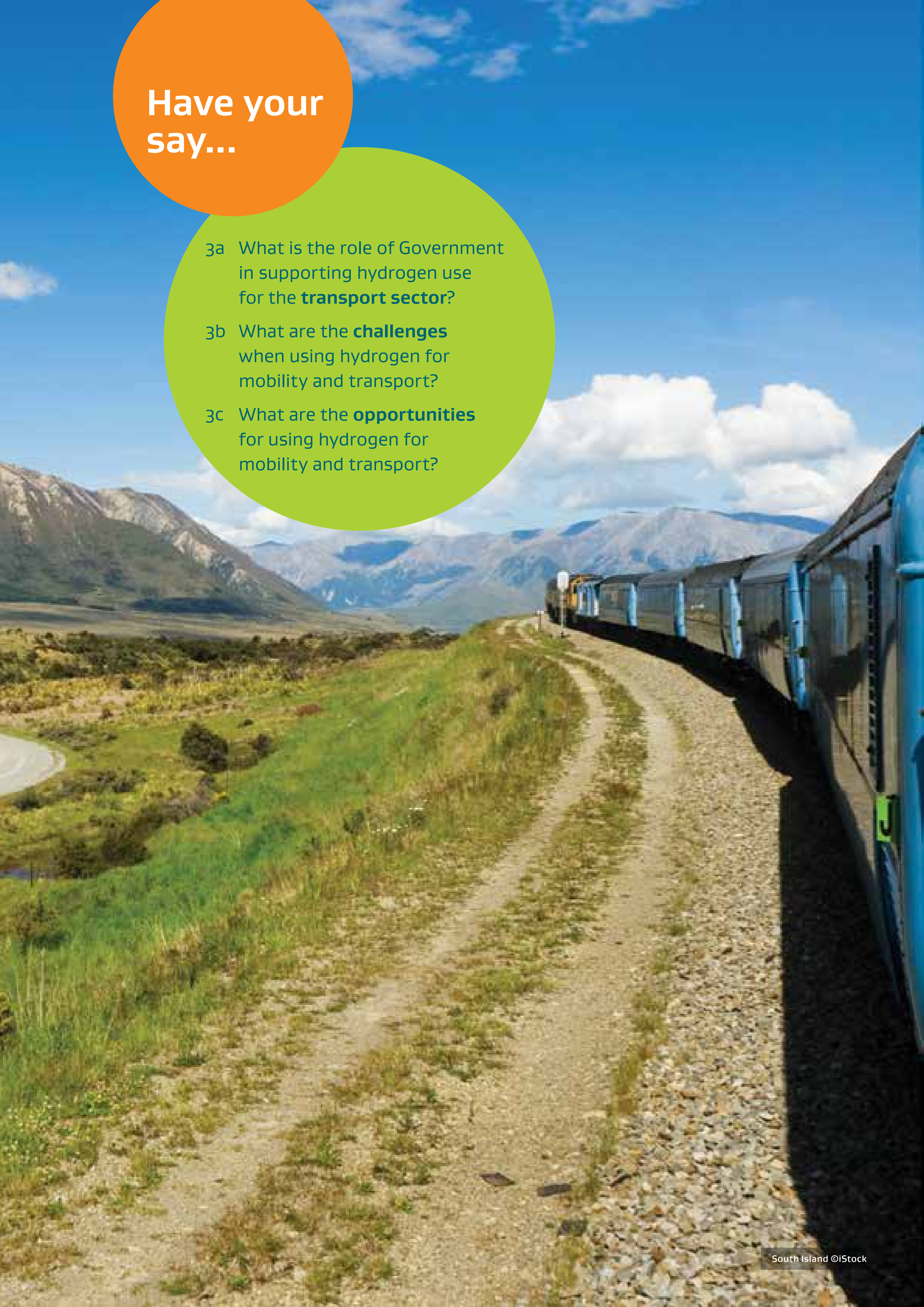
- Easing regulatory burdens associated with the transport of hydrogen (e.g. in vehicles on bridges and tunnels) and with the permitting and construction of necessary infrastructure.
- Undertaking an in-depth business case and implementation plan to de-risk the commercialisation of technology and test the supply chain for New Zealand.
- Building on existing demonstration projects like the Ports of Auckland, Hiringa Energy and Tuaropaki Trust and undertaking further demonstration projects and trials as soon as possible.
- Engaging with industry stakeholders, for example through the New Zealand Hydrogen Association, that can make the required investments and brokering commitments among industry partners to support credible and well-structured business plans and offering a regular critical assessment (e.g. based on audits) of areas to improve.
- Developing and confirming the potential stages for hydrogen and wider renewable energy through a roadmap and implementation plan fit for investment by companies and the public sector, working backwards from 2040 and taking note of New Zealand's net-zero carbon emission 2050 target.

Have your say...

3a What is the role of Government in supporting hydrogen use for the **transport sector**?

3b What are the **challenges** when using hydrogen for mobility and transport?

3c What are the **opportunities** for using hydrogen for mobility and transport?



South Island ©iStock

Hydrogen for Industrial Processes

Hydrogen can be used as both a feedstock in industrial processes and to produce process heat. This is heat used to produce hot water or steam, typically generated on-site using a boiler or air heater. Some sites have cogeneration facilities that produce both steam and electricity; some may be exported if in surplus to local demand (29).

HYDROGEN FOR INDUSTRIAL PROCESS HEAT

The industrial and process sectors consume around 18 per cent of New Zealand's end-use energy through electricity, natural gas, wood, coal and diesel (30). In 2016, supplying industrial process heat accounted for GHG emissions of around 8.3 Mt CO_2 equivalent (30).

Process heat energy demand is approximately 35 per cent of total energy used in New Zealand and contributes around 28 per cent of all energy-related emissions (30). The majority of this was for industrial process heat (80 per cent) including for kilns in sawmills, pulp and paper mills, petroleum refining, basic chemical manufacturing and food processing plants (30).

Hydrogen has the potential to displace the use of fossil fuels over time thereby significantly reducing GHG emissions in process heat applications.

Hydrogen production and use is not new to New Zealand, having been used domestically since the early 1900s. It can be used as a pre-combustion or post-combustion feedstock. Like natural gas, hydrogen can be combusted directly to generate heat with the flame reaching temperatures over 2,200°C under ideal conditions.

In Europe, hydrogen is considered to offer benefits over electric boilers for industrial high-grade heat used for melting metals and chemical manufacture etc, due to its ability to generate high temperatures using processing plants similar to present designs (13).

MBIE (30) has classified industrial process heat requirements (See Table 3), indicating some applications potentially suitable for hydrogen. This includes a wide range of heating applications, from relatively low-grade domestic heat to high-grade industrial process heat (6).

Temperature requirements can be classified as low, medium or high:

CATEGORY	Temperature requirements	Uses	Examples
Low	Less than 100°C	Water heating Space heating	Sanitation of equipment in the food processing sector
Medium	Between 100 and 300°C	Industrial processes	Drying wood products Drying food products, such as milk powder
High	Greater than 300°C	Industrial processes	Oil refining Melting metals Chemical manufacturing

Table 3: Classification of industrial, domestic and commercial heat requirements in New Zealand (30)

Two sub-sectors with high energy use and high emissions have significant opportunities to decarbonise.

The **petroleum, basic chemicals and rubber product manufacturing sector** is the largest user of natural gas. This sector, and the primary metal and metal products sectors, has a few large sites, with the use of heat tending to be tightly integrated to the process.

Process heat is generated on-site using a boiler or furnace, and typically used to produce steam, hot water, or hot oil. There are 22 process using sites in New Zealand 15 in the North Island and seven in the South Island.

Taranaki (49) is the most advanced region in pursuing opportunities in this sector including:

- The development of a renewable hydrogen hub integrated with the existing Kapuni industrial complex that provides an excellent co-location for a number of industrial hydrogen projects that could leverage the existing facilities.
- Hiringa Energy and Ballance Agri-Nutrients jointly evaluating integration of renewable electricity for hydrogen and green ammonia production using existing ammonia production infrastructure at Kapuni. This project would potentially provide renewable electricity to power the plant and generate hydrogen from excess electricity generation. The hydrogen would be used to produce approximately 7,000 tonnes per annum of urea (See Figure 18). The hydrogen with high purity would be able to be diverted for supply to a transport market and could also provide a supply for future pilot industrial projects.

The **dairy manufacturing sector** accounts for around 68 per cent of energy use in food manufacturing, predominantly using fossil fuels including coal, to generate process heat or from cogeneration or CHP facilities. It is the largest user of coal for process heat.

There are 66 dairy manufacturing sites using process heat in the North Island and 33 in the South Island. In the North Island, reticulated natural gas is available and delivered to 75 per cent of the dairy processing heat demand (30).

In the South Island, because coal delivers 89 per cent of fuel demand, dairy processing is more emissions intensive (30).

Various temperatures are needed for different processes. Recent media coverage indicates increasing pressure on large dairy manufacturers such as Fonterra to stop using coal-powered boilers to dry milk into milk powder (43). Fonterra announced in July 2019 that it would not install any new coal boilers or increase capacity to burn coal. The company is trialling alternative, lower emitting fuels such as wood chips and using electricity to dry milk at its plant in Stirling in South Otago.

The key opportunity for Fonterra and other large dairy manufacturers is to work closely with Government and other industrial processing sectors on an integrated approach to decarbonise across the manufacturing process.

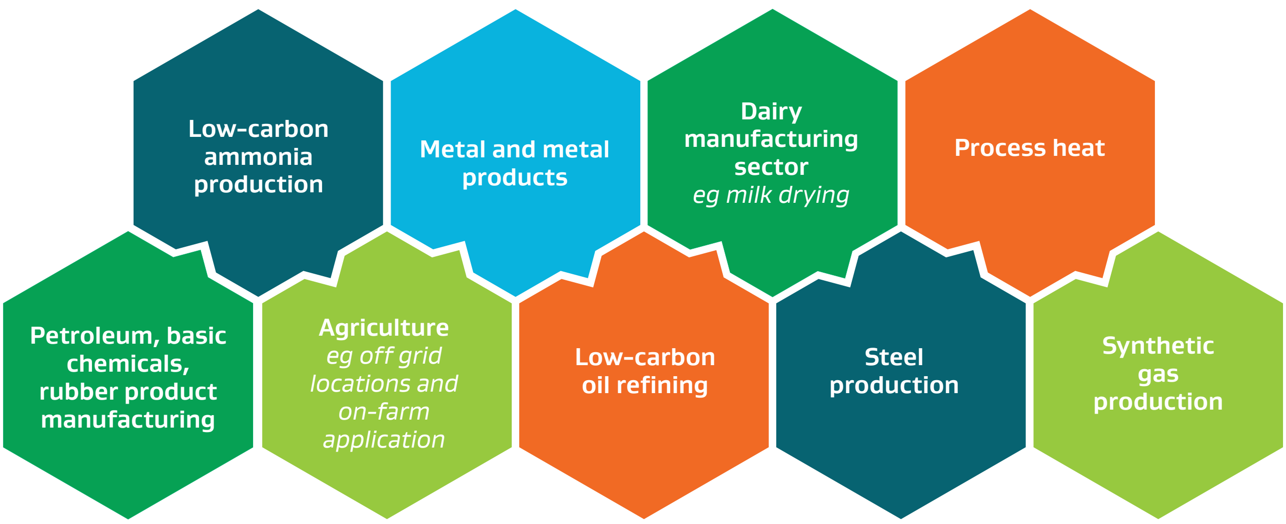


Figure 17: Industrial uses of hydrogen

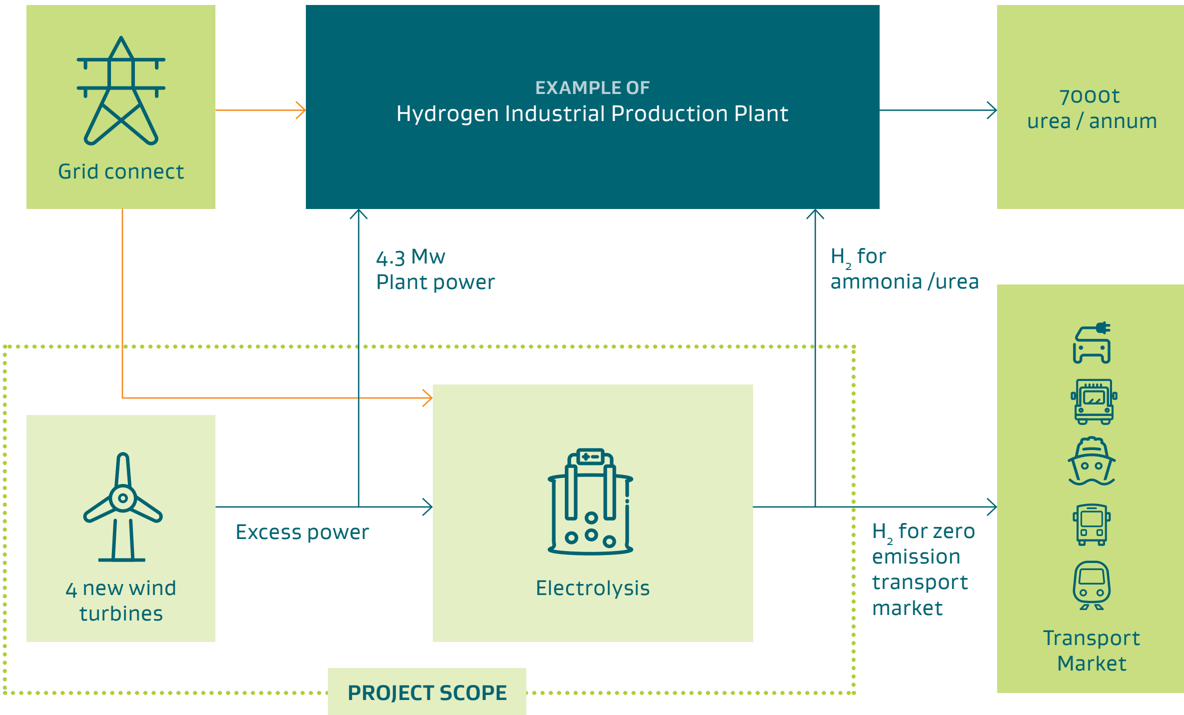


Figure 18: Process for production of green hydrogen and green ammonia using surplus power available from wind turbines (53)

GREEN INDUSTRIAL FEEDSTOCK SUBSTITUTION

World-wide, the top four single uses of hydrogen (in both pure and mixed forms) are oil refining (33 per cent), ammonia production (27 per cent), methanol production (11 per cent) and steel production via the direct reduction of iron ore (three per cent) (30).

Replacing existing brown and grey hydrogen with green hydrogen would help decarbonise these and other industrial sectors:

- **Low carbon ammonia production:** green hydrogen feedstock can be used for chemical reactions to produce ammonia (NH_3). World-wide demand for ammonia and methanol is expected to increase over the short to medium term particularly for petrochemical feedstocks (20).
- **Low-carbon oil refining:** The development of green hydrogen production is being actively explored at the Marsden Point Oil Refinery. If the project proceeds, it will materially reduce the emissions from petroleum refining as a result of introducing green hydrogen into the process.
- **Agriculture:** The biggest opportunity will be storing energy as hydrogen in off-grid locations and for direct on-farm applications using fuel cell technology to produce electricity, or direct hydrogen use in heating such as for hot water.
- **Steel production:** There are alternative ways to produce steel with zero-carbon emissions, assuming green hydrogen and renewable electricity are available. It is possible that in the future steel could be produced with a low carbon footprint assuming the technological challenges that currently inhibit the widespread adoption of hydrogen can be overcome.
- **Synthetic gas production:** Another promising application is the possibility to create synthetic methane gas from off-gases emitted as the by-product of a chemical process. If the hydrogen is added to carbon monoxide and carbon dioxide after the combustion process of coking coal, for example, hydrogen can serve as a post-combustion feedstock (57).

Hydrogen can act as an intermediate energy carrier as well as an input chemical to several important industrial processes. The transition includes timely displacement of high-emitting energy sources used in the current industrial processes. Hydrogen is a very versatile energy vector that can complement current industrial processes in New Zealand and add to them.

In addition, the production of hydrogen could become a new industrial process activity, requiring new skills to be developed and allowing an additional career path for people with experience in oil refining, LPG and industrial processes related to ammonia and fertiliser production.

Challenges and Opportunities

Decarbonisation of the industrial sector through pragmatic electrification and further integration of green hydrogen into process heating, input chemical substitution and energy storage will be complex.

Key requirements for manufacturers will be security of energy supply, competitive price points for alternative energy sources, the costs of transitioning to hydrogen boilers and certainty in the phasing of large-scale changes to the energy network or supply to minimise disruption. Successful pilot projects and lessons learned from them will be critical for gaining confidence for the changes.

The take-up of green hydrogen will be determined by the economics of substituting hydrogen for fossil fuels or electricity as an energy input, and the potential for growth in export from the relevant industry given the realistic scale of New Zealand's production, the distance from those markets and the costs to deliver them relative to other potential suppliers.

All these issues will need to be addressed through an open and factual discussion, further investigation through research and demonstration of applicable technologies.

However, there are no insurmountable technical challenges to using green hydrogen as a feedstock and energy source for industrial, food and agricultural processes in New Zealand.

It can burn at higher temperatures than natural gas making it especially useful for high-grade heating. For domestic use, up to around 20 per cent hydrogen in a mix of combustible gases can be used by most existing heating equipment with no modifications needed (6).

The economics of generating intermediate and high-temperature industrial heat from green hydrogen will be determined by the hydrogen fuel costs and the capital costs of the boilers and furnaces.

Most process heat is now generated in older boilers. Despite their economic life span of 15 to 20 years, boilers are often in use for 20 to 40 years. This contributes to lock-in of higher emissions.

Research on future capital costs is limited, although in principle it should be similar to conventional gas boilers. Currently, the total costs of generating heat with hydrogen are significantly higher than with natural gas (54).

The rate at which green hydrogen production can be brought online for New Zealand's process industries will be key in determining how quickly decarbonisation of this sector using hydrogen can occur. Achieving scale with hydrogen production should see cost reductions.

Lifecycle analysis of the supply chain for industrial processes can help determine the best pathway for introducing hydrogen, either as a feedstock or energy source. Because different emission impacts and costs will result from different hydrogen production routes, such analysis can be complex and time-consuming.

Introducing green hydrogen, if done in collaboration with existing industries and the public sector over reasonable time frames, could allow additional growth in value-added industrial output, export potential, reduced costs through process integration, and energy efficiency measures at the same time as reducing carbon emissions.

This should be possible without negative impacts on existing jobs, although job reskilling may be required.

Looking Ahead

There are many avenues for industrial and food processing industries to substitute hydrogen for existing fuel sources, reducing the need for hydrocarbon-based fuels and thereby reducing GHG emissions.

New Zealand has built a reputation as a source of high-quality dairy, livestock and other agricultural products. To support the agricultural sector, local production of nitrogenous urea fertiliser occurs using large volumes of natural gas. The H2 Taranaki Roadmap (49) and Taranaki Draft Roadmap 2050 (53) identify an opportunity to produce urea from greener inputs including hydrogen from electrolysers powered by renewable energy.

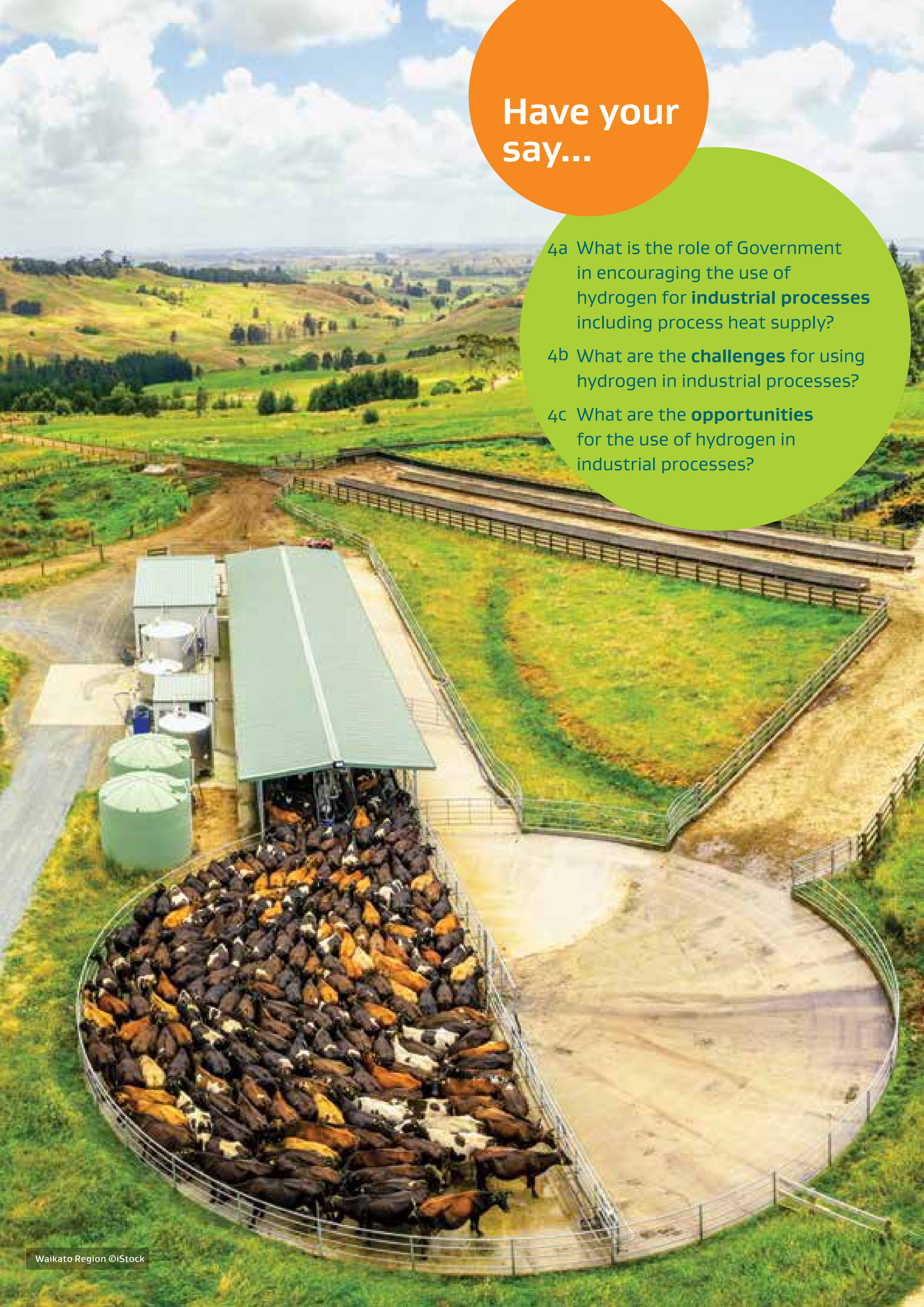
There is a potential opportunity to expand this production and export of ammonia and/or urea derived from green hydrogen.

These and other options could be investigated further at the planned National New Energy Development Centre including establishment of demonstration projects funded by industry with Government support. This could include a techno-economic assessment of the potential for hydrogen and electrification options for intermediate and high-temperature heat. It could consider specific circumstances, particularly with respect to the intermediate and high temperature heat demands across industrial sectors (54).

Subsequently, or in parallel, hydrogen gas blending trials such as those carried out in Australia and the UK could strengthen the evidence base for the technical and economic feasibility of wider deployment.

Government could help to remove barriers to the early adoption of green hydrogen and distribution in New Zealand that underpin the changes possible in the industrial process sector.

Key focus areas include working with iwi, the private sector and local authorities to facilitate investment in renewable energy infrastructure, streamlining approval processes, and examining existing regulations which may hinder the development of expanded industrial scale, or transition to, the use of hydrogen as feedstock or energy source.



Have your say...

4a What is the role of Government in encouraging the use of hydrogen for **industrial processes** including process heat supply?

4b What are the **challenges** for using hydrogen in industrial processes?

4c What are the **opportunities** for the use of hydrogen in industrial processes?

Waikato Region ©iStock

Decarbonising Gas Supplies

In New Zealand, natural gas currently has a wide range of applications. These range from fuelling thermal power generation plants and providing heat for large industries – including key export sectors of meat, dairy and timber processing as well as steel manufacture – to providing the feedstock for petrochemical production (methanol and ammonia/ urea). In homes and in essential services such as hospitals it is used for cooking and water and space heating.

There is potential to convert or blend hydrogen into the existing natural gas network. This gives New Zealand the opportunity to continue to use the national gas transmission and distribution infrastructure assets (estimated to be valued at $1.7 bn) (54), supply chains and workforce as we transition to a low emission energy future.

Currently, natural gas is supplied to about 280,900 industrial, commercial and residential customers in New Zealand (15). It accounts for 22 per cent of total primary energy supply (27) and 14 per cent of total small consumer energy use (15).

New Zealand's only operational oil and gas fields in the Taranaki basin distribute natural gas around the North Island through 3,400 km of high-pressure gas transmission pipelines and 11,600 km of intermediate, medium and low-pressure networks (14). Natural gas is not available in the South Island, however, LPG, a mix of propane and butane extracted from natural gas, is distributed throughout both islands (15).

In the UK, Europe, Australia and New Zealand there has been considerable recent and ongoing work by Governments and gas utilities to establish a roadmap to decarbonise existing natural gas networks. First Gas, owner and operator of the majority of New Zealand's gas network (11), is proposing a trial of hydrogen pipelines as one of the first projects at the new National New Energy Development Centre in Taranaki (9).

In this context, the focus has been on establishing the safe operating level for injecting hydrogen into the existing gas distribution networks. Current thinking is that hydrogen concentrations up to 20 per cent by volume could be the limiting condition for domestic gas (6). This is driven by the perceived ability of end-users to accommodate the hydrogen blend using existing industrial/ commercial equipment and residential appliances, rather than pipeline limitations (20).

However, it is acknowledged hydrogen can accelerate embrittlement of some metals usually present (in small amounts) in older and high-pressure networks, usually within valves, seals and at pipe joints (See Figure 19). Polyethylene pipes, which are already used in New Zealand for low pressure gas delivery, could withstand much higher concentrations of hydrogen, depending on the materials used in the joining and control equipment. Trials proposed by First Gas (9) will explore what is needed for the existing transmission and distribution network to become hydrogen-ready.

Tolerance of selected existing elements of the natural gas network to hydrogen blend shares by volume

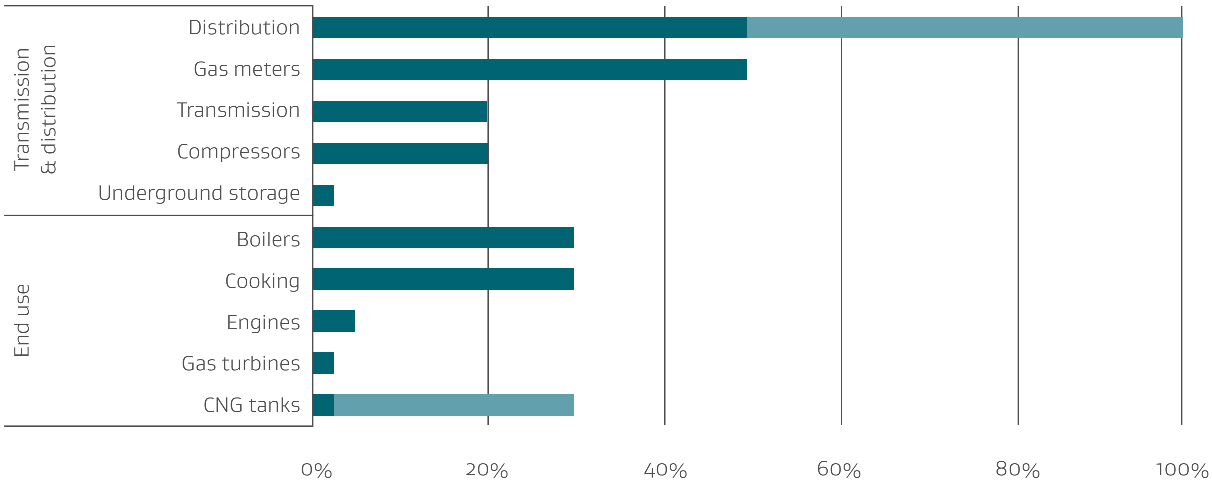


Figure 19: Tolerance of selected existing elements of a typical natural gas network to hydrogen blend shares (% by volume) (20)

Opportunity

New Zealand could move to partially decarbonise the gas distribution network using hydrogen as part of the transition to a low emissions and zero-carbon economy.

A short-term opportunity is to use the pipeline itself to store green hydrogen. This would require less investment than tank storage of hydrogen.

Learnings from the decarbonisation of gas distribution networks globally, including in the UK, Europe and China, will enable First Gas to have an evidence-based approach to decarbonising natural gas networks.

Examples of decarbonising the gas distribution network include *HyDeploy,* a UK project trialling up to 20 per cent hydrogen blend in the gas network, and the Leeds City H21 project that has been successfully trialling and repurposing the gas distribution network for hydrogen.

Blending hydrogen into natural gas would allow partial decarbonisation of the space heating, cooking and water heating energy needs for residential and small to medium enterprise customers, with limited performance impacts. This would also enable hydrogen to be produced at larger scales than currently possible, which could reduce costs.

The option to use hydrogen directly will also benefit customers located remotely from the electricity grid but with access to the gas network, or those who can create their own hydrogen from renewable energy sources.

The transmission of gas via the pipeline network is generally more efficient than the transmission of electricity by the transmission/distribution network where energy losses can reach 10 per cent.

A longer-term opportunity is to explore whether hydrogen can completely displace natural gas in the network fed from New Zealand's oil and gas production sector. This would require considerable expansion of renewable electricity to create sufficient hydrogen volumes, and the ability to feed the hydrogen produced into the existing low-pressure gas distribution network.

Another opportunity in the longer term might be for bottled hydrogen to displace bottled LPG as distributed throughout both islands. This would depend on the speed and availability of cost-competitive hydrogen.

Challenges

There are a range of challenges to analyse, address and overcome with hydrogen's use for industrial purposes.

The safe concentration of hydrogen in existing New Zealand gas pipelines needs to be determined. Trials proposed by First Gas are important steps in understanding potential issues and solutions.

Issues associated with up-to-date asset management information on existing pipelines will need to be managed so that materials or infrastructure which cannot withstand increasing hydrogen concentrations can be identified and replaced. Work is required to test examples of existing pipeline infrastructure and controls to assess their performance and resilience under such usage.

New or replacement infrastructure which is fit for this purpose will need to be selected and communicated between distribution networks and energy businesses, Government regulators and safety authorities. Leveraging work being undertaken in the UK and Australia will help New Zealand to understand whether, and how, existing infrastructure including consumer installations, appliances and associated equipment can perform safely and reliably with hydrogen rich gases.

Looking Ahead

A possible future is the partial decarbonisation of the New Zealand gas distribution network with up to 20 per cent of green hydrogen by 2035. Within this time-frame it is likely that research and development both internationally and within New Zealand will have established the safe level for hydrogen concentrations in our existing (or possibly enhanced) gas distribution networks that can be achieved by 2050.

The IEA 2019 report (20) on the future of hydrogen notes that hydrogen blending faces a number of challenges.

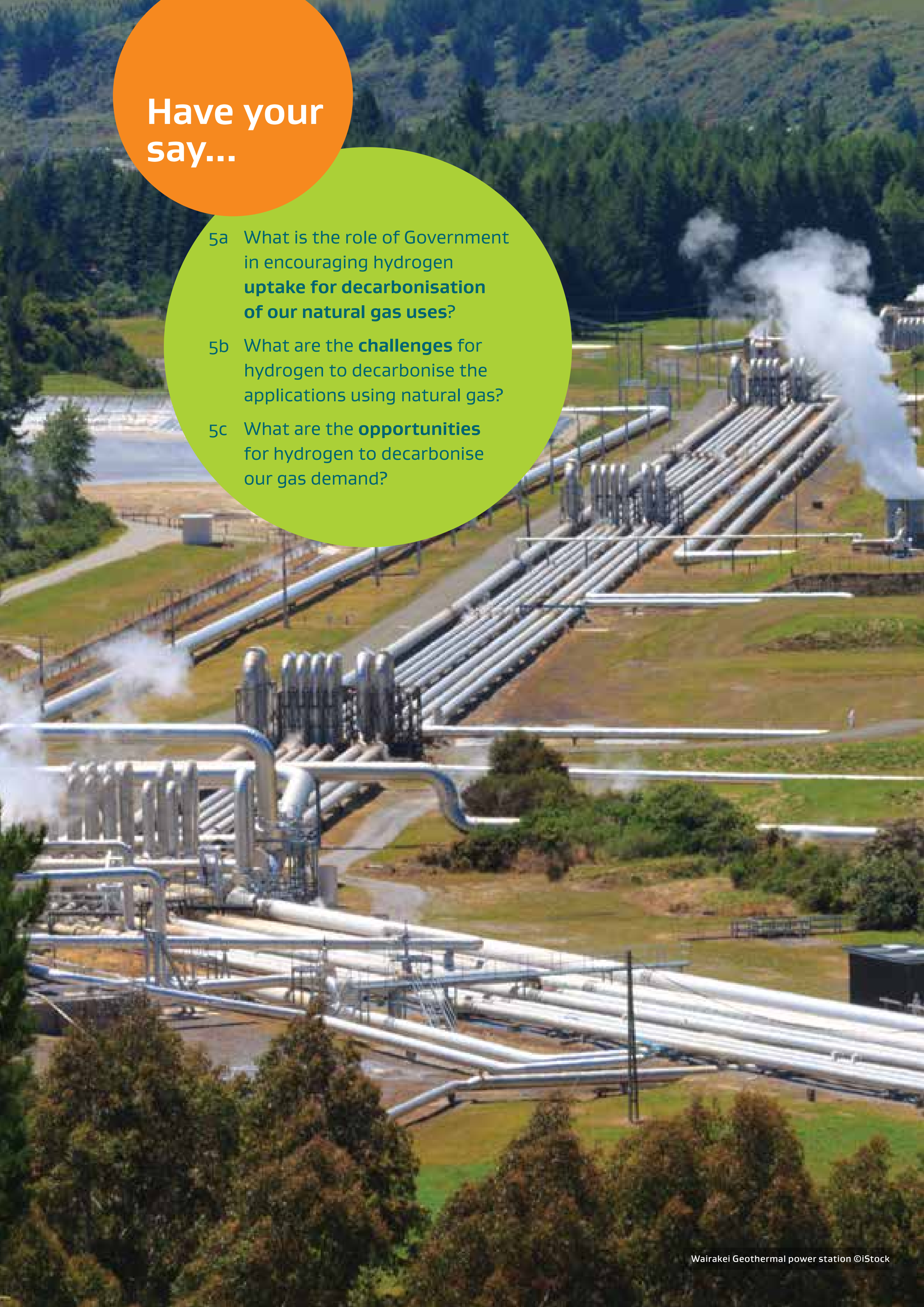
- "The energy density of hydrogen is around a third of that of natural gas and so a blend reduces the energy content of the delivered gas: a three per cent hydrogen blend in a natural gas transmission pipeline would reduce the energy that the pipeline transports by around two per cent. End users would need to use greater gas volumes to meet a given energy need. Similarly, industrial sectors that rely on the carbon contained in natural gas (e.g. for treating metal) would have to use greater volumes of gas.
- "Hydrogen burns much faster than methane. This increases the risk of flames spreading. A hydrogen flame is invisible and odourless when burning. New flame detectors would probably be needed for high-blending ratios.
- "Variability in the volume of hydrogen blended into the natural gas stream would have an adverse impact on the operation of equipment designed to accommodate only a narrow range of gas mixtures. It could also affect the product quality of some industrial processes.
- "The upper limit for hydrogen blending in the grid depends on the equipment connected to it, and this would need to be evaluated on a case-by-case basis. The component with the lowest tolerance will define the tolerance of the overall network." (20).

Have your say...

5a What is the role of Government in encouraging hydrogen **uptake for decarbonisation of our natural gas uses**?

5b What are the **challenges** for hydrogen to decarbonise the applications using natural gas?

5c What are the **opportunities** for hydrogen to decarbonise our gas demand?



Wairakei Geothermal power station ©iStock

Hydrogen for Export

The export industry could unlock our renewables potential to support and accelerate domestic decarbonisation and a new export revenue for New Zealand.

Today, New Zealand has only a small local market for hydrogen. The focus is on industrial products (hydrogen carriers) or feedstocks used in the chemical and oil refining industry with around 3.5 Mt/yr of ammonia transported by sea globally (20).

New Zealand has an opportunity to take advantage of the hydrogen export market which is still in its infancy at over 70 Mt annually (20) worldwide, with very limited inter country trade, but expected to grow significantly over the coming decades.

This new demand will come from countries that will need to turn to imported renewable energy to further their decarbonisation efforts.

The global market for green hydrogen will be stimulated by the development of an export industry to countries including Japan and South Korea, which have limited renewable energy alternatives. To illustrate, Japan currently imports around 90 per cent of its energy needs and sees hydrogen as a source of diversification and emissions reduction (20). Its Government has targeted hydrogen (ideally green) imports of 300,000 tonnes annually by 2030, ramping up to 5-10 Mt as the country transitions towards a decarbonised and more resilient energy system, relying less on nuclear and fossil fuels (31).

Beyond this, there are prospective markets for hydrogen throughout the Asia Pacific region, and further afield to China and parts of Europe (20). Each potential importer has different drivers, including its own energy production capability and capacity, energy security and affordability, a desire to decarbonise or denuclearise.

The export market would make use of New Zealand's abundant renewable resources, effectively transporting our renewable wind and solar energy to provide a new source of export revenue. The H2 Taranaki Roadmap proposes exporting around 0.3 MtH_2 per annum, around 40 per cent of production (49). Hydrogen export is likely to initially be as a chemical compound, or as a cryogenic liquid as technologies mature. The best method for doing so will depend on geography, volume, distance and end use.

With appropriate policies in place, an export market for green hydrogen may enable New Zealand to transition more rapidly to a low emissions economy with an affordable, resilient and sustainable energy system. Economies of scale will be created when export facilities are constructed which may lower the cost of hydrogen available domestically.

Some countries have set ambitious hydrogen targets for domestic production, vehicles and infrastructure. Those with abundant natural resources (renewables or hydrocarbons) are prospective producers including Chile, Middle East, North Africa and Australia (20). With the development of global export industries, New Zealand may also have the opportunity to import hydrogen as domestic demand necessitates.

Hydrogen is not the only means of exporting renewable energy. Other technologies include high-voltage direct current cables, biofuels and synthetic fuels and embodied energy in minerals/metals (4).

Opportunity

New Zealand has abundant renewable energy potential that can be used in part to produce green hydrogen for domestic and export markets.

The IEA considers that New Zealand has a potential flow of hydrogen of 700 kt H_2/yr in 2030, with 60 per cent used for domestic purposes and the remainder exported (20). Excess hydrogen production could be directed to establishing additional export products to supply international and domestic products by 2030.[2]

2 Japan's Energy strategy calls for higher renewable imports (e.g. hydrogen) by 2030 (30).

The H2 Taranaki Roadmap considers that an export facility with an electricity consumption of around 500- 1000 MW could be established by 2030 (49).

On this basis we are well placed to initially export green hydrogen to Japan, following the signing of a Memorandum of Cooperation in October 2018 (55) which signalled our interest in working in partnership with Japan to develop hydrogen technology. We are also interested in exporting green hydrogen to other countries such as South Korea.

As an energy importer Japan is looking to establish a resilient, secure source of energy and has set ambitious targets in its hydrogen roadmap around import, domestic production and infrastructure (31). Hydrogen will even be used to power the 2020 Olympic and Paralympic Games in Tokyo (50). In preparation for this, Australia has carried out the first proof of concept export of green hydrogen to Japan, as part of a collaboration between Queensland University of Technology and the University of Tokyo (44).

Further, New Zealand has the potential to offer Japan a secure source of green hydrogen that does not require CCS, produced in a stable political environment and on a relatively fast, safe and established shipping route (8).

Following the recommendations made in the 2019 report *The Role of Innovation in Getting to Carbon Zero* (8), New Zealand has the opportunity to work with other countries who share interests in developing green hydrogen. These include Japan, Norway, the Netherlands, Europe, South Korea and Australia. Through these alliances, New Zealand can push for international carbon transparency standards for hydrogen based on environmental principles while supporting our economic interests.

New Zealand currently exports 2.4 Mt of methanol annually, 95 per cent of which is exported to the Asia Pacific region (23). As discussed earlier in this report, hydrogen can be stored and transmitted as methanol. Methanol is a transition fuel and contains carbon and NO_x emissions and there will be carbon emissions at point of use and specific health and safety requirements which will need to be met.

As a result of this existing large scale production, New Zealand already has the infrastructure, facilities and skills that would enable the export of hydrogen gas after conversion to liquid methanol (49). There is potential for this to support existing jobs and create new ones along the supply chain, while simultaneously attracting investment and research in domestic and export applications and technologies.

Challenges

There are several key challenges that will need to be considered before establishing an export supply chain for green hydrogen.

Any form of energy generation will require additional infrastructure, which is likely to have associated economic, cultural, environmental and social costs. Ideally, we should make the most of the opportunity to retrofit and reuse existing infrastructure where possible. Generating volumes of hydrogen greater than required to meet New Zealand's domestic demand will need to ensure there is no adverse effect on the security of our electricity supply or pricing levels. The establishment of a large hydrogen plant to meet export demand will require careful grid and generation planning and investment to ensure that stability is maintained.

In addition, any impacts resulting from using our natural capital for export will be felt primarily by New Zealanders. The scale and type of indirect benefits that would be received would need to be considered to determine their value and significance in relation to any negative impacts from the further use of our natural capital. Another challenge will be to ensure local supply and pricing is not used to subsidise export production to the disadvantage of domestic consumers.

There is currently no international market for hydrogen, and no common price. Cost competitiveness of the market depends on the scale, distance from the market and cost of electricity. Hydrogen importers may choose to focus on cheaper, brown hydrogen if the drivers behind the hydrogen market do not include emissions reductions.

Timing of any investment in a hydrogen export market will need to be carefully considered in relation to the development of receiving facilities by importing nations and the securing of purchase agreements in a competitive global commodity market.

At present there are no identifiable established international supply chains, logistics or infrastructure established, and these may involve significant costs and risks. Although there has been some progress in establishing international standards and codes on hydrogen production and transport, these have not been universally accepted or adopted in the energy or transport sectors. Getting international agreement takes time.

New Zealand standards and codes would also need to be adapted or developed to fit within current local safety and standard frameworks and requirements, while at the same time meeting emerging international standards and allowing trials and pilots while standards and codes are being developed.

Looking Ahead

New Zealand is internationally renowned for The Treaty of Waitangi, its tourism brand and strong agricultural sector. It is respected as a dynamic early adopter of technological and societal change. It is important to use our reputation to our advantage, leveraging export opportunities in order to grow a sustainable and resilient part of the economy.

Green hydrogen exports, with internationally recognised green hydrogen certification, should be the aspirational goal. With a clear and stable development path, combined collegial but competitive markets, and focussed investments, this goal should be able to be achieved in the short to medium term.

Other export sectors could also benefit through the decarbonisation of the domestic energy and transport system to provide greener goods and services.

Hydrogen's contribution to decarbonising the local transport, process heat and electricity requirements for the food processing, fertiliser manufacturing and other industries, could further position New Zealand goods as premium sustainable products, in sectors otherwise difficult to abate emissions. This would benefit economic development, growth and employment, and support our wellbeing targets.

The export of hydrogen could take a number of forms, including as:

- compressed / liquified gas (although some evaporation losses will occur)
- in other chemical forms such as methanol, ammonia, or LOHC, which will need to be processed on receipt to liberate the hydrogen (thus creating round-trip efficiency loss), unless the ammonia is used directly in industrial processes or as a fuel at the destination.

Māori culture and Te Ao Māori (Māori view of the world) take a partnership approach to energy from a kaitiakitanga and Māori business perspective. These factors, in conjunction with our reputation as dynamic adopters of change, innovation and creativity form the basis of our global standing.

Hydrogen presents an opportunity to use this to our advantage, through encouraging innovation and investment and leveraging export opportunities. This will contribute to growing a sustainable and resilient economy while furthering these positive aspects of our global image.

At a local level, collaboration with industry, iwi, community and other stakeholders will foster support for, and engagement with, hydrogen.

There is also a need to further investigate how developing an export market for green hydrogen may support domestic decarbonisation and create a local green hydrogen market.

Have your say...

6a What is the role of Government in **producing hydrogen in sufficient volume for export**?

6b What are the **challenges** for hydrogen if produced for export?

6c What are the **opportunities** for hydrogen if produced for export?

Auckland ©iStock

Next Steps

This Green Paper outlines the role hydrogen could potentially play in New Zealand. The previous chapters examined how hydrogen could contribute to our goal of a net zero carbon economy by 2050.

Decisions about these pathways and their implementation will be part of a Government renewable energy strategy. This will be developed over the next year, informed by feedback on this Green Paper.

This wider strategy will outline the renewable energy pathway to a net zero future for New Zealand by 2050.

Hydrogen has great potential to be the catalyst for decarbonising the New Zealand energy system and with public and private collaboration, this aspiration can be transformed into reality. We need to see rapid progress in the coming years to meet our legally binding emission targets, and this vision shows we all have a role to play on this journey.

Figure 14 illustrates the various ways in which hydrogen can integrate into our economy.

However, for hydrogen to succeed in New Zealand there are numerous significant challenges that need to be managed successfully – overcoming economic and policy uncertainty, attracting demand from a broad range of end users while technology matures and because costs are high, addressing investment and infrastructure needs, setting policy that stimulates demand, establishing standards and regulations, analysing lifecycle costs and changing public perceptions around safety.

Government has an essential role to play to establish hydrogen's place in the New Zealand energy system. The challenge for Government is to establish how it can ensure there are no barriers to hydrogen's potential being developed while cost effectively stimulating its use in a low emissions economy, domestically and internationally.

There is opportunity for industry to collaborate with Government and speak with one voice about what is needed, utilising the New Zealand Hydrogen Association. Ultimately it is consumer demand that will support and sustain the business case for a future hydrogen economy.

The perception of hydrogen must continue to mature so it is seen as a trusted alternative to current fuels by providing consumers a choice to transition from one fuel source to a mixture of renewable energy fuel sources. Continuing to bring together key players and stakeholders in a collaborative way will help push the cause further. Raising the awareness about the challenges we face, identifying solutions and establishing relationships across the supply chain and Government are essential next steps alongside developing a hydrogen road map for New Zealand.

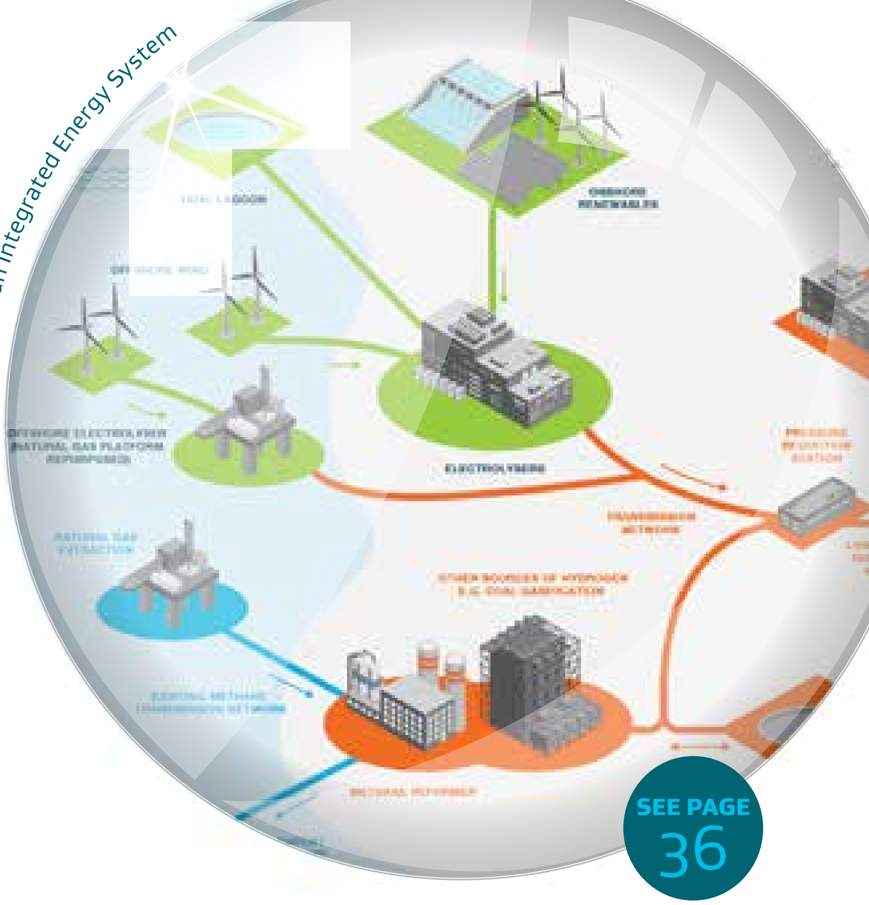


Figure 14: Hydrogen in an Integrated Energy System

SEE PAGE 36

Collaboration between Government, iwi, industry and stakeholders is key for realising the hydrogen opportunity for New Zealand. This includes coordinating research across academia and industry to determine knowledge gaps and agree a portfolio of evidence gathering research. There are opportunities to learn and build on best practice from across the world, from advanced blending to repurposing transmission pipelines. Government and industries must work together to develop innovative market structures that provide value for money for tax payers and offer options to de-risk for industry.

Pilot projects are important in understanding the role hydrogen can play in New Zealand's low emissions economy. New technology often takes time to reach a commercial level of development, making its deployment a more risky decision for company boards. However, these projects may have critical value when making long term decisions in a market where technology is developing rapidly and investments have a long life. Internationally many Governments recognise the value of pilot or demonstration projects and fund them jointly with industry.

Pilots will help support the development of policy, business cases, technology, consumer confidence and build supply chain capacity. Pilots and demonstration projects will ensure lessons can be learnt and policy can be informed by evidence. This will inform the public and decision makers about the role hydrogen could play in decarbonising New Zealand's entire energy system.

New Zealand should work with other countries which share interests in developing and receiving green hydrogen including Japan, South Korea, Norway, Europe and possibly Australia (where we can agree standardisation of the definition of green hydrogen. Through these alliances, New Zealand can push for international carbon transparency standards for hydrogen). As well as being based on environmental principles, this approach can also serve New Zealand's economic interests by creating a global market for green hydrogen, which we are well positioned to manufacture.

The Roadmap (See Figure 20) outlines an indicative pathway for New Zealand to harness the potential of hydrogen for a sustainable and resilient energy system. It illustrates the different aspects of hydrogen's story that will need to be developed according to a timeline and shows how the different pathways integrate with other parts of Government strategy.

Figure 20 provides an indicative hydrogen roadmap as one view of how this pathway may develop. Many of the work programmes illustrated in this diagram have yet to commence and some are several years in the future. This roadmap should be taken as illustrative of the work that needs to be carried out to achieve this vision, bearing in mind that the goals and targets we may set now will evolve as technology and requirements change in the future.

Indicative Hydrogen Roadmap

KEY EVENTS	Up to 2020	2020–2025
POLICY AND REGULATION	**Regulatory review process:** Electricity price review, Gas Act review, Resource Management Act review	**Regulatory review and amendments process:** Gas Act, NZ Transport Rules and Legislation & Health and Safety legislation
	Green H_2 vision Lessons learnt from pilots	Green H_2 Strategy Renewable Energy Strategy
	Climate Change Response (Zero Carbon) Amendment Bill	Zero Carbon Act
PARTNERS	Hapū, iwi and Māori Trusts	Hapū, iwi and Māori Trusts
	NZ Hydrogen Association Japanese H_2 Memorandum of Cooperation CEM Hydrogen Initiative	Other international agreements
STAKEHOLDERS ENGAGEMENT AND COMMUNICATIONS	Industry, power generators and network distribution companies	International standards agreement
	Universities and Research Institutes Local and Regional Council and Central Government	Improved societal / industry attitudes to pollution from vehicles, heating and industry
	Stakeholders and community	Public awareness and engagement
EXPORT	Domestic use of H_2	International export agreements
	Evaluate opportunities for international investment for H_2	H_2 proof of concept trials
PRODUCTION	Green H_2 trials	Develop regulations, standards and pricing
	Possible brown and grey H_2 production	Green H_2 and potential blue H_2 CCS
DEMONSTRATIONS AND RESEARCH	Tuaropaki Trust / Ports of Auckland / Hiringa	Forklifts / Buses and Coaches / Car share
NETWORK AND INFRASTRUCTURE	Plan to future proof for H_2 blending in gas network	Gradual blending in existing gas network Develop regional hubs surplus to gas network
TRANSPORT	Cars / Forklift / Farm bike / Buses	Vans / Trucks / Intercity buses / Coaches
INDUSTRIAL	Develop pathways and demonstrations for decarbonising industry	Demonstrations and trial Develop H_2 regional hub
HEATING	Development and safety case approval	Hydrogen for heating trial
	Prepare pathway for H_2 ready appliances	Appliance development and certification
STORAGE	Consider economics of storage facilities – potential dual use for: export and dry-year energy	International proof of concept facility Consider existing oil gasfields at the end of their lives for CCS storage
STATIONARY AND RESILIENT ENERGY	Develop pathway for storage and resilience	Trial storage solutions Small scale distributed storage

Figure 20: Indicative Hydrogen Roadmap

2025–2030	2030–beyond
Updated regulations and standards International standards	
Energy market for H_2 in place	Low emissions economy Re-purposing infrastructure for H_2 including the NZ coal and gas power plants
UN Sustainable Development Goals agenda widespread	Net Zero Carbon economy 2050
Hapū, iwi and Māori Trusts	Hapū, iwi and Māori Trusts
Extend agreements based on surplus of H_2	
Public normalisation of H_2	
Public acceptance	
H_2 production facility	
Trains / Ferries / Trucks / Aviation	Cargo ships / Cruise ships
Regional hubs to supply industrial demand	H_2 network available in main cities Network extensions Gas network replacement
Trains and H_2 available at motorway service stations	Ferries / Cruise ships 200 refueling stations available across NZ Zero emission transport
Regional hubs complete & operational	Decarbonising industrial zones and decarbonising dairy industry Zero emission industry
Appliance delivery Commence property conversion	Property conversion Widespread property conversion
Develop large scale facility operational for export and dry-year energy	Expand number of facilities based on demand / cost / comparative advantage
Large Fuel Cell applications suitable for Local Government and emergency services applications	Implement fuel cells in all applicable remote locations Grid stabilisation

see page 31

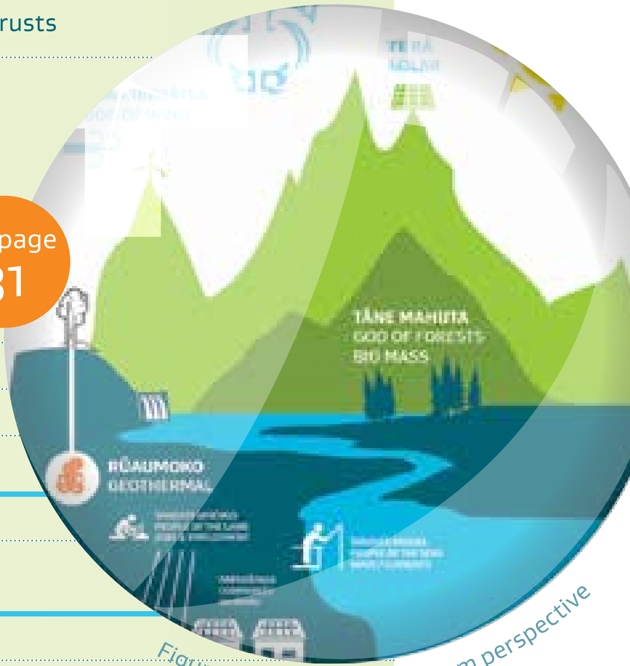


Figure 9: Māori energy system perspective

Have Your Say

We welcome your feedback on the questions outlined in this Green Paper. To help us analyse of your feedback, we would appreciate clear *written submissions* that indicate the number and question being addressed.

1a What is the role of Government in developing hydrogen for storage and distribution?

1b What are the challenges for using hydrogen for storage and distribution?

1c What are the opportunities for using hydrogen for storage and distribution?

2a What is the role of Government in developing the complementary role of electricity and hydrogen?

2b What are the challenges for achieving this complementary role of electricity and hydrogen?

2c What are the opportunities for this complementary role of electricity and hydrogen?

3a What is the role of Government in supporting hydrogen use for the transport sector?

3b What are the challenges when using hydrogen for mobility and transport?

3c What are the opportunities for using hydrogen for mobility and transport?

4a What is the role of Government in encouraging the use of hydrogen for industrial processes including process heat supply?

4b What are the challenges for using hydrogen in industrial processes?

4c What are the opportunities for the use of hydrogen in industrial processes?

5a What is the role of Government in encouraging hydrogen uptake for decarbonisation of our natural gas uses?

5b What are the challenges for hydrogen to decarbonise the applications using natural gas?

5c What are the opportunities for hydrogen to decarbonise our gas demand?

6a What is the role of Government in producing hydrogen in sufficient volume for export?

6b What are the challenges for hydrogen if produced for export?

6c What are the opportunities for hydrogen if produced for export?

In addition, we welcome your feedback about the opportunities of hydrogen to Māori and how this will support their aspirations for social and economic development.

You can make a formal submission by filling in our new online submission form on the MBIE webpage

https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-strategies-for-new-zealand

This online form is compatible with your computer, laptop, tablet and smartphone. Please note, you will need to fill this online form out in one session as there is no save or pause function.

If you have difficulty using the online form, or wish to make a confidential submission (in either word .doc or .pdf format), please email us on hydrogen@mbie.govt.nz

If you submit via email, please clearly indicate which feedback area you are commenting on.

www.mbie.govt.nz

thank you

tēnā koutou

for taking the time to read our Green Paper. We look forward to reading your submissions.

All submissions are due by **Friday 25 October 2019** at 5pm.

Submissions received after this time are unlikely to be considered. Unless marked confidential, submissions will be published on the MBIE website, in compliance with the Official Information Request 1982 and the Privacy Act 1993.

Glossary

TERM	DEFINITION	SOURCE
Autothermal Reformation (ATR)	Similar to steam methane reforming (SMR), although it uses oxygen together with steam or carbon dioxide and is exothermic. Output temperature of 950-1100ºC. Smaller, but less efficient than SMR. www.arup.com/perspectives/publications/promotional-materials/section/five-minute-guide-to-hydrogen	Five Minute Guide to Hydrogen
BEV	Battery Electric Vehicle	
Biofuel	A generic term to describe liquid (or gaseous) fuels produced from biomass. www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-generation-and-markets/liquid-fuel-market/biofuels/	Ministry of Business, Innovation and Employment (MBIE)
Biomass	Organic material that comes from plants and animals, and a renewable source of energy. www.eia.gov/energyexplained/?page=biomass_home	US Energy Information Administration
Blue Hydrogen	Production of hydrogen from fossil fuels with CO_2 emissions reduced by the use of carbon capture underground storage. www.iea.org/hydrogen2019/	International Energy Agency
Brown Hydrogen	Hydrogen produced from fossil fuels.	
Carbon capture storage (CCS)	CCS technologies involve the capture of carbon dioxide (CO_2) from fuel combustion or industrial processes, the transport of CO_2 via ship or pipeline, and either its use as a resource to create valuable products or services or its permanent storage deep underground in geological formations. www.iea.org/topics/carbon-capture-and-storage/	International Energy Agency
CHP	Combined Heat and Power	
EECA	Energy Efficiency and Conservation Agency	
Electrolysis	Water electrolysis is the process in which hydrogen is produced from splitting water through the application of electrical energy into hydrogen and oxygen. www.ieahydrogen.org/Resources/FAQs-and-H2-Primer-(1).aspx	IEA HIA
	The carbon footprint of the hydrogen depends upon the carbon footprint of the source electricity and electrolysis efficiency. Polymer Electrolyte Membrane is based on a solid polymer electrolyte operating at 70-90ºC, while an Alkaline Electrolyser uses a Sodium or Potassium Hydroxide or solid alkaline electrolyte at 100-150ºC and the Solid Oxide Electrolyser uses a solid ceramic electrolyte operating at about 700-800ºC. www.arup.com/perspectives/publications/promotional-materials/section/five-minute-guide-to-hydrogen	Five Minute Guide to Hydrogen
Energy Carrier	Either a substance or a phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes.	International Organisation for Standardisation
Energy intensity	Compares production in the economy, as measured by real GDP, with total energy demand, as measured by total consumer energy. It determines whether our reliance on energy to generate economic growth is increasing or decreasing. www.mbie.govt.nz/assets/346278aab2/nzeecs-2017-2022.pdf	MBIE

TERM	DEFINITION	SOURCE
Energy efficiency	Something is more energy efficient if it delivers more services for the same energy input, or the same services for less energy input. www.mbie.govt.nz/assets/346278aab2/nzeecs-2017-2022.pdf	MBIE
Energy emissions	Greenhouse gas emissions from the energy sector, including the production and use of energy. www.mbie.govt.nz/assets/346278aab2/nzeecs-2017-2022.pdf	MBIE
Energy productivity	The value we get from our energy, defined as Gross Domestic Product per unit of energy used. www.mbie.govt.nz/assets/346278aab2/nzeecs-2017-2022.pdf	MBIE
FCEV	Fuel Cell Electric Vehicle.	
Feedstock	Any renewable material that can be used directly as a fuel, or converted to another form of fuel or energy product. www.energy.gov/eere/bioenergy/biomass-feedstocks	Office of Energy Efficiency and Renewable Energy
Fossil fuels	Energy sources formed in the Earth's crust from decayed organic material. The common fossil fuels are petroleum, coal, and natural gas. www.ieahydrogen.org/Resources/FAQs-and-H2-Primer-(1).aspx	Energy Information Administration
Fuel switching	Fuel switching replaces inefficient fuels with cleaner and economical alternatives, such as substituting coal or kerosene for natural gas. Complimented by modern equipment upgrades, fuel switching is a simple approach to reducing energy consumption and costs for end-users, while also curbing carbon emissions. www.ifc.org/	IFC
GHG	Greenhouse Gas	
Green Hydrogen	Low carbon hydrogen produced from renewable energy sources. www.iea.org/hydrogen2019/	International Energy Agency
Grey Hydrogen	Hydrogen derived from industrial processes.	
Gross emissions	Gross emissions come from agriculture, energy, industrial processes and product use, and waste sectors. They do not include emissions and removals from land use, land-use change and forestry. www.mbie.govt.nz/assets/346278aab2/nzeecs-2017-2022.pdf	MBIE
HTE + Concentrated Solar Power	High Temperature Electrolysis works on the basis that electrolysis of water can be more efficiently achieved at high electrolyte temperatures in the range of ~100-850ºC. In a CSP or parabolic solar system the electricity generated can be more effectively converted into hydrogen by sequestering some of the process heat. www.arup.com/perspectives/publications/promotional-materials/section/five-minute-guide-to-hydrogen	Five Minute Guide to Hydrogen
Hydrogen	The simplest, lightest and most abundant element in the universe, making up >90% of all matter. In its normal gaseous state, hydrogen is odourless, tasteless, colourless and non-toxic. Hydrogen burns readily with oxygen, releasing considerable amounts of energy as heat and producing only water as exhaust. It has a high energy content by weight – nearly three times that of gasoline. Today, the commercial production of hydrogen worldwide amounts to about 40 million tons, corresponding to about 1% of the world's primary energy needs. www.ieahydrogen.org/Resources/FAQs-and-H2-Primer-(1).aspx	Energy Information Administration

TERM	DEFINITION	SOURCE
Industrial processes and product use	A category used for UNFCCC reporting, this refers to emissions from industrial activities (eg, from steelmaking) that are not a direct result of consuming energy, and emissions from using greenhouse gases in products (eg, from the use of refrigeration systems). www.productivity.govt.nz/sites/default/files/Productivity%20Commission_Lowemissions%20economy_Final%20Report_FINAL_2.pdf	Productivity Commission
Low Temperature Plasma Reformation	Partial oxidation plasma pyrolysis of methane. This process is at an early technology readiness level but is showing promising low energy reformation potential.	Five Minute Guide to Hydrogen
LNG	Liquified natural gas.	
LPG	Liquified petroleum gas.	
Microbial Biomass Conversion	Dark fermentation of biomass using micro-organisms produces hydrogen and carbon dioxide. Alternatively, Microbial Electrolysis Cells (MECs) combine biomass, micro-organisms and a small electrical input to increase hydrogen yield. This approach has long-term potential to use wastewater.	Five Minute Guide to Hydrogen
Net emissions	The total of a country's emissions across all sources, minus offsets from land use, l and-use change and forestry. www.productivity.govt.nz/sites/default/files/Productivity%20Commission_Lowemissions%20economy_Final%20Report_FINAL_2.pdf	Productivity Commission
Net-zero	Net-zero emissions describes a situation whereby the amount of greenhouse gases emitted into the atmosphere is equal to the amount sequestered or offset (eg, by forestry). www.productivity.govt.nz/sites/default/files/Productivity%20Commission_Lowemissions%20economy_Final%20Report_FINAL_2.pdf	Productivity Commission
Partial Oxidisation (POX)	Endothermic partial oxidisation of natural gas followed by 'Water-Gas-Shift'. Faster and smaller than SMR, but produces less hydrogen per unit of gas feedstock.	Five Minute Guide to Hydrogen
Photobiological	Micro-organisms such as micro-algae or cyano-bacteria absorb sunlight to produce hydrogen. Alternatively, photo-synthetic microbes photo-ferment biomass to produce hydrogen. These processes currently have a low hydrogen yield and are inhibited by concurrent oxygen generation. Further research is anticipated to increase effectiveness.	Five Minute Guide to Hydrogen
Photo Electro Chemical	The PEC process uses semiconductors immersed in a water based electrolyte or a photo-reactive slurry to convert solar energy into chemical energy in the form of hydrogen and oxygen as a by-product. This developing technology can be applied in a similar manner to photovoltaic panels at various scales, both centralised and distributed.	Five Minute Guide to Hydrogen
Process Heat	Process heat is energy used for commercial purposes, manufacturing or heating; it is often generated by boilers. The heat is then used by businesses for a wide variety of applications such as timber processing and paper making, food processing or milk drying. Emissions from heat energy are direct emissions from combustion of fuel (eg, coal used in a boiler). www.mbie.govt.nz/assets/346278aab2/nzeecs-2017-2022.pdf	MBIE

TERM	DEFINITION	SOURCE
Reformer Electrolyser Purifier	A developing technology which reforms and purifies in one step, combining electrolysis and using waste heat to support an efficient endothermic conversion. More efficient than SMR and scalable for centralised of distributed use.	Five Minute Guide to Hydrogen
Steam Methane Reforming	Steam methane reforming is a process in which methane is reacted with high temperature steam (700°C-1000°C) under 3-25bar pressure, in the presence of a catalyst to produce hydrogen, carbon monoxide and some carbon dioxide. www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming	Office of Energy Efficiency and Renewable Energy
Thermo Chemical Water Splitting	Using high temperatures generated from solar (Solar Thermochemical Hydrogen) or nuclear energy, water splitting cycles produce hydrogen and oxygen from water. Typically, dual stage cerium oxide (2000/400ºC) or copper chloride hybrid (500/400ºC), but ~300 process variants are at various technology readiness levels.	Five Minute Guide to Hydrogen
Māori terms		
Atua	Māori Gods of the spiritual and natural realm	
Hapū	Subtribe	
Hononga	Union, connection, relationship, bond	
Iwi	Tribe	
Kaitiaki, Kaitiakitanga	Custodian, caregiver, steward, guardian. To express kaitiakitanga.	
Papakāinga	Home, communal ancestral land	
Papatūānuku	Earth, earth mother, wife of Ranginui	
Rā	Sun	
Rangatira, rangatiratanga	Leader, authority, sovereignty, self determination	
Ranginui	Sky Father	
Rūaumoko	God of Earthquakes	
Tāne Mahuta	God of the Forests and Birds	
Tangata whenua, tangata moana	People of the Land, People of the Water	
Tangaroa	God of the Seas and Fish	
Tāwhirimātea	God of Winds, Weather, Cloud, Storms	
Whānau	Extended family	

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