H2 TARANAKI ROADMAP

HOW HYDROGEN WILL PLAY A KEY ROLE IN OUR NEW ENERGY FUTURE

A TAPUAE ROA PROJECT

MAKE WAY TAPUAE ROA FOR TARANAKI

H2 TARANAKI

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FOREWORD

New Zealand is moving into a new low-emissions future that will substantially alter our current energy ecosystem.

The New Zealand Government has set national targets of:

- A 30% reduction in greenhouse gas emissions by 2030 compared with 2005 levels,
- 100% renewable electricity by 2035, and
- Net zero emissions by 2050.

Currently, only 40% of the country's total energy supply is met from renewable sources.

While electricity production is largely from renewable sources (around 80%), the rest of our energy needs are met from a mix of fossil fuels, both domestic and imported. These are used for generating electricity to meet periods of peak and dry year demand, fuelling the majority of our transport fleet, supplying heat for households and industrial processes and as feedstock for products such as urea fertiliser and methanol.

There is now widespread agreement that in future the energy currently provided by fossil fuels in New Zealand will be progressively replaced by lower-emission alternatives.

New Zealanders can expect to see significant investments in wind, geothermal and solar electricity generation over the next three decades; while new sources of renewable generation such as marine are under development.

Renewable electricity however, is only part of the solution for achieving our low-emissions targets. There will be an ongoing demand for molecules (of gas or liquids) as well as electrons in the energy ecosystem for the foreseeable future.

These molecules will be necessary to:

- Form the products we need (e.g. ammonia , urea, resins and methanol).
- Provide light convenient energy carriers to help power our commercial and heavy transport.
- Store our surplus energy for later use (e.g. via hydrogen, biogas, synthetic gas and ammonia).

Therefore it is critical we explore opportunities to develop hydrogen, and products made using hydrogen, as part of the future mix of options available to deliver our long-term energy future.

Neil Holdom
Chair Tapuae Roa Steering Group
Mayor of New Plymouth District

ABOUT THIS REPORT

It is with great pleasure that the New Plymouth District Council, Venture Taranaki Trust, and Hiringa Energy team present this report on the application of hydrogen technologies in Taranaki and their application more broadly in the New Zealand context.

This report includes a roadmap underpinned by a series of business cases for the adoption of hydrogen technologies in the region, encouraging Taranaki participation in what is an exciting and rapidly developing global industry.

This report is the culmination of a process that commenced in 2016. It builds on the Tapuae Roa Taranaki Economic Development Strategy and was a key part of the resulting Action Plan, supported by the Taranaki district and regional councils.

At its heart is the desire to build on the strong industrial tradition and technical capability in the region to create a sustainable and prosperous future that is consistent with the core values of Tapuae Roa: Whanaungatanga, Kaitiakitanga and Tuakana teina.

ABOUT THE PROJECT PARTNERS

NEW PLYMOUTH DISTRICT COUNCIL (NPDC)

New Plymouth District in north Taranaki is one of three districts in the region and home of the region's largest city. New Plymouth NPDC's strategic priorities focus on building a lifestyle capital through an approach that centres on people, place and prosperity.

VENTURE TARANAKI TRUST (VTT)

Venture Taranaki is Taranaki's regional development agency, with responsibility for delivering economic development services and projects, strategic economic growth initiatives and sector growth projects, regional tourism marketing, destination development and promotion, district marketing for New Plymouth district and management of NPDC major events fund.

HIRINGA ENERGY LIMITED (HIRINGA)

Hiringa Energy is a Taranaki based company focused on developing hydrogen supply infrastructure and transport solutions across NZ to enable the country's transition to a low-emission hydrogen economy. Hiringa Energy has expertise in hydrogen systems development, engineering, commissioning, and the operation of integrated energy systems.

WHAT IS HYDROGEN?

Hydrogen is the smallest and lightest element. It is the most common element in the universe but is not readily available on earth as pure hydrogen as it rapidly combines with other substances to create compounds such as water, hydrocarbons and carbohydrates.

Hydrogen is produced commercially from:

- **Hydrocarbons, and classified as either:**
  - **'Brown' hydrogen – when carbon dioxide is released**
  - **'Blue' hydrogen – when carbon dioxide is captured and stored**
- **Water, and classified as:**
  - **'Green' hydrogen when produced with zero emissions using renewable electricity.**

EXECUTIVE SUMMARY

THE CASE FOR HYDROGEN

ENERGY STORAGE AND USE

Achieving New Zealand's energy targets will be challenging. The main challenge is balancing supply with demand – both within days and between seasons and years (particularly in dry years). It will be very difficult for New Zealand to meet electricity demand peaks if 100% of electricity is supplied from renewable sources such as hydro, wind, solar and marine as these cannot be turned on and off when needed. Storage of electrical energy will therefore be required to meet demand peaks.

Batteries will likely perform an important role in short-term electricity storage, but they are not the solution to storing electricity from month-to-month and year-to-year as scaling up is expensive and batteries lose power over time. Hydrogen offers excellent potential for medium-to-longer term energy storage when produced using renewable electricity. This green hydrogen can then be captured, stored and used later either in a fuel cell[1] or peaker power plant (as hydrogen, or transformed to ammonia or synthetic natural gas) to generate electricity as needed. The storage of hydrogen (and related products) is scalable and does not degrade over time. Hydrogen production plants, coupled with renewable energy, can also perform the role of providing 'virtual' energy storage over the short-term, whereby hydrogen production can be turned off within seconds and the resulting excess power from the renewable generation can be fed into the grid to meet demand peaks.

VEHICLE FUEL

Hydrogen has clear advantages over battery-powered vehicles for the electrification of New Zealand's heavy transport and commercial fleets. Commercial freight vehicles look to carry as much commercial payload as possible but batteries are a heavy form of energy storage compared to hydrogen. This extra weight limits payload capacity of battery-powered vehicles. In addition, commercial vehicle fleet owners often require high utilisation i.e. vehicles are driven long distances or continuously for long time periods and refuelled quickly. Hydrogen powered vehicles have a similar range to current petrol or diesel-powered vehicles and can be refuelled rapidly, enabling efficient fleet optimisation.

Major advancements in battery-powered electric vehicles are occurring and will enable emissions reductions across the entire transport sector, including light vehicles. This has the potential to save the equivalent of 7.4 million tonnes of CO_2 emissions across New Zealand[2]. Light hydrogen fuel cell electric vehicles are already being commercially produced, while hydrogen powered heavy and commercial vehicles are in development.

While there is an argument that battery electric vehicles are more energy efficient from charging through to the wheels, it is in the broader system efficiency that the business case for hydrogen fuel cell technology lies. Hydrogen's ability to capture excess renewable energy without requiring large stationary battery storage or major grid upgrades, combined with the scalability of production and supply infrastructure, translates to total system efficiencies that will lower the cost of low-emissions transport.

It is anticipated that hydrogen fuel cell vehicles will be more competitive than the incumbent diesel technology within the next five to seven years. To remain competitive, fleet operators will need to have plans in place to convert their fleets by this time.

INDUSTRIAL FEEDSTOCK

A number of industrial processes including the production of methanol and urea currently use natural gas as a feedstock to source hydrogen. Green hydrogen produced from renewable electricity can instead be used as a clean feedstock to reduce emissions. This approach is referred to as "Power to X", as the hydrogen molecules produced can be applied to a number of applications.

EXPORT POTENTIAL

Both green hydrogen and/or related products such as methanol or urea can be exported. Hydrogen has the potential to become a major export earner for New Zealand. Japanese companies have already shown interest in procuring hydrogen from New Zealand, and there is current exploration into the use of liquid hydrogen, hydrogen in combination with a liquid organic hydrogen carrier (LOHC)[3] or as ammonia to facilitate international transportation.

1 *A fuel cell combines hydrogen and oxygen to produce electricity. The electricity from a fuel cell can be used in vehicles to power an electric motor. A fuel cell's only emissions are water.*

2 *Assumes 100% of heavy trucking is supplied by hydrogen and 33% of light duty vehicles.*

3 *LOHCs are hydrocarbons that can bond with hydrogen. The resulting compounds are stable at ambient temperature and pressure for safe, cost effective transportation. At destination the hydrogen can be removed and the LOHC returned to source for carrying more hydrogen.*

THE OPPORTUNITY FOR TARANAKI

For Taranaki, a region whose prosperity has been built on the abundance of natural hydrocarbons, the imperative to be part of the transition to new energy systems is particularly pressing. This transition offers a once-in-a-generation opportunity for the region to leverage its human and natural resources to take a leading role in delivering a low-emissions future.

As the centre of New Zealand's energy sector, Taranaki is ideally placed to underpin and enable advancements in renewable energy through:

- The establishment of hydrogen production and refuelling infrastructure to build upon the region's existing energy sector skills and distribution networks. This will enable Taranaki to grow new business opportunities across New Zealand and deliver integrated hydrogen networks for the whole country.
- Storage of hydrogen or synthetic natural gas in depleted gas fields.
- Electricity generation using green hydrogen in Taranaki's gas-fired peaker plants. These plants can be rapidly powered-up to produce vital electricity during periods of peak need, typically supplying the crucial final 15% of electricity demand.
- Development of significant new design, construction and operations capability around the region's natural offshore wind and wave resources, onshore wind, geothermal, hydro, and solar resources, to combine with an integrated hydrogen gas and electricity system.
- Development of hydrogen refuelling infrastructure throughout the region and networked to neighbouring regions and across New Zealand to allow heavy vehicle freight movements.
- Development of a low-emissions hydrogen ecosystem in Taranaki's vital industrial chemical sector[4] to enable major decarbonisation – leveraging existing skills and infrastructure, and ensuring the sector remains viable in the future. This includes use of renewable electricity to produce green hydrogen as a feedstock for methanol and urea production.
- The supply of green hydrogen. Taranaki could become one of several New Zealand regions exporting renewable energy to meet global demand.
- Port Taranaki becoming a key hub for hydrogen export. The Port is already experienced in handling industrial chemical products. Utilising gas infrastructure already centred on Taranaki will allow hydrogen produced elsewhere to be moved cost effectively to the region.

There is potential for integration with international supply chains already in existence through the oil and gas industry, supporting the transition of the region's energy services sector and creating new opportunities for New Zealand businesses.

4 *Most significantly, Methanex produce methanol and Ballance Agri-Nutrients produce urea fertiliser in Taranaki.*

WHY TARANAKI?

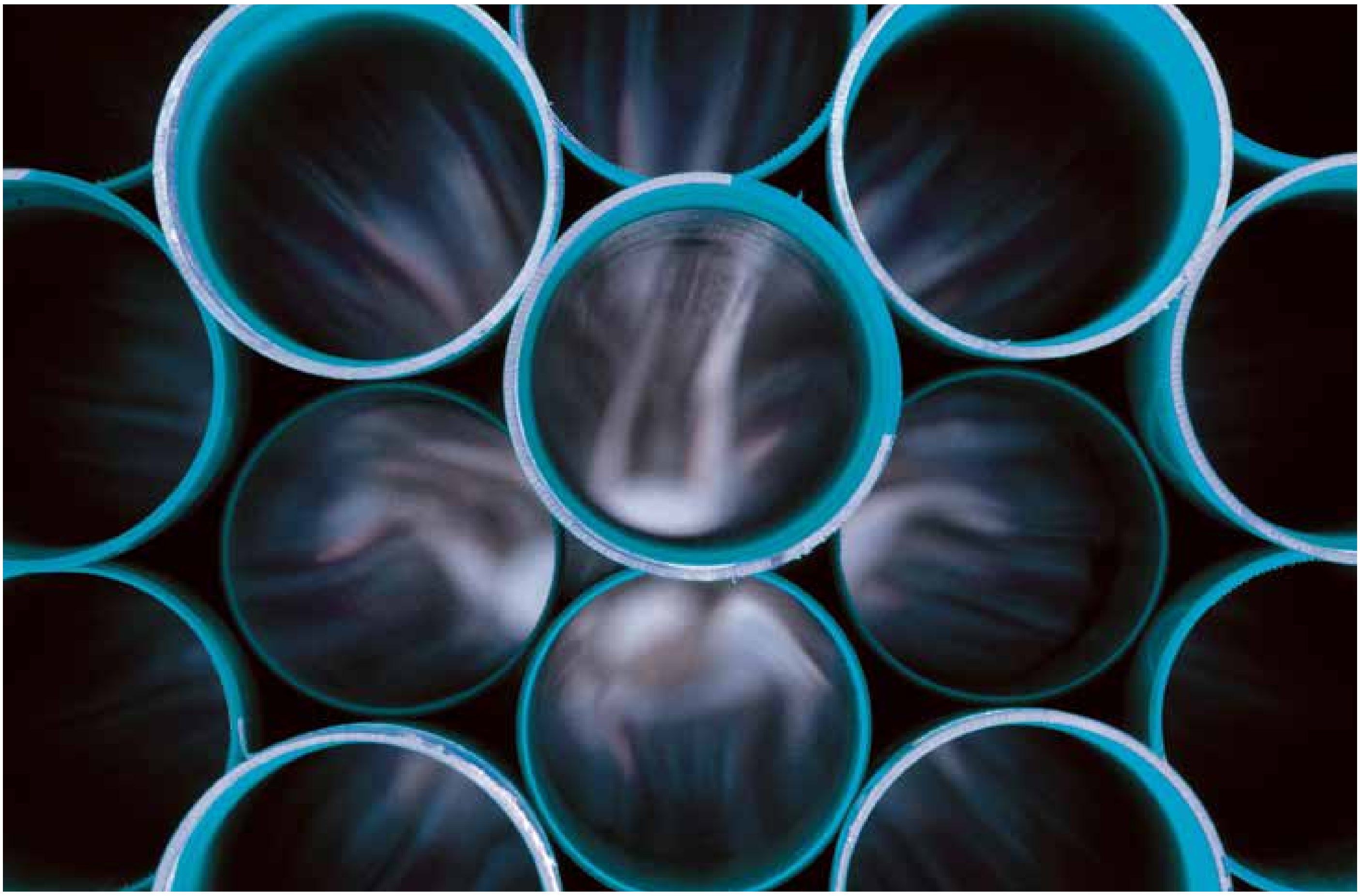
While hydrogen initiatives will occur across New Zealand, Taranaki has a unique collection of strengths that position the region as the major player in the New Zealand hydrogen opportunity.

- Significant water, wind and solar resources
- Already home to large producers and users of hydrogen
- Hydrogen infrastructure design and engineering expertise
- Deep-water port
- Geographically close to Australia and Asia
- Established energy generation and electricity and gas distribution infrastructure
- Local and regional government support
- Significant industrial chemical, engineering and manufacturing capability
- Manufacturing, on and off-shore fabrication and construction expertise
- Supporting service industry including pipeline integrity, very high pressure test facilities
- Operation & maintenance of gas plants
- Leading safety culture with experience of working safely with hazardous materials, gases, drilling for oil and gas, and high voltage power

POTENTIAL INTEGRATION OF HYDROGEN INFRASTRUCTURE

THE MAP SHOWS HOW FUTURE HYDROGEN AND RENEWABLE ELECTRICITY DEVELOPMENTS WOULD INTEGRATE WITH TARANAKI'S EXISTING ENERGY INFRASTRUCTURE.

Offshore Gas Platform
Fixed Offshore Wind and Wave Generation
H2 Powered Heavy Transport
H2 Powered Bus
H2 Production
Green methanol production
NEW PLYMOUTH
Gas Pipelines
Gas Peaker Plant
Blue H2 Production
Remote Stationary Power for Farms
Mount Taranaki
Gas Peaker Plant
STRATFORD
KAPUNI
Onshore Wind
Underground Storage
Green H2 Production
Synthetic fuels
H2 gas storage
Green ammonia
H2 Refuelling Depot
KAPUNI
H2 Powered Milk Tanker
HAWERA
Dairy Factory
H2 Refuelling Depot
H2 Powered Train
Fixed Offshore Wind and Wave Generation
Onshore Wind
PATEA
WAVERLEY



THE H2 TARANAKI ROADMAP

The *H2 Taranaki Roadmap* was developed by Hiringa Energy with support from Venture Taranaki, New Plymouth District Council and the New Zealand Government's Provincial Growth Fund. It is an initiative of Taranaki's Tapuae Roa Regional Economic Development Strategy and Action Plan.

The Roadmap outlines a series of projects that together with leveraging the existing heavy energy industry skills and infrastructure in the region, will help seed the establishment of a low-emissions hydrogen sector. The opportunities have the potential to become multi-billion dollar development projects, create significant employment opportunities, and generate billions of dollars in domestic and export revenue.

At its heart and to start the journey, a critical mass of near-term public and private sector projects are proposed to create the ecosystem and establish a hydrogen industry in New Zealand, including:

- Establishment of a New Plymouth refuelling station and out-of-region connecting hubs, to service buses, trucks, light commercial, waste and contractor specialised vehicles.
- Development of a green ammonia project at Kapuni, establishing hydrogen production to support the growth of hydrogen transport and provide the foundation for transition to a low-emissions chemical industry.
- Implementation of hydrogen into a stationary energy application within regional infrastructure such as one of the region's aquatic centres, council buildings or district health facilities, providing combined heat and power, energy storage and resilience.
- Deployment of near-term projects with Japanese and other international partners that enhance business and regional relationships and create the basis for future export developments.
- Studies and trials for hydrogen injection into the gas grid, including 100% hydrogen scenarios.
- Investigation of carbon capture and storage using the Taranaki gas fields together with carbon capture utilisation options, including synthesis of fuels and industrial chemicals.
- Exploration of opportunities to use hydrogen-based fuels in peaker electricity generation plants.

H2 TARANAKI

H2 Taranaki will coordinate delivery of the Roadmap.

H2 Taranaki will initially be a public-private partnership between New Plymouth District Council, Venture Taranaki and Hiringa Energy, with the inclusion of formation partners Taranaki Regional Council, Stratford District Council and South Taranaki District Council.

Participation of local businesses and organisations will be highly encouraged, with the expansion of activities beyond the initial partners a key objective.

H2 Taranaki will support the development of a hydrogen ecosystem in the region, aiming to:

- Attract investment in hydrogen production, leveraging existing energy industry capability and access to renewable energy.
- Accelerate local demand for hydrogen as an economic, low-emissions, renewable and secure input for transport, energy and industry.
- Position Taranaki businesses to participate in a growing international industry.
- Nurture and enable the development of a hydrogen export industry.

THE ROADMAP ENVISAGES A SERIES OF PROJECTS THROUGH TO 2030:

	2020
TRANSPORT	Forklift pilots
	Carshare pilots
	Bus pilot
	Medium truck pilot (Waste truck & civil contractor)
	Heavy truck pilot
REFUELLING & DISTRIBUTION	400-600 kg/day supply capacity (NP) 3 x refueling stations (2 external to region)
	Liquid Organic Hydrogen Carrier (LOHC) distribution pilot
INDUSTRIAL	Hiringa/Ballance Kapuni ammonia project
LARGE SCALE STORAGE	H_2 pipeline injection trial
	Blended H2 peaker
STATIONARY & REMOTE ENERGY	Council ammonia fuel cell project trials
EXPORT	
PRODUCTION (TARANAKI)	2000-3500 kg/day production (8 MW installed renewable generation)


2025
2030
Scale up forklift fleets
Light vehicle public refueling access and fleet expansion
Scale up light fleets
Intercity bus pilots / expand regional fleet
Scale up light fleets
Full waste fleet adoption
Scale up medium truck fleets
Heavy long haul and short haul fleet trials
Fleet conversion and expansion to dairy, forestry
800-2000 kg/day supply & expansion outside region. Light vehicle public refueling access
Scale up existing refueling stations, additional stations in Taranaki and across NZ
LOHC full commercial
LOHC for domestic & export
New-build green ammonia production
Green ammonia export
Carbon capture and synfuel pilot
Scale up of synfuel
Synthesised methanol pilot
Scale up methanol
H₂ pipeline injection blending/storage
100% H₂ pipeline conversion
plant trials
100% H2 peaker plant trials
100% H₂ peaker plant conversion
10MW methanation plant pilot
100MW methanation plant
Multiple distributed methanation plants
Trial large backup fuel cell applications for infrastructure
Large scale integration of fuel cells with district infrastructure for backup and grid stabilisations
Large FC system suitable for all council remote applications
Implement fuel cells in all applicable remote applications
Grid stabilisation
Pilot export technology (LOHC or Liquid)
500-1000 MW export facility
12,000 kg/day production (50 MW installed renewable generation)
700-2,000 T/day production (3-8GW installed renewable generation)

PURPOSE

This report provides a contemporary outline of the emerging hydrogen energy opportunity from a global context, but more importantly describing the role for Taranaki to leverage its natural advantages to help seed the establishment of a hydrogen economy in New Zealand.

The report presents a road map supported by a series of preliminary qualitative and quantitative business cases for key projects to underpin the H2 Taranaki initiative. The intended focus was on the development of refuelling infrastructure and piloting of hydrogen transport solutions.

H2 Taranaki was envisaged as public/private initiative that supports the development of a hydrogen ecosystem in the region. At its heart will be a critical mass of public and private sector projects that demonstrate the use of hydrogen in a number of end use applications.

The aims of H2 Taranaki are to:

- Attract investment in hydrogen production, leveraging gas industry capability and access to renewable energy.
- Accelerate local demand for hydrogen as an economic, low emission, renewable and secure input for transport, energy and industry.
- Position Taranaki businesses to participate in a growing international industry.
- Nurture and enable the development of a hydrogen export industry.

The initiative will establish a hydrogen-based energy ecosystem for the demonstration of low emission transport solutions for heavy transport, renewable energy storage solutions, industrial feedstock and heating, and the export of renewable energy.

The scope of work covered by this report includes:

- Identification of the applications for hydrogen in the Taranaki energy ecosystem including transport, industrial use, energy storage and export potential
- Preliminary business case development for public fleet conversions to hydrogen
- Identification of other public sector applications for H2 usage / projects
- Identification of required procurement processes, regulation and compliance requirements
- Mapping of potential adoption and uptake and infrastructure requirements
- Identification and mapping of private sector projects that could utilise shared infrastructure or benefit from combined vehicle trials
- Identification of potential sources of funding for projects

Preliminary business cases for public and private sector have been developed to support the roadmap but are not included in this report. Further business case development will be undertaken as part of the planned H2 Taranaki initiative.

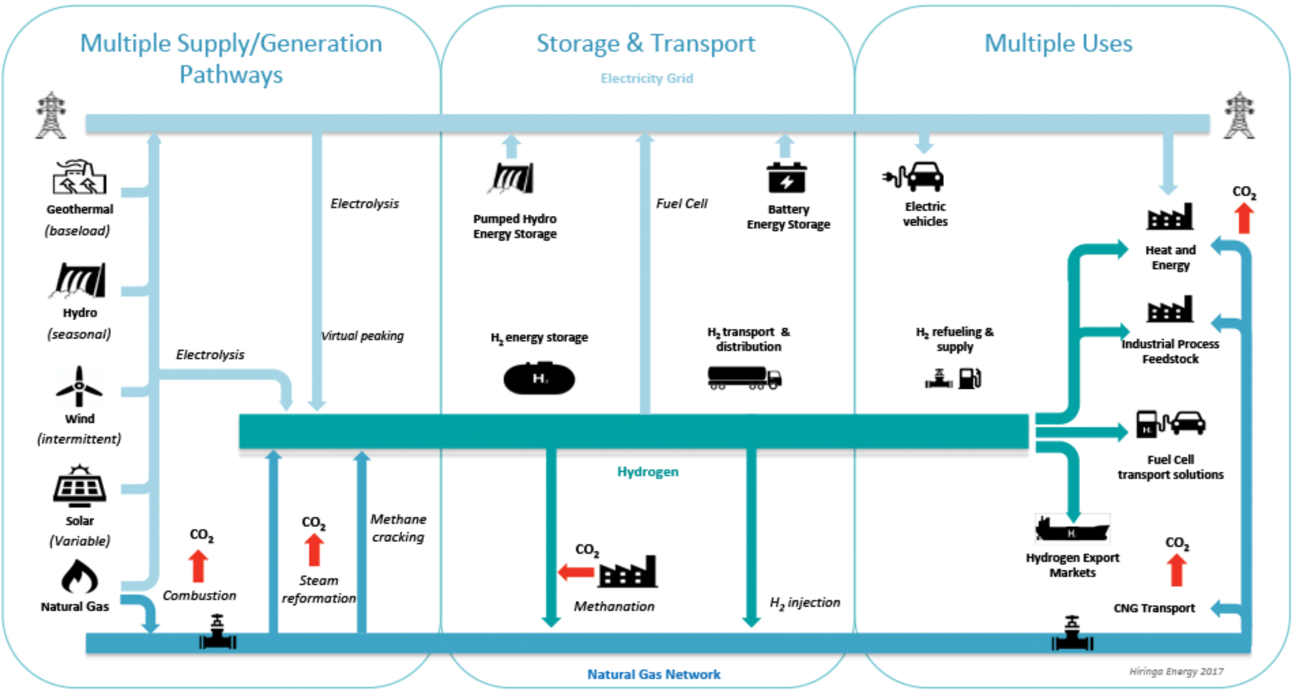
BACKGROUND

The desire for renewable low-emissions transport and heat and energy storage solutions is driving international interest in hydrogen as a clean energy carrier. McKinsey estimates that industry and government investments in hydrogen of US $20-$25 billion per annum could create a self-sustaining market by 2030, turning over more than $2.5 trillion and creating some 30 million jobs along the value chain.

Taranaki is particularly well suited to pilot and develop a low-emissions hydrogen ecosystem. It has significant water, wind and solar resources, established gas and power infrastructure and production, and a deep-water port with convenient geographical position for access to Asian export markets. Uniquely, Taranaki is also home to two of the largest hydrogen producers in New Zealand (Methanex and Ballance Agri-Nutrients), the significant technical capability they possess, and a geographical cluster of heavy industry users. These assets could be leveraged by the H2 Taranaki initiative.

Hydrogen can become the backbone of low-emissions energy production, storage, distribution, and use for transport fuel, heating, manufacturing, and industrial feedstock. It is therefore one of the technology areas capable of reducing regional greenhouse gas (GHG) emissions. When used in fuel cell electric vehicles, hydrogen can provide increased range and the ability to carry heavier loads than battery-only electric vehicles. These features become increasingly important in commercial mobility applications in geographically isolated regions such as Taranaki.

In an integrated system hydrogen becomes an energy vector that can link the “electron world” to the “molecule world”. In so doing it becomes a bridge for renewables to achieve greater penetration of the energy system enabling deep decarbonisation.



Hydrogen provides an “energy vector” connects the electrical and the molecular world, enabling penetration of renewable low-emissions energy to the whole energy system.

HYDROGEN GENERATION & PRODUCTION

Hydrogen has been used industrially for over 100 years, and is used in Taranaki as part of the process of producing methanol, urea fertiliser, and other industrial chemical products. Hydrogen can be produced either by separating it from oxygen molecules in water through the process of electrolysis, or by splitting it off hydrocarbon chains in fossil fuels.

There are four different classifications of hydrogen production, with each having different emission profiles:

Brown Hydrogen Most widely produced from natural gas via steam-methane (from natural gas) reforming, which produces hydrogen and CO_2. Currently, 95% of hydrogen produced globally is brown hydrogen.

Grey hydrogen Grey hydrogen is a relatively niche method where excess waste hydrogen from a brown hydrogen industrial process is purified and used to supply a secondary hydrogen market. As long as the source is truly excess waste and this activity does not increase the CO_2 emissions of the process, grey hydrogen can provide a source of hydrogen without additional emissions.

Blue Hydrogen Produced from natural gas via steam-methane reforming, or from coal gasification where the majority of CO_2 is captured and sequestered (not released into the atmosphere). This is done via CCS (Carbon Capture Storage) or via CCU (Carbon Capture Utilisation) which has a low emissions profile.

Green Hydrogen Typically produced via electrolysis, which is the process of using electricity to split water into hydrogen and oxygen. When using renewable energy electricity sources, this type of hydrogen is effectively emission free.

To achieve global emissions targets the production of brown hydrogen will need to be replaced by blue or green hydrogen. Blue hydrogen is dependent on ongoing gas supply and CO_2 sequestration or use and will ultimately need to be replaced by green hydrogen due to the finite nature of gas reserves.

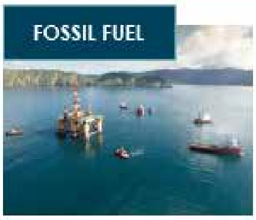
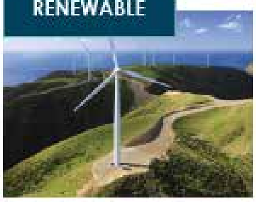
The relative economics of blue hydrogen and green hydrogen will depend on a combination of technology, markets and regional factors.

Green hydrogen production economics are largely influenced by:

- The potential of a region to produce commercial and industrial scale low cost renewable electricity.
- The size of an accessible market to support larger volumes enabling economies of scale in distributed production facilities.
- Continuation of the technology cost reduction curve of electrolysis with volume and technology improvements.
- The ability to integrate both renewable generation as distributed base load electricity production and efficient hydrogen production from excess generation.

Blue hydrogen production economics are influenced by:

- The availability of natural gas reserves, and cost competitive gas supply.

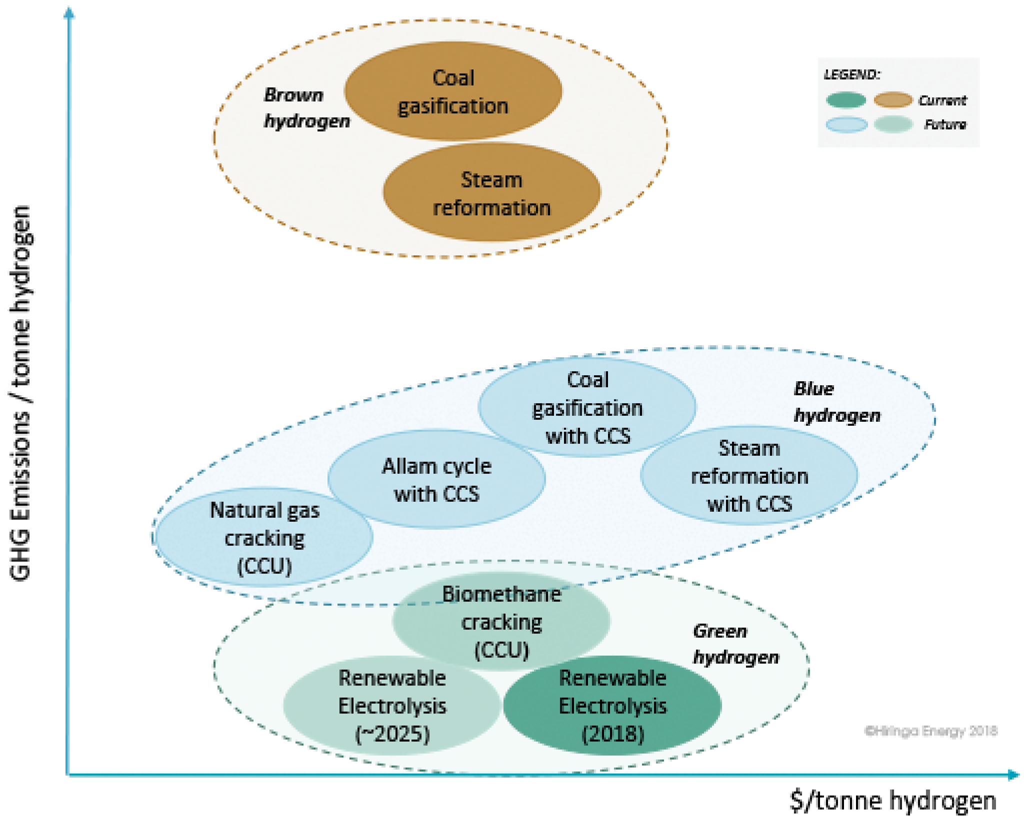
	Classification	Source	Current Use
FOSSIL FUEL 	BROWN	Fossil Fuel – CO & CO_2 released	98% Now
	GREY	By-product / waste stream capture	Small percentage today
	BLUE	Fossil Fuels with Carbon Capture & Storage (CCS) or Carbon Capture & Use (CCU)	R & D Feasibility
RENEWABLE 	GREEN	Electrolysis of water using renewable power	Small percentage today

- The potential to economically utilise or store large volumes of captured CO_2
- The size of an accessible market to support larger volumes enabling economies of scale in production facilities.

Taranaki hydrogen production is presently 100% brown hydrogen however, with the existing gas infrastructure and renewable energy potential the region has significant opportunity for the production of both large scale blue and green hydrogen. Given the current gas reserves position in New Zealand the best use of blue hydrogen is likely to be for the transitional decarbonisation of the existing natural gas energy system (process heat, existing industrial chemical production, peak power generation).

Green hydrogen can be applied to both the existing gas energy system as well as new hydrogen markets such as transport, export, and remote/backup energy.

With the potential of Taranaki's undeveloped wind, water, solar and wave resources there is significant opportunity to develop large scale green hydrogen production to supply multiple markets including industrial feedstock, transport, stationary energy and export. The economy of scale of multi-megawatt electrolysis facilities and reduced cost of renewable energy is projected to drive green hydrogen electrolysis pricing to parity and likely below cost of installing new brown hydrogen production (Jon André Løkke, CEO NEL Hydrogen, Hydrogen Energy Ministers Meeting Tokyo 2018).



HYDROGEN APPLICATIONS

Hydrogen can be applied across broad energy markets and applications. This report categorises these applications into four main groups:

	APPLICATIONS	ADVANTAGES	ENABLERS
Transport & Mobility	Materials handling Light vehicles Buses, trams & trains Medium & heavy vehicles	Range Weight/payload Quick refuelling Energy security	Hub fleets Vehicle availability Demand aggregation Availability of H_2
Stationary Energy and Storage	Large scale storage Back-up energy Remote energy supply Grid stabilisation Power to gas	Low emissions Reliable Low maintenance Efficient storage and use Dry season storage	Reducing cost of renewables Off-peak pricing Legislation New custom solutions
Industrial Heat & Feedstock	Industrial chemicals Urea Fertiliser Refining & smelting Process Heat	Feedstock for low-emissions chemicals Low-emissions heat	Premium for green products Cheap power Scale
Export	Japanese & Korean energy markets	International emissions reduction Export earnings	Hydrogen Carriers (Ammonia, Liquid Hydrogen, Liquid Organic Hydrogen Carrier.) Domestic market offtake Power market integration

TRANSPORT AND MOBILITY

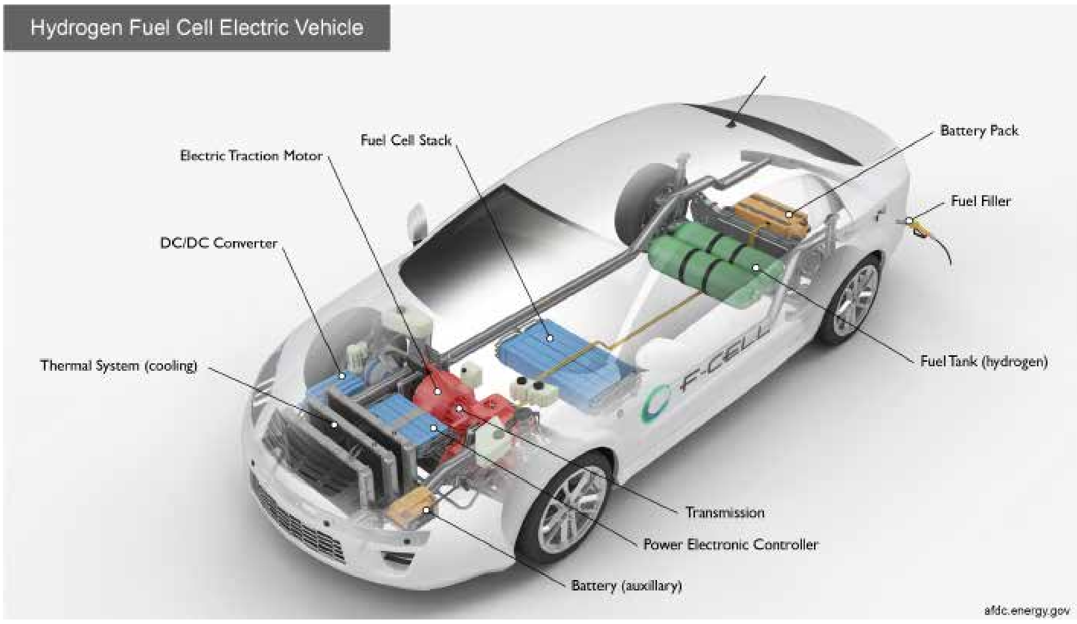
A significant emerging market for hydrogen is its use in Fuel Cell Electric Vehicles (FCEVs). FCEVs are electric vehicles that utilise a fuel cell to convert hydrogen carried on board together with oxygen extracted from the air to provide electrical energy to the electric drive train. The by-product of the process is clean water vapour. Smaller batteries are used to provide a buffer of electrical storage to enable acceleration and regenerative breaking.

FCEV's have all the benefits of battery powered electric drive trains in comparison to Internal Combustion Engines (ICEs):

- They provide higher drive train efficiency in comparison to ICEs and turbines
- They emit very low noise levels enabling operation in more noise sensitive areas
- They provide high torque and acceleration, increasing average speeds
- They provide regenerative breaking increasing safety and further improving efficiency
- The overall vehicle lifecycle maintenance costs will be lower than Internal Combustion Engines (ICE) due to the the significant reduction in moving parts subject to wear.

In addition to these benefits, FCEVs also remove key barriers associated with Battery Electric Vehicles (BEVs) when looking to electrify commercial fleets and heavy transport. These features have been demonstrated in real operating environments in a number of fleets internationally:

- FCEVs can be refuelled in comparable time as a diesel or petrol ICE vehicle therefore incurring no loss of productivity.
- Fuel cells demonstrate an extended performance lifespan in comparison to lithium batteries that have experienced standard charging, this performance gap increases with batteries that have been fast charged for significant periods of their service. Fuel cells can be refurbished and at the end of their life are 95% recyclable, reducing overall battery disposal requirements and lifecycle costs.
- Hydrogen fuelling infrastructure is scalable and uses much less real-estate than individual chargers. Fleets don't need to have dedicated parking space and charging infrastructure made available.

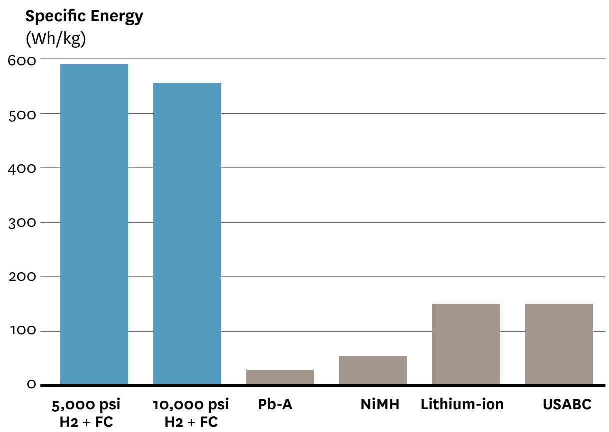


- High torque and acceleration
- Zero emission – no NOX
- Low noise
- Low maintenance cost
- High drive-train efficiency versus internal combustion engines and turbines

- Hydrogen fuel cell systems can store significantly more energy per kg than current battery technology (550-600 Wh/kg compared to 150 Wh/kg for lithium batteries). This has a major impact on commercial payloads and road loads, particularly as vehicle size increases.

The business case for FCEV fleet adoption is particularly strong in operations where vehicle utilisation, and/or range and/or payload represents commercial benefits. In addition, the infrastructure and space savings through avoiding charging logistics can provide incremental value for commercial operators. This feature is already an established driver for large warehouse material handling fleets with over 50,000 fuel cell forklifts operational in warehouses in US, Canada and Europe.

The Vivid Economics report published December 2018, prepared for FIrstGas and Powerco titled “Gas infrastructure futures in a net zero New Zealand” also recognized this key benefit of hydrogen and assumes hydrogen FCEVs become the main type of heavy goods vehicles in its modelled scenarios, stating, “The high energy needs of large, long-distance heavy goods vehicles, and low energy density of batteries, mean that battery solutions are likely to be too large and heavy to accommodate in an HGV without radical breakthroughs in battery technology.”



The energy storage per unit weight (Wh/kg) of hydrogen tanks and the associated fuel cell is significantly more than Li-Ion batteries.

10 000 psi (700 bar) tanks are heavier than 5000 psi (350 bar) due to the additional fiber wrap to provide the required strength.

Source: Fuel Cell and Battery Electric Vehicles Compared By C. E. (Sandy) Thomas, Ph.D., President H2Gen Innovations, Inc.

Fast refuelling times	High vehicle utilisation	More loads/ day	Reduced OPEX
Increased range	Route flexibility	Less vehicles required	Reduced CAPEX and OPEX
High torque and acceleration	Increased average speeds	More loads/ day	Increased revenues
Reduced maintenance requirements	Reduced OPEX	Extended vehicle life	Reduced Vehicle CAPEX
Weight advantage over BEV	~3-8 tonnes/ truck	Increased payloads	Increased revenues
Reduced fuelling/charging infrastructure	Reduced infrastructure footprint	Improved space utilisation	Increased revenues/ reduced opex
Renewable fuel supply	Energy security	Opportunity to invest in supply chain	Reduced OPEX
True zero emission logistics	Sustainability benefits	Workforce & community benefits	Branding benefits

Benefits of FCEV's for vehicle fleets are multi-faceted and aggregate to improved Total Cost of Ownership (TCO) outcomes

This report outlines the current status of FCEV technologies and their potential applications for fleet adoption in local councils, contractors and commercial fleet operations.

Hydrogen has been proven to be as safe as or even safer than other flammable fuels such as gasoline or natural gas.

- Hydrogen is 14 times lighter than air, so it disperses very quickly in the atmosphere.
- Hydrogen is non-toxic.
- The optimal mixture for hydrogen combustion is 29%, which is difficult to achieve due to its diffusion propriety.
- Its flame does not radiate, therefore fires do not spread as easily as hydrocarbon fuels.

However, there are additional features of hydrogen that need to be managed:

- It has a wide explosive range, compared to other fuels, it ignites more easily.
- It burns with an invisible flame.
- It is difficult to odourise to aid in leak detection, due to contamination of fuel cells by odourising agents.

To tackle these issues the safety systems for refuelling and on-board storage involves:

- Adequate ventilation and leak detection.
- Pressure relief devices and a safe shutdown program to lock and isolate components.
- Carbon-fibre storage tanks, stronger and more crash-proof than conventional petrol and diesel tanks

The storage of hydrogen is undertaken on-board the vehicle under high pressure between 5000psi (350bar) – 10,000psi (700 bar) dependent on vehicle type. The technology to safely refuel and store hydrogen at these pressures in vehicles has been fully developed with alignment of international standards and a strong track record of safety in operating environments.

STATIONARY ENERGY AND STORAGE

Hydrogen has the potential to act as a large-scale energy carrier for mid to long time durations and relatively small to very large amounts of energy. Hydrogen generated from excess renewable electricity can be:

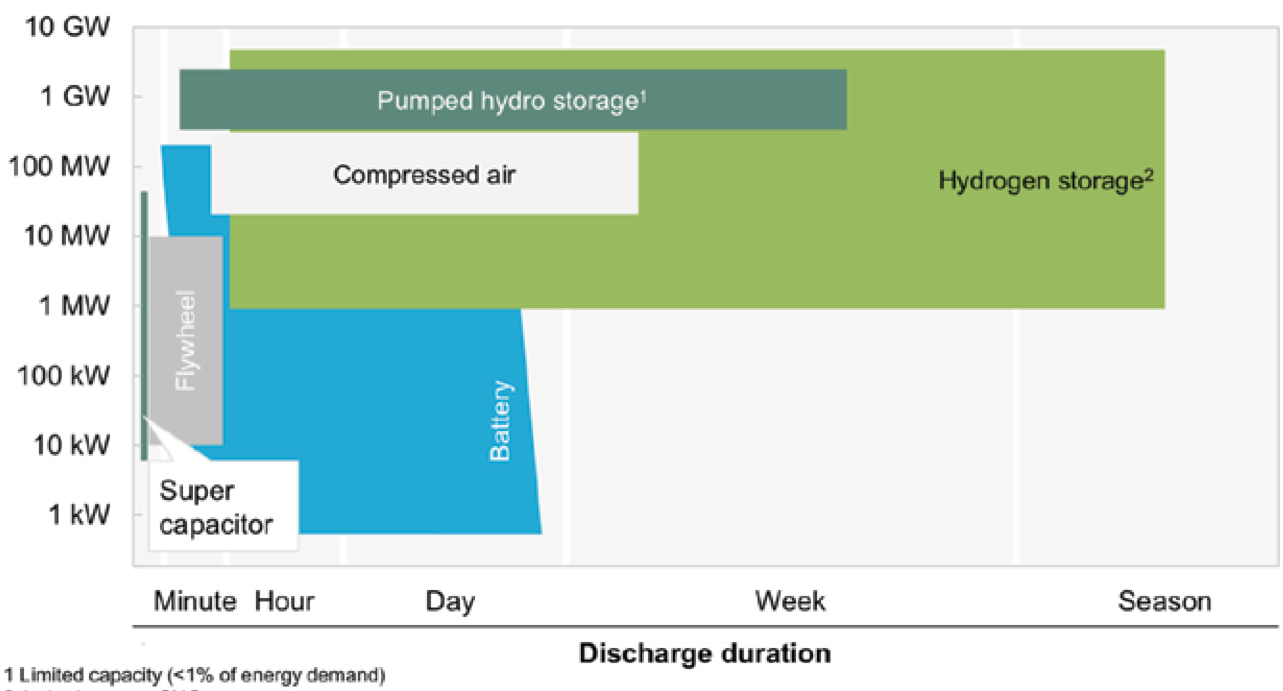
- stored as hydrogen,
- converted to ammonia,
- bonded with liquid carriers
- synthesised into methane for later use.

Electrolysers can respond rapidly to load fluctuations enabling short term demand response.

There are various ways that renewable energy can be stored. Hydrogen, whether as hydrogen gas or a bonded molecule, is likely to be the best opportunity for storing large quantities of energy over large periods of time. This is a vital issue for New Zealand to resolve during dry years where there will be considerable stress on the electricity supply as the proportion of renewable electricity generation increases. This dry year problem could be addressed by creating renewable electricity and storing it in the form of hydrogen, synthetic methane (otherwise known as Synthetic Natural Gas – SNG), or ammonia to be turned back into electricity when needed.

The graph below outlines the wide application potential of hydrogen to provide near, mid and long term storage.

In a later section, this report will explore how hydrogen can be used to store energy in the Taranaki and greater New Zealand energy system. The strategic creation of a hydrogen ecosystem could provide the ability to both efficiently build new renewable energy infrastructure but also leverage the existing energy infrastructure for maximum economic and environmental benefit.



1 Limited capacity (<1% of energy demand)
2 As hydrogen or SNG

SOURCE: IEA Energy Technology Roadmap Hydrogen and Fuel Cells

INDUSTRIAL HEAT AND FEEDSTOCK

The production of green hydrogen based on renewable energy can provide a key building block for the transition of the existing industry to low emission production. An illustration of the potential integration of green hydrogen into the existing electricity, gas and gas derivatives industry infrastructure is presented below.

Hydrogen is already a critical input to the industrial scale production of ammonia via the Haber-Bosch process. Typically, the hydrogen is produced by reformation of natural gas, however using green hydrogen enables production of green ammonia using only water, air and renewable energy. Ammonia is also looked at as an energy carrier for hydrogen transport by leveraging the existing ammonia supply chain rather than building out new compressed gas distribution networks.

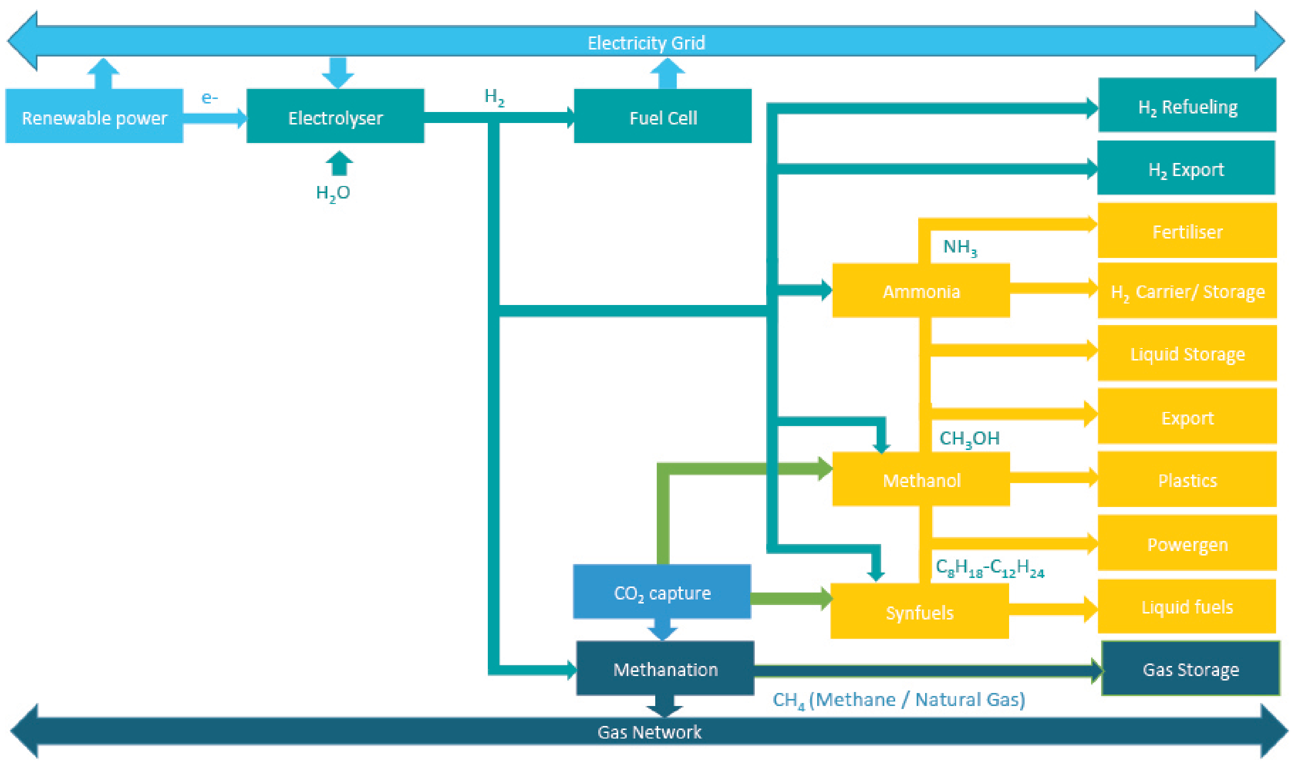
Another potential use for hydrogen is in the substitution of natural gas for use in process heat. Hydrogen releases no additional CO_2 emissions upon combustion and has far greater energy density than natural gas. While industrial boilers and combustion components would need retrofit to utilise hydrogen as fuel, several projects are looking at this at scale, the largest of which is the H21 project in the UK which aims to convert the entire Northern Gas Network over to hydrogen. Hydrogen can also be blended in the gas network to incrementally reduce emissions, or piggyback on the existing gas network for large scale distribution.

Hydrogen can also be combined with captured carbon dioxide to produce a range of liquid hydro-carbons (via the Fischer-Tropsch process) for transport fuels, methane, methanol, plastics and other synthetic petro-chemicals. Many companies are commercializing technologies that combine H2 and CO_2.

Carbon Recycling International (CRI) has developed a low temperature and low-pressure conversion technology that combines hydrogen, and CO_2 to produce synthetic methanol. The technology is applicable over a range of plant sizes, enabling distributed plant deployments into a variety of niche markets. CRI has built a 5 million litre per year synthetic methanol plant in Iceland which uses green electricity from the national hydroelectric and geothermal grid, and sources CO_2 from a nearby geothermal power plant. The synthetic methanol is then used both domestically and exported internationally for blending with gasoline and in biodiesel production.

Carbon Engineering in Canada uses air captured CO_2 to produce transportation fuels like diesel and jet kerosene. Enabled by hydrogen, this technology de-couples biological feedstock aggregation and land use issues from the production of drop-in transportation fuels.

Electrochea in Germany uses a biological catalyst to combine hydrogen and CO_2 to make pipeline quality renewable natural gas. This technology is already being demonstrated at MW scale at the Avedore water treatment facility in Copenhagen.



HYDROGEN EXPORT

Hydrogen in its molecular form H_2 is an energy carrier. This hydrogen can be utilised to transport energy from countries and locations with excess energy potential to countries and locations with insufficient energy potential. If the hydrogen can be produced from renewable energy and stored in a transportable form such as compressed or liquid H_2, a liquid carrier or ammonia it effectively becomes a means to export renewable energy. This could have significant future potential for New Zealand given the undeveloped renewable potential.

Establishment of a global hydrogen supply chain is gaining momentum with the technology moving from R&D to pilot scale demonstrations. Japan is the major driver in these activities with the large-scale importation of hydrogen a key part of the Japanese hydrogen society road map.

RELEVANT INTERNATIONAL ACTIVITIES

UK AND EUROPEAN ACTIVITIES

During October 2018 a delegation from the H2 Taranaki team travelled to Northern Europe and the UK to visit a number of hydrogen projects, meet with similar regions' officials and businesses involved in the energy transition and attend relevant conferences and summits.

A more detailed outline of the tour is presented in the report appendices.

The UK/Europe regions visited were experiencing similar issues around energy transition and have identified similar opportunities to those identified in the H2 Taranaki framing. It became apparent that recognition has grown significantly in both the political and private sectors that hydrogen has a major part to play in the deep decarbonisation needed to achieve COP21 commitments.

For Europe it has almost become a race to keep European technology at the forefront with the recognised risk that the major Asian economies such as Japan, China and Korea could potentially outcompete the traditional energy and transport technology manufacturing industries of Europe. A stark example is the recent announcement by Hyundai of an agreement to sell 1000 medium duty fuel cell trucks into the Swiss market, while European truck companies are still experimenting with multiple technology platforms.

There have been numerous demonstration projects around fuel cell vehicles and fuelling infrastructure. Historically the majority of projects have been focused on trials in public sector fleets such as buses, waste trucks, and street sweepers. A major challenge for these early projects has been the sub-commercial scale of the facilities and fleet sizes, with a heavy reliance on ongoing subsidies and a lack of commercialisation pathway.

These projects have however, been successful in proving feasibility of a number of technologies and applications. Technologies are still improving further and costs are continuing to drop (from a high base) from both technical improvements and increased manufacturing volumes. There is a growing focus on integration of projects to create networks and eco-systems rather than stand-alone projects. The aggregation of demand through focused public sector and commercial fleet establishment enabling development of refuelling hubs is becoming recognised as the most robust commercial model. This is the model that Hiringa Energy is looking to develop with partners in New Zealand.

The recent shift is towards scaling up the projects to commercial volumes and integration of hydrogen production from excess renewable energy, storage and refuelling. European funding is primarily focused on grant and loan models that address early Capex barriers to stimulate large commercial scale roll-outs of both public and private sector transport fleets, and industrial and storage projects. The aim is to achieve the operating scale that avoids the need for ongoing subsidisation. Examples include a €40m ($66m) H2BusEurope grant to support 600 fuel cell buses in a series of large bus fleets, a €16m ($27m) REFHYNE project 60% grant from the FCHJU[2].

To support both the increased electricity and hydrogen demand it is recognised there is a need to materially increase renewable generation in north-western Europe. Due to resource constraints this is largely being addressed by wind. This is likely to include major offshore fixed and floating wind developments (in the order of 180 GW of turbines are being envisaged).

Consideration is being given to utilising retired offshore North Sea O&G platforms as sites for electrolysers connected to offshore turbines. The hydrogen generated could then be sent onshore using existing pipelines. Alternatively, electrolysers could be sited on a proposed artificial island in the North Sea.

A consortium of European energy and infrastructure companies have formed the North Sea Wind Power Hub project which is proposing to build an artificial island in the North Sea as a base for hydrogen production and distribution

To further address the intermittency/energy storage challenge, with renewable electricity a number of peaker-plant technology modifications are being explored based on using renewable electricity to produce hydrogen, which is either stored as hydrogen or converted to ammonia and then fed into modified turbines.

Several major gas transmission infrastructure companies are also exploring how their networks can be used to distribute either blended hydrogen or 100% hydrogen. Studies are underway on using hydrogen to wholly or partially replace natural gas in domestic networks.

The region of Northern Netherlands including the city of Groningen is a very good example of the development a hydrogen ecosystem as a key transition strategy for an economy that has been built on the gas industry. There is significant regional and central government stimulus being applied to the development of hydrogen projects and supply chain capability. The strategy is well outlined in vision and roadmap document "The Green Hydrogen Economy in the Northern Netherlands" (Northern Netherlands Innovation Board (NIB), 2017).

Overall the hydrogen eco-system in Europe is moving rapidly from initial projects with academics testing feasibility through demonstration projects to large scale commercial reality.

CHINA ACTIVITY

China has been developing fuel cell technology since the early 2000's. However, it is more recently that the acceleration to fleet adoption has begun to make an impact. China has been a major adopter of battery electric vehicles which has driven down the cost of lithium batteries and electric drive trains. The government has recently shifted its focus to fuel cell technology as a means to both address GHG emissions and pollution, particularly for heavy and fleet vehicles where battery electric only is too limiting.

2 *FCHJU – Fuel Cell and Hydrogen Joint Undertaking – an EU funded public/private body www.fch.europa.eu*

A number of fuel cell factories have been established in China, including Ballard and Hydrogenics facilities. This move to mass Chinese production has potential to be the tipping point for fuel cell technology adoption.

Latest data suggest 80-150 small trucks are running commercially in China, with 300-500 fuel cell buses and 100-150 specialty vehicles.

A key difference in China is the focus of early fuelling infrastructure around fleets rather than retail stations.

Several heavy truck and bus projects have been announced with co-operation agreements between international hydrogen technology companies and Chinese partners.

JAPAN ACTIVITIES

Japan has become a major driver of the modern push to the hydrogen economy. The country is a significant energy importer due to a lack of domestic natural energy resources. With curtailment of nuclear power post Fukushima there is a need to rapidly apply other methods to decarbonise the energy system.

Japan has announced and reconfirmed that it will develop a "Hydrogen Society" over coming decades. Hydrogen provides a mechanism to import large amounts of renewable energy from regions that have excess production capability. This imported hydrogen can then be applied across the energy system for transport, heat and power, and industrial feedstock. For example, it is likely that a relatively large proportion of Japan's vehicle fleet will be hydrogen fuel cell vehicles due in part to an inability to provide sufficient renewable electricity for vehicle charging.

New Zealand represents an excellent potential energy trading partner, having:

- Existing renewable production and significant potential for further production capacity
- Renewable energy industry skills and capability
- Strong existing trading ties with Japan
- A stable political climate

To complement these strengths, Japan has much to offer with its hydrogen technology capability from fuel cell vehicles, to power generation and storage technologies. New Zealand imports large numbers of second-hand vehicles from Japan and it is likely that this will continue when Japan transitions to hydrogen FCEVs resulting in an increasing number of fuel cell vehicles available.

Near term tangible activities include:

- The signing of a Memorandum of Cooperation between Japan and New Zealand by the respective Energy Ministers to develop a partnership allowing the exchange of information to enhance hydrogen development;

A near term major activity to stimulate the "Hydrogen Society" in Japan is the creation of a hydrogen ecosystem for the 2020 Tokyo Olympic Village.

- The establishment of a joint venture between Japan's Obayashi Corporation and Tuaropaki Trust for the planned construction of a pilot hydrogen production plant near Taupō using geothermal energy.

Taranaki has potentially a large part to play in the future of a Japanese/New Zealand hydrogen trading relationship, as discussed in this document.

KOREAN ACTIVITIES

South Korea, an energy poor country has also identified hydrogen as an important part of its energy mix and technology future. The Korean government has proposed a Hydrogen Economy Act that has received strong bipartisan support and has also set hydrogen as one of three strategic investment areas.

In 2016 the Finance Minister announced a government plan to replace the country's approximately 26,000 compressed natural gas (CNG) buses with Fuel Cell Electric Buses (FCEBs).

In June 2018, the Ministry of Industry, Trade and Energy announced a 2.6 trillion won plan to supply 16,000 hydrogen-powered vehicles and build 310 hydrogen refuelling stations across the country. Under the five-year plan, businesses are expected to get state support for the development of fuel cell stacks and fuel cell storage containers, as well as tax breaks for hydrogen vehicle drivers.

Hyundai has been accelerating its activities internationally with the new Nexo FCEV SUV moving to full production by the end of 2018 and the development of a commercial heavy trucking solution to be sold into Europe commencing 2019. It is also looking to move to mass production of FCEBs by 2020.

The development of hydrogen ecosystems across the energy mix is also getting significant attention with major projects such as the world's largest hydrogen fuel cell power plant in Seosan. Like Japan, it is also likely that Korea will look to import hydrogen to supply its energy needs.

Hanwha Energy and Korea East-West Power have started construction on the world's first 50 MW hydrogen fuel cell power plant. The plant is expected to cover over 20,000 square meters and provide 40,000MWh of energy per year, enough to power 17,000 thousand households. Construction is scheduled to be finished by 2020.

New Zealand has a free trade agreement with Korea that would potentially provide a strong platform for the trade of hydrogen and importation of fuel cell vehicles.

CANADIAN ACTIVITIES

Canada has been involved in fuel cell development for many years.

Several significant fuel cell and hydrogen technology companies are based in Canada with examples such as Ballard, Hydrogenics, PowerTech, Greenlight Innovation, HTEC and Hydrogen in Motion. Canada developed one of the first hydrogen fuel cell electric bus projects for the Vancouver/ Whistler Winter Olympics. However, this early adoption of hydrogen fuel cell solutions in many ways slowed down the broader adoption as these early demonstration projects were not commercially viable.

Recent years have seen a resurgence in hydrogen technology adoption with a programme to install refuelling stations in British Colombia and significantly a hydrogen rail "Hydrail" feasibility study announced by Metrolinx the Crown agency that manages and integrates road and public transport in the Golden Horseshoe region, which includes the cities of Toronto and Hamilton, in the province of Ontario.

With the global acceleration of hydrogen developments, Canada is well positioned to further strengthen its capability in hydrogen technology which will provides an excellent technology access pathway for New Zealand given the close trading ties.

UNITED STATES ACTIVITIES

The United States is effectively developing hydrogen at two speeds. California, through a strong range of state-based carbon and pollution reduction legislation has driven significant advancements in hydrogen infrastructure and technology development. Examples include the establishment of a network of 36 retail refuelling stations and many more planned.

Port of Los Angeles and Port of Long Beach have been instrumental in the encouragement of fuel cell adoption for heavy vehicles and port infrastructure.

As of November, 2018, there were:

- Over 5000 light vehicles, predominantly comprising leased vehicles as introduced by Honda, Hyundai and Toyota.
- Over 25 Fuel Cell Electric Buses (FCEB's) in operation with planned developments to add a further 27 buses.
- 4 heavy truck/drayage units in operation out of the Port of LA

While the approach of building out retail stations has been challenging economically, the network is now established hence the barrier for further FCEV adoption has been lowered.

The California Fuel Cell Partnership, established in 1999 has proven to be a very successful and strong association providing guidance, advice globally and championing the potential of hydrogen.

Outside of California hydrogen infrastructure activities are more restricted to hubs of technology activity such as on the North-East where companies like Plug Power have established a large market in the conversion of fork lifts to fuel cells. Four public retail stations are in place in the North East with more planned.

In terms of vehicle development US truck companies are amongst the leaders in heavy duty trucks FCEV development with companies such as Kenworth, Peterbilt, and Nikola Motors all developing products.

HYDROGEN PRODUCTION

With the renewed interest in hydrogen, commercialisation and scale of hydrogen production technology has accelerated. In addition, research has continued to both improve existing hydrogen production technologies and develop a number of new technologies.

Many options exist for developing hydrogen production in Taranaki and New Zealand with the likelihood that many of these approaches will find their role.

GREEN HYDROGEN PRODUCTION TECHNOLOGIES

Electrolysis of water is an established technology for producing hydrogen by separating water into hydrogen and oxygen. Several green hydrogen production technologies are under various stages of development. Rapid technology improvements and cost decreases have occurred over the past 10 years.

Technologies of note include:

ALKALINE ELECTROLYSIS

Alkaline electrolysis is the most mature form of electrolysis of water. It has been used industrially for over 100 years to produce hydrogen feedstock for industry. Alkaline electrolysis has achieved relatively large-scale production volume and economies of scale with several projects involving 5-10MW plants and plans for plants >100 MW. The technology uses two electrodes (anode and cathode) operating in a liquid alkaline electrolyte solution separated by a non-conductive diaphragm. Energy is supplied to the electrodes producing hydrogen at the cathode, and oxygen at anode. The combined anode and cathode reactions are given below:

$$2H_20_{(l)} \rightarrow 0_{2(g)} + 2H_{2(g)}$$

Compared to alternative electrolysis technologies, alkaline electrolysis uses less expensive catalysts, is proven at large scale, and has long-term stability due to the easy replacement of electrolyte solution. Disadvantages include low current densities, corrosivity of the electrolyte, and poorer response to dynamic and changing loads.

POLYMER ELECTROLYTE MEMBRANE (PEM) ELECTROLYSIS

PEM electrolysis was developed to address the disadvantages of alkaline electrolysis. The technology uses a solid polymer electrolyte for ionic conductivity, gas separation and electrical isolation. The solid membrane enables higher current densities which provide better responses to non-continuous loads such as wind and solar than alkaline technology. Membrane degradation can however, be costly as the specialised membrane material needs to be replaced. Long term durability testing and materials optimization for membrane longevity is a focus of PEM electrolysis developers, and continuously improving. While the technology is newer, it is maturing quickly. Large (> 1 MW) stacks are quickly being commercialised and costs are rapidly decreasing.

SOLID OXIDE ELECTROLYSIS CELLS (SOEC)

Solid Oxide Electrolysis Cells operate at higher temperature than conventional alkaline and PEM cells requiring 500-800°C to activate the catalytic process. When operating at this temperature the electrolysis process achieves a higher efficiency than PEM or alkaline electrolysis. The potential to utilise this technology on a source of steam to achieve significant efficiency improvements makes it potentially of interest in electrolysis using geothermal energy or other waste heat sources.

BIOGAS AND WASTE CONVERSION

There are several pathways to use biomass to produce hydrogen that can broadly be split into two categories: direct production, and conversion of storable intermediates. The most common and commercially mature direct production method is gasification followed by the water gas shift reaction. Gasifiers can utilise either dedicated crops, forestry residues and other bio-wastes as feedstocks. Common conversion methods include anaerobic digestion to produce renewable methane followed by reformation to produce hydrogen or conversion of bio-oil produced by pyrolysis. Agricultural and municipal wastes are common feedstocks for anaerobic digestion, which is well proven at large scale. Drawbacks of biological methods include feedstock variability and aggregation of sufficient quantities to meet demand. However, opportunities exist in Taranaki on farms where waste is collected, and in some cases already converted to methane, and use of municipal waste.

PHOTOELECTROCHEMICAL WATER SPLITTING

This technology has attracted a great deal of attention recently with the concept of the artificial leaf. In photoelectrochemical (PEC) water splitting, hydrogen is produced from water using sunlight and specialized semiconductors called photoelectrochemical materials, which use light energy to directly dissociate water molecules into hydrogen and oxygen. This is a long-term technology pathway, with the potential for low or no greenhouse gas emissions. Some potential advantages of the technology is the potential for the process to utilise seawater or brine, thus reducing the demand on freshwater sources and cost of pre-treatment.

BLUE HYDROGEN PRODUCTION TECHNOLOGIES

Blue hydrogen technologies involve the extraction of hydrogen from natural gas with capture of the associated CO_2 byproduct are being developed and commercialised.

METHANE CRACKING

A promising process is methane cracking through the use of low-cost catalysts.

The fundamental process of methane cracking involves:

$$CH_4(g) \xrightarrow{\text{catalyst}} 2H_2(g) + C(s, \text{graphite})$$

An Australian company, Hazer Group Limited (ASX:HZR) (Hazer), is commercialising a low-cost methane cracking process with the use of iron ore as the catalyst. This is known as the Hazer Process.

Hiringa Energy is conducting research with Massey University into the ability to utilise locally sourced titanomagnetite or "iron sands" as a catalyst for this process. Hiringa and Hazer are continuing discussions about how the Hazer Process may be implemented in New Zealand.

Both products (hydrogen and graphite) produced from the Hazer Process, have commercial applications. Commercial graphite, is a key building block in a number of carbon products requiring graphite including energy storage materials, fibre and conductors. This type of technology has potential applications for cracking both natural gas (producing blue hydrogen) and biogas (producing green hydrogen). On large scale the graphite obtained would be able to be stockpiled for future processing and use.

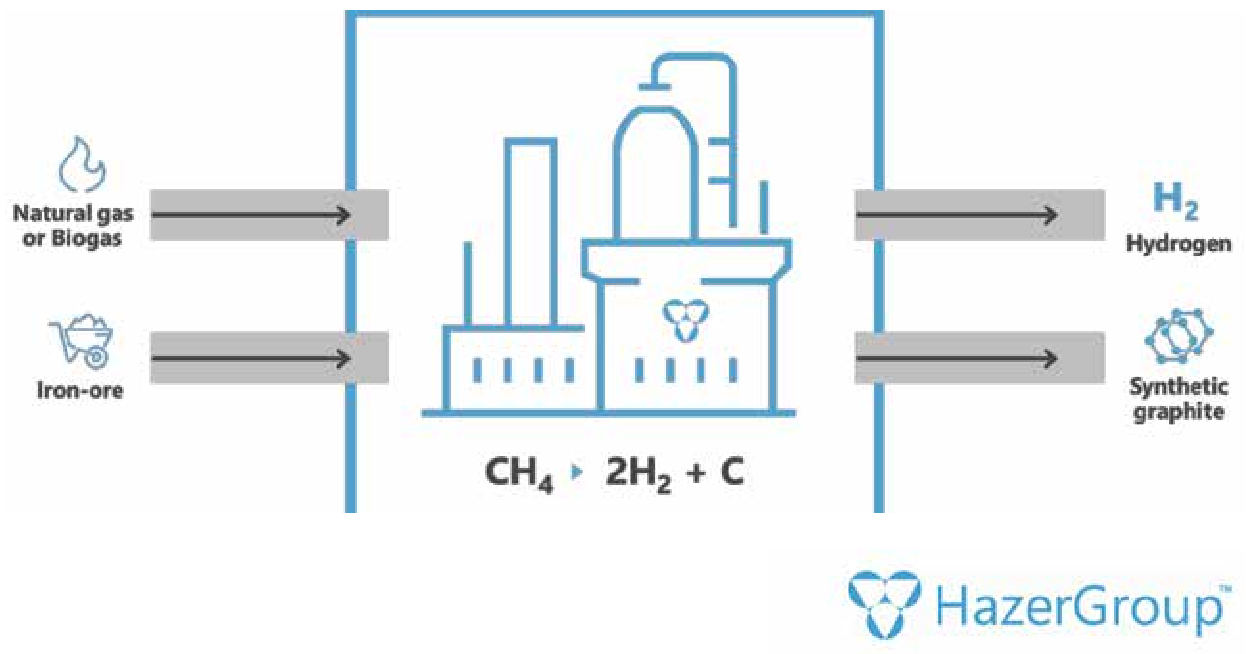
Potential exists for piloting a commercial scale Hazer Process facility utilising either conventional iron ore catalyst or iron sands catalyst in Taranaki to supply a hydrogen market. The process can be designed to either:

- provide higher purity hydrogen that would be more suited to fuel cell use, with the graphite being lower grade, or alternatively,
- higher grade graphite with the hydrogen being more suited to grid distribution for decarbonisation of residential and processes heat.

The commerciality of this type of project would be influenced by availability, and access to, the required gas reserves, and economics of transport of produced graphite to international off-takers unless a market is developed in New Zealand. This technology does not require CO_2 sequestration as the carbon is converted to a solid carbon product with an established market.

CARBON CAPTURED POWER GENERATION AND ELECTROLYSIS

8 Rivers Capital has recently announced a plan to conduct development activities relating to a large scale hydrogen, power and ammonia/urea plant in Taranaki (known as Pouakai NZ). The Pouakai facility would be based on Allam



The Hazer Process, being commercialised by Hazer Group produces hydrogen and graphite from natural gas using iron ore as catalyst.

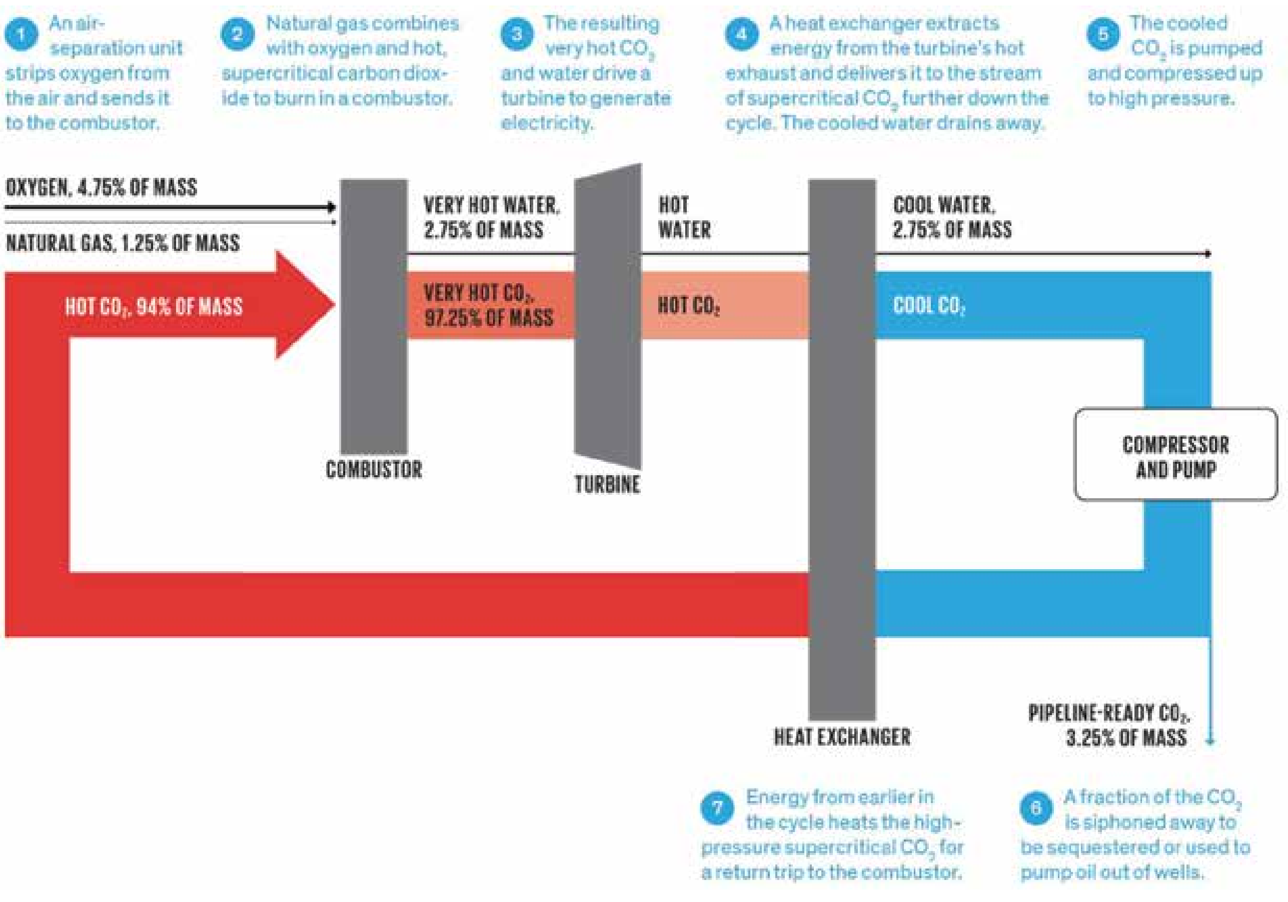
cycle technology it has developed through its partially owned subsidiary, NET Power. The Allam cycle produces power through a captured oxygen/CO_2 rich combustion cycle and extracts the CO_2 in a concentrated compressed form suitable for pipeline transmission and subsequent CCS. The sequestered CO_2 has potential for use in Enhanced Oil Recovery (EOR) through targeted injection into Taranaki's depleting oil fields.

That Allam Cycle process can be integrated with an 8 Rivers proprietary natural gas-fed POX/GHR/ATR process (called 8RH2) that exchanges high and low grade heat with the Allam Cycle, which generates H_2 with 100% carbon capture. The Allam Cycle + 8RH2 process promises H_2 generation with much higher thermal conversion than competing SMR-processes – approximately 87% efficiency (with carbon capture) as opposed to around 65% without carbon capture.

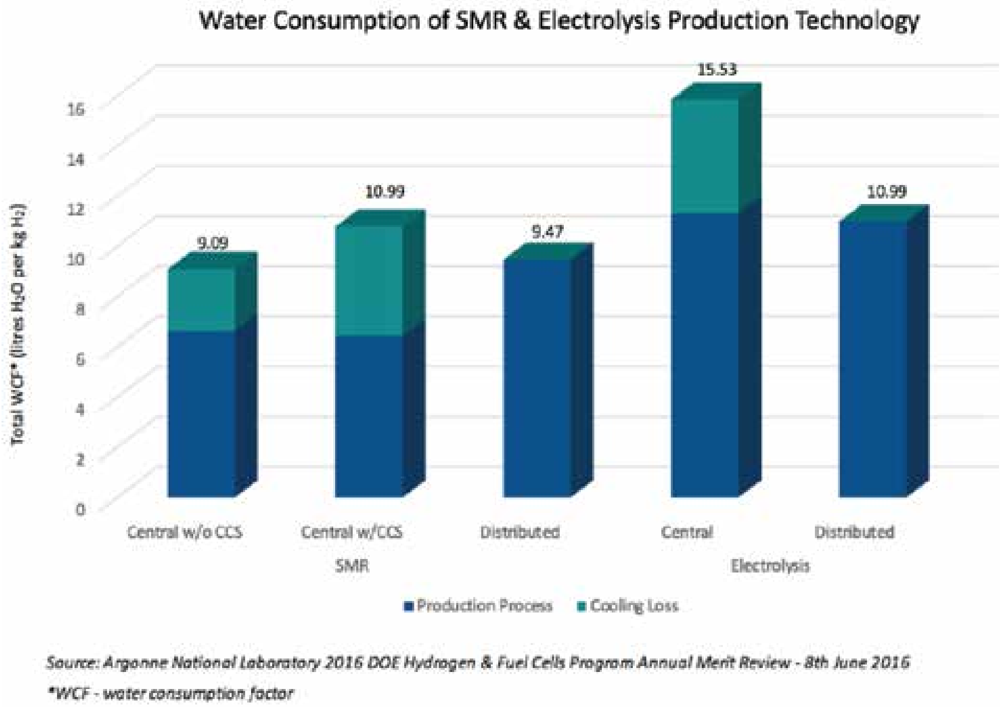
The proposed Pouakai facility would generate approximately 600 tons per day of hydrogen. In this proposed facility, the high-efficiency H_2 feedstock is then used in other processes (particularly production of ammonia and urea), or as a domestic hydrogen market is developed, hydrogen could be sold directly into this market. The Pouakai facility will also produce electricity. At normal operations it will have net export availability of around 160MWe, but by buffering certain internal feedstocks, could peak as high as 360MWe.

It is likely the commercial feasibility of this project would be enhanced with certainty of availability, and access to, the required gas reserves together with the ability to conduct large scale CCS via sequestration into the region's depleted gas reservoirs.

While the Allum Cycle is not strictly a hydrogen production technology it is a technology that potentially enables large scale production of blue hydrogen, and future deployments of the system could be Allam Cycle plus hydrogen generation only.



By using supercritical carbon dioxide as most of the mass, the Allam cycle can burn natural gas to generate electricity while delivering carbon dioxide at the proper temperature and pressure for sequestration (Image from Spectrum – the journal of the IEEE)



OTHER CONSIDERATIONS FOR HYDROGEN PRODUCTION

Other considerations for hydrogen production include :

- **Water usage** is a general consideration with all forms of hydrogen production. Water is required for both the supply of hydrogen as well as utilised in the cooling process. Water supply and quality is a consideration in site selection. Considerable potential exists for coupling electrolysis production with waste water treatment plants.
- **Electricity transmission grid access & pricing structures** is an important factor for both centralised and distributed hydrogen generation from electrolysis. The conventional lines and transmission price models applied in New Zealand are not necessarily designed for the ancillary benefits that hydrogen electrolysis brings. Electrolysis is able to provide peak shaving, demand response and grid stabilisation through its ability to increase and decrease loads in response to both supply and demand market signals. Agreements will be required between lines companies, Transpower, wholesale generators and hydrogen producers to enable pricing reflective of these benefits. For example, an electrolyser that is producing hydrogen from a local renewable source might seek to draw additional renewable power from the grid during off-peak periods, enabling the monetisation of otherwise curtailed renewable generation without overloading the grid. At other times it may be beneficial to decrease electrolysis and supply power from the "behind the meter" connected renewable to the grid to support demand.
- **Gas supply and suitable structures for carbon capture and storage** are key considerations for blue hydrogen production. The capture and storage of carbon will require appropriate infrastructure and large geologically stable structures that require investigation into their suitability.
- **Location of energy supply relative to the hydrogen market** has a significant influence on the economics of the hydrogen supply chain. The cost of distributing hydrogen from a production site to a fuelling station is a material factor in the cost of the supplied hydrogen. The proximity of commercial scale renewable power generation potential to a commercial scale hydrogen market is a driver for refuelling site selection. Hydrogen production, through its ability to respond to variable power supply and grid demand enables commercial development of distributed renewables at a smaller scale than conventional models.
- **Land zoning and consenting** for refuelling sites and production of hydrogen from new renewable power generation. For large scale production of hydrogen from renewables, additional renewable generation will be required including onshore and possibly offshore wind turbines.

HYDROGEN STORAGE & DISTRIBUTION

Hydrogen can be produced both at the point of use as a form of distributed energy production or produced at scale at a central location and subsequently distributed to markets. Both methods are likely to evolve in a hydrogen ecosystem.

METHODS OF HYDROGEN STORAGE AND DISTRIBUTION

The three methods used commercially for hydrogen distribution are compressed gas trailers, liquid hydrogen and dedicated pipelines.

Key new technologies are being commercialised for the transport of hydrogen include liquid organic hydrogen carriers, such as Chiyoda Corporation's SPERA technology that utilises toluene[3] as the carrier liquid, and Hydrogenious' technology based on di-benzyl-toluene.

Ammonia is also emerging as a potential hydrogen carrier for large scale distribution.

COMPRESSED HYDROGEN

Compressed hydrogen transported in high pressure tanks typically arranged into a tube trailer configuration. The hydrogen is pressurised between 250 Bar and 500 Bar. This method is most suitable for transporting low to medium volumes (500kg-1000kg/container) of gas over a relatively short distance (up to ~300km). The containers are generally multi-modal meaning they can be transported on road, ship and rail. This method provides a flexible distribution solution for an early hydrogen market and "spoke" distribution from hydrogen production hubs. Hiringa Energy plans to utilise this proven technology for initial hydrogen supply distribution. As market volumes and distances increase, the economics and practicality of utilising compressed tube trailer distribution decreases.

LIQUID STATE HYDROGEN STORAGE AND DISTRIBUTION

Hydrogen in a liquid form has potential application for near to mid-term use. It is also the likely form enabling the transport of significant volumes of hydrogen from large scale production facilities in countries such as Australia, New Zealand, and Norway to energy poor countries such as Japan and Korea. All three of the methods described below are being considered as possible options for establishment of international hydrogen supply chains. Integration with such supply chains

3 A colourless, water insoluble, aromatic hydrocarbon.

would enable both export of New Zealand's renewable energy as hydrogen as well as potential importation in the case of a domestic energy shortfall.

Cryogenic Liquified hydrogen distribution is most commonly utilised in the US, Japan and parts of Europe. Liquefaction economics requires relatively high volumes of product movements due to the high capital associated with the liquefaction plant and refrigerated trailers (a 5T/day plant costs approximately $60m). Liquified hydrogen distribution might become a method used in New Zealand to distribute medium to high volumes where hydrogen pipeline distribution is not available.

Liquid Organic Hydrogen Carriers (LOHCs) carry hydrogen in a stable state at ambient temperature and pressure through bonding the hydrogen with a hydrocarbon carrier. This technology has the potential to significantly reduce the cost of large-scale distribution through leveraging existing infrastructure. This would allow hydrogen to be delivered in bulk tankers and potentially stored in fuel tanks in existing fuel stations before being converted back to hydrogen. There is potential to incorporate a trial of this technology as a subsequent activity in Hiringa Energy's pilot refuelling infrastructure project.

The two main carrier technologies in commercial development are Chiyoda Corporation's SPERA technology that utilises toluene as the carrier liquid, and Hydrogenious's technology based on di-benzyl-toluene. Each have their advantages and disadvantages, however a key benefit of both forms of LOHC is the ability to store hydrogen at atmospheric pressure and temperature and with low flammability and toxicity. This technology is also being considered by Japan as one of the options for international transportation of hydrogen. Chiyoda's SPERA process has been selected by METI and NEDO for a demonstration project between Brunei and Japan, which is under construction and will be complete in 2019. It also has a potential application for domestic hydrogen distribution.

Storage as liquid ammonia. International and domestic supply chains are already established for the storage and transport of ammonia. Ammonia can be produced from renewable hydrogen combined with atmospheric nitrogen. Once in the form of ammonia, a number of options are being developed to provide power, including direct combustion of ammonia in modified turbines and reciprocating engines, direct use of ammonia in fuel cells and ammonia "cracking" back to hydrogen and nitrogen. Large scale production of ammonia from renewable hydrogen is being developed in Australia together with a number of complementary technologies for the conversion back to hydrogen for subsequent use. Taranaki has existing ammonia production, storage and transport infrastructure and capability. The Hiringa-Ballance green ammonia project described in this report would demonstrate the commercial viability of renewable hydrogen stored and distributed as ammonia. It should be noted that typically, due to its toxicity, storage and use of ammonia is constrained to industrial and remote applications rather than residential and commercial environments.

GASEOUS HYDROGEN STORAGE AND DISTRIBUTION

Natural Gas grid storage – hydrogen produced by electrolysis during periods of excess renewable production could possibly be directly injected into the gas network. The resulting blended gas mix of approximately 5-20% hydrogen could be utilised across the gas network both for commercial and residential use. Peaker plants could potentially be modified to combust a methane/hydrogen blend and there is significant technology development looking at pure hydrogen turbines such as the Carbon-Free Gas Power Project at the Nuon Magnum plant which aims to convert one of the three 440MW CCGT power plants to hydrogen by 2023.

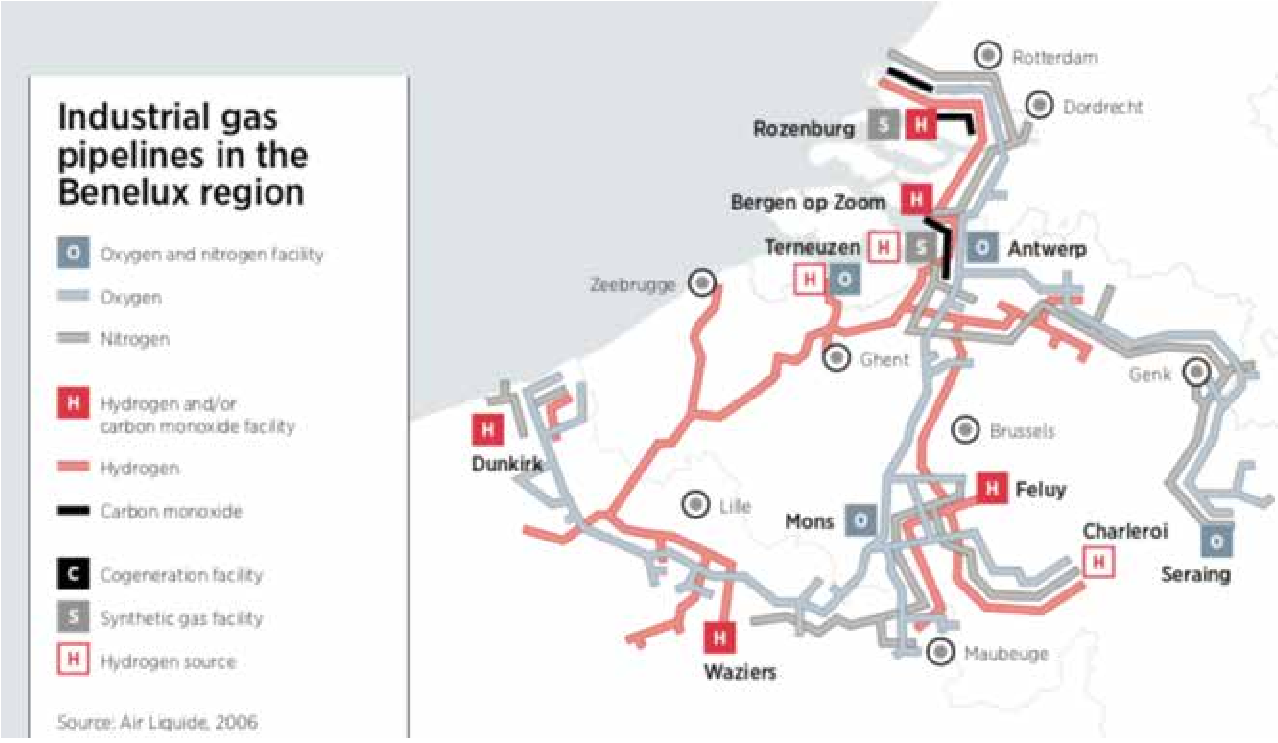
Large scale hydrogen fuel cells to generate peak electricity when required are also under development with examples such as Nedstack's 2MW plant in operation in Yingkou, China and large multi-MW systems under development by companies such as Toshiba.

Commercial mechanisms such as green certificates would enable the matching of renewable hydrogen production to use such as in peaker-plants. Significant work is being undertaken in the United Kingdom to identify a pathway for moving towards 100% hydrogen conversion of the existing gas networks. HyDeploy is focused on establishing an initial blended network (up to 20%) with H21 and H100 looking to create the environment for 100% hydrogen network repurposing. A similar study is proposed by FirstGas to evaluate both the feasibility of a blended system, practical blending percentage and the viability of the future repurposing of the existing gas network to 100% hydrogen. Work needs to be done regarding the gas pipeline regulations to enable such repurposing. This study, outlined below is strongly supported in this roadmap.

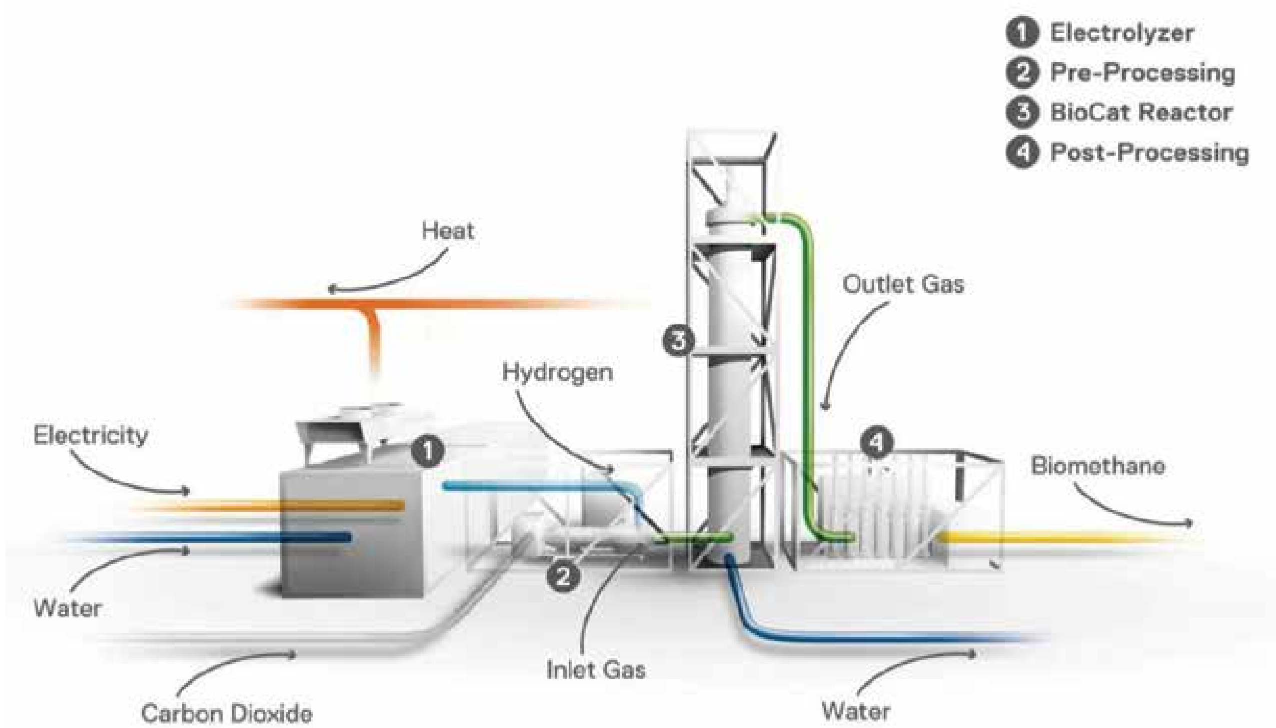
Dedicated Hydrogen pipelines are in large scale use with 1500km operating in north-east Europe and over 2000km operating in the US. These networks typically operate between 10 and 20 bar to distribute hydrogen across the industrial chemical, refining and steel industries. Localised, high pressure distribution is utilised at some hubs. Smaller scale networks are also operating in Italy, Sweden, Singapore, South Africa, Brazil, Thailand, Korea, and Indonesia. Rather than dedicated construction of pipelines, as outlined above, work is proposed to evaluate the potential of conversion of the existing New Zealand natural gas transmission system to hydrogen.

Synthetic Methane (Methanation) – Hydrogen can also be combined with CO_2 to form synthesised methane through the process known as methanation. Two forms of methanation exist:

- **Bio-catalyst methanation** primarily utilises the naturally occurring microbe arcaea to absorb hydrogen and carbon



Air Liquide operates a hydrogen pipeline network in the Benelux region (Belgium, Netherlands, Luxemburg)



The BioCat plant developed by Electrochaea is a 1-MW commercial-scale bio-methanation field trial. This project is operated by Electrochaea and its BioCat project partners Hydrogenics, Audi, HMN Gashandel, NEAS Energy and BIOFOS.

dioxide, producing almost pure methane and low-grade heat. The hydrogen can be produced from electrolysis and CO_2 can be captured from industrial processes or direct atmospheric capture. This technology is particularly well suited to integration with intermittent renewable electricity as it is relatively robust to feedstock variability and can be cycled on and off for peak shaving. 1MW pilot plants are currently operating (for example the Electrochaea BioCat plant in Copenhagen, Denmark), with small scale commercial 10MW plants in design. Concepts for multiple 50MW facilities to provide intra-seasonal storage are envisaged.

- **Metal-catalyst methanation (Sabatier process)** primarily utilises a nickel-based catalyst. These plants operate at higher temperatures 300-600 DegC and tend to have higher efficiencies than bio-catalyst plants, however they are not as readily able to manage variable feedstock and load variations from intermittent renewables. Significant research is being undertaken in improvements to the catalytic efficiencies. Potential exists for this technology to efficiently produce large scale methanation volumes.

Both bio-catalytic and metal-catalytic methanation have a very large potential beneficial application in the storage of significant volumes of methane. Methane storage in the New Zealand gas network including in the gas storage fields would require minimum reconfiguration of the existing gas infrastructure.

SOLID STATE HYDROGEN STORAGE AND DISTRIBUTION

Solid state storage and distribution – Emerging solid-state technologies have the potential to provide a simple hydrogen distribution model for smaller volumes. An example is H2Motion's carbon-based nanomaterial. The product stores gas at 50 bar and ambient temperature. This product will enable twice the storage per unit volume and at significantly lower pressures than conventional high-pressure gas tanks that operate at 350-700 bar.

Storage in this form could provide simple distribution for more remote locations such as farms and for spoke distribution from production hubs.

GAS NETWORK INJECTION, BLENDING AND CONVERSION

FirstGas is proposing to conduct a project evaluating the potential for hydrogen to facilitate the decarbonisation of the gas grid. The project would seek to demonstrate that the existing gas network can be repurposed and is suitable for conversion to transport hydrogen. A major benefit would be the ongoing utilisation of the gas network, a significant national asset.

The project would build upon this H2 Taranaki report and seek to extend the work on identification and potential scale of end use markets accessible via the gas grid, forecast CO_2 emission reductions, air quality benefits, hydrogen production options as well as CCS infrastructure requirements.

Technical feasibility of converting the gas grid

- Assess how the existing gas network and infrastructure could support the development of a regional hydrogen economy
- Undertake a technical assessment of the existing gas network to ascertain its suitability for conversion to transport hydrogen / hydrogen blends against the range of end use scenarios
- Establish a clear roadmap of activities required to provide the technical evidencing required to convert the existing gas network to transport hydrogen, making use of the primary research being conducted in UK/Europe
- Develop a conversion strategy to demonstrate the networks can be converted to match the developed range of end use scenarios
- Assess the regulatory issues, to understand the required changes to enable a transition to hydrogen, such as design codes, gas quality specifications and proving the safety case for transporting hydrogen
- Identify the actions required to develop the safety case, amendments to design codes and regulation in subsequent phases of the project

Demonstration Network Selection

- Undertake a review of the existing Taranaki gas networks to identify a suitable location for a closed network demonstration project opportunity. Selection will be based on the range of end use technologies that could be demonstrated, technical feasibility of conversion and possible integration with constrained renewable power generation.
- Develop a conceptual layout for the selected scheme
- Produce a high-level cost estimate and benefits analysis for the project.

With the number of industrial projects that could utilise a renewable hydrogen feedstock discussed in this report, there is potential to establish a hydrogen supply pipeline connecting large scale generation associated with renewable projects (for example the Waverley wind farm), with the Kapuni complex, Motunui and an export facility at Port Taranaki.

SUPPLY & REFUELLING INFRASTRUCTURE

REFUELLING INFRASTRUCTURE FOR TRANSPORT AND MOBILITY

Lessons learned from early hydrogen refuelling developments and roll-outs visited and studied demonstrate a varying range of success. Early establishment of retail refuelling stations such as in Germany, Denmark, California and Norway were initially based on small capacity stations designed to refuel private cars. These stations involved a high cost per unit kilogram of hydrogen due to a lack of economy of scale and have experienced low capacity use due to the lack of private hydrogen vehicles.

More successful early developments have instead primarily focused on vehicle fleets where there is a security of demand. Good examples of this include:

- **H2 Aberdeen** has established two stations in the city, servicing Aberdeen City Council service vehicles, light fleets and the 10 strong city bus fleet that is looking to expand. Public refuelling is now offered as a supplemental feature. A challenge of this infrastructure has been a lack of access to low cost electricity for hydrogen production.
- **Colruyt Group**, a company active in distribution of food and non-food products in Belgium, France and Luxembourg has developed a commercial hydrogen hub based on integrated renewable power generation, hydrogen production, refuelling for their 75 strong forklift fleet (to be expanded to 150) and public refuelling integrated with a multi-fuel station adjacent to the company's distribution centre.

SUPPLY AND REFUELLING INFRASTRUCTURE TO SUPPORT H2 TARANAKI INITIATIVE

Hiringa Energy has been awarded a Provincial Growth Fund grant to develop pilot refuelling infrastructure to support the H2 Taranaki initiative and develop a framework for supply infrastructure roll-out across NZ.

The scope of the pilot project entails:

- **Supply/Generation** – Establishment of 1-2 hydrogen production facilities (including both centralised and distributed options).
- **Storage/Distribution** – Development of a New Zealand suitable solution for high capacity mobile compressed hydrogen tube trailer distribution system.
- **Refuelling** – Development of 2-3 hydrogen refuelling stations (1 in Taranaki directly supporting H2 Taranaki), 2 outside of the region creating a pilot network and connectivity.

The grant funding, together with Hiringa Energy and partners' co-funding will support the pilot project's development to a Final Investment Decision (FID).

A series of Joint Ventures are planned for project execution with target of the first stations being operational in early 2020.

The economics of refuelling infrastructure is driven by a number of elements:

- **The cost of initial up-front capital** required to construct commercial scale hydrogen supply and refuelling

H2 Aberdeen's refuelling station at Kittybrewster

The Colruyt integrated refuelling facility demonstrates the hydrogen refuelling hub model of distributed generation powering facilities, producing hydrogen with the excess power and fuelling both forklifts and trucks and cars at different refuelling points.

- **Capacity utilisation growth** – The rate at which the installed commercial refuelling capacity is fully utilised.
- **The cost of hydrogen production and delivery** relative to the hydrogen sales price, influenced by:
  - The cost of electricity and the efficiency of electrolysis
  - In the case of centralised production and distribution: the cost of compression, transport and distribution of produced hydrogen
  - In the case of distributed production at the refuelling site: the cost of compression and storage of produced hydrogen.
  - The operations and maintenance costs of the infrastructure
  - Economies of scale applicable to all these elements

Hiringa Energy has developed a series of tools and strategies to optimise the economics to help accelerate the commercialisation of hydrogen.

In New Plymouth, Hiringa is working with New Plymouth District Council, its key contractors and third-party fleet operators (including partner TIL, one of New Zealand's largest freight and logistics companies) to underpin demand for the first fuelling station. A number of locations are being considered taking into account proximity to early fleets, expansion potential, grid access and opportunity for renewable power generation.

To complement the New Plymouth supply, the project is also assessing key locations across New Zealand to establish an initial network of refuelling facility operations. The focus is in areas of large commercial and heavy vehicle fleets such as industrial parks and logistics infrastructure such as ports, bus

Hiringa Energy together with partners has identified a series of refuelling locations across New Zealand that could form part of an initial hydrogen supply network.

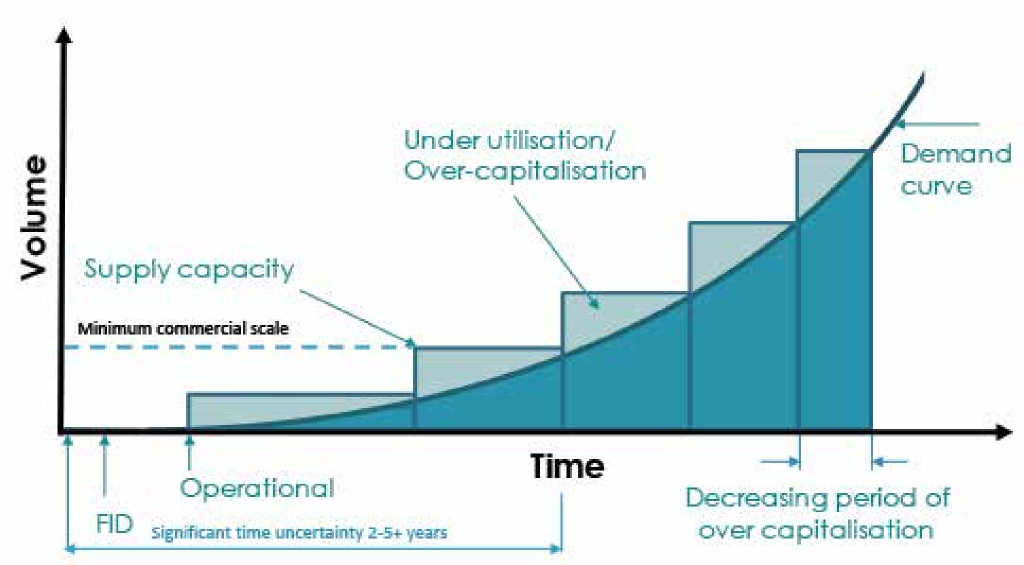
Location selection and type is prioritised based on:

- **Potential for aggregation of suitable fleets such as industrial complexes, commercial & logistics hubs, dairy factories, ports, airports**
- **Proximity to potential renewable energy and/or hydrogen supply**

The network would include:

- **Centralised generation with distributed refuelling**
- **Distributed generation**
- **Third party generation with offtake**

Sites have been identified in locations such as: Tauranga, New Plymouth, Auckland Airport, Palmerston North, Rolleston, Marsden Point/ Northport and Wellington.



and rail depots. Hiringa aims to build engineering, operations and maintenance capability and create an efficient roll-out of infrastructure to support the broader development of hydrogen supply in New Zealand.

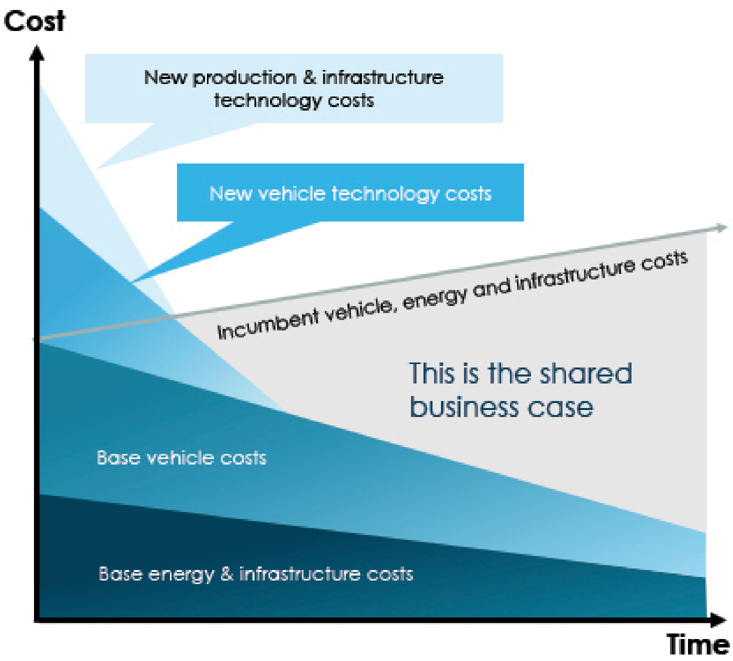
A significant challenge facing the early pilot projects is the initial capitalisation of infrastructure and vehicle fleets and uncertainty around the speed of adoption of the technology by end users to increase utilisation.

- **Production and refuelling infrastructure costs** are capital intensive due to the need to create a supply chain of hydrogen and the relatively complex refuelling equipment. While the technology required to achieve this is fully commercially available, it has not achieved an economy of scale required to significantly reduce costs of manufacturing to compete directly with fossil fuels. Regardless of manufacturing economies, the establishment of an infrastructure network in a system such as New Zealand also needs to achieve an economy of scale. Once this scale is achieved, the economics will become more robust as the efficiency of hydrogen production and distribution improves and the cost of delivered hydrogen drops. This benefit of scalability is a key feature of hydrogen infrastructure.

  It is worthwhile noting that the adoption of battery electric vehicles did not experience this aspect of barrier to entry as the first vehicles were able to be charged from the existing electrical grid. However, the expansion of recharging infrastructure is becoming a challenge and will continue to be as the New Zealand fleet grows, due to the strain this will place on the existing grid, requiring significant upgrades.

- **Fuel cell vehicle costs** are also a challenge at the early stage of adoption. While commercially available vehicles exist such as cars, forklifts and buses, the vehicle costs remain relatively high due to both the technology cost of the fuel cell and the lack of manufacturing economy of scale. Fuel cell costs have been dropping significantly as manufacturing technology improves and large factories are established. However, a tipping point needs to be achieved that will be driven by large fleet adoption. The first example of this occurring is with fuel cell forklift fleets, where large scale adoption has driven down the cost per unit, and fleet adoption is now accelerating. For heavy vehicles, a number of fuel cell manufacturers have developed solutions, but the adoption by the heavy vehicle Original Equipment Manufacturers (OEMs) who own their own internal combustion engine technology, but not fuel cell technology has been slow.

  A significant challenge still exists for vehicle types that have not developed commercial fuel cell solutions. This applies to heavier vehicles and specialist vehicles – the conventional market for diesel and where hydrogen provides the best alternative. This lag in vehicle availability provides a barrier to adoption. This issue is compounded in New Zealand with the right-hand drive requirements and road load restrictions, which results in a more bespoke solution for New Zealand. Another feature of heavier vehicle fleets is the longer lifecycle and cost of these vehicles results in fleet replacement taking considerable time.



The outcome of this scenario is that conversion to hydrogen vehicle fleets will take time and there will continue to be the need to support this conversion into the more challenging areas of heavy transport. Opportunities exist to accelerate the adoption of the technology through vehicle conversion, rather than waiting on OEM production. This is particularly viable for large vehicles such as heavy trucks, trains, ferries, and mobile plant. It is important to note that larger vehicles will also provide a natural hydrogen demand profile helping stimulate supply.

HYDROGEN APPLICATIONS

HYDROGEN FOR TRANSPORT AND MOBILITY

The highest value application of hydrogen is in the transport sector, particularly decarbonising large fleets and heavy transport. The various transport and mobility sectors are considered for the current state of technology, commercial availability and key applications.

Based on Ministry of Transport data, the Taranaki fleet consists of approximately 4,650 trucks, 230 buses and 76,000 light vehicles. However, based on average kilometres travelled and fuel consumed, trucks are by far the largest transport sector in the region, representing the largest potential demand for hydrogen and potential for de-carbonisation.

A barrier for early electric vehicle implementation in New Zealand (both BEV and FCEV) is the right-hand drive requirement. For early adoption prior to mass manufacture this restricts the available vehicles to those developed and manufactured for right-hand drive countries (Japan, UK, India, Australia and New Zealand) or requires relatively large manufacturing run orders. Commercial development of BEV small to medium commercial vehicles is more advanced than FCEVs, providing the opportunity for FCEV modifications and range extension piggybacking on the BEV fleet developments.

For heavy trucking an additional feature of New Zealand are the road axle load restrictions, which are amongst the lowest in the world. This results in the need for more multiple axle vehicles for a given service requirement. Given this situation the opportunity for truck conversion is of interest.

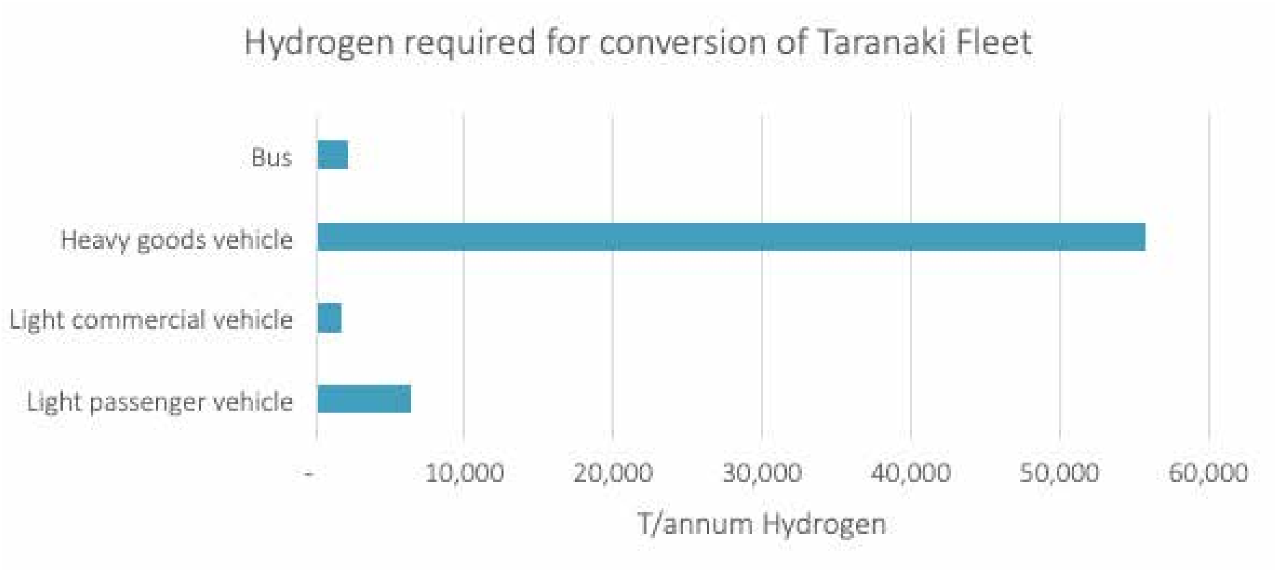
MATERIALS HANDLING

Large fleets of hydrogen powered forklifts (>50,000 worldwide) are operational in many warehouses in the US and Europe (Walmart, Amazon, Colruyt). This is a mature technology experiencing rapid growth. While the hydrogen volumes per unit are small (~1kg/day) the relatively low cost per unit and larger volumes can drive commercial scale, particularly when aggregated with other fleets. The business case for forklifts for an operating business is driven by:

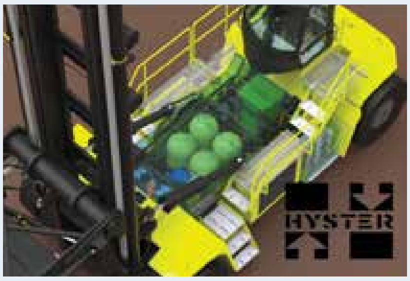
- Performance – fuel cells can operate over an 8-hour shift at full speed, including -30°C cold stores, without performance degradation.
- Increased utilisation – hydrogen fuel cells can be rapidly refuelled in just 1-3 minutes, removing the need for battery charging logistics and additional forklifts.
- Elimination of battery rooms and battery change infrastructure, thus increasing floor space available for warehousing.

Applications in Taranaki and New Zealand

Each forklift utilises a small amount of hydrogen, which on a stand-alone basis makes it difficult to build a commercial supply business case. However, aggregation of fleets with



Estimated hydrogen required to power the existing Taranaki fleet based on average travel and registered vehicle numbers.



Large lifters under development (Hyster)

OEM's producing indoor units (Toyota, Hyster, Linde, Crown, Jungheindrich)

Large scale fleet conversions from battery-electric (PlugPower, Nuvera) >50,000 operational (2018)

The Toyota Mirai has been in production since 2015 with sales currently at 3000pa and plans to produce >30,000 pa by 2020. It has a range of 500km

Hyundai Nexo will be available in Australasian markets in early 2019. It has 6.3kg hydrogen storage and a range of 600-800km on a 3-5 minute refill.

Hype Taxis in Paris operate a fleet of 100 FCEV taxis with plans to extend to over 600 vehicles by 2020.

The Renault Kangoo BEV van, pictured here operating on the Orkney Islands has been converted to a range extended battery/FCEV.

SymbioFC are also offering a Nissan e-NV200 small van with a range extender.

Volkswagen Crafter HyMotion concept carries 7.5 kg hydrogen tanks to cover ranges exceeding 500 km. Fuel consumption is 1.4 kg/100 km and re-fuelling takes four minutes. It will carry the same payload as it's diesel equivalent (up to 3T). It is based on the same electric drive train as eCrafter battery electric van but significantly improves on the eCrafter's max range of 160 km and max payload of 1.7T.

multiple warehouses combined with other FCEV fleets can help underpin initial generation and refuelling infrastructure.

On the equipment side, the NZ distributors of the forklifts require upfront commitments to import the forklifts into NZ and provide a start-up and technical support service. Based on discussions with the suppliers there isn't any one operation in Taranaki that would meet that threshold (and few in NZ at a single location). However, Hiringa Energy's work across New Zealand identifying multiple sites will help achieve this aggregated fleet size with up to 10-unit pilot fleets in multiple distribution centres and warehouses.

In the Taranaki region, Bell Block in New Plymouth provides a location for enabling the aggregation of multiple warehouses. Other sites such as Fonterra's production facilities at Whareroa and Kapuni are also hubs with large mixed fleets.

LIGHT VEHICLES

Several thousand light FCEVs are operational globally with primary sales in California, Japan and Germany, coinciding with the most retail refuelling stations. Three models of light vehicles are in production as of November 2018, the Honda Clarity, the Toyota Mirai and the Hyundai Nexo SUV (which has superseded the Tucson/iX35). The Mirai and the Nexo are available in right-hand drive versions and both Toyota and Hyundai New Zealand have indicated an interest in importing these vehicles pending infrastructure availability.

A number of vehicle manufacturers have announced FCEV models moving to production over the next 5 years. The focus is on larger vehicles such as SUVs where the hydrogen FCEV has range and weight benefits. These include Mercedes GLC-FCell plug-in battery/hydrogen hybrid, the Audi H-tron and the GM Chevrolet Colorado.

Light FCEVs are best suited to fleet operations where high utilisation and/or vehicle range is required. Examples include the Hype taxi fleet in Paris that, as of November 2018, had 100 FCEV taxis with plans to extend the fleet to over 600 vehicles.

Applications in Taranaki and New Zealand

Fuel cell light vehicles offer an excellent solution to the electrification of light vehicle fleets in the regions where range, refuelling times, payload and operating temperatures are important.

As an example, NPDC operate around 45 light fleet vehicles including over 25 SUVs. The district's area spans from Okato to Mohakatino with a number of the fleet vehicles needing to service the entire district. Transitioning the SUV fleet with current FCEV SUV pricing would require an approximately $1.5m incremental investment over petrol/diesel equivalent vehicle pricing.

Purchasing a vehicle fleet would ideally leverage inclusion of fuel cell vehicle options in the all-of-government vehicle purchasing contract. This would also help encourage fleet adoption in other regions and enhance buying power.

One potential approach for NPDC is to develop a car share program between a number of entities located in New Plymouth. A similar program has been established in Christchurch, called Yoogo Share that established a public/private partnership with Christchurch City council and gained co-funding support from the Government Low Emission Vehicle Contestable Fund administered by EECA. Similarly, Wellington car share operator MEVO has partnered with Wellington City Council and attracted EECA funding for its 50 PHEV car fleet.

This approach would help improve the business case for vehicle purchase with the incremental cost spread amongst more partners. The car share model could subsequently be extended to include private users. FCEVs are well suited to car share and taxi fleets due to the high utilisation that can be achieved due to the short refuelling time.

This is a model that could be applied to other regions to help promote the uptake of fuel cell vehicle fleets.

If produced using clean energy, H2 can reduce GHG emissions by approximately 2.5 kg-CO2e/L-diesel equivalent. For example, the NPDC used ~98,000 L of diesel in 2016 and could reduce its GHG emissions by 245,000 kg per year.

Other light vehicle fleets include a number associated with the energy sector where vehicles are used by staff for visiting production sites across the region.

VANS

Several hundred fuel cell vans are in operation in UK and Europe. These vans are fuel cell conversions of battery electric vans, particularly the Renault Kangoo ZE and the Nissan e-NV200. The conversions are undertaken by third party integrators under license from the vehicle OEMs. Both the Renault and Nissan conversions are available in right hand drive.

Both FedEx and UPS in the United states have invested in hydrogen fuel cell delivery vans to achieve range, payload and utilisation.

OEMs developing fuel cell vans include Hyundai and Volkswagen. The availability of these vehicles in a right-hand drive version is uncertain however, there would be the opportunity to conduct conversion of existing vans. Companies such as Holthausen in Netherlands offer this service. The H2 Taranaki team visited their facility and will be further exploring this opportunity.

Applications in Taranaki and New Zealand

Fuel cell vans in Taranaki would be suitable to a number of applications. A number of service vans operating in the regions require long range and/or high payload. Examples include postal and courier services where route flexibility and range are limiting factors for battery electric options.

NPDC has a fleet of 7 Toyota Hiace and Ford Courier vans with 2-3 potentially due for replacement in the next 2-3 years which should coincide with availability of FCEV options. Other potential fleets in the region would be NZ Post and NZ Couriers, and civil and general contractors such as Downers, Fulton Hogan and Programmed.

FUEL CELL ELECTRIC BUSES (FCEB)

Hydrogen fuel cell electric buses (FCEBs) have been in operation for over 8 years. Bus fleet adoption has typically been driven by progressive city councils looking to reduce emissions. Fleets of FCEBs are in operation in UK and Europe in cities such as Aberdeen, London and Sheffield.

Large scale Chinese activity is driving fuel cell bus prices down with significant increase in production in 2018 with Hydrogenics supplying 150 buses since opening their new plant in 2018. South Korea has also announced they will change their entire 26,000 strong CNG bus fleet to FCEBs over the next 5-8 years.

The European FCHJU has recently announced a roll-out of 600 buses with 200 of these in Denmark.

Buses have provided reasonable hydrogen demand to underpin early investments in fuelling infrastructure, however conversion of an entire bus fleet to underpin commercial scale infrastructure requires planning to manage the vehicle asset investment costs and the management of change of fleet operations.

Fuel cell buses have a number of significant advantages over battery electric buses in city fleets. Battery bus fleets on average require 25-30% larger fleet numbers (based on European JIVE bus analysis data) than diesel and fuel cell bus fleets due to the range and weight/payload restrictions. The charging infrastructure and logistics add further cost and

Operating FCEB fleets are increasing in number in Europe, the US and Asia

Korea converting 26,000+ Compressed Natural Gas (CNG) bus fleet to hydrogen

China and Korea are leading the development of intercity coaches

operating complexity. Fuel cells also have a longer life than lithium batteries and are 95% recyclable.

Battery electric bus roll-outs have occurred in New Zealand in Wellington and Auckland.

Early analyses in New Zealand considering battery electric buses and FCEBs recognised performance benefit of FCEBs, however the bus cost was assumed to be $2.7m per bus and therefore prohibitive for implementation at the time. Recent FCEB costs are less than a third of this and comparable to battery electric bus costs, illustrating the rapid decreases in costs of the technology that have occurred over the past 10 years.

It is likely that battery electric buses and FCEBs will co-exist in fleets, applied to different service applications.

Types of electric buses can be categorised into four main classes according to their service requirements.:

BUS TYPE	DESCRIPTION	TECHNOLOGY REQUIREMENTS	STATUS
Inner city “city circle”	Buses on a relatively small fixed route on urban roads, requiring high uptime but low range (~100-150km) and low speeds (50-60km/hr)	~30kw fuel cell, small battery, few hydrogen tanks	Operational
Urban bus	Buses on a longer fixed route based on urban roads requiring medium range (100-200km+), low speeds (50-60km/hr)	Small-medium fuel cell (~30-70 kW), small battery, additional hydrogen tanks	Operational – mass production in China FCHJV
Highway suitable urban/ regional bus	Buses on a longer fixed route based on both urban roads and highways requiring medium range 100-200km+), high speeds (80-90 km/hr)	Large fuel cell (200kW), additional hydrogen tanks	Operational in Korea & China Mass production Korea 2020
Intercity bus	Buses requiring range ~400+km and high speeds (90-100 km/hr)	Large fuel cell (200kW), additional hydrogen tanks	Operational in Korea

TRC operates the regional Connector bus service and the New Plymouth CityLink service.

FCEV waste trucks – operational in Europe (Holthausen, e-Trucks). Diesel dual fuel waste trucks are also in operation in Aberdeen.

Street sweepers – operational in Europe (Holthausen)

Airport ground service vehicles – operational in US (Plugpower/FedEx)

Applications in Taranaki and New Zealand

Regional bus services are funded by Taranaki Regional Council (TRC) and are contracted under the public transport operating model in conjunction with NZTA. Regional bus services typically operate with low passenger numbers making cost recovery challenging.

Further discussion with the NZTA and central government support will be required for conversion or replacement of the existing fleet of buses.

The regional public transport bus fleet in Taranaki is characterised by peak loads around school times and peak commuter hours with relatively low overall utilisation. The fleet consists of 30 buses on the City link service and a bus each on the Connector service (Hawera-NP), Southlink (Opunake-NP), Southlink (Opunake-Hawera) and Southlink (Waverley-Hawera) services. The fleet could be serviced by one relatively small hydrogen station by total demand, although a refuelling station would be best placed in New Plymouth for the city link services and south Taranaki for the connector and southlink services.

A potential trial could be the city link and connector service initially refuelled from a station in New Plymouth, aggregated with the other fleet demands. These services operate around the more populated parts of Taranaki, that would raise community awareness of the technology and its advantages.

A good application for FCEBs in Taranaki are the private sector regional and inter-regional coaches where range and utilisation requirements will likely favour fuel cell technology over battery electrification. There are currently 230 buses registered in Taranaki, and a number of these are used for intercity transport, travelling 250,000-400,000km/annum. Locally based coach operators such as Withers' Coaches, are potential early adopters of these solutions.

New Zealand has a bus fabrication industry with manufacturers experienced in bus electrification. Recent examples include Kiwibus in Tauranga, who have recently fabricated and integrated electric drive and the opportunity exists for these companies to extend their electrification to integration of fuel cells and storage systems. Tauranga as a potential complementary early refuelling infrastructure location could also build upon this broader hydrogen opportunity.

There is also potential to convert existing buses. The economics of conversion is favourable if the cost and the remaining chassis life is sufficient. Taranaki companies have imported and retrofitted buses previously.

MEDIUM TRUCKS AND SERVICE VEHICLES

Since 2017 there has been a significant increase in fuel cell vehicle developments for medium trucks. China stimulus models have encouraged hydrogen fleet development with several trucks in operation and many being manufactured. Most of the vehicles available are BEV with fuel cell range extenders.

As part of the H2 Taranaki discovery trip, Hiringa Energy met with the WaterstofNet team, key drivers of the Waterstofregio Vlaanderen-Zuid-Nederland initiative (Hydrogen Region for Flanders and the southern Netherlands). WaterstofNet have been and continue to be involved in a number of key medium and heavy trucking projects and could be a good vehicle solutions development partner.

Several service vehicles have been developed that utilise the additional electricity supply provided by hydrogen fuel cells for auxiliary applications like hydraulic power, and specialized airport service requirements like ground service equipment (GSE).

Memphis Airport deployed 15 fuel-cell ground service vehicles with ~23,000 kg towing capacity for 24-hour operations (4 hours use until 3-4 minute refuel required). This is an excellent example of the advantages of a fuel cell solution that can provide high-power outputs at high utilization rates. Overall the program was a success, demonstrated 96% availability and the Memphis Airport plans to expand its use of fuel cell GSE further into its operations.

Waste collection trucks have been developed in multiple trials in Europe. WaterstofNet together with partners, developed a range extension project for a DAF CF FA freight truck extending the truck's range from 200 km to 360 km. These vehicles reduce CO_2 emissions by 109 kg/d or ~25 tonnes of CO_2 per year depending on the weekly usage. Furthermore, the utilization of the trucks was significantly increased due to reduced fuelling times.

H2 Aberdeen have also implemented waste truck and street sweeper trials using hydrogen as a dual fuel supported by technology developed by Ultra Low Emission Mileage Company Limited (ULEMCo). Hydrogen as a dual-fuel offers a low adoption cost solution but is less efficient in its utilization of hydrogen by using an internal combustion engine rather than a fuel cell. In a street-sweeper application, the H2 Aberdeen project was able to improve the vehicle's fuel consumption from 4.8 to 6.68 miles per gallon (MPG). For each kg of hydrogen consumed, the vehicle displaced approximately 3.3 L of diesel

Service vehicle fleets tend to be smaller volumes and higher unit costs. This tends to support fuel cell integration. Potential exists for this integration to be undertaken in New Zealand with companies such as ZEV active in vehicle electrification.

Electric light trucks as a market will likely be a blend of battery only, battery plus fuel cell range extenders, and full fuel cell, driven largely by fleet utilisation and range requirements.

Applications in Taranaki and New Zealand

A waste collection fleet would be an excellent solution for New Zealand. BEV vehicles offer low-emission options, however reduced range, load-capacity and charge times may limit their applications, especially in geographically larger regions with long travel distances. The chart below compares total cost of ownership (TCO) for waste truck operators, and a crossover point at around 300 km range produced as part of the WaterstofNet project.

The figure above does not take into account the limited load capacity of BEVs due to increased weight of the battery systems, and subsequently the additional trucks required to haul the same mass of waste to the depot which is another key factor in the business case.

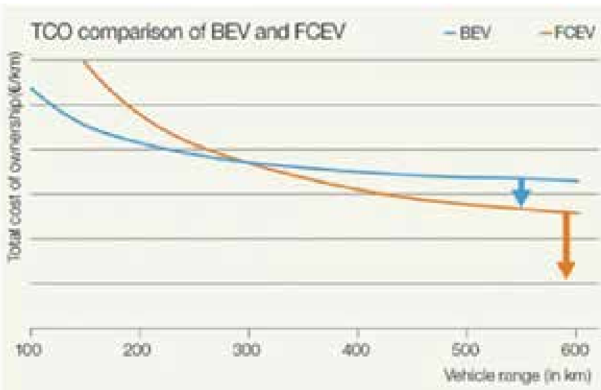


Image from "Waste collection vehicle using a hydrogen fuel cell" (WaterstofNet 2013)

Based on the project in the Netherlands, the observed hydrogen consumption for the waste trucks was 6-9 kg/100 km. Referencing Envirowaste's 2016 Sustainability Report (EnviroNZ, 2015), in 2015 the 561 strong diesel vehicle fleet travelled 9,361,000 km, consuming 8,423,000 Litres of diesel resulting in emissions of ~22,491 tonnes of CO_2. This fleet has achieved continual emission reductions per vehicle since 2013 however further material reductions will require vehicle electrification. The entire fleet emissions could be reduced to effectively zero with adoption of FCEVs, requiring 2,200-2,300 kg /day renewable hydrogen production.

There are several companies both within and external to New Zealand that could facilitate adoption of hydrogen waste truck technology:

- ZEV, based in Palmerston North has developed an electric drive technology that could enable conversions and new builds of waste and municipal service vehicles.
- DAF has a strong presence in New Zealand and are driven to supply more electric vehicles into different markets.
- SEA Electrical based in Australia is currently producing a BEV waste vehicle platform that EnviroWaste is utilising.

HEAVY TRUCKS

Heavy trucks demonstrate a number of the key advantages of FCEV such as high payload, high utilisation and long range, thus helping support a Total Cost of Ownership (TCO) business case. They also represent an opportunity to have the most significant reduction in greenhouse gas and particulate emission.

Heavy FCEV truck development has been more recent but is gaining significant momentum. The need to decarbonise heavy transport has placed the focus on the heavy transport space.

As of November 2018, no trucks are in commercial production however, a number are in development and operating.

New Zealand has a relatively large trucking fleet due to the distributed nature of the main industrial sectors. Large fleets of trucks of note include:

- The dairy sector utilises large fleets for milk collection and bulk product delivery between factories
- The food processing industry freights large volumes point to point for export
- In Taranaki the energy sector freights bulk liquids between plants
- The forestry industry conducts hub collection out from the ports and pulp mills including Taranaki, Tauranga, Whangarei, Napier, Kawerau, Nelson, and Napier
- General freight and logistics companies operating between the major industrial and commercial centres

Hyundai is working with Swiss company H2 Energy to deliver 1000 FCEV 18 Ton trucks starting 2019. Estimated range is 400km.

Esoro and Coop has developed a 34 Ton refrigerated demonstration truck with a 400km range.

Norwegian foodstuffs company Asko has ordered 3 x 27 ton fuel cell trucks developed by Scania.

VDL of Netherlands is developing a 28 ton fuel cell truck conversion together with a number of partners via the H2 Share programme www.nweurope.eu/H2Share coordinated by WaterstofNet.

Kenworth & Ballard are testing a fuel cell drayage truck in Port of LA

Toyota are developing a series of drayage trucks in partnership with Port of LA. Their Project Portal 2.0 can travel 480km.

Nikola Motors are developing a series of long-haul truck designs and aim to establish a large network of fuelling stations across US & Canada.

Nikola plans to introduce the "Tre", a long haul truck for the European market by 2023.

The business case for adoption of hydrogen fuel cell heavy trucking is primarily driven by the application of the benefits of the technology to these types of fleets. Hiringa Energy has conducted analysis of a standard 800km daily duty with the latest available truck performance data and New Zealand logistics costs. This distance could involve:

- Line haul, e.g. Wellington to Whangarei, New Plymouth-Auckland
- Return-haul, e.g. Tauranga-Palmerston North, Auckland-New Plymouth, New Plymouth-Tauranga
- Continuous short haul, e.g. milk collection, industrial bulks.

NZ$ per tonne-kilometre has been selected as the most appropriate total cost of ownership metric that takes into account fuel, labour, maintenance and depreciation cost on a unit of load transported.

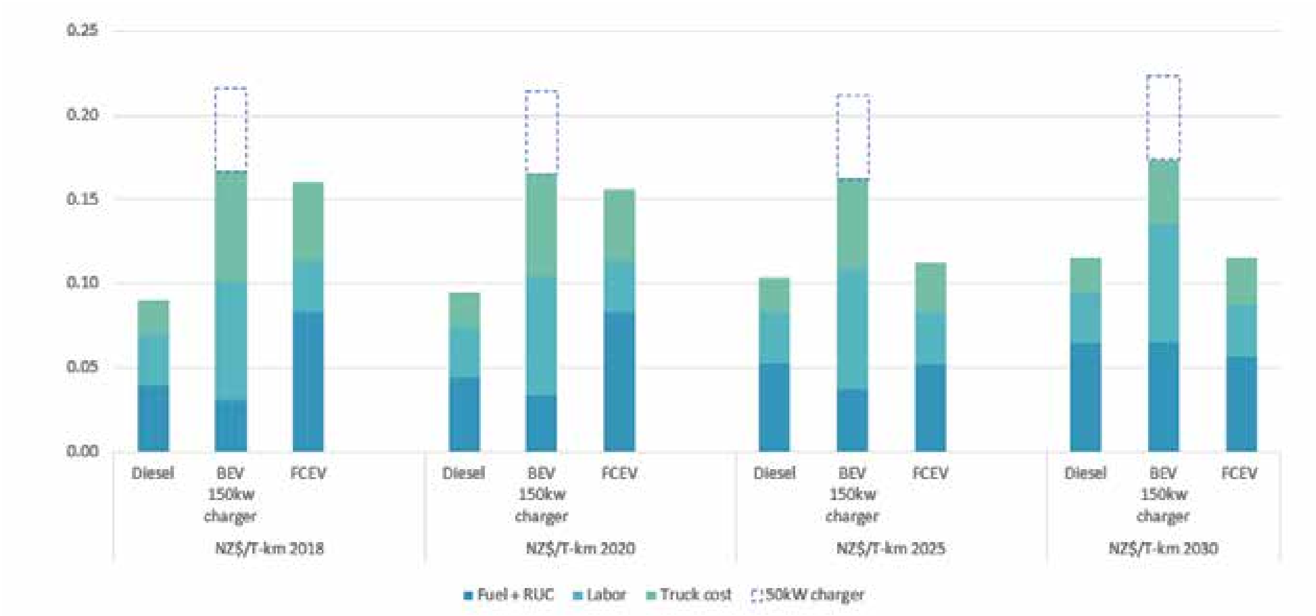
Two cases for battery electric costs have been analysed, one utilising conventional 50 kw charging and one utilising 150 kw fast charging.

The relative costs of these inputs have also been projected ahead to 2030, with allowance for:

- Projected increase in diesel costs,
- MBIE projected increase in grid electricity costs, and
- Projected decrease in hydrogen price as infrastructure builds out
- Projected decreases in BEV and FCEV truck purchase and maintenance costs

Key assumptions:

- Freight weight: Diesel & FCEV trucks: 20 T / EV trucks: 13 T
- RUC: road usage charges – BEV and FCEV trucks are assumed to have RUC exemption until 2025 (inclusive)
- Kilometers a year: Diesel & FCEV trucks: 208 000km/ EV (50kW charger):120 000km/ EV (150kW charger): 203 000 km



- The travelled kilometers is smaller for battery trucks due to charging time

The total $/tonne-kilometer cost of hydrogen FCEV trucks is projected to reach parity with diesel in the mid 2020s with BEV trucks not expected to achieve parity with diesel until after 2030, if at all. The FCEV advantage over both diesel and BEV will improve further as the vehicle costs and delivered hydrogen price reduces.

The major opportunities in Taranaki for heavy trucks are for line haul freight, milk collection and dairy product delivery, industrial solid & liquid bulk delivery fleets and forestry fleets.

Hiringa Energy has partnered with Transport Investments Limited (TIL), a New Plymouth based national freight and logistics company, to develop FCEV transport solutions in New Zealand. TIL's national fleet comprises 900 trucks, 310 forklifts and 170 light vehicles. Hiringa, TIL, and other large fleet owner operators are jointly working with the international OEMs and fuel cell manufacturers to develop heavy vehicle solutions for the NZ market.

The development of a heavy trucking solution is of particular interest and is incorporated in the planned H2 Taranaki Roadmap.

ROADMAP AND ENABLERS FOR IMPLEMENTATION IN TARANAKI

Taranaki FCEV Transport Roadmap	Phase 1 Pilot fleets	Phase 2 Commercial fleets	Phase 3 Scale Up
Total Hydrogen Vehicles	10 light vehicles 2 medium trucks 1 heavy truck	10 light vehicles 10 medium trucks 3 heavy trucks 2 buses	1000+ light vehicles 25+ medium trucks 70+ heavy trucks 15+ buses 1 train
Councils	NPDC light vehicle carshare trial	TRC, SDC, STDC light/ SUV vehicles Ute/Van trials	Light & medium fleet conversion
Contractors	Waste collection trucks trial Civil contractors light vehicles	Scale up of waste collection Civil contractors medium truck trials Regional bus trial	Full contractor fleets conversion
Third Parties	TIL light & heavy truck trial	Inter-city heavy vehicles expansion Coach trials	Full TIL fleet conversion, Train trial Coach fleet scale-up
Hydrogen Consumption	150 kg/day	600 kg/day	7000+ kg/day
Government Support Activities	Inclusion of FCEV models in all of government vehicle purchasing scheme NZTA engagement & mechanism for purchasing hydrogen buses RUC exemptions for hydrogen vehicles. EECA support for FCEV heavy trucks and FCEV fleets Government funding support for early infrastructure investment Tax relief mechanisms for capital investment into hydrogen Establishment of green certificate scheme Renewable transport fuel obligations		
Regulator activities	NZTA support for vehicles Regulatory exceptions as required for infrastructure & distribution	Fit for purpose regulations for vehicles, infrastructure and distribution as required.	Fit for purpose regulations for vehicles, infrastructure and distribution as required.
Hiringa & partner activities	Establish NP supply & RFS infrastructure Support pilot fleet introduction Possible LOHC pilot	Establish additional supply & RFS outside region Support fleet scaling & further piloting Commercial LOHC	Scale up refuelling from existing stations Additional refuelling in Taranaki and across NZ LOHC distribution system
Hydrogen Supply (Taranaki)	400-600 kg/day	800-2000 kg/day	8000+ kg/day

STATIONARY ENERGY & STORAGE

LARGE SCALE ENERGY STORAGE AND POWER GENERATION

The application of hydrogen becomes particularly relevant in energy systems such as New Zealand where large scale inter-seasonal and dry year effects results in a significant energy shortfall from hydro-electricity baseload. Presently, this shortfall is addressed through a combination of Huntly coal thermal plant (Huntly 1-4) and the use of natural gas thermal peaker-plants.

On average during recent years, gas thermal generation has accounted for 20% of total electricity generation. At present the year to year flex generation requirement provided by natural gas is 20-25PJ with the remainder ~15PJ provided by the Huntly Coal power station. With the closure of the Huntly station planned for 2022, the requirement for gas thermal generation flex is expected to increase to 35-40PJ (Gas Industry Company Limited, 2017).

Recent work by Transpower examining the feasibility of achieving the 100% renewable electricity target by 2035 concluded that there would be an approximately 42 PJ dry season shortfall on an average once every 7 years.

The majority of flexible gas thermal generation is based in Taranaki (at Stratford & McKee) with Huntly providing the remainder capacity.

Natural gas storage capacity exists in Ahuroa, Kapuni and McKee fields. Given the existing gas network, gas fields & storage, peaker-plants and generation transmission infrastructure in Taranaki, the opportunity exists to explore the use of produced and stored renewable hydrogen for future peak power generation utilising the storage and distribution methods outlined such as gas grid storage, synthetic methane in gas storage facilities or as liquids.

SMALLER SCALE ENERGY STORAGE AND BACKUP GENERATION

A number of smaller scale energy storage and backup generation technologies utilising hydrogen and fuel cells exist that are commercially available.

Combined Heat and Power (CHP) Fuel Cell systems

Combined heat and power fuel cell systems have a number of areas of application, such as:

- **Commercial buildings** – office buildings, hotels, health clubs, nursing homes
- **Residential** – apartments, houses, planned communities
- **Institutions** – colleges and universities, hospitals, prisons, military bases
- **Municipal** – district energy systems, wastewater treatment facilities, schools
- **Manufacturers** – chemical, refining, ethanol, pulp and paper, food processing, glass manufacturing

Commercial and residential scale CHP systems utilising fuel cells have been installed in Europe, US, Japan and Korea. The majority of commercial systems utilise Solid Oxide Fuel Cells (SOFC) operating at high temperatures and with natural gas as the feedstock. When both the heat and power are utilised the systems deliver approximately 30% energy efficiency savings over conventional heat and power technologies and equivalent savings in emissions. Another significant feature is that energy supply resilience gained through being independent of a central electricity grid. This is a particular attraction for populations exposed to natural disasters such as earthquakes. The challenge is the capital cost of the fuel cell technology.

Commerciality has come via the use of large fuel cells where significant amounts of power are required thus creating an economy of scale. Companies such as Bloom Energy, Doosan and FuelCellEnergy have installed numerous fuel cells into applications such as data centres, distribution centres and manufacturing facilities.

Bloom Energy's Bloom Server provides reduced emission resilient power from natural gas

Nedstack has installed a 3.6 MW rated unit capable of delivering 2MW nominal electrical output and up to ~2MW in heat. The unit utilises waste hydrogen from the adjacent chemical process to produce heat and power.

GenCell's G5rx back-up fuel cells installed at a substation for San Diego Gas & Electric (SDG&E). The fuel cell will automatically operate in the event the power grid goes down. The fuel cell can operate 10 times longer than existing back-up power sources, and has the capacity to maintain all substation operations versus only critical operations.

Hydrogen PEM Fuel Cells

True zero emission fuel cell CHP requires a pure hydrogen fuel cell. A number of companies have been developing this technology such as Toshiba, Nedstack, Hydrogenics and Proton Motor. The installed fuel cells require a steady supply of hydrogen to operate. Options include hydrogen delivery via a repurposed gas pipeline or a practical supply of hydrogen in a stored form such as ammonia or LOHC. One possible trial CHP application has been identified at the Todd Energy Aquatic Centre where a 400KW unit would be able to provide pool heating and supplementary power.

Remote and back-up fuel cell power systems

Back-up and resilience systems are an area of specific potential for hydrogen fuel cells. Such systems have potential to be applied to smaller scale services such as water pump stations and telecom towers through to large critical infrastructure such as hospitals, airports and water treatment plants.

The Israeli company GenCell has developed a low cost 5 kW small scale hydrogen fuel cell system that has potential application for both remote water pumps and back-up systems. The system can either be supplied by stored hydrogen as a back-up system (G5rx) or, for continuous operations with liquid ammonia that is then cracked to produce hydrogen (A5 system). The business case for this system is in comparison to a diesel generator system. The higher capital cost of the system is offset by the reduced maintenance and cost of ammonia in comparison to diesel.

Given the availability of ammonia in Taranaki, and the intention to generate green ammonia via the Ballance-Hiringa green ammonia project, this is potentially a good early application of pure hydrogen fuel cells in the region. NPDC and Hiringa are working together to identify early pilot sites.

On a larger scale, facilities up to 2MW have been installed with a number of modular units available in the range 100kW – 1MW.

A number of locations and opportunities have been identified as potential applications in Taranaki for fuel cell projects with both public and private sector examples such as integration with Powerco gas and electricity infrastructure and potentially Taranaki District Health Board infrastructure.

Hiringa Energy and Powerco are looking to partner on identification and implementation of a suitable demonstration/trial project.

ROADMAP AND ENABLERS FOR IMPLEMENTATION

Stationary Energy & Storage Roadmap	Phase 1 - Pilot	Phase 2 – Commercial	Phase 3 – Scale Up
Storage	H_2 injection trial	H_2 injection storage with blending	100% hydrogen pipeline
Storage	10 MW methanation biocatalyst plant pilot	100 MW plant	4 x 100 MW plants
Stationary & Back-up Energy	5kW H2 fuel cell with H2 storage	400kW fuel cell to replace diesel generators at aquatic centre or hospital	Hydrogen fuel cells integrated with district facilities
Remote Energy	5kW H2 fuel cell with ammonia to run remote pump stations	Implement larger system suitable for all council remote applications	Use fuel cells for all remote use cases
Government Support Activities	Government commitment to hydrogen fuel cell trials in suitable government owned infrastructure Government funding support for early infrastructure investment Tax relief mechanisms for capital investment into hydrogen Establishment of green certificate scheme		
Regulator activities	Regulatory exceptions as required for infrastructure & distribution leveraging international best practice	Fit for purpose regulations for infrastructure and distribution as required.	Fit for purpose regulations for infrastructure and distribution as required.
H2 Taranaki partner activities	Establish initial supply of ammonia and hydrogen Support pilot equipment introduction	Establish additional supply of green ammonia & hydrogen Support potential H_2 pipeline delivery trials Support larger scale equipment integration	Scale up H_2 supply chain Possible pipeline infrastructure integration Support large scale equipment supply chain development

The use of stationary energy and storage will require some key enablers:

- Regulatory change will be required in a number of areas to enable gas pipeline injection and transmission, and installation of hydrogen fuel cell systems in homes and facilities
- Hydrogen supply certainty will be required prior to installation of fuel cells. This might initially be achieved through compressed hydrogen tanks or ammonia and may evolve into hydrogen delivery through future pipeline conversion.
- Initial installation costs for fuel cell solutions will be relatively high. The establishment of a supply chain involving the local energy service sector will enable a growing local supply, installation and operations and maintenance capability. Local service companies such as Entec have been investigating the technology and would be good candidates for supporting such projects.

INDUSTRIAL APPLICATIONS

Renewable hydrogen is increasingly being recognised as a key ingredient for decarbonising a number of large industrial processes.

KAPUNI HYDROGEN HUB CONCEPT

An example opportunity for Taranaki is the development of a renewable hydrogen hub integrated with the existing Kapuni industrial complex.

The Kapuni complex provides an excellent co-location for a number of industrial hydrogen projects that could leverage the existing facilities.

The complex consists of:

- The Todd Energy operated Kapuni gas field that produces CO_2 rich natural gas. This field has gas storage potential for either CO_2 or synthesised methane.
- The Kapuni Gas Treatment Plant operated by Vector that treats the Kapuni gas field production, extracting the CO_2 and producing LPG from the gas stream.
- The Ballance Ammonia/Urea plant that produces Urea from natural gas supplied via the gas network
- Infrastructure consisting of gas pipelines operated by FirstGas, 11 kV, 33 kV electricity lines, and rail infrastructure.

Piloting and upscaling of this transitional strategy could be undertaken in a series of staged projects.

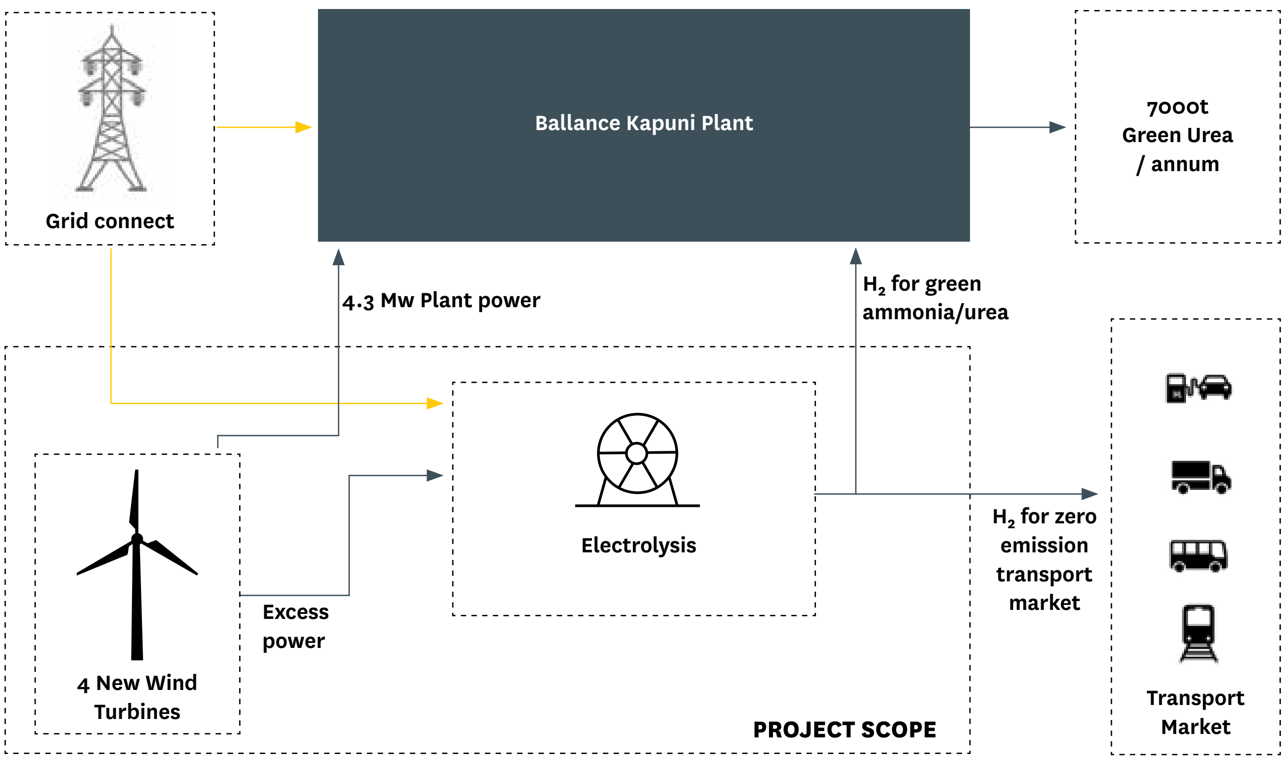
RENEWABLE HYDROGEN AND GREEN AMMONIA

Hiringa Energy and Ballance Agri-Nutrients are jointly evaluating a project involving integration of renewable electricity for hydrogen and green ammonia production utilising existing Kapuni ammonia production infrastructure. This project would potentially provide renewable electricity to power the plant and generate up to 2000kg/day hydrogen from excess electricity generation. The hydrogen would supply the plant, enabling approximately 7,000 tonnes per annum incremental urea production. The high purity hydrogen would be able to be diverted for supply to a transport market. The hydrogen would also provide a supply for subsequent pilot industrial projects.

PILOT METHANATION PLANT

Once renewable hydrogen production has been established at the Kapuni industrial hub this could be combined with CO_2 production from the regional gas fields to provide base feedstock for a pilot methanation plant based on either bio-catalyst or metal-catalyst technology.

For example, a ~10MW facility running on excess renewable electricity could provide approximately 0.4 TJ/day methane production which could subsequently be stored in the gas network or in a gas field. Commerciality would depend on the utilisation of the low-grade heat produced and the price of the methane. One mechanism to support a higher price for the produced methane might be through the use of green certificates issued at production and claimed when the gas is consumed, at a peaker plant for example.



A 10 MW biomethanation plant could produce up to 500 Nm3/hr methane and 3.2 MW heat

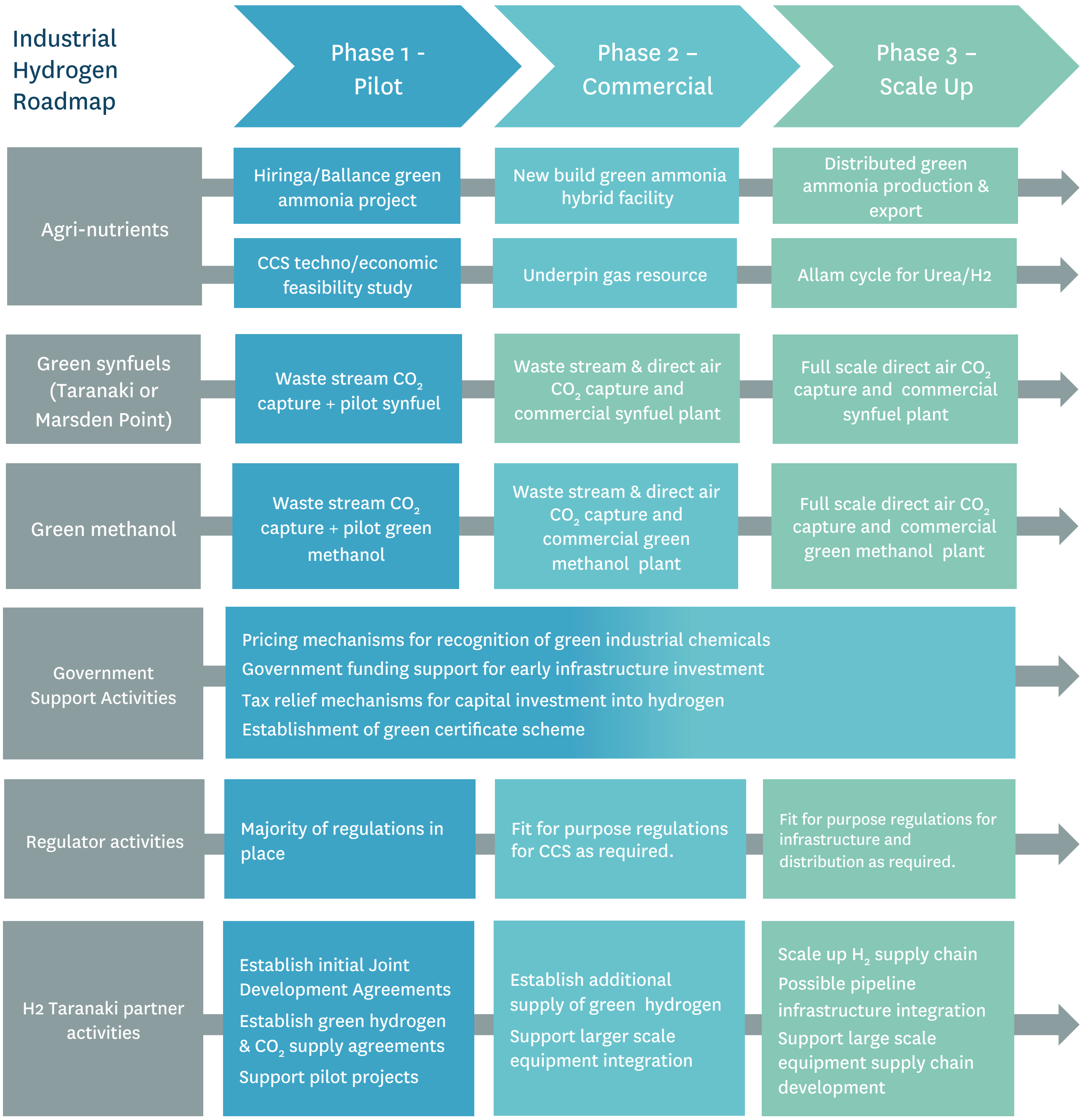
The utilisation of excess heat from processes such as this can provide a secondary efficiency, enhancing the process economics.

SYNTHESISED LIQUID FUEL PLANT

The synthesis of liquid fuels via the Fisher Tropsch reaction could also leverage the Kapuni hub. The CO_2 could initially be sourced from the excess CO_2 from the gas fields. Modern catalytic technology has improved the efficiency of this reaction. A plant could subsequently be coupled with an atmospheric carbon capture process.

SYNTHESISED METHANOL PLANT

Synthesis of methanol from captured CO_2 and renewable hydrogen provides a net zero chemical product and liquid fuel. If methanol is subsequently utilised to manufacture plastics, then the process actually becomes carbon negative. A pilot plant operated by CRI (Carbon Recycling International) is in operation in Iceland. This plant sources its electrolysis power from geothermal energy and the CO_2 feedstock from the geothermal field's production. In Taranaki the electrolysis power could come from new installed renewable generation.


Industrial Hydrogen Roadmap
Phase 1 - Pilot
Phase 2 – Commercial
Phase 3 – Scale Up
Agri-nutrients
Hiringa/Ballance green ammonia project
New build green ammonia hybrid facility
Distributed green ammonia production & export
CCS techno/economic feasibility study
Underpin gas resource
Allam cycle for Urea/H2
Green synfuels (Taranaki or Marsden Point)
Waste stream CO_2 capture + pilot synfuel
Waste stream & direct air CO_2 capture and commercial synfuel plant
Full scale direct air CO_2 capture and commercial synfuel plant
Green methanol
Waste stream CO_2 capture + pilot green methanol
Waste stream & direct air CO_2 capture and commercial green methanol plant
Full scale direct air CO_2 capture and commercial green methanol plant
Government Support Activities
Pricing mechanisms for recognition of green industrial chemicals
Government funding support for early infrastructure investment
Tax relief mechanisms for capital investment into hydrogen
Establishment of green certificate scheme
Regulator activities
Majority of regulations in place
Fit for purpose regulations for CCS as required.
Fit for purpose regulations for infrastructure and distribution as required.
H2 Taranaki partner activities
Establish initial Joint Development Agreements
Establish green hydrogen & CO_2 supply agreements
Support pilot projects
Establish additional supply of green hydrogen
Support larger scale equipment integration
Scale up H_2 supply chain
Possible pipeline infrastructure integration
Support large scale equipment supply chain development

EXPORT OPPORTUNITIES

The export of hydrogen as a renewable energy carrier is receiving increasing strategic focus from countries such as Japan and Korea. A number of Japanese consortia have been evaluating the options of export from New Zealand and Australia. Locations under consideration in New Zealand include New Plymouth which has a number of significant benefits:

- The deep-water port with existing industrial chemicals handling skills and supporting infrastructure
- A number of industrial chemical plants already exist in Taranaki, the region is very comfortable with this sort of industry
- Significant industrial engineering capability and support services based in New Plymouth
- The gas transmission network originates from Taranaki and could become a hydrogen gathering system
- High voltage power transmission also exists in Taranaki and connects to major infrastructure
- Good availability and relatively low cost of industrial zoned land
- Significant potential for large scale development of renewable electricity in the region to support electrolysis.

The export medium, liquid hydrogen, LOHC or ammonia, is still to be determined. It is possible more than one method emerges in the global supply-chain. Export facilities being considered are in the order of 500 MW to 1GW.

One possible scenario could be that New Plymouth forms part of an offtake route visiting at least one other facility in New Zealand or Australia.

Integration of such an export offtake facility with a domestic energy market could provide excellent flexibility for both markets. If the selected export facility and storage medium enables short term interruptible hydrogen supply then the facility can be utilised as a virtual peaking plant, load shedding and providing virtually instant peak power to the domestic market. This is a key advantage of electrolysis and hydrogen. The benefit of such a project to the grid should be able to be recognised and reflected in reduced grid connection costs.

Possible project options could be Motunui, South Taranaki, or Port Taranaki production facilities with export from Port Taranaki:

OPTION A – MOTUNUI PRODUCTION FACILITY AND PORT TARANAKI EXPORT FACILITY

Establishment of a large (500-1000 MW) electrolyser facility adjacent to the Methanex Motunui methanol facility with hydrogen being transported to Port Taranaki in gaseous, liquid or LOHC form. The facility converting H_2 to the export medium could potentially be separate from the electrolysis facility and placed at the port. This approach could leverage the industrial zoning of the Motunui complex and the pipeline infrastructure between Motunui and Port Taranaki. The renewable power could come via direct coupling to a large-scale offshore wind farm or through grid connection and a Power Purchase Agreement (PPA) with a large regional or out of region renewable energy project. This facility could be combined with a green methanol facility.

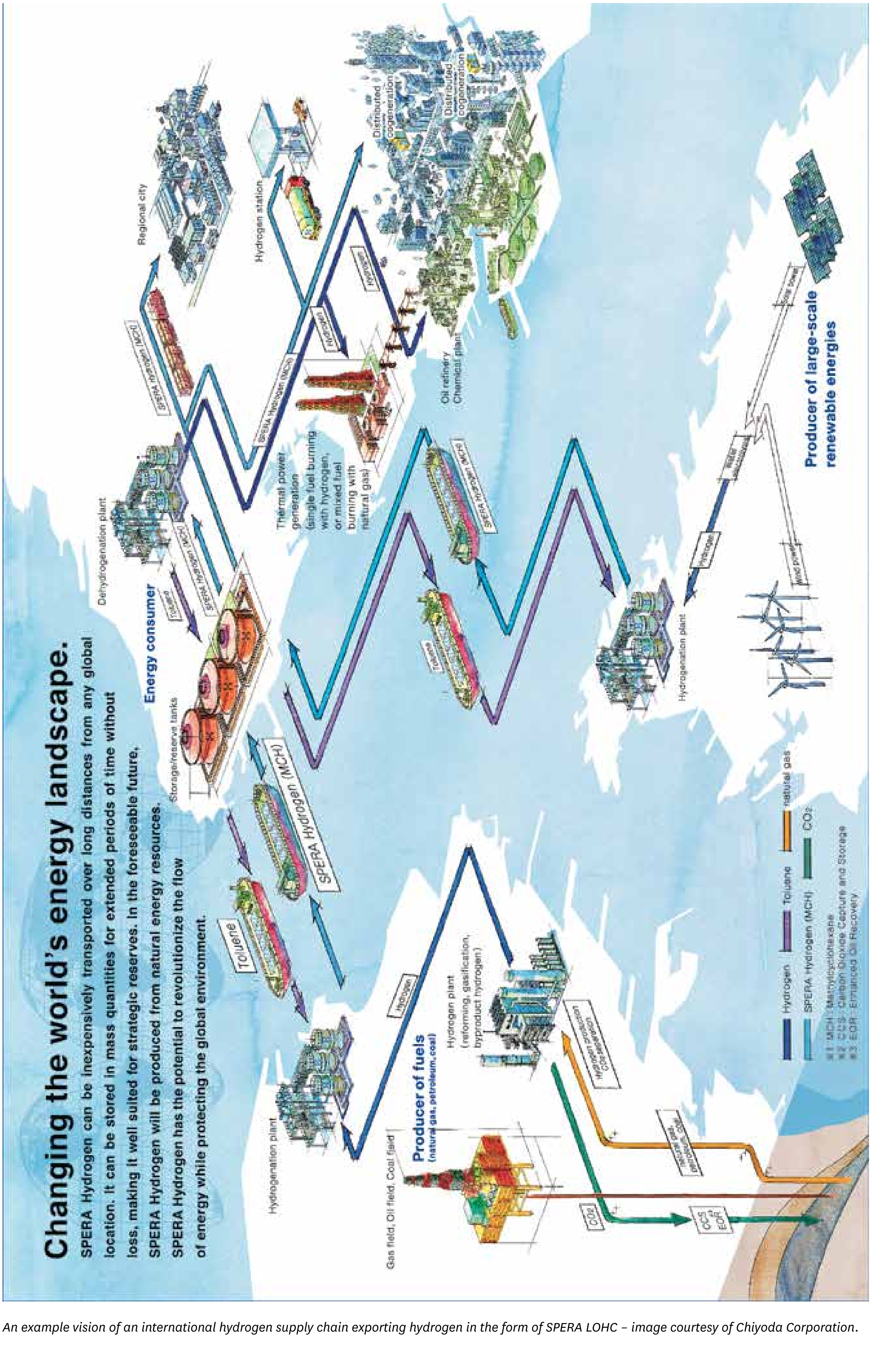
OPTION B – PORT TARANAKI PRODUCTION AND EXPORT FACILITY

Establishment of a large electrolyser and export facility at Port Taranaki, utilising spare land at the Port and the power supply infrastructure. Renewable energy could come from grid connection and a Power Purchase Agreement (PPA) with a large regional or out of region renewable energy project. In order to ensure this option remains available, retention of the existing high voltage lines to the port is crucial.

OPTION C – SOUTH TARANAKI PRODUCTION FACILITY AND PORT TARANAKI EXPORT FACILITY

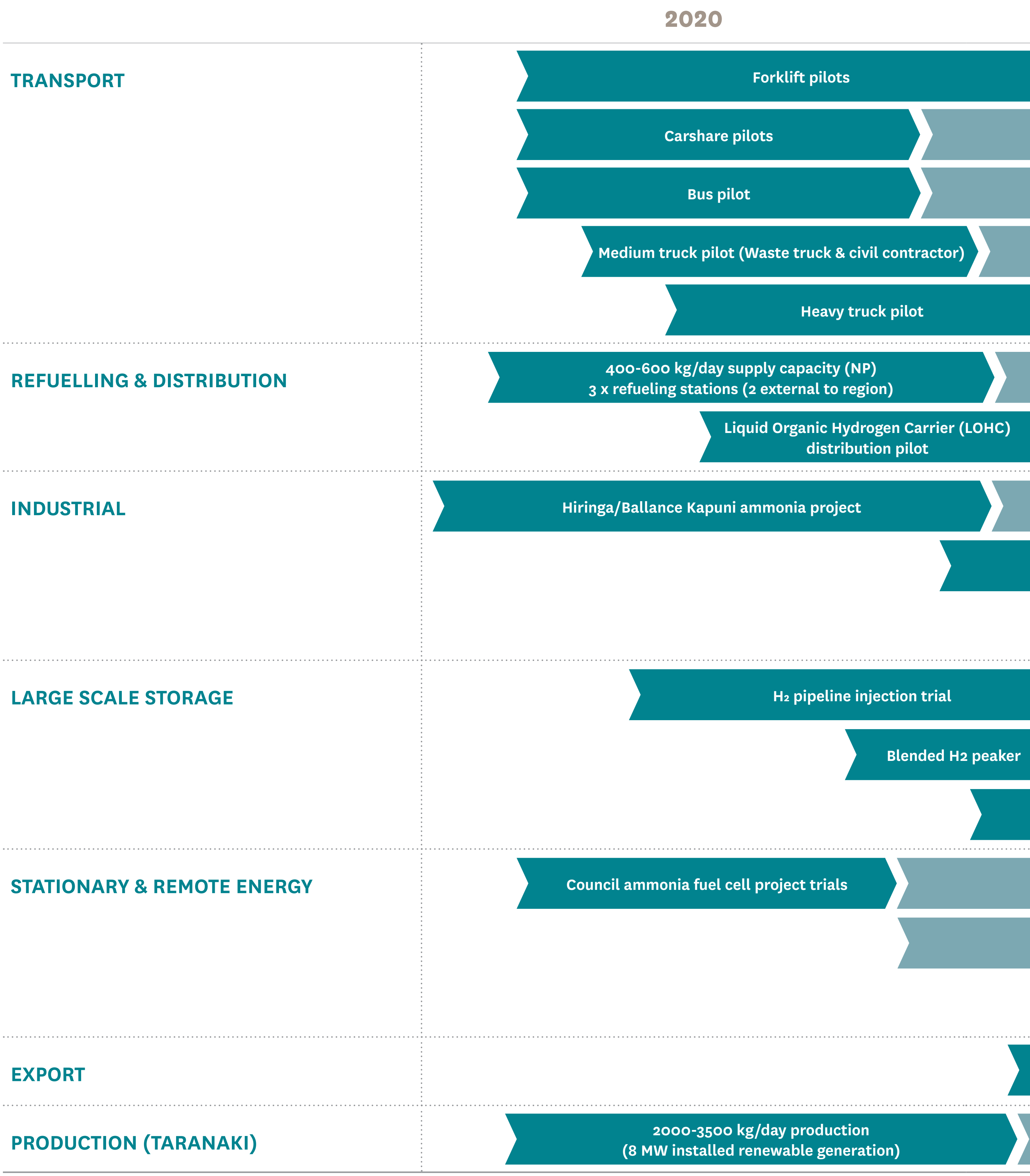
Establishment of a very large-scale electrolyser facility (1000-2000 MW) in South Taranaki supplied by regional renewable energy projects such as the Waverley wind farm and a possible future multi-gigawatt offshore wind and wave power farm in the South Taranaki Bight. Pipeline transfer (via repurposed pipelines) of produced hydrogen from the plant via the Kapuni hydrogen hub with a partial offtake for ammonia production and gas storage, the pipeline could continue north to supply hydrogen for Methanol production before delivery to an export facility at Port Taranaki.

This project would tie many of the large-scale opportunities discussed in this report together, significantly leveraging existing energy assets in the region.

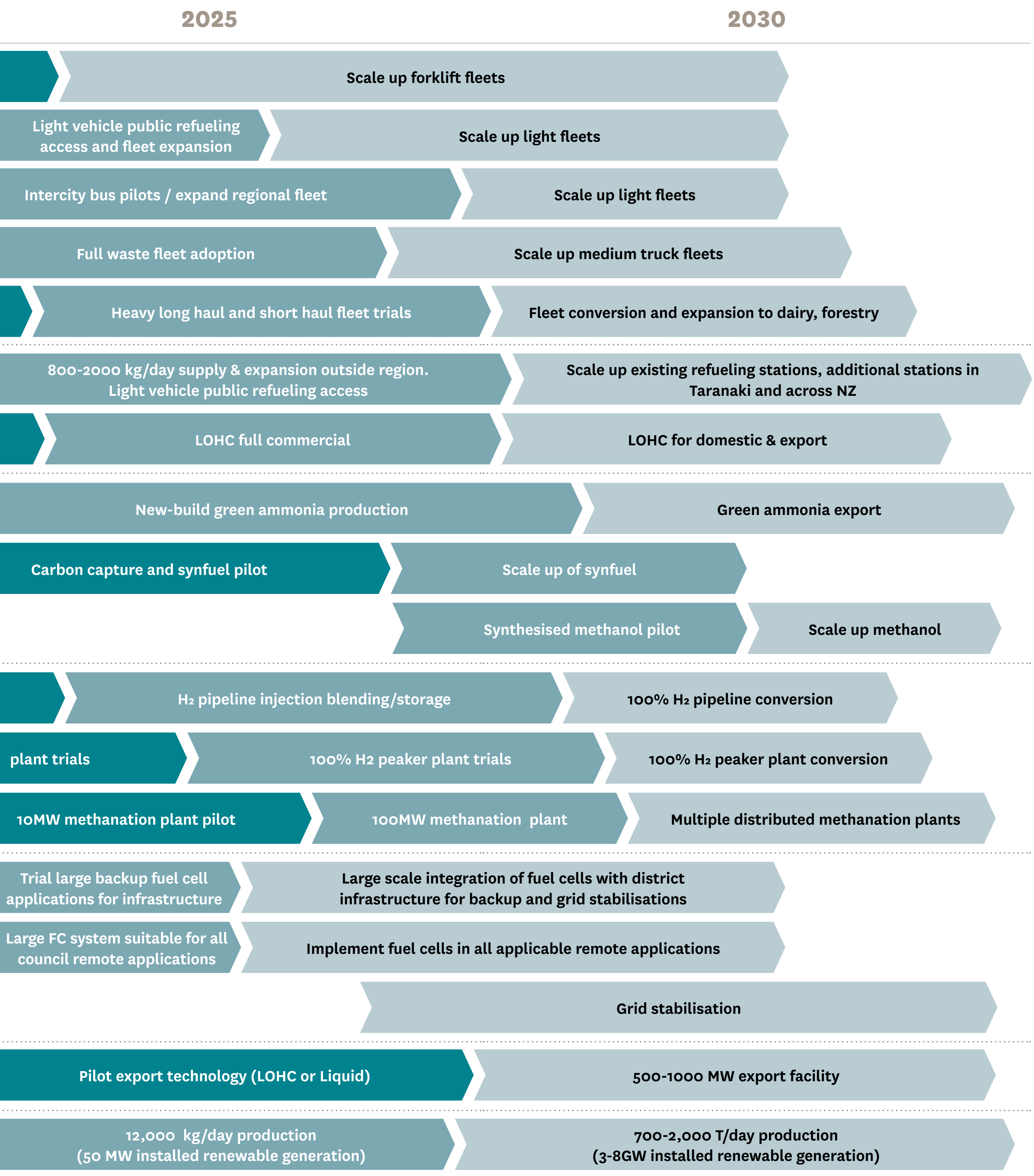


An example vision of an international hydrogen supply chain exporting hydrogen in the form of SPERA LOHC – image courtesy of Chiyoda Corporation.

INTEGRATED HYDROGEN ROADMAP AND ENABLERS

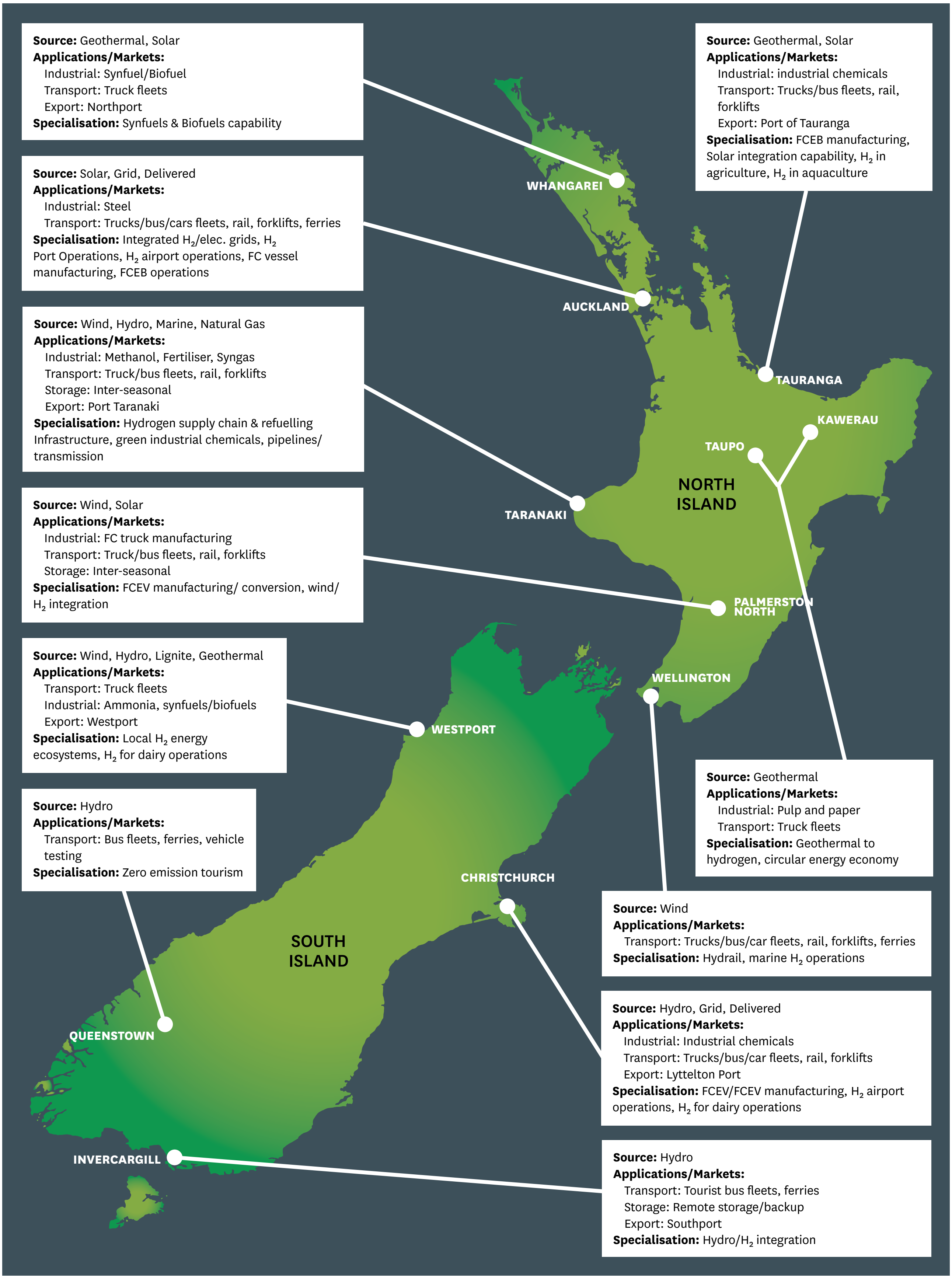


The various elements of a Taranaki ecosystem hydrogen roadmap are presented in the diagram below. The different activities will be subject to demonstrating a valid business case however, the relative sequence provides some framework to enable the identification of related activities including precursors and dependent activities.



HYDROGEN OPPORTUNITY IN THE BROADER NEW ZEALAND CONTEXT

A possible vision of the hydrogen opportunity taken to the broader context can be envisaged.



THE ROLE OF H2 TARANAKI AND THE BROADER CONTEXT

H2 Taranaki is envisaged to be a focussed initiative that brings public and private sector partners together to mature and implement projects as outlined in this roadmap. H2 Taranaki will initially be a public private partnership between NPDC, VTT and Hiringa Energy with the inclusion of formation partners Taranaki Regional Council, Stratford District Council and South Taranaki District Council. Participation of local businesses and organisations will be highly encouraged, with the expansion of activities beyond the initial partners a key objective.

H2 Taranaki will be a focal point for projects in the region and encourage local industry participation in the sector. The ability to leverage the private sector projects and share infrastructure is key to ensuring the efficient use of capital and the greatest benefit to the region.

H2 Taranaki and this roadmap will provide a critical mass of activity and leverage the regional energy sector to accelerate the adoption of hydrogen into the broader New Zealand energy mix.

The roadmap is an example of a region framing its part to play in the hydrogen economy, other regions are encouraged to take this as a template and work together with H2 Taranaki partners, Hydrogen New Zealand and the New Zealand Government to develop their own roadmap, leveraging their own areas of strength.

The public / private approach helps ensure no stone is left unturned to identify opportunities and enable hydrogen to penetrate into the areas of the energy system that are particularly difficult to decarbonise.

The roadmap document becomes a powerful communications tool and a public facing document to bring hydrogen to front in the region and across NZ.

With the region's industrial pedigree and imperative for change, the Taranaki region is perhaps more comfortable to take an active role. This provides a strong message to the rest of the country that the key energy region believes in the transition and is determined to be an energy leader into the future.

Support of this roadmap will encourage businesses in the region that have the skills, to develop and deliver commercial hydrogen business models and infrastructure across New Zealand.

H2 Taranaki would also work with the proposed National New Energy Development Centre (NNEDC) to identify future hydrogen technologies and enable their development and commercialisation in New Zealand.

Projects outlined will provide the platform for the region to refine its large scale energy infrastructure capability & skills to grow this new energy industry.

THE ROLE OF CENTRAL GOVERNMENT

Upon reviewing international progress, successes and barriers in the establishment of hydrogen as a viable low emission energy carrier in transitioning energy systems, it is clear that significant government assistance will be required to stimulate, nurture and then help accelerate the adoption of the technology and the establishment of the supporting infrastructure and supply chains.

There are a number of areas that the government can assist. These include:

- Development of a New Zealand Hydrogen Strategy that can inform policy, create regulatory framework and provide guidance to the various relevant ministries.
- Contributions to the infrastructure cost through grants, low-interest and interest-free loans and underwrites. Funding sources might include the Provincial Growth Fund (PGF), the Green Investment Fund and reinvestment of Emissions Trading Scheme income.
- Creating market demand via public sector projects such as bus, rail and vehicle fleets
- Strategic approach to Inclusion of FCEV models in all of government vehicle purchasing schemes
- NZTA engagement & funding for public sector purchasing of hydrogen buses
- EECA support for FCEV heavy trucks and FCEV fleets via Low Emissions Vehicle Contestable Fund and Technology Demonstration Fund
- Applications of market support mechanisms until the sustainable levels are reached such as renewable transport fuel certificates as utilised in the United Kingdom.
- Tax incentives/relief for capital investment into hydrogen
- RUC exemptions for hydrogen vehicles for a defined period of time
- Establishment of green certificate scheme for hydrogen production

REGULATORY FRAMEWORKS TO SUPPORT H2 TARANAKI AND NZ INITIATIVES

The establishment of H2 Taranaki initiatives together with other projects being considered or implemented in New Zealand must comply with the New Zealand regulatory framework. The New Zealand regulatory framework does not specifically recognise the modern hydrogen supply chain industry. It is important to note that hydrogen is currently handled and transported safely in New Zealand within this framework.

- The 1992 Gas Act (reprint December 2017) provides for the regulation, supply, and use of gas in NZ, includes biogas, coal gas and refinery gas but not hydrogen. However, the Act includes the mechanism for declaration of a substance to be classified as a gas under the Act. The Act is written from a relatively generic model that provides a framework for hydrogen inclusion. WorkSafe as the regulator is given the ability to require the use of standards and codes of practice.

Other key relevant acts for a hydrogen supply chain are:

- Health and Safety at Work Act 2015, which covers hazardous activities, workplaces and facilities;
- Hazardous Substances and New Organisms Act 1996, which covers storage and use of gas containers;
- Land Transport Act 1998 and amendments, which covers technical aspects of land transport; and
- Electricity Act 1992 providing for the regulation, supply, and use of electricity in NZ.

At the regulatory level there are several regulations that are in place that might be applicable, however, many of these are significantly more prescriptive based on hydrocarbon-based gas properties.

International and AS/NZ Standards, while not statutory documents, provide best practice guidelines and may be used to determine whether sufficient standards have been achieved and maintained. Specifically, significant development has occurred internationally with hydrogen standards in particular the International Standards Organisation (ISO) and the Society of Automotive Engineers (SAE) portfolios.

Where possible, the preferred approach for the regulation of hydrogen in New Zealand is to favour the application of existing international standards and best practises within the regulatory framework rather than seeking to tailor equipment and practises to New Zealand via prescriptive regulations. Initially, international standards qualified inspectors can be used to provide the verification as required under the various acts, while local specialists become familiar with hydrogen specific standards.

Minimising the amount of tailoring equipment and practises to New Zealand, will accelerate deployment of hydrogen-related projects, and leverage the vast amount of international work done previously to standardise and ensure project safety.

PROPOSED NATIONAL NEW ENERGY DEVELOPMENT CENTRE (NNEDC)

The proposed National New Energy Development Centre would be a nationwide hub, based in Taranaki, connecting industry, government, research expertise and leaders.

It is envisaged that major companies and small and medium-sized enterprises from across industry and New Zealand will be able to work together in diverse, seamless teams to solve energy challenges by unlocking innovation at scale.

A hub and spoke model will connect the NNEDC with other regions and institutions across New Zealand and internationally, while also championing new-energy innovation in Taranaki and harnessing the region's capability and expertise to build, test and deploy new energy solutions.

1. Proposed NNEDC Mission

- An organisation of national significance that fosters a new energy eco-system to leverage national and global industry knowledge and specialist expertise to reduce the time, cost, and risk associated with developing new energy technologies

2. The proposed NNEDC Vision:

- A globally successful new energy industry that leads New Zealand into a low-emissions future

H2 Taranaki and the NNEDC

The H2 Taranaki initiative initially has a near-term project development and execution focus. Project activities will be to roll out existing hydrogen technologies into the Taranaki and New Zealand context. Further out the roadmap has identified several potentially valuable technologies that require maturation. It is envisioned that a body such as NNEDC, should it become established, would help develop and commercialise these technologies, thus actively supporting future projects.

HYDROGEN NEW ZEALAND – THE NEW ZEALAND HYDROGEN ASSOCIATION

A very positive development for the realisation of the hydrogen opportunity in New Zealand is the recent establishment of the New Zealand Hydrogen Association. It is envisaged that this association will become the primary body that represents the industry. Membership is open to all interested parties from industry, government & academia from across the hydrogen supply chain.

1. Mission

- Assist New Zealand transition to a low-emissions future using low carbon hydrogen as an integral part of our evolving energy needs.

2. Vision

- Utilise New Zealand's renewable energy resources to decarbonise our domestic energy needs and reduce our reliance on imported fossil fuels.
- Help to protect and enhance the value of the New Zealand brand to maintain our competitive advantage in the global economy.
- Facilitate and enable cooperation between industry, government and academic stakeholders in order to position New Zealand at the forefront of the global hydrogen economy.

3. Aims

- Facilitate collaboration and cooperation with national and international governmental, institutional and private sector agencies to advance the commercialisation and uptake of low carbon hydrogen both in New Zealand and for export.
- Support and facilitate the delivery of world leading hydrogen innovation in New Zealand through public and private sector collaboration.
- Support and promote the development and adoption of effective policy and internationally recognised codes, standards and regulatory frameworks for the efficient and effective use of hydrogen infrastructure and associated technologies.
- Deliver and facilitate the collection and dissemination of national and international hydrogen related information and resources.
- Enable the realisation of business opportunities in hydrogen through linkages with technology developers, service providers, research capability, operational partners and financers in New Zealand and worldwide.
- Provide thought-leadership in order to advance the development of a hydrogen economy in New Zealand.

A key activity of the Association will be working with the government and regulators championing both the needs and the potential of the hydrogen opportunity.

RECOMMENDATIONS

To start the journey, H2 Taranaki proposes and supports a series of near-term public & private sector projects aimed to seed a hydrogen ecosystem in the region and the creation of a hydrogen industry in New Zealand

- Establishment of a New Plymouth refuelling station together with out of region connecting hubs, servicing buses, trucks, light commercial, waste and contractor specialised vehicles.
- Development of a green ammonia project at Kapuni, establishing hydrogen production to support the growth of hydrogen transport and providing the foundation for transition to a low-emissions chemical industry.
- Implement hydrogen into a stationary energy application within regional infrastructure such as one of the region's aquatic centres, council buildings or district health facilities, providing combined heat and power, energy storage and resilience.
- Assess the technical feasibility of converting the gas grid, select a suitable location and conduct a closed network demonstration project.
- Deploy near-term projects with Japanese and other international partners that enhance the business and regional relationships and create the basis for future export developments.
- Exploration of opportunities to use hydrogen-based fuels in peaker electricity generation plants.
- Investigate the technical and economic feasibility of utilisation of the region's existing oil & gas facilities and reservoirs for Carbon Capture and Storage (CCS), thus enabling blue hydrogen production.

Recommended next steps are:

- Establish H2 Taranaki initiative
- Enter public-private partnership to establish the first hydrogen refuelling stations in Taranaki
- Apply for funding for initial pilot projects to demonstrate hydrogen technology across a range of end applications.
- Encourage transition of public sector contractor fleets by:
  - Inclusion of hydrogen fuelled vehicles in tender documentation and evaluation criteria
  - Inclusion of mechanisms to enable hydrogen fuelled vehicles in the Public Transport Operating Model
  - Inclusion of hydrogen fuelled vehicles in whole of government purchasing
- Continue to develop relationships with key hydrogen regions and cities internationally – Scotland, North East England, Groningen (Northern Netherlands), Benelux, Norway, Japan, California and Australia
- In coordination with Hydrogen New Zealand, engage with relevant central government departments and government bodies regarding regulatory framework development and policy, working with the broader New Zealand hydrogen strategy
- Start community engagement to raise public awareness of hydrogen technology and benefits

ROADMAP IMPLEMENTATION PLANNING AND REQUIREMENTS

The initiative will require the ongoing support of the founding partners. One option is to form H2 Taranaki as a legal entity, another is that H2 Taranaki operates as a committee in partnership with another organisation, similar to how the Energy & Industrial Group (EIG) operates.

In additional to applications for funding for the proposed projects, support is required for the H2 Taranaki project co-ordination, promotion, and community engagement.

Council resources will be required for any review of internal procurement policies required, council project management officer(s) time and integration into council's asset management system/processes.

There is a need for H2 Taranaki advertising, marketing and engagement moving forward.

H2 TARANAKI ROADMAP INVESTIGATION UK/ EUROPE VISIT

A delegation of the H2 Taranaki partners undertook an investigative trip to the UK & Europe in October 2018. The delegation included:

- A general manager from Venture Taranaki Trust (VTT)
- A senior infrastructure planning official from New Plymouth District Council (NPDC)
- An executive from Hiringa Energy
- An elected member representative of NPDC

The trip encompassed visits to Norway, Denmark, United Kingdom, Netherlands and Belgium.

PURPOSE OF TRIP

1. **Attend key conferences in the areas of relevance to H2 Taranaki initiatives to gain a contemporary view of the development of hydrogen opportunities in UK/Europe, identify lessons learned and establish networks.**

   In total, four highly relevant conferences were attended by some or all of the delegates. These have provided excellent insights into the progress, barriers encountered, lessons learned, and commercial & government strategies being applied to stimulate hydrogen development. Strong networks have been established that have already borne fruit in the preparation of this report.

2. **Establish a relationship with Aberdeen City Council and discuss the opportunity to establish an MOU between the two cities for mutual sharing of information and resources pertaining to the energy sectors and in particular hydrogen.**

   A positive relationship was established at both Officer and Councillor level with Aberdeen City Council. Research and information was shared between the two parties, and an ongoing relationship developed. A formal MOU was discussed and is an option between the two cities. However, the opportunity to become a member of the Global Energy Cities Network would provide a partnership between the two cities as part of this network (alongside 19 other cities worldwide), so would negate the need for a specific MOU with Aberdeen City Council. This can still be investigated further if the option for an MOU was a preferred option by New Plymouth District Council.

3. **Discuss opportunities and support for joining the Global Energy Cities Network.**

Discussions were held with Aberdeen City Council officers and representative councillors around the benefits and commitment required to be part of the Global Energy Cities Network (GECN). As an existing member, Aberdeen City Council would be happy to consider supporting a New Plymouth District Council or Taranaki Region application to be part of the GECN (which requires a recommendation from an existing city member). There is potential for this membership to encompass the greater Taranaki region.

4. **Research current projects in hydrogen production and consumption and renewable energies.**

   Site visits and meeting with key personnel were undertaken for all key hydrogen projects in Aberdeen, Orkney Islands, Fife, Groningen, Copenhagen, and Belgium. The delegation gained a thorough understanding of their strategies, implementation and policies to achieve their projects to date, as well as key lessons they have learnt and future plans with hydrogen and renewable energies.

   Meetings were also held in Edinburgh with the Scottish Cities Alliance Hydrogen Project Manager and the Scottish Hydrogen & Fuel Cell Association. New Zealand has recently established a Hydrogen Association. It is recommended that H2 Taranaki and/or the Councils of the region join the Association. The connection with the Scottish counterpart was productive in establishing the link between the two organisations for future mutual benefit, and additional contacts in the Hydrogen Associations within Europe were provided.

   Connections were also developed with Orkney Islands Council at both Officer and Councillor level. The Orkney Islands are producing 120% renewable energy and are developing their own Hydrogen Economy to manage and exploit this asset. They are keen to continue the relationship with New Plymouth with mutual sharing of information and research.

5. **Build connections with training and research institutions and industry groups**

   The European Marine Energy Centre (EMEC) was the main Scottish research training institute connected with. They provide purpose-built grid connected open sea testing facilities for developers of both wave and tidal energy convertors. The delegation discussed tangible opportunities to link EMEC with our New Energy Development Centre.

Contacts have also been established between North East Scotland College and Western Institute of Technology Taranaki around hydrogen qualifications and training.

There is a great deal to be gained working closely with bodies such as H2 Aberdeen.

In the Netherlands, the New Energy Coalition, based in Groningen is somewhat similar to the proposed concept of the New Energy Development Centre initiative proposed in Tapuae Roa. This organisation promotes the development of new energy technologies, including, but not restricted to, hydrogen. They were instrumental in introducing the delegation to the companies embarking on hydrogen innovation.

WaterstofNet, based in southern Netherlands/Belgium also proved to be an excellent connection. WaterstofNet has several years of experience driving hydrogen adoption, facilitating projects and promoting the opportunity.

RESEARCH INVESTIGATION ITINERARY, CONTACTS, KEY LESSONS AND LINKS

Date:	Wednesday 2nd to Thursday 3rd October
Conference:	Maritime Hydrogen & Marine Renewable Energy, Floro, Norway
Key Personnel:	Attended by CEO Hiringa Energy

Norway is aggressively pursuing a decarbonisation pathway for industry, transport and looking to create export opportunities. Major developments discussed include:

- The competitive tender for a large scale hydrogen passenger ferry (500 NM range) to extend low emission ferry services beyond the existing battery solutions.
- Large scale offshore wind to hydrogen developments
- Development of large scale blue hydrogen projects utilising CCS
- Development of renewable hydro based hydrogen export project.

The Norwegian government has recently shifted gears on hydrogen as a key decarbonisation tool (beyond the electrification and battery only approach) and has gained increased recognition and funding support from central and regional governments.

Date:	Monday 8th October
Meeting with:	Aberdeen City Council
Key Personnel:	Andrew Win – Programmes & Projects Manager Councillor Philip Bell Wendy Devall – Project Officer HyTrEc2
Site Visit:	Aberdeen City Hydrogen Energy Storage & Refuelling Station Kittybrewster Station (Hydrogen production and refuelling station) Kittybrewster Depot (Hydrogen Bus & Vehicle maintenance)

Aberdeen is considered the centre for the oil and gas service sector for Scotland, similar to New Plymouth in the context of the Taranaki energy industry. Aberdeen City Council, with considerable investment from the Scottish and UK Governments has undertaken a hydrogen pilot project which includes 10 hydrogen powered buses (currently Europe's largest bus fleet), a car fleet, and hybrid model refuse trucks. This was to stimulate demand and profile for the emerging hydrogen market as part of their strategy to move to renewable energies. Refer to the link below for Aberdeen's Hydrogen Strategy:

http://www.h2aberdeen.com/home/H2-Aberdeen-resource.aspx

Alongside this pilot project the Council is also integrating hydrogen into new building infrastructure. An example of this is their new €330milion conference and exhibition centre which will be fully powered by hydrogen via fuel cell technology. *https://www.aecc.co.uk/largest-fuel-cell-installation-uk-new-aecc/*

Key Lessons:

- All buses and systems were developed outside of Aberdeen and they want to move to developing increased supply chain within their local market.
- Ambitions to move from the 'demonstration' phase and scale up to a commercial roll out of hydrogen infrastructure and vehicles.
- Hydrogen is not a small industry and is considered to have the potential to grow to a comparable scale to oil and gas globally.
- Development of example fleet with multiple funding partners, primarily from the public sector, has created the stimulus, but now requires investment from the private sector.

Kitty Brewster Hydrogen Production Station – Aberdeen City

Kitty Brewster Hydrogen Refuelling Station – Aberdeen City

Hydrogen Buses at the Kitty Brewster Depot – Aberdeen City

Hybrid hydrogen Road Sweeper – Aberdeen City

Date: Tuesday 9th October

Meeting with: Conference: Hydrogen – A Business Opportunity for Scotland

Attended a one-day conference which presented on the many opportunities for a hydrogen economy. For the full conference agenda and access to all presentations please follow the link:

https://www.erm.com/Hydrogen-Scotland-Conference-Oct2018

Key Lessons:

- 95% of hydrogen produced currently is from fossil fuels.
- International activity around hydrogen and renewable energies is accelerating, we need to keep pace.
- UK Government policy is looking into the decarbonisation of heat. They are working with Canada, Japan and Australia
- Scotland Decarbonised Gas Alliance have a feasibility study into a 100% hydrogen gas grid. Demonstration scale gas grid to be constructed. Current pipes could carry up to 20% hydrogen mixed with gas
- Government policy and incentives are crucial in the implementation and transition
- Carbon Capture Utilisation and Storage (CCUS) will need to play an integral role to transition using natural gas but lowering emissions due to the relative lack of renewable potential and electricity costs in the UK
- Scottish Gas Network has 25,000 km of pipeline servicing 5.9 million homes across Scotland. Government investigated putting in electric heat pumps in every home in order to transition to the target of 100% renewable energy, but this was highly cost prohibitive and disruptive to consumers. A more logical solution was to utilise the current infrastructure with necessary upgrades to the pipes to transition to hydrogen heat production. Please refer to SGN strategy below to see how the gas network can transition to a hydrogen system.

https://www.sgn.co.uk/uploadedFiles/Marketing/Pages/Publications/Docs-Environment/SGN-The-future-of-gas-networks.pdf

Billia Croo Site (Wave & Tidal Research Base) off the coast of the Orkney Islands

Inside the Billia Croo Site (each machine on the right-hand side is linked to a company wave mechanism off the coast)

Date: Wednesday 10th October

Meeting with: EMEC (European Marine Energy Centre)

Key Personnel: Jon Clipsham – Hydrogen Development Manager

Neil Kermode – Managing Director

Caron Oag – Hydrogen Marketing Manager

Site Visit: EMEC Research Centre

Billia Croo Site (Wave & Tidal Research Base)

EMEC is based in the Orkney Islands and was established in 2003 and provides the world's only multi-berth purpose built open sea test facility for wave and tidal energy converters.

Our time was spent understanding how EMEC functions, which was originally as a public entity but is now a stand-alone Not for Profit Organisation. Wave and tidal energy is a very real prospect for New Zealand as a renewable energy, and EMEC are keen to continue the discussion with us to maintain a relationship as we develop our own New Energy Development Centre.

Watch the video link for further information: *https://youtu.be/uPQzZzK6orA*

Date: Thursday 11th October

Meeting with: Orkney Islands Council

Key Personnel: Councillor Andrew Drever

Adele Lidderdale – Project Officer Hydrogen Development and Infrastructure

Site Visit: Orkney Islands Council, Kirkwall

Kirkwall Hydrogen Facilities including Fuel Cell and Hydrogen Refuelling Station

One of Orkney Islands Council main projects we investigated was BIG HIT. This project develops and builds innovative green hydrogen systems in isolated territories. It develops a fully integrated system with hydrogen production, storage, transportation and utilisation for heat, power and mobility. It is important to note that there are 12 partners involved in this collaborative project which include Denmark, France, Italy, Malta, Spain and the UK. Click the link to read more: *https://www.bighit.eu/*

Another project is the Surf 'n' Turf, which takes the surplus energy from tidal power located at EMEC test sites and the community owned onshore wind turbines and routes it to a 500kW electrolyser which generates hydrogen by splitting water. The hydrogen is then stored as a compressed gas and transported by trailer on road and sea to Kirkwall, the capital of Orkney, where it then powers a fuel cell to generate clean electricity on demand. Click here for more info *http://www.surfnturf.org.uk/*

Key Lessons:

- The Orkney Islands are currently producing 120% renewable energy with some of the curtailed electricity being used to create hydrogen instead of wasting it.
- Onshore wind turbines are community owned with a percentage of energy revenue going back to the community.

Date: Tuesday 16th October

Site visit with: Biocat Biomethanation Plant, Copenhagen

Delegate Personnel: CEO Hiringa Energy

The BioCat biomethanation plant designed by Electrochaea is operating at the Avedore water treatment facility in south Copenhagen. This 1MW pilot facility takes renewable wind power to generate hydrogen that is then passed through a biocatalytic reactor together with CO_2 and manufactures 98.5% pure methane in a concept known as Power to Gas.

Date: Wednesday 17th – Thursday 18th October

Conference: Power to Gas Conference, Copenhagen

Key Personnel: Attended by CEO Hiringa Energy

This conference covered all major "Power to X" activities occurring in Europe. Power to X is the utilisation of electricity to produce hydrogen carbons such as synthesised methane, synthesised fuels and industrial chemicals such as ammonia. At the core of all these processes sits hydrogen. Significant discussion was around the ability to achieve the scale required to fully decarbonise the energy system. The scale of hydrogen production development will be a major factor, but also the need for efficiency improvements in the synthesis technologies.

Date: Wednesday 17th October

Meeting with: New Energy Coalition – *www.newenergycoalition.org*

Key Personnel: Patrick Cnubben

The New Energy Coalition is based in the Energy Transition Centre (EnTrance) at the Zernike campus of the University of Groningen and the Hanze University of Applied Sciences. We met with their team involved in preparing and providing a range of university level courses on energy transition matters including the hydrogen sector. There may be opportunity for these courses to be delivered in New Zealand. Also on the campus is a startup unit for New Energy businesses and we visited a couple of these.

Patrick Cnubben also introduced us to Drenthe Regional Government Minister Tjisse Stelpstra who is involved in the Under2 Coalition – an international grouping of state and regional government committed to keeping global temperature rises to under 2°C. There may be an opportunity for Taranaki to join.

We were also taken to Green Planet – the world's first multi-fuel service station of full commercial scale. The long term aim is to normalise renewable fuels. In the short-term it operates as a full service fuelling station for a wide range of fuels both traditional and renewable (hydrogen infrastructure is currently under development and will be deployed in 2019). Like any large service station the retail component is very important to profitability and the Green Planet shop is comparable to a "normal" Shell station – though there is a green angle to some of the food sold. Before agreeing to be involved in Green Planet Shell did their modelling on how much normal petrol

and diesel the site should sell. Green Planet apparently sells twice as much normal fuel as Shell had expected. The green branding pays off.

Date: Thursday 18th – Friday 19th October

Conference: Wind meets Gas Symposium, Groningen, Netherlands

Key Personnel: NPDC, VTT, Hiringa Energy

This symposium outlined the large scale commitment of the Benelux region (Belgium, Netherlands, Luxemburg) to transition their energy economy to a low emission system with hydrogen as a key element. Groningen is a region similar to Taranaki with a strong history of gas production. The gas fields are due to be decommissioned in the next few years due to the onset of earthquakes following major subsidence of the fields lying under the city. This has accelerated the transition for the region with the development of a Green Hydrogen Economy in the Northern Netherlands roadmap.

http://verslag.noordelijkeinnovationboard.nl/uploads/bestanden/dbf7757e-cabc-5dd6-9e97-16165b653dad/3008272975/NIB-Hydrogen-Full_report.pdf

Date: Saturday 20th October

Site visit with: Holthausen FCEV vehicle integrators, Groningen

Key Personnel: Max Holthausen – Hydrogen FCEV Engineer

Carl Holthausen – CTO

Holthausen conduct conversions and FCEV integrations into light, medium and heavy vehicles. They have developed a number of the vehicles in service in Groningen such as waste trucks, street sweepers and sucker trucks. They have also infamously produced the Hesla – a Tesla S with a fuel cell range extender. They have recently extended their manufacturing facility to convert/integrate up to 500 vehicles per year. This initiative has gained strong financial support from the regional government.

Key lessons:

- Holthausen has the potential capability to conduct FCEV conversions for NPDC vehicles

Date: Monday 22nd October

Site visit with: Colruyt Group, Belgium, Groningen

Key Personnel: Jonas Cautaerts – Business Development dats24.be (ColruytGroup)

Wouter Van Der Laak – WaterstofNet – Project Manager

Stefan Neis – WaterstofNet – Project Manager

The Colruyt facility is an excellent example of an integrated renewable energy, hydrogen production, distribution and multiple refuelling facilities. It has many similarities with Hiringa Energy's planned refuelling sites.

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HIRINGA

Te Kaunihera-ā-Rohe o Ngāmotu
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