STANDARDS NEW ZEALAND
TE MANA TAUTIKANGA O AOTEAROA

Hydrogen standards review

INTEGRATING HYDROGEN INTO NEW ZEALAND'S ENERGY LANDSCAPE

MAY 2023

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

Te Kāwanatanga o Aotearoa
New Zealand Government

Technical Advisory Group representation

This report was prepared by Standards New Zealand following a technical standards review. The review resulted in a suite of hydrogen and related equipment standards recommendations, determined by Technical Advisory Group (TAG) P3652 convened by Standards New Zealand on behalf of WorkSafe New Zealand – Energy Safety.

The membership of this group was approved by the New Zealand Standards Approval Board and appointed by the New Zealand Standards Executive under the Standards and Accreditation Act 2015. The TAG consisted of representatives from the following nominating organisations:

BOC Limited

BP New Zealand

Callaghan Innovation

Certified Energy Ltd

PEC (formerly Gallagher) Fuel Systems

GasNZ

Gas Industry Company

GNS Science

H2H Energy

Hiringa Energy

HyPotential Limited

Master Electricians

New Zealand Hydrogen Council

New Zealand Trade and Enterprise

Ports of Auckland

WorkSafe New Zealand – Energy Safety

Worley

Z Energy

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Figure 8 was kindly provided by Robert Holt, Team Leader: Electrical Engineering (Callaghan Innovation).

Figure B5 was kindly provided by Aaron Webb, Director, PwC New Zealand.

Disclaimer

Before initiating the adoption of any international standard mentioned in this report, Standards New Zealand will ensure the latest version is used.

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Foreword

New Zealand is preparing for its largest energy transition in more than 100 years, with hydrogen set to play a key role. To ensure standards and compliance mechanisms are in place to enable the safe supply and use of hydrogen as an alternative to fossil-based fuel sources and industrial feedstock, WorkSafe New Zealand – Energy Safety commissioned a review of relevant New Zealand, joint Australian/New Zealand, and international standards (see Appendix A). This report is the result of that review. Its recommendations and proposed strategy are aligned to a multi-year prioritisation plan, based upon a staged approach to adoptions, as dictated by the needs of the supply chain.

Although hydrogen is a highly versatile energy vector, there are many challenges to producing it at scale and having infrastructure capable of supporting it. Therefore, the review considered the use of hydrogen in its gaseous and liquefied states, as well as other two-way carriers for hydrogen transmission, storage and export such as toluene-MCH (methylcyclohexane) and ammonia so that the hydrogen standards framework would reflect these supply chain considerations.

Also, hydrogen's application cuts across multiple sectors and up to six ministerial portfolios, with a number of Acts and regulations playing an integral role in the value chain. This legislation will need to be addressed in conjunction with any adoption of standards.[1] However, for the purposes of this report, the focus is on those directly related to WorkSafe's remit. They include gas (safety and measurement), electricity (safety), health and safety at work (hazardous substances), and pressure equipment, cranes and passenger ropeways (PECPR).

In the first instance, WorkSafe New Zealand – Energy Safety wanted to ensure that standards solutions are fit for purpose and support a framework of compliance appropriate to the triggers (identified by the regulator) relative to each application. To that end, Standards New Zealand convened a technical advisory group, P3652, of subject matter experts within the energy sector.

The petrochemical industry, including gas, transport fuels and distribution, electrical and mechanical engineers, the New Zealand Hydrogen Council and key government agency regulators are represented.

The framework focuses on 10 key application-specific areas aligned to the needs of the supply chain. As such, the framework is a point of reference on the current regulatory state in New Zealand relative to hydrogen. It identifies areas where gaps currently exist and offers solutions (contingent on technological advancements) through the adoption of international standards to ensure the removal of barriers to international trade and investment.

The technical advisory group has drawn upon a wealth of industry experience and knowledge gained during members' participation in international standards development committees relating to hydrogen. The latest research and learnings from our Organisation for Economic Co-operation and Development (OECD) partners – who are advancing their own implementation strategies – have been considered, and Standards New Zealand believes the recommendations outlined in this report reflect an appropriate alignment with our international trading partners.

[1] To address the bigger picture of regulatory settings alignment, MBIE – Energy and Resource Markets has established the Interagency Hydrogen Working Group.

1. Executive summary

Hydrogen has the potential to play a significant role in advancing New Zealand's transition from fossil fuels to a decarbonised future (see Figure 1). It could possibly replace or, in the intermediate term, supplement natural gas (NG) and liquefied petroleum gas (LPG) as fuel gas. This extends to transport fuel (including aviation) and an industrial chemical feedstock for domestic use and export.

New Zealand has a legislated target of net zero greenhouse gas emissions (other than from biogenic methane) by 2050, and a target under the Paris Agreement[2] to reduce emissions by 30 per cent below 2005 emissions by 2030. The Government has also set a target of 100 per cent renewable electricity by 2030. New Zealand has considerable renewable energy resources that could be used to sustainably produce hydrogen as a next-generation fuel.

The Government is also focused on supporting thriving and sustainable regions. Hydrogen infrastructure built upon a region's existing energy sector, skills and supply chains could enable regions such as Taranaki, Northland and Southland to grow new business opportunities based on low-carbon hydrogen, and create new jobs. However, from a regulatory perspective this is not without its challenges; the application of hydrogen cuts across multiple sectors means a number of regulations will be affected in areas such as gas (safety and measurement), electricity (safety), health and safety at work (hazardous substances), and pressure equipment, cranes and passenger ropeways (PECPR).

Irrespective of scenarios that will enable New Zealand's hydrogen future, all possible future paths have a critical bottleneck within the current regulatory system. The existing system was not built to cater for a hydrogen-based economy, nor facilitate large-scale hydrogen uptake. Hydrogen is a hazardous substance that can, for example, explode if it is not managed carefully.

Looking through a health-and-safety-at-work lens, risks arise across the entire supply chain from production, through distribution and transportation, to on-site storage and refuelling facilities. Currently, these risks are managed through overlapping regulatory regimes (see Table 1) that cover gas safety and measurement, health and safety surrounding pressure equipment, electrical safety, land transport – dangerous goods and health and safety at work (covering major hazard facilities and hazardous substances). Yet there is no coordinated cross-agency guidance to provide clarity for regulators and clear, concise compliance requirements for equipment suppliers, installers and end users to enable the safe integration of hydrogen into the New Zealand supply chain. This causes delays in MBIE's processing of applications for exemption by industry, which consequently not only impacts project development timelines, but also makes New Zealand less attractive (in comparison to other competing countries) for investment in equipment and infrastructure necessary to establish and support a thriving hydrogen industry.

2 The Paris Agreement is a legally binding international treaty on climate change. It was adopted by 196 parties at the United Nations Climate Change Conference (COP21) in Paris, France, on 12 December 2015. It entered into force on 4 November 2016.

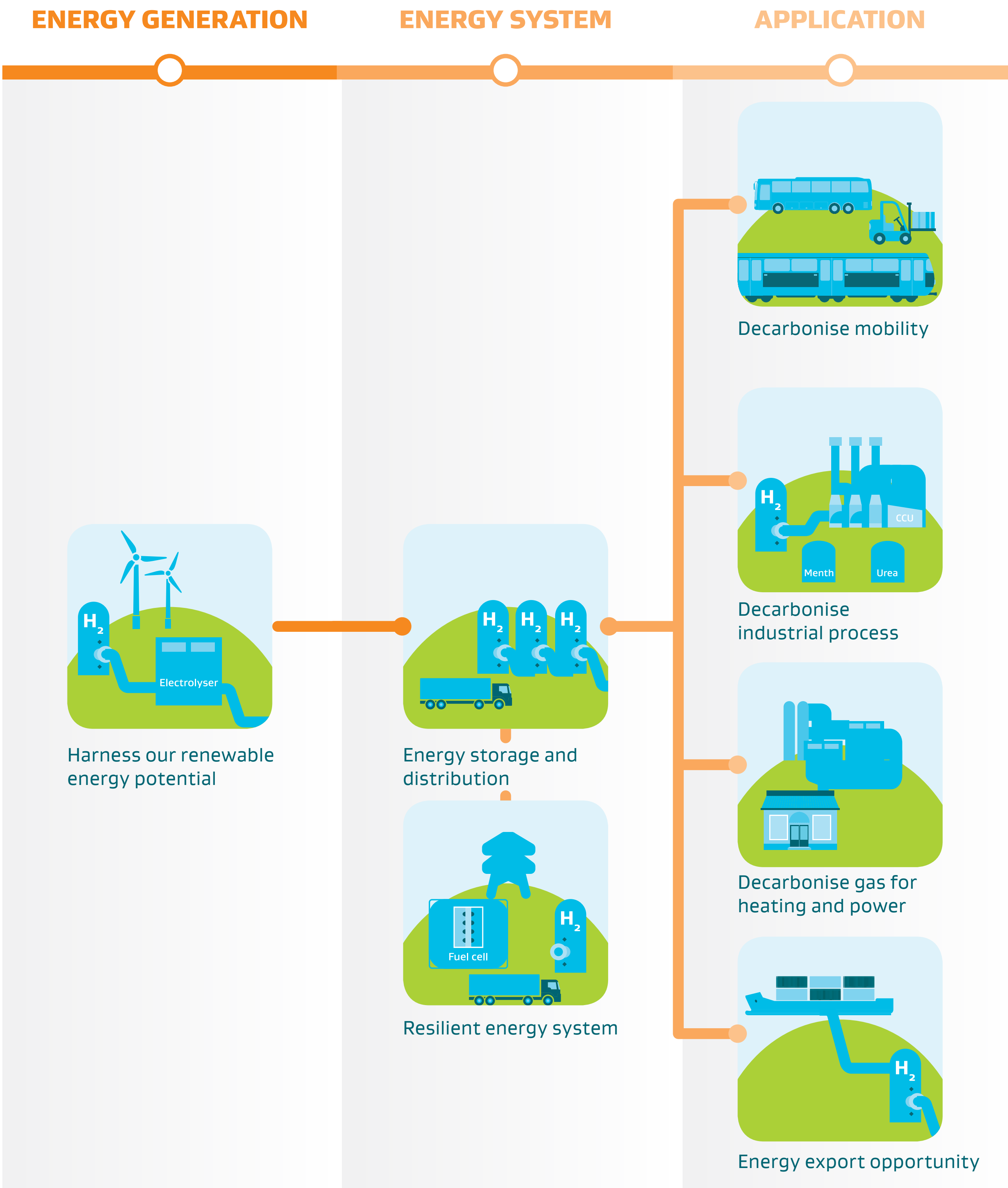

Figure 1 – Decarbonisation through hydrogen integration

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Table 1 – Integrating hydrogen into New Zealand's regulatory framework

Applicable WorkSafe New Zealand legislation
Gas (Safety and Measurement) Regulations 2010
Health and Safety in Employment (Pressure Equipment, Cranes, and Passenger Ropeways) Regulations 1999
Electricity (Safety) Regulations 2010
Land Transport Rule: Dangerous Goods 2005 Rule 45001/1
Health and Safety at Work Act 2015: • Health and Safety at Work (General Risk and Workplace Management) Regulations 2016 • Health and Safety at Work (Major Hazard Facilities) Regulations 2016 • Health and Safety at Work (Hazardous Substances) Regulations 2017

Addressing regulatory settings

Today, most firms engaged in the production of hydrogen are, to a large degree, operating under exemptions that fall within WorkSafe – Energy Safety's regulatory mandate. This is clearly a less than desirable outcome, given the concerns raised above. To that end, the MBIE – Energy and Resource Markets team has agreed to instigate a programme of work (led by PricewaterhouseCoopers [PwC]) to address the regulatory settings pertaining to hydrogen.

MBIE established a cross-agency working group in March 2022. Its role is to ensure that the current regulatory settings are fit for purpose as they are critical in facilitating the safe introduction of new hydrogen technologies and novel applications of hydrogen and promoting domestic and international investment in hydrogen in New Zealand.

The Acts and regulations that need to be reviewed primarily fall within the portfolios of six separate ministers:

- the Minister of Energy and Resources
- the Minister for the Environment
- the Minister for Building and Construction
- the Minister of Workplace Relations and Safety
- the Minister of Transport, and
- the Minister of Commerce and Consumer Affairs.

The working group was tasked with providing input into a report prepared by PwC on New Zealand's hydrogen regulatory pathway and then signalling the next steps on the development of a regulatory work programme for novel uses of hydrogen.

The final version of the report was prepared and submitted to the ministers affected in September 2022 and provides a starting point for agencies to make legislative and regulatory changes in their respective areas so as to advance the hydrogen industry and support New Zealand's climate change response.

The scope of the report included:

- identifying all the relevant Acts, regulations and standards that impact the regulation of hydrogen in New Zealand, organised into categories such as transport, commercial, and health & safety
- a definition of "fit for purpose" and a criterion to evaluate how fit for purpose the current regulatory settings are for hydrogen
- an evaluation of how fit for purpose the current regulatory settings are for hydrogen, including identification of current regulatory gaps, and barriers that need to be considered as the industry matures
- a systems-approach analysis of the impacts (short, medium, and long term) of the current regulatory system on the hydrogen industry, the economy, iwi, international relations, the environment, and so on, based on different potential future scenarios outlined by the modelling completed in the hydrogen standards implementation strategy or "roadmap" (see Figure A2)
- consideration of the alignment with international standards and good practice in order to ensure the settings support trade in hydrogen and hydrogen technology

- clarification and confirmation of the roles and responsibilities of the different government departments, agencies and co-regulators in the regulation of hydrogen, and
- high-level advice on any regulatory changes that need to be made (outlined by priority), including corresponding timelines and how they might align with any broader regulatory reviews that are being undertaken (for example, in the health and safety portfolio).

Regulatory alignment recommendation

To supplement the above review of regulatory settings, TAG P3652 deems it necessary that appropriate cross-agency policy alignment occurs in the form of a jointly developed compliance guideline or code of practice (CoP).

The proposed publication would effectively act as an interim compliance stopgap, thereby enabling players within the energy sector to operate (currently under regulatory exception on a per project basis) safely within this environment.

The desired outcome of such a publication would be to provide sectoral assurance and certainty that suppliers, installers, on-site personnel and end users have a clear understanding of their compliance and safety obligations. The publication could also be a valuable source of step-by-step guidance for first responders dealing with hydrogen-related incidents involving leaks, fires, burns and so on.

TAG P3652 considers the following agencies to be instrumental in the development of the above publication: MBIE (Energy Markets, Standards New Zealand, Building System Performance), the Energy Efficiency and Conservation Authority (EECA), the Environmental Protection Agency, WorkSafe New Zealand – Energy Safety, the Gas Industry Company, Waka Kotahi (NZTA) and Fire and Emergency New Zealand (FENZ).

Standards New Zealand suggests that the development of a compliance publication occurs in parallel with the adoption of the suite of standards solutions outlined within this report.

Standards recommendations

Projects 1 and 2 (production & purification and green credentialling and fuel station equipment & design) identified the following international standards adoptions for the regulator to consider:

Identical adoptions of seven ISO/IEC[3] standards	
ISO/IEC 17050-1	*Conformity assessment – Supplier's declaration of conformity – Part 1: General requirements*
ISO 14687	*Hydrogen fuel quality – Product specification*
ISO 19880-3	*Gaseous hydrogen – Fuelling stations – Part 3: Valves*
ISO 19880-5	*Gaseous hydrogen – Fuelling stations – Part 5: Dispenser hoses and hose assemblies*
ISO 19881	*Gaseous hydrogen – Land vehicle fuel containers*
ISO 19882	*Gaseous hydrogen – Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers*
ISO 26142	*Hydrogen detection apparatus – Stationary applications*

Adoptions with modifications of five ISO/IEC standards	
ISO 16110-1	*Hydrogen generators using fuel processing technologies – Part 1: Safety*
ISO 16110-2	*Hydrogen generators using fuel processing technologies – Part 2: Test methods for performance*
ISO 22734	*Hydrogen generators using water electrolysis – Industrial, commercial, and residential applications*
ISO TS 19883	*Safety of pressure swing adsorption systems for hydrogen separation and purification*
ISO 19880-1	*Gaseous hydrogen – Fuelling stations – Part 1: General requirements*

TAG P3652 also suggested that the regulator consider if the following joint and New Zealand cited standards could accommodate hydrogen and align with the international adoptions:

Revision of 10 joint Australian/New Zealand standards	
AS/NZS IEC 60079-0:2019	*Explosive atmospheres – Part 0: Equipment – General requirements*
AS/NZS IEC 60079-33:2012	*Explosive atmospheres – Part 33: Equipment protection by special protection 's'*
AS/NZS 60079.10.1:2009	*Explosive atmospheres – Classification of areas – Explosive gas atmospheres*
AS/NZS 60079.11:2011	*Explosive atmospheres – Part 11: Equipment protection by intrinsic safety 'i'*
AS/NZS 60079.14:2017	*Explosive atmospheres – Part 14: Design selection, erection and initial inspection*
AS/NZS 60079.17:2017	*Explosive atmospheres – Part 17: Electrical installations inspection and maintenance*

[3] International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC).

Revision of 10 joint Australian/New Zealand standards *continued*	
AS/NZS 60079.18:2016	*Explosive atmospheres – Part 18: Equipment protection by encapsulation 'm'*
AS/NZS 60079.29.2:2016	*Explosive atmospheres – Part 29.2: Gas detectors – Selection, installation, use and maintenance of detectors for flammable gases and oxygen*
AS/NZS 3800:2020	*Electrical equipment for explosive atmospheres – Repair and overhaul*
AS/NZS 3820:2020	*Essential safety requirements for electrical equipment*

Revision of two New Zealand standards	
NZS 5263:2003	*Gas detection and odorization*
NZS 7901:2014	*Electricity and gas industries – Safety management systems for public safety*

Projects 3 and 4 (mobility & safety and network distribution & inspection) identified the following international standards adoptions for the regulator to consider:

Identical adoptions of eight international standards	
ISO 11114-4	*Transportable gas cylinders – Compatibility of cylinder and valve materials with gas contents – Part 4: Test methods for selecting steels resistant to hydrogen embrittlement*
ISO 16111	*Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride*
ISO 19880-8	*Gaseous hydrogen – Fuelling stations – Part 8: Fuel quality control*
ISO 17268	*Gaseous hydrogen land vehicle refuelling connection devices*
ISO 23273	*Fuel cell road vehicles – Safety specifications – Protection against hydrogen hazards for vehicles fuelled with compressed hydrogen*
ISO 21266-2	*Road vehicles – Compressed gaseous hydrogen (CGH2) and hydrogen/natural gas blends fuel systems – Part 2: Test methods*
ASME B31.12	*Hydrogen piping and pipelines*
ASME B31.3	*Process piping*

Adoptions with modifications of three ISO/IEC standards	
IEC 62282-3-200	*Fuel cell technologies – Part 3-200: Stationary fuel cell power systems – Performance test methods*
IEC 62282-3-201	*Fuel cell technologies – Part 3-201: Stationary fuel cell power systems – Performance test methods for small fuel cell power systems*
IEC 62282-3-300	*Fuel cell technologies – Part 3-300: Stationary fuel cell power systems – Installation*

TAG P3652 also suggested that the regulator consider if the following joint and cited standards could accommodate hydrogen and align with the international adoptions:

Revision of 12 joint Australian/New Zealand and cited standards	
AS 2885.0:2018	*Pipelines – Gas and liquid petroleum – Part 0: General requirements*
AS/NZS 2885.1:2018	*Pipelines – Gas and liquid petroleum – Part 1: Design and construction*
AS/NZS 2885.2:2020	*Pipelines – Gas and liquid petroleum – Part 2: Welding*
AS/NZS 2885.3:1997	*Pipelines – Gas and liquid petroleum – Operation and maintenance*
AS/NZS 2885.4:2016	*Pipelines – Gas and liquid petroleum – Part 4: Submarine pipeline systems*
AS/NZS 2885.5:2012	*Pipelines – Gas and liquid petroleum – Part 5: Field pressure testing*
AS/NZS 2885.6:2018	*Pipelines – Gas and liquid petroleum – Part 6: Pipeline safety management*
AS/NZS 4645.1:2018	*Gas distribution networks – Part 1: Network management*
AS/NZS 4645.2:2018	*Gas distribution networks – Part 2: Steel pipe systems*
AS/NZS 4645.3:2018	*Gas distribution networks – Part 3: Plastics pipe systems*
AS/NZS 5601.1:2013	*Gas installations – Part 1: General installations*
AS/NZS 5601.2:2020	*Gas installations – Part 2: LP Gas installations in caravans and boats for non-propulsive purposes*

Revision of six New Zealand standards	
NZS 5255:2014 + A1	*Safety verification of existing gas installations*
NZS 5256:2014	*Verification of the safety of gas appliances*
NZS 5259: 2015	*Gas measurement*
NZS 5263:2003	*Gas detection and odorization*
NZS 5266:2014	*Safety of gas appliances*
NZS 5442:2008	*Specification for reticulated natural gas*

For Standards New Zealand, identical adoptions and minor modifications to ISO/IEC standards for New Zealand requirements are generally straightforward in that they typically require only minor tweaks or clarifications. Specifically, the cover and other relevant pages are replaced and the foreword is used to identify regional modifications, leaving the original document intact. Most standards adopted in this manner can be implemented relatively quickly – often within 12 months of a project's initiation.

2. Transitioning to a low-carbon economy

According to the Ministry for the Environment,[4] New Zealand's gross greenhouse gas (GHG) emissions in 1990 were 65,129.2 kilotonnes carbon dioxide equivalent (kt CO2-e). Between 1990 and 2019, GHG emissions increased by 17,188.6 kt CO2-e (26.4 per cent), reaching 82,317.9 kt CO2-e in 2019.[5]

Energy sector emissions in 2019, were the second largest contributor to New Zealand's gross emissions at 42 per cent or 34,263.10 kt of carbon dioxide equivalent (kt CO2-e). Outside of agriculture, energy presents some of the biggest opportunities and challenges to decarbonising the domestic economy.

More than half of the energy sector's emissions are attributed to transport. Other key contributors include manufacturing and construction, electricity generation, and fugitive emissions (for example, from the geothermal and gas sector). Energy sector emissions are also known to be closely linked with emissions from industrial processes, such as the production of steel, cement, aluminium and glass. It is believed these other processes contribute up to 6.5% of total energy sector emissions.

In conjunction with biofuels, green hydrogen[6] is internationally recognised as a key component in reducing emissions and is set to play a major role in supporting the decarbonisation of New Zealand's industrial processes, process heat and transportation.

For New Zealand, hydrogen offers excellent potential for medium-to-longer term energy storage, when produced using renewable electricity. It is a strong contender in the near term for decarbonisation of the heavy transport fleet and in the medium- to longer-term shipping, as well as aviation.

A number of industrial processes (including the production of methanol and urea) use NG as a feedstock to convert to hydrogen. Green hydrogen produced from renewable electricity can instead be used as a clean feedstock to reduce emissions.

Green hydrogen also has the potential to become an attractive future export earner for New Zealand, most likely to countries such as South Korea and Japan, once an economy of scale can be sufficiently realised for the volumes required.

Hydrogen projects and studies under way in New Zealand include:

- Callaghan Innovation on-site (nanogrid) hydrogen production at Matiu/Somes island (since 2012)
- Callaghan Innovation on-site (nanogrid) hydrogen production at Gracefield, Lower Hutt (since 2016)
- Ballance Agri-Nutrients and Hiringa Energy's green hydrogen project at Kapuni for urea production
- Hiringa Energy's hydrogen fuelling network – North Island at present, with nationwide plans
- Halcyon Power – Obayashi and the Tuaropaki Trust pilot hydrogen plant
- Ports of Auckland's hydrogen production and refuelling facility paired with hydrogen bus trial for Auckland Transport
- FirstGas's Hydrogen Pipeline Feasibility study, published in March 2021
- Contact Energy/Meridian Energy's study to investigate the value of large-scale hydrogen development in Southland.

[4] MfE 2021.

[5] From 1990 to 2019, the average annual growth in gross emissions was 0.8 per cent (MfE, 2021).

[6] 'Green hydrogen' is produced by splitting water into hydrogen and oxygen, using renewable electricity.

The hydrogen ecosystem and energy transition

The hydrogen ecosystem (see Figure 2) has many constituents, though a logical starting point to understand this ecosystem is to consider the existing supply chain.

Leveraging existing NG available gas infrastructure network and enabling it to integrate with low emission gas-fuel mixes (such as biomethane and hydrogen) contributes to building economy of scale. Additionally, electrolysers can enable us to take advantage of constrained renewable sources.

The keys to unlocking opportunity for the hydrogen supply chain are:

- understanding where existing capability can be expanded with minimal effort to include hydrogen, and
- raising awareness for companies that are not specialist hydrogen technology providers, but which have complementary skill sets, such as those that exist within New Zealand's existing energy sector, then leveraging those skills and evolving them to support New Zealand's energy transition.

In transportation, hydrogen fuel-cell technology is now internationally entering the market, and high-energy density requirements such as those for shipping and aviation are being addressed through the development of synthetic fuels.

We are also seeing the emergence of hydrogen-fuelled combined heat and power (CHP) systems. They assist with industry decarbonisation and are very effective in applications when other energy sources are constrained (for example, following a nuclear disaster) as they provide low- to high-grade heat, as well as electricity.

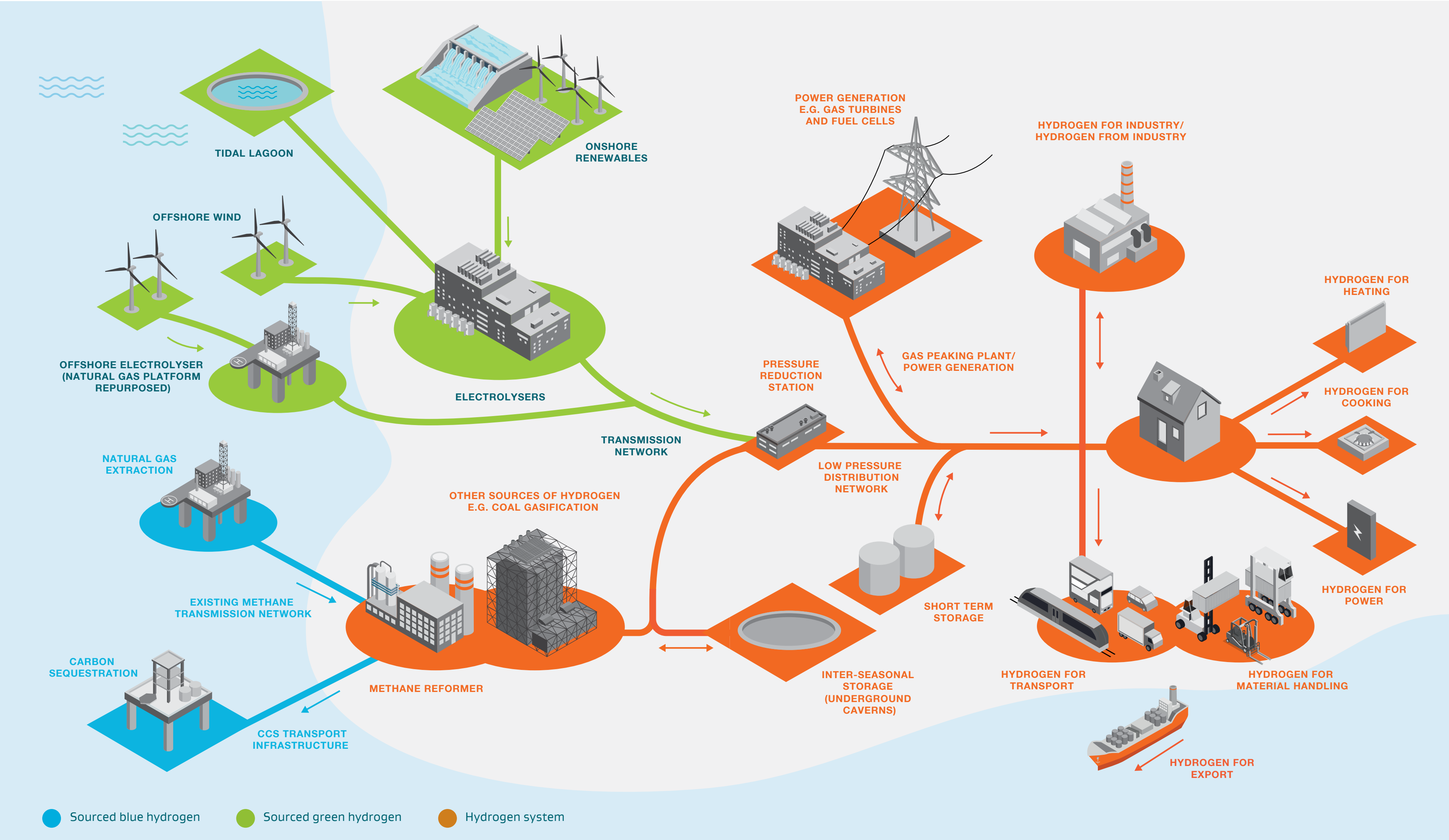


Figure 2 – Hydrogen ecosystem

Hybrid microgrids

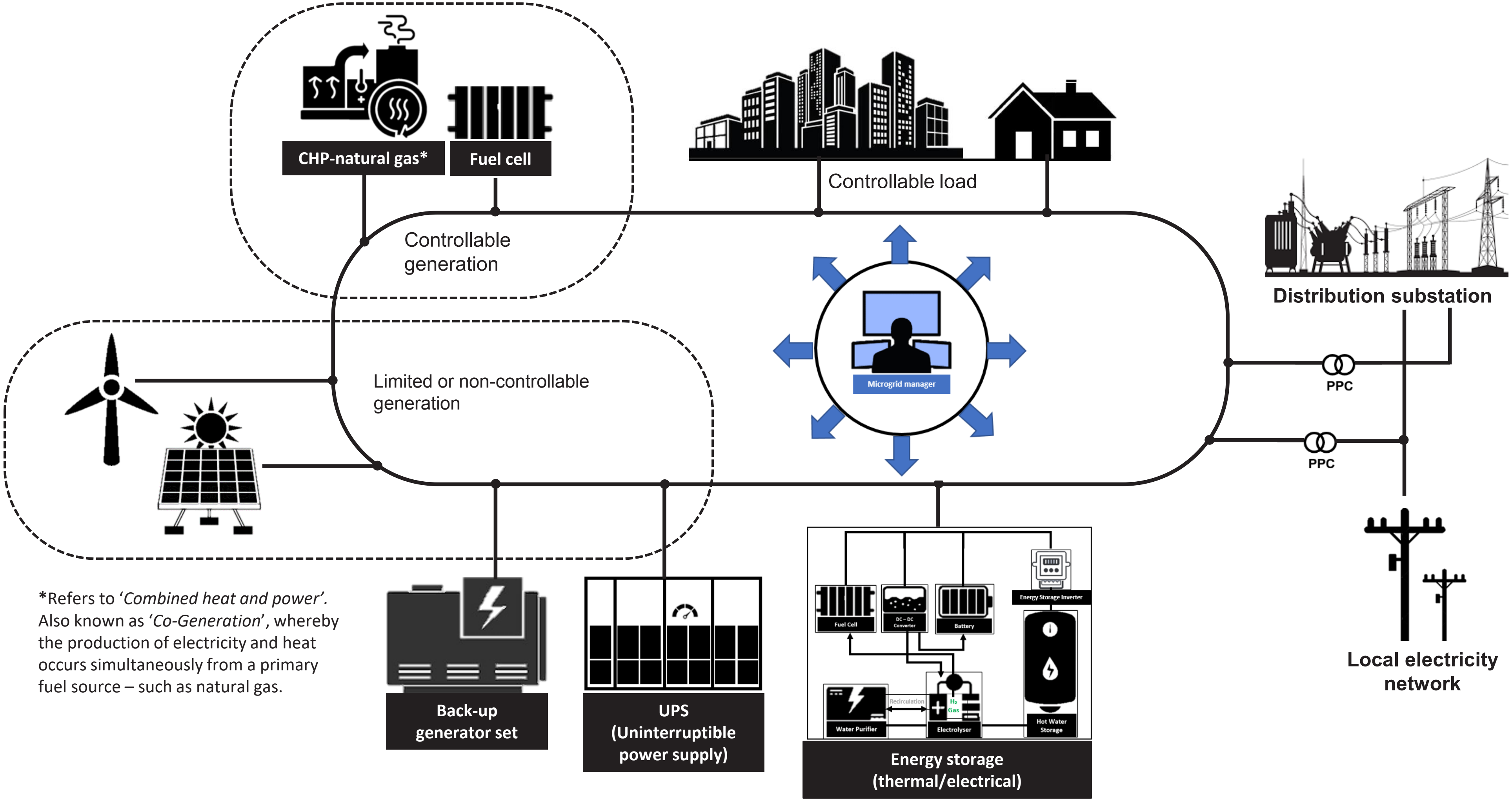
A parallel path to sustainability that uses both renewable and clean-carbon-based methods must be developed because new and renewable forms of energy that emit less carbon dioxide might not materialise quickly enough or at a price that is conducive to widespread consumer uptake. Hybrid microgrids offer that parallel pathway.

A microgrid (Figure 3) is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controlled entity with respect to the grid. Producing hydrogen on-site using a variety of distributed energy resources that feed into microgrids is a particularly useful way that renewable energy can be generated in remote regions. Examples of remote regions include islands and farms outside the reach and therefore financial viability of connecting to a regional electricity network.

A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode[7] and microgrids are generation agnostic. Low- or medium-voltage grids are typically not geographically spread out. For residential applications, the term 'nanogrid' is used for low-voltage grids that typically serve a single dwelling and are less than 50 Kw.

For more information on the integration of hydrogen involving microgrids, see Stage 3 – Decentralised hydrogen distribution.

7 Mueller, 2018.



*Refers to '*Combined heat and power*'. Also known as '*Co-Generation*', whereby the production of electricity and heat occurs simultaneously from a primary fuel source – such as natural gas.

Figure 3 – Microgrid interface

The role of energy vectors in hydrogen production

According to Kellogg Brown & Root,[8] "Energy vectors [are] aptly described as the human made energy that is not directly usable, but which must be extracted or produced before being transported and stored in appropriate quantities for a prolonged use over time, in applications that are not always calculable in advance."

The use of renewable energy resources with integration of energy vectors into the flow chain is pivotal for promoting sustainable energy systems. Examples of momentous energy vectors with plentiful potential for realisation of a global comprehensive energy system include electricity, synthetic-fuels and heat-transfer fluids.

There are many sources and ways of producing hydrogen as a fuel. It can be used as a feedstock to produce chemicals such as methanol and ammonia. These chemicals have desirable energy characteristics but are less desirable in other respects. Alternatively, it can be combined with carbon dioxide to produce methane, which can be injected into the NG network.

Hydrogen's versatility for industrial applications extends beyond ammonia production. It has been very effective in creating petroleum (hydrocracking) as well as in electronics manufacturing, metalworking, welding, medical uses (hydrogen peroxide) and food production (turning unsaturated fats into to saturated oils and fats, including hydrogenated vegetable oils like margarine).

Other known methods of producing hydrogen with a high-Faradic efficiency include using ultraviolet (UV) light irradiation as an energy source. The process involves the conversion of toluene (a common paint thinner) and water to methylcyclohexane (MCH).[9] The conversion of toluene (see Figure 4) occurs through a photoelectrochemical reaction in the presence of niobium-doped strontium titanate (Nb:$SrTiO_3$) photoelectrodes. MCH is considered by many as a promising hydrogen carrier that enables hydrogen to be harnessed as an alternate fuel source.

Other production pathways being researched include:

- using microbes that use light to make hydrogen
- converting biomass into gas or liquids, then separating the hydrogen, and
- using solar energy technologies to split hydrogen from water molecules.

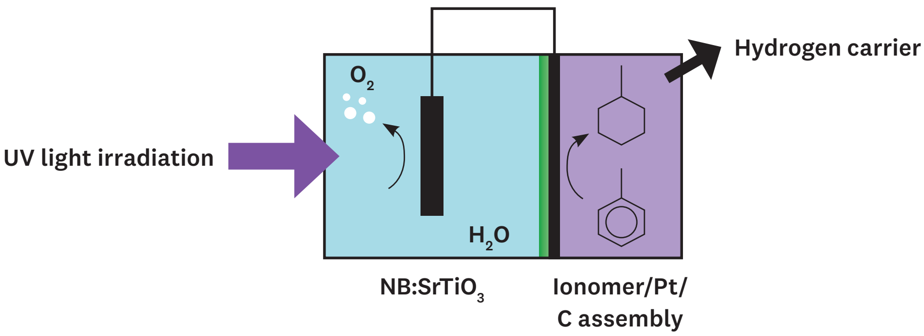


Figure 4 – Producing hydrogen using UV light irradiation

[8] KBR, undated.

[9] Kalousek, Wang, Minegishi, Hisatomi, Nakagawa, Oshima, Kobori, Kubota, and Domen, 2014.

Key supply chain considerations

When it comes to choosing which method of hydrogen production is most appropriate, It is not the role of TAG P3652 to pick winners, but there does need to be a starting point for investment in New Zealand's energy transition that is aligned with internationally recognised good practice. To that end, there are two recognised and common ways of producing hydrogen as a fuel. These are *steam-methane reforming* and *electrolysis* (splitting water with electricity).

For the purposes of this report (and in the first instance) we focus on hydrogen supply chains that support transport as well as industrial feedstock, because energy sector emissions were identified as the second largest contributor to New Zealand's gross emissions.

There are many reasons for considering broader non-transport applications to maximise the potential for supply chain engagement and growth of transport applications. Reasons for including non-transport applications are supply chain commonality across applications, maximising supply chain engagement, and the reduction in costs through increased activity levels.

Supply chain commonality across applications

Supply chains cut across applications in a mature energy sector. Most aspects of the hydrogen supply chain will support transport and non-transport aspects. Examples include the electrolysis and storage supply chains, which are common to multiple applications.

Maximising supply chain engagement

New Zealand is still very early in the process of transition, so to gain greater traction in the marketplace, it is important for supply chain companies to be made aware of the breadth of hydrogen-related applications so that they can:

- appreciate the volume of activity, and
- identify specific areas where their capabilities can be best applied.

Reduction in costs through increased activity levels

By considering a wider variety of applications beyond transport, the supply chain will mature at a greater rate. In doing so, the cost of products and services will reduce as volumes increase and standardised approaches evolve, thereby creating greater efficiencies in production.

3. Developing a hydrogen supply chain prioritisation plan

The basic premise is to concentrate initial efforts on three fundamental stages:

Stage 1 – Stationary energy and storage

Stage 2 – Semi-centralised hydrogen distribution

Stage 3 – Decentralised hydrogen distribution.

Breaking core components of the hydrogen ecosystem into the three fundamental supply chain aspects helps us target standards to specific applications and prioritise the implementation of those standards relative to the way the system currently operates, whereby leveraging off as much of the existing gas infrastructure as possible creates a more attractive investment proposition.

TAG P3652 accepts that adopting a staged approach to support an evolving hydrogen ecosystem is appropriate. It also acknowledges that despite this being a medium- to long-term perspective, there are current hydrogen demonstration projects (as well as other proposals such as refuelling stations under consideration) where the regulator(s) will make allowances by exception until such time as an appropriate compliance framework is embedded.

Stage 1 – Stationary energy and storage

Stage 1 (see Figure 5) considers a two-pronged approach.

i. The first prong involves leveraging off key strategic assets that support the existing NG network (centered in Taranaki) and directly feeding large consumers (medium to large-scale industry) with blended gas for industrial needs.

ii. The second prong includes developing multi-megawatt-capacity hydrogen facilities (powered by renewable energy) in strategic locations, as well as leveraging off other regions, such as the geothermal-powered Halcyon hydrogen plant north of Taupo. High-purity hydrogen is targeted at heavy-transport fleets, including shipping, rail and the aviation sector. Excess hydrogen can be stored and converted back into electricity as demand dictates or to another form of energy carrier (ammonia or toluene-MCH) for either export or conversion at the destination. This approach gives assurance to hydrogen systems developers by ensuring long-term off-take.

A *compliance handbook or code of practice* would provide the necessary overarching safety criteria and therefore needs to be developed and embedded at the same time. (A staggered approach to international standards adoptions will be required over the next 12 to 18 months.)

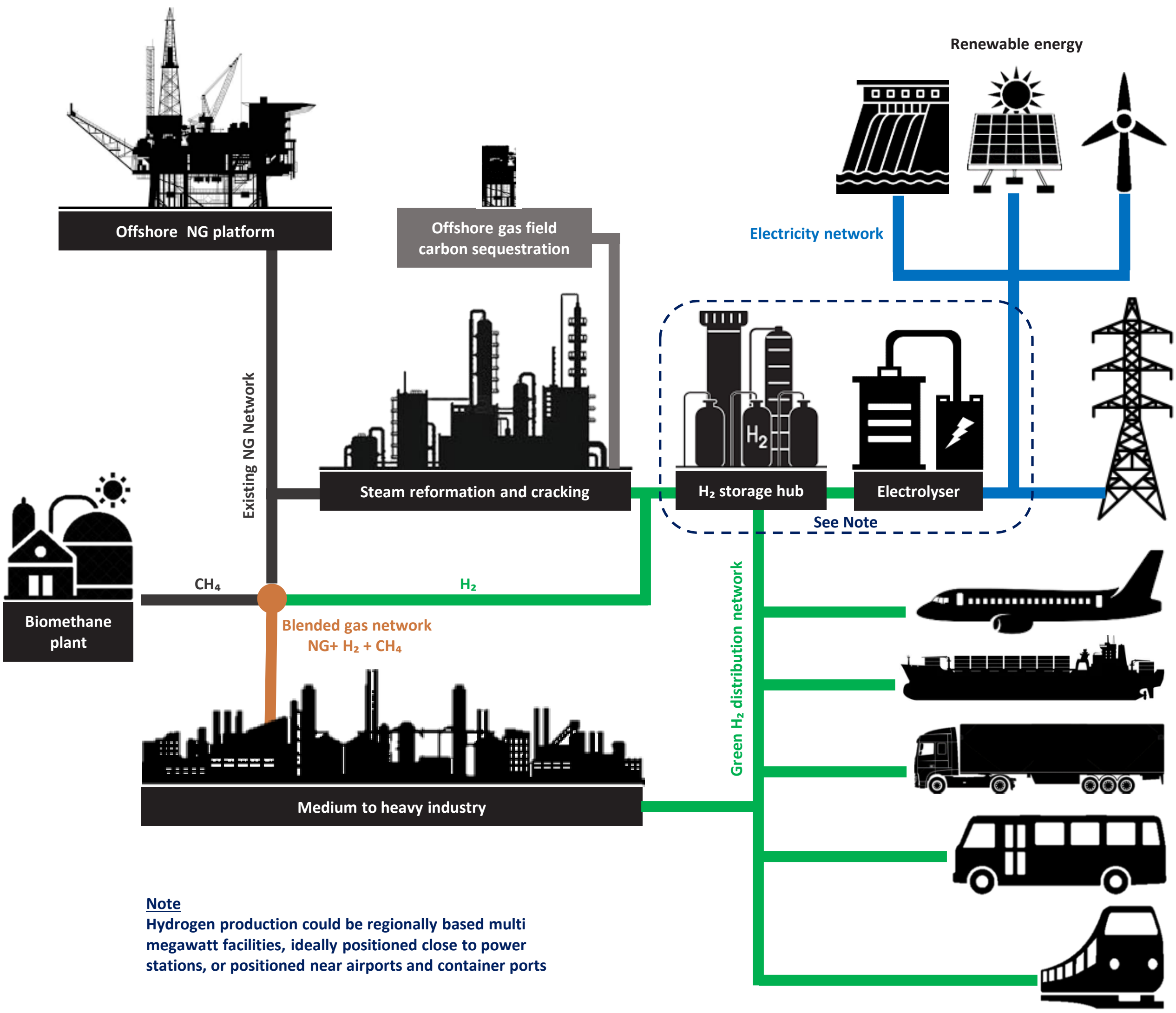


Figure 5 – Stationary energy and storage[10]

[10] Steam reformation and cracking imagery reflects technology examples and not necessarily government policy.

Stage 2 – Semi-centralised hydrogen distribution

Stage 2 (see Figure 6) seeks to support a semi-centralised form of hydrogen distribution (where CGH2 pipeline infrastructural investments may be uneconomic or some years away). It uses the existing road and rail network to mobilise liquid hydrogen (LH2) tanks and CGH2 tube-trailers and containerised units for smaller industrial material-handling business and refuelling sites (with on-site conversion equipment) to support regional commercial transport needs.

This form of distribution would also be useful for fuel retailers wishing to offer hydrogen as an alternative fuel option for light-fleet customers at selected state highway refuelling sites.

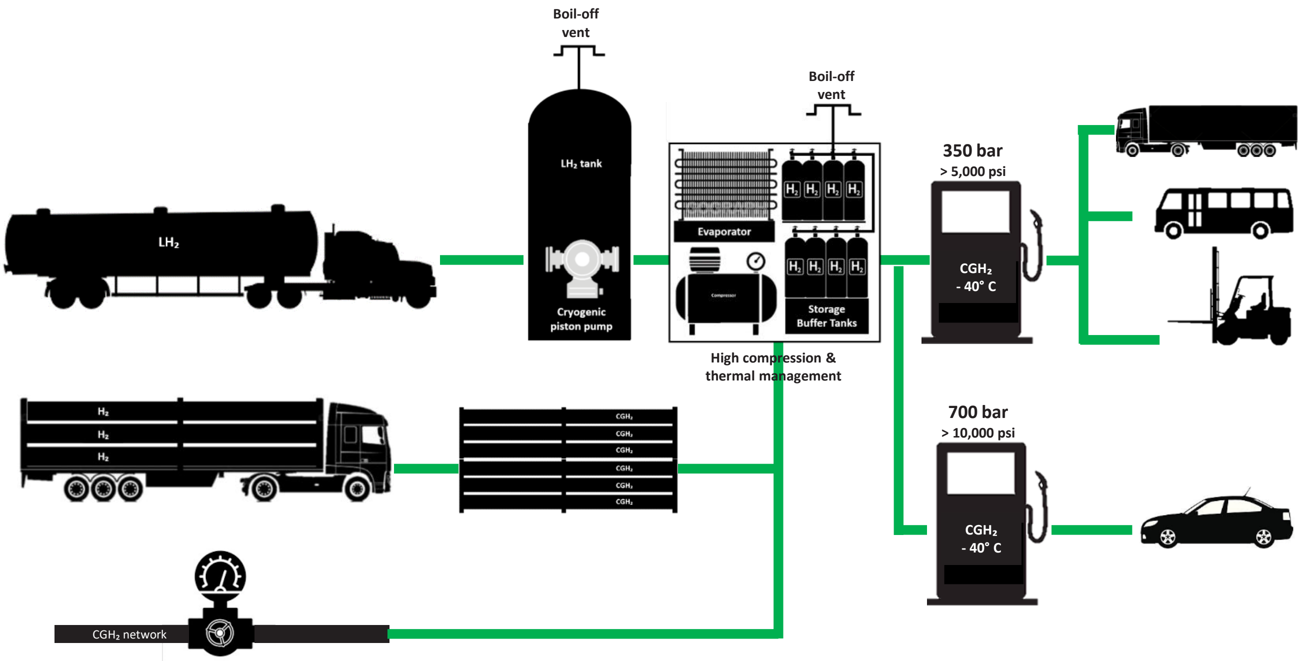


Figure 6 – Semi-centralised hydrogen distribution

Stage 3 – Decentralised hydrogen distribution

Stage 3 (see Figure 7) occurs once the international challenges of blending hydrogen and biomethane into the existing natural gas network have been resolved (including updating NZS 5442:2008 – *Specification for reticulated natural gas*). This would mean a decentralised form of distribution could now come into effect.

It is expected that by FY 2023/24, international standards for residential gas appliances will be far enough advanced in terms of their review and development process for adoption in New Zealand. The timing for this is crucial, because the move away from reliance on fossil fuels and the impacts of climate change are affecting security of electricity transmission supply,[11] particularly during seasonal peak demand. These factors are contributing to New Zealand experiencing a technological seismic shift in how we relate to energy use, in all its forms, in both businesses and the home.

To mitigate concerns that the Electricity Authority might have over unbalanced electricity networks and to address New Zealand's carbon emission reduction targets, the government is beginning to take a systems-based approach to energy use. The outcome is an implementation of demand response–flexibility energy management policies, which are likely to require the adoption of common communication protocols. Electrical distribution businesses (EDB) will be able to interface with home energy management systems to balance the demand side of the network, thereby creating greater network certainty for all consumers through flexibility.

This transition will turn consumers into prosumers (producers of energy) by using distributed generation (DG) within the home such as photovoltaics, electric vehicles, on-site hydrogen generation and some home energy storage systems. This will enable the homeowner to interact with EDB in real time and help reduce day-to-day energy costs while at the same time mitigating the likelihood of electricity-phase brownouts during peak demand cycles.

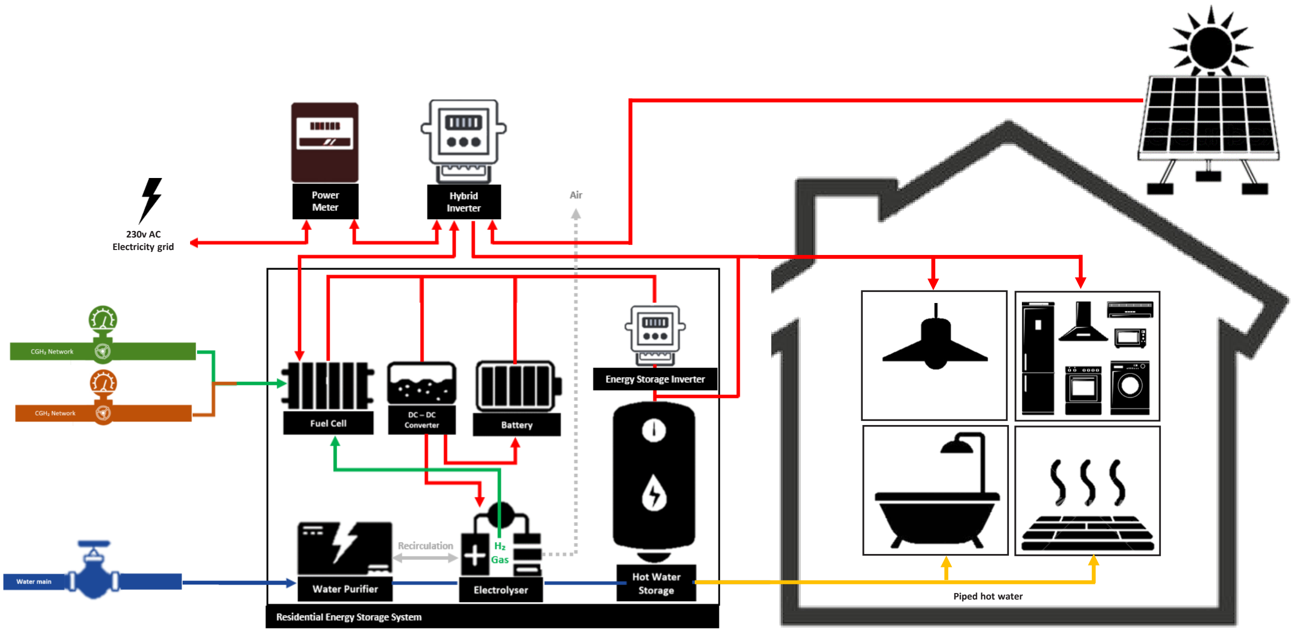


Figure 7 – Decentralised hydrogen distribution

[11] On Monday, 9 August 2021, about 34,000 customers experienced an electricity cut without warning. The biggest impact was felt in the Waikato region, where more than 17,000 were customers disconnected. – Electricity Authority, 2021.

Blended distributed NG networks (in the first instance), and progressing to pure CGH2, will play a fundamental role in supporting and helping to balance New Zealand's future residential energy requirements. Figure 7 shows how this scenario typically works.

The distributed gas network not only provides a fuel source for residential gas appliances, but when it is connected to an energy storage system (containing fuel-cell technology), hydrogen is converted to electrical energy through an electrolyser and inverter that power hot water and underfloor heating systems, and store electrical energy in a battery to use at peak times.

The advantage of energy storage systems is that excess electrical energy derived from multiple means of distributed generation could be sold back to the EDB when rates within a given period are attractive enough to do so. This is essentially how an electricity consumer becomes a prosumer.

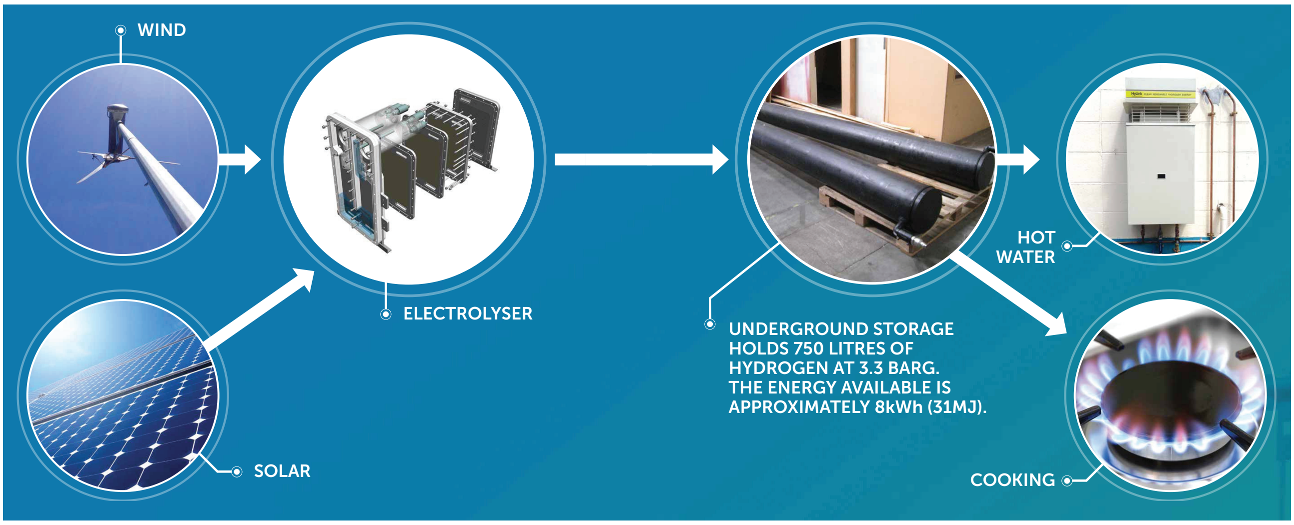


Figure 8 – HyLink renewable energy system

© Callaghan Innovation

On-site hydrogen production

Local hydrogen production in remote locations or in situations where electricity is primarily generated by renewable energy systems will provide carbon-free fuel gas that may be used for instant hot water heating and hydrogen-burning appliances. With a lower cost of energy storage (at low pressure) compared to battery storage (thereby enabling more of the available renewable energy to be captured), consumers could have the option to cook with gas. Callaghan Innovation is trialling such a system, the HyLink (see Figure 8).

Domestic-scale systems can be aggregated using the hydrogen storage as a communal resource, providing a scalable gas microgrid. Distributed clean energy installations are attractive to remote tourist sites and marae that rely on bottled LPG for cooking, hot water and space heating.

Future opportunities include private fuel cell electric vehicle (FCEV) filling. A local fuel cell will also provide emergency electrical back-up, but in most cases, electricity will be provided from batteries because of the superior efficiency afforded by charger-inverter technology compared to electrolyser and fuel cell conversions.

Mobilising hydrogen

Before determining whether liquid hydrogen (LH2) or CGH2 would be appropriate, it is important to recognise hydrogen's unique chemical and physical properties.

- Hydrogen atoms are very small and can permeate solid metals. Once absorbed, hydrogen lowers the stress required for cracks in the metal to initiate and propagate, resulting in embrittlement. Embrittlement occurs most notably in steels, iron, nickel, titanium, cobalt, and their alloys.
- Hydrogen can easily escape from containment.
- Its flammability range is wide and it takes only a limited amount of energy to ignite.
- Its extremely low density means the gas will probably ascend upon escaping, rather than forming dense, dangerous clouds as other hazardous gases do.
- It should be stored at an extremely low temperature (in liquid form) or a very high pressure (gas).

Given the challenges (including the possibility of fire, explosion, asphyxiation, and exposure to extremely low temperatures and high working pressures), LH2 and CGH2 must be handled carefully.

Liquid hydrogen (LH2)

LH2 is colourless, odourless, tasteless, and highly flammable, as are its vapours. It is non-corrosive, but because it is -253°C, vessels and piping must be selected to withstand the pressure and temperatures involved and comply with applicable codes and regulations.

In light of these challenges, LH2 Europe, which is focused on the sustainable supply chain of green LH2 to markets in Northwestern Europe, is working with C-Job Naval Architects[12] on a 141-metre liquid hydrogen tanker (see Figure 9). The ship is 34.9 m wide, has installed power of 5,000 kWe and can travel at 14 knots. Each of its three deck-mounted tanks can hold 12,500 m^3. Because LH2 is high in volume but 20 times lighter than liquefied natural gas (LNG), the hull is trapezium shaped so that additional ballast is not required. Such a tanker could carry enough fuel for 400,000 cars, or 20,000 heavy trucks in a single voyage.

Figure 9 – Artist's impression of C-Job Naval Architects' design carrier for LH2 Europe

© C-Job Naval Architects

[12] C-Job Naval Architects, undated.

Compressed hydrogen gas (CGH2)

CGH2 is odourless and non-toxic, but by diluting the concentration of oxygen in air below levels necessary to support life, it can cause suffocation. The amount needed to produce an oxygen-deficient atmosphere is well within the flammable range (4 per cent to 74 per cent in air), making fire and explosion the primary hazards associated with hydrogen and air atmospheres.

Table 2 shows some key safety factor considerations for developing a compliance guidance handbook or CoP. These initial thoughts warrant cross-agency discussion to identify and implement appropriate risk-mitigation procedures (in accordance with existing codes and regulations) and, as such, the list is not exhaustive. For further risk assessment and mitigation, see ISO TR 15916, *Basic considerations for the safety of hydrogen systems*.

Table 2 – Key safety considerations – Very high risk

Applications	Factor	Risk
All	General comments	• Hydrogen migrates quickly through small openings. • The minimum ignition energy for flammable mixtures containing hydrogen is extremely low. • Because hydrogen burns with a very pale blue, almost invisible flame, injury may occur if someone walks into a hydrogen fire. • Careful evacuation and purge operations should be used to prevent the formation of flammable or explosive mixtures. • Cold burns may occur from short contact with frosted lines, liquid air that may be dripping from cold lines or vent stacks, vapouriser fins, and vapour leaks. Extensive tissue damage or burns can result from exposure to liquid hydrogen or cold hydrogen vapours. • Air will condense at liquid hydrogen temperatures and can become an oxygen-enriched liquid due to the vapourisation of nitrogen. Oxygen-enriched air increases the combustion rate of flammable and combustible materials (including clothing).

Table 2 – Key safety considerations – Very high risk *continued*

Applications	Factor	Risk
• Production & purification • Fuel station equipment & design • Mobility • Network distribution	Equipment and manufacturing materials	• Pressure and extremely low (cryogenic) operating temperatures.
	Flammability	• Broad flammable range in air. Can explode and may burn with a pale blue, almost invisible flame.
	Human health	• Suffocation potential by diluting concentration of oxygen in air below the level necessary to support life. • **First aid:** Self-contained breathing apparatus may be required to prevent asphyxiation of rescue workers.
	Liquid transference	• Closed system requirements apply. Liquid transfer lines must be vacuum insulated to minimise product loss through vapourisation or the formation of liquid air on the lines, with subsequent oxygen enrichment. • All equipment must be electrically grounded and bonded before transferring liquid.
	Purging	• Gaseous and liquid hydrogen systems must be purged of air, oxygen, or other oxidisers prior to admitting hydrogen to the systems and purged of hydrogen before opening the system to the atmosphere. Purging should be done to prevent the formation of flammable mixtures.

LH2 versus CGH2

Each form has its own challenges, so the choice will come down to financial and logistical factors. Table 3 sets out some things to consider, as well as pros and cons, relating to research by the United States Department of Energy (DOE)[13] on new fuelling stations in California at the end of 2021.

[13] Koleva and Melaina, 2021.

Table 3 – LH2 vs CGH2

Delivery method	Delivery pressure	Tank capacity	Delivery distance	Time to fill	Off-load and invest costs	Pros	Cons
CGH2 (Gaseous tube-trailer)	200 – 500 bar (2900 – 7251 psi)	> 1000 kg	< 250 km	> 4 hours	45 minutes (trailer swap)	• Economical for short to medium distances • Average on-site storage capacity 770 kg per day • Typical on-site H_2 equipment capital cost estimate: ~ US$1.4 million[a] (NZD$2.24 million)	• Comparatively low capacity (high delivery frequency) • Comparatively large on-site footprint (4 x that of liquid) • Residual gas in trailer (equals waste). The higher the pressure in supply chain, the higher the amount/tonnage of CGH2 in circulation
LH2 (Liquid hydrogen tanker)	1 bar (14.7 psi) at -253°C	> 4000 kg	> 300 km	> 4 hours	60 minutes	• Economical for medium to long distances • Comparatively small equipment footprint • Average on-site storage capacity of 1400 kg to 1620 kg per day • Typical on-site H_2 equipment capital cost estimate: US$1.9 million – US$4.2 million[b] (NZD$3 – 6.7 million)	• Comparatively high energy demand (~12 kwh/kg for liquefaction). Some liquid needs to remain in the distribution equipment to keep it cryogenic cold during return to LH2 source • Useable volume < 90%
LH2 (Liquid hydrogen containerised unit)	1 bar (14.7 psi) at -253°C	> 1000 kg	> 300 km	> 3 hours	30 minutes (container swap)	• Economical for medium to long distances • Comparatively small equipment footprint • Average on-site storage capacity 500 kg to 1000 kg per day • Typical on-site H_2 equipment capital cost estimate: US$1.0 million – US$2.0 million[c] (NZD$1.6 – 3.2 million)	• Comparatively high energy demand. (~12 kwh/kg for liquefaction). Some liquid needs to remain in the distribution equipment to keep it cryogenic cold during return to LH2 source • Useable volume < 90%

[a, b, c] Koleva, M, and Melaina, M., 2021.

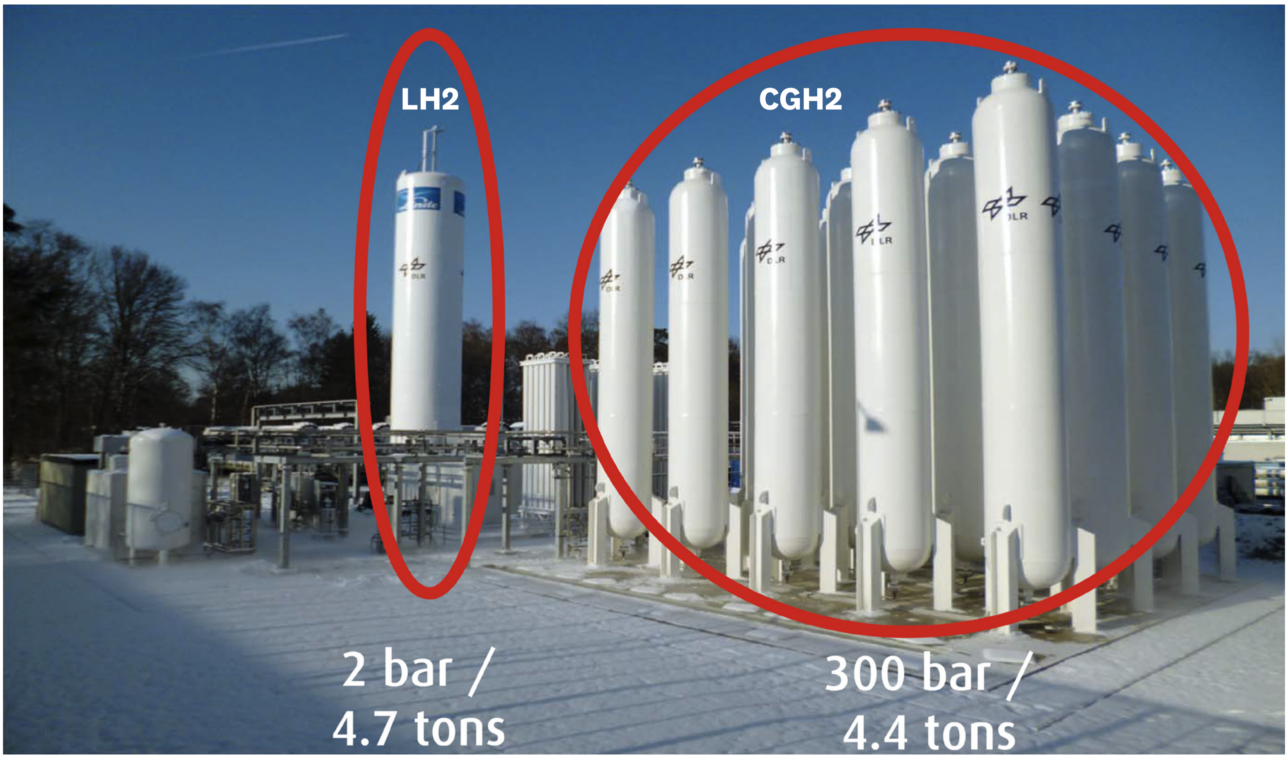


Figure 10 – LH2 and CGH2: A comparison of energy densities

© German Aerospace Centre (DLR)

On the face of it, CGH2 appears more economic than LH2 but there are limitations to transporting compressed hydrogen at high pressures. Delivery distance from the production source (hub) is constrained to about 250 km. Tube-trailer capacity is typically 25 per cent that of an LH2 tanker, so refuelling stations require more frequent deliveries. CGH2 also has a larger on-site storage footprint (see Figure 10), with more storage vessels and additional supporting structures. Additionally, the higher the pressure in the supply chain, the higher the amount/tonnage of CGH2 in circulation, so the greater the waste.

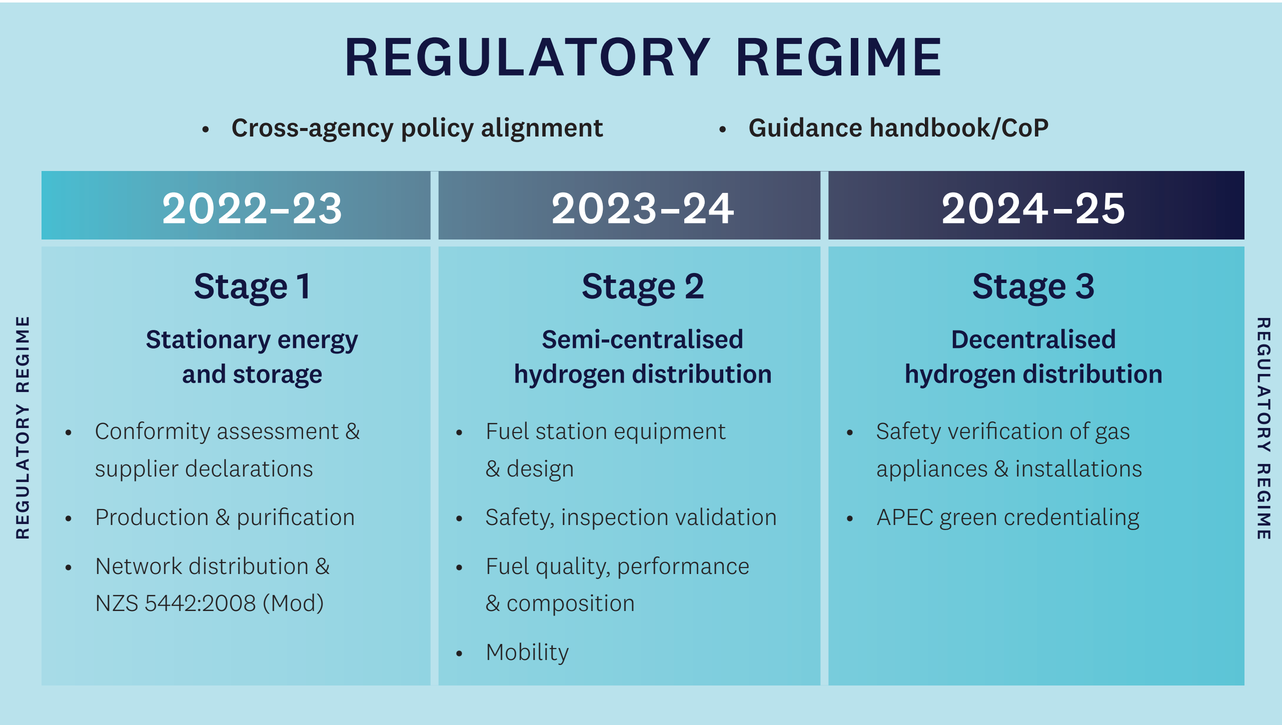
Hydrogen is an excellent energy carrier with respect to weight (1 kg of hydrogen contains 33.33 kWh of usable energy, whereas petrol and diesel hold about 12 kWh/kg). However, from a volumetric energy-density perspective, hydrogen (see Table D2) is outperformed by liquid fuels. This poses a challenge when hydrogen must be transported from the site of its generation to a refuelling station. Petrol and diesel carry around 8.8 kWh/litre and 10 kWh/litre, respectively. Under ambient conditions, 1 m^3 of hydrogen provides some 3 kWh (equivalent to 0.003 kWh per litre). CGH2 contains about 0.5 kWh/litre at 200 bar, 1.1 kWh/litre at 500 bar, and 1.4 kWh/litre at 700 bar. Therefore, the best way of transporting hydrogen in terms of energy density is in its liquid form, achieving more than 2.3 kWh/litre.

A drawback to LH2 is having to depend on storage tank construction (boil-off rates are between 0.25 per cent and 0.95 per cent per day). Also, liquefaction carries a comparatively high energy demand. Current state-of-the-art liquefaction technology places energy consumption at typically 12kWh/kg. This is partly due to the very low temperature (-253°C) required to condense hydrogen into a liquid state and equates to 36 per cent of the useable energy contained in 1 kg of hydrogen at 33.33 kWh/kg. However, IdealHy (Integrated Design for Efficient Advanced Liquefaction of Hydrogen), a consortium of eight organisations and institutions, is developing a process that can halve the specific power consumption for hydrogen liquefaction. Based on technology analysis, conceptual work and process optimisation, 6.4 kWh/kg has been accomplished. This reduces the useable energy contained in 1 kg of hydrogen to 19 per cent. IdealHy believes there is scope for further reductions in specific power consumption (pending tests of appropriate components, such as turbo machinery). From New Zealand's perspective, innovative process optimisation, including more intensive and innovative use of renewable energy in the form of on-site power generation (photovoltaics) and energy storage systems, could be key to further power consumption reductions.

When it comes to LH2, smart designs maximise delivery and storage system efficiencies with complete containerised solutions. Multi-modal containers can be transported by road, ship and rail, providing a highly flexible distribution solution during the early adoption phase of a hydrogen market. Internationally, in some instances off-loading times (through swap-outs) have been reduced to as little as 30 minutes.

Despite the challenges, both LH2 and CGH2 have merits and, depending on the application, are considered ideal for rapid deployment and scalability, relative to the availability of capital investment. Either way, both methods will provide the flexibility necessary to support a decentralised, nationwide hydrogen distribution network.

Standards prioritisation



Note: Subject to funding/resource availability.

Figure 11 – Supply chain standards prioritisation

Looking toward FY 2024/25, we would expect to see established a robust hydrogen-related compliance regime pointing to international standards to underpin New Zealand's future hydrogen-based economy (see Figure 11). The adoption of such standards will follow Standards New Zealand internationally recognised standards development procedures and protocols.

TAG P3652 accepts that the development of a fully functioning compliance regime as complex as this one will take time to establish, which is why in Figure 11 this activity circumnavigates all three stages of a standard's adoption and development.

We also expect to see substantial advancement by the New Zealand-led APEC technical working group on the development of a globally recognised green credentialling standard that will underpin a potential New Zealand green-hydrogen export market.

To provide context on the significance of this opportunity, we need only look at one component of the global logistics industry: cargo shipping. Since 2018, there has been an escalation in capital investment in research and development (R&D) on clean energy across shipping fleets towards hydrogen. One such example is being led by Maersk. At the 2021 TED Countdown climate conference, Maersk's chairman, Jim Hagemann Snabe, said,

> *"Our fleet [750 vessels] today consumes 10 million tons of bunker oil. If we replaced that with green fuel, we estimate that we need 220,000 GWh of green electricity. That is the equivalent to 10 per cent of the global installed base of solar and wind energy in 2019. Maersk is 20 per cent of the cargo shipping industry, and the cargo shipping industry alone would consume 50 per cent of the entire installed base of green electricity … In other words, we need dramatic, exponential scale of installations, of solar, of wind, and of green fuel production to solve this problem. We estimate that the total investment will be in the neighbourhood of US$2 trillion, which granted is a lot of money – but this is the equivalent of only four years of capital expenditure in the oil and gas industry today."*[14]

Hagemann Snabe also predicted that in the next 10 years, the global demand for green fuel will be significantly higher than the supply. Higher supply and demand translates to great business opportunities for New Zealand's potential hydrogen export market.

Figure 12 – Cargo shipping industry evolution

© Fitzgerald/Shutterstock.com

[14] Hagemann Snabe, J, 2021.

4. Hydrogen standards implementation strategy

Having considered the regulatory regime and addressed the three fundamental constituents of the hydrogen supply chain (stationary energy storage, semi-centralised hydrogen distribution and decentralised hydrogen distribution), a standards implementation strategy aligned to the three stages can be developed.

Tables 4, 5, and 6 outline TAG P3652's recommendations for the implementation of standards, covered by the review of all four projects:

1. production & purification and green credentialling
2. fuel station equipment & design
3. mobility & safety
4. network distribution & inspection.

Positioning statement on LH2

TAG P3652 acknowledges that LH2 will play a significant role in New Zealand's evolving hydrogen industry. However, ISO technical committees (such as TC 197) are focusing on CGH2, and the adoption of standards outlined in the following tables reflect that stance. Standards New Zealand is keeping an eye on standards development activities relating to liquid hydrogen (see Figure B4). Of particular interest are ISO 13985:2006, *Liquid hydrogen – Land vehicle fuel tanks* and ISO 13984:1999, *Liquid hydrogen – Land vehicle fuelling system interface*. These standards will probably come up for review and could then be included in the list.

Table 4 – Stage 1: Standards implementation

Direct adoptions of international standards	
ISO/IEC 17050-1	*Conformity assessment – Supplier's declaration of conformity – Part 1: General requirements*
ASME B31.12	*Hydrogen piping and pipelines*
ASME B31.3	*Process piping*
Modified adoptions of ISO/IEC standards	
ISO 16110-1	*Hydrogen generators using fuel processing technologies – Part 1: Safety*
ISO 16110-2	*Hydrogen generators using fuel processing technologies – Part 2: Test methods for performance*
ISO 22734	*Hydrogen generators using water electrolysis – Industrial, commercial, and residential applications*
ISO TS 19883	*Safety of pressure swing adsorption systems for hydrogen separation and purification*

Table 4 – Stage 1: Standards implementation *continued*

IEC 62282-3-200	*Fuel cell technologies – Part 3-200: Stationary fuel cell power systems – Performance test methods*
IEC 62282-3-300	*Fuel cell technologies – Part 3-300: Stationary fuel cell power systems – Installation*
IEC 62282-3-201	*Fuel cell technologies – Part 3-201: Stationary fuel cell power systems – Performance test methods for small fuel cell power systems*
Revision of joint standards[15]	
AS/NZS IEC 60079-0:2019	*Explosive atmospheres – Part 0: Equipment – General requirements*
AS/NZS IEC 60079-33:2012	*Explosive atmospheres – Part 33: Equipment protection by special protection 's'*
AS/NZS 60079.10.1:2009	*Explosive atmospheres – Part 10.1: Classification of areas – Explosive gas atmospheres*
AS/NZS 60079.11:2011	*Explosive atmospheres – Part 11: Equipment protection by intrinsic safety 'i'*
AS/NZS 60079.14:2017	*Explosive atmospheres – Part 14: Design selection, erection and initial inspection*
AS/NZS 60079.17:2017	*Explosive atmospheres – Part 17: Electrical installations inspection and maintenance*
AS/NZS 60079.18:2016	*Explosive atmospheres – Part 18: Equipment protection by encapsulation 'm'*
AS/NZS 60079.29.2:2016	*Explosive atmospheres – Part 29.2: Gas detectors – Selection, installation, use and maintenance of detectors for flammable gases and oxygen*
AS/NZS 3820:2020	*Essential safety requirements for electrical equipment*
AS/NZS 5601.1:2013	*Gas installations – Part 1: General installations*
AS/NZS 5601.2:2020	*Gas installations – Part 2: LP Gas installations in caravans and boats for non-propulsive purposes*
AS 2885.0:2018	*Pipelines – Gas and liquid petroleum – Part 0: General requirements*
AS/NZS 2885.1:2018	*Pipelines – Gas and liquid petroleum – Part 1: Design and construction*
AS/NZS 2885.2:2020	*Pipelines – Gas and liquid petroleum – Part 2: Welding*
AS/NZS 2885.3:1997	*Pipelines – Gas and liquid petroleum – Part 3: Operation and maintenance*
AS/NZS 2885.4:2016	*Pipelines – Gas and liquid petroleum – Part 4: Submarine pipeline systems*
AS/NZS 2885.5:2012	*Pipelines – Gas and liquid petroleum – Part 5: Field pressure testing*
AS/NZS 2885.6:2018	*Pipelines – Gas and liquid petroleum – Part 6: Pipeline safety management*
AS/NZS 4645.1:2018	*Gas distribution networks – Part 1: Network management*
AS/NZS 4645.2:2018	*Gas distribution networks – Part 2: Steel pipe systems*
AS/NZS 4645.3:2018	*Gas distribution networks – Part 3: Plastics pipe systems*

15 The revision of joint standards is subject to discussion and negotiation between Standards New Zealand, Standards Australia, and WorkSafe New Zealand – Energy Safety.

Table 5 – Stage 2: Standards implementation

Direct adoptions of international standards	
ISO 14687	*Hydrogen fuel quality – Product specification*
ISO 19880-3	*Gaseous hydrogen – Fuelling stations – Part 3: Valves*
ISO 19880-5	*Gaseous hydrogen – Fuelling stations – Part 5: Dispenser hoses and hose assemblies*
ISO 19881	*Gaseous hydrogen – Land vehicle fuel containers*
ISO 19882	*Gaseous hydrogen – Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers*
ISO 26142	*Hydrogen detection apparatus – Stationary applications*
ISO 11114-4	*Transportable gas cylinders – Compatibility of cylinder and valve materials with gas contents – Part 4: Test methods for selecting steels resistant to hydrogen embrittlement*
ISO 16111	*Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride*
ISO 19880-8	*Gaseous hydrogen – Fuelling stations – Part 8: Fuel quality control*
ISO 17268	*Gaseous hydrogen land vehicle refuelling connection devices*
ISO 21266-2	*Road vehicles – Compressed gaseous hydrogen (CGH2) and hydrogen/natural gas blends fuel systems – Part 2: Test methods*
ISO 23273	*Fuel cell road vehicles – Safety specifications – Protection against hydrogen hazards for vehicles fuelled with compressed hydrogen*
Modified adoptions of ISO/IEC standards	
ISO 19880-1	*Gaseous hydrogen – Fuelling stations – Part 1: General requirements*
Revision of New Zealand standards	
NZS 7901:2014	*Electricity and gas industries – Safety management systems for public safety*
NZS 5263:2003	*Gas detection and odorisation*

Table 6 – Stage 3: Standards implementation

Revision of New Zealand standards	
NZS 5263:2003	*Gas detection and odorisation*
NZS 5256:2014	*Safety of gas appliances*
NZS 5255:2014 + A1	*Safety verification of existing gas installations*
NZS 5259:2015	*Gas measurement*
NZS 5442:2008[16]	*Specification for reticulated natural gas*

[16] Standards New Zealand and WorkSafe New Zealand – Energy Safety have, as an interim measure, agreed to the revision of NZS 5442:2008 *Specification for reticulated natural gas* to enable blending of biofuel (specifically biomethane). The standard is then expected to go through further revision to enable blending of hydrogen with natural gas.

Procedural requirements

To adopt or modify any standard on behalf of a sponsor, Standards New Zealand must make a submission to the Standards Approval Board (SAB), which convenes once a month. Submissions include a project brief and the intention to convene a standards development committee (unless pre-existing) to seek approval for committee membership from nominating organisations. Grouping multiple standards under a single submission can streamline the SAB approval process.

Development times are, relative to subject matter complexity, publication length, and the ability to reach consensus, typically:

- six to eight months for new project scoping, proposal, sponsorship and approvals
- nine to 12 months for guidance publications, handbooks and publicly available specifications
- six to nine months for direct and modified adoptions of international standards
- 18 to 36 months for New Zealand or joint standards development.

Table 7 – Standards adoption

Stage	DA[a] ISO/IEC/ASME	MA[b] ISO/IEC	R[c] Joint standards	R[c] New Zealand standards
S1	3	7	20 1 (AS only)	1[d]
S2	12	1	0	2
S3	n/a	n/a	0	5[d]

[a] DA = Direct adoptions

[b] MA = Modified adoptions

[c] R = Revisions

[d] Standards New Zealand and WorkSafe New Zealand – Energy Safety have, as an interim measure, agreed to the revision of NZS 5442:2008 *Specification for reticulated natural gas* to enable blending of biomethane. The standard is then expected to go through further revision to enable blending of hydrogen with natural gas.

Once sponsorship is secured, Standards New Zealand will set up a committee to oversee the:

- direct adoption of 15 ISO/IEC/ASME standard
- modified adoption (for New Zealand regional conditions) of eight ISO/IEC standards.

Existing standards

Of the six existing standards listed below, we will review five (excluding NZS 5442:2008) for possible revision.

- NZS 5263:2003 *Gas detection and odorization*
- NZS 5266:2014 *Safety of gas appliances*
- NZS 5255:2014 + A1 *Safety verification of existing gas installations*
- NZS 5259: 2015 *Gas measurement*
- NZS 5266:2014 *Safety of gas appliances*
- NZS 5442:2008 *Specification for reticulated natural gas*

Standards New Zealand will also liaise with Standards Australia and WorkSafe New Zealand – Energy Safety regarding the ongoing relevance, potential revision and timing of any updates to the 20 existing joint standards and one Australia-only standard potentially impacted by the integration of hydrogen across the sector.

- AS/NZS IEC 60079-0:2019 *Explosive atmospheres – Part 0: Equipment – General requirements*
- AS/NZS IEC 60079-33:2012 *Explosive atmospheres – Part 33: Equipment protection by special protection 's'*
- AS/NZS 60079.10.1:2009 *Explosive atmospheres – Classification of areas – Explosive gas atmospheres*
- AS/NZS 60079.11:2011 *Explosive atmospheres – Part 11: Equipment protection by intrinsic safety 'i'*
- AS/NZS 60079.14:2017 *Explosive atmospheres – Part 14: Design selection, erection and initial inspection*
- AS/NZS 60079.17:2017 *Explosive atmospheres – Part 17: Electrical installations inspection and maintenance*
- AS/NZS 60079.18:2016 *Explosive atmospheres – Part 18: Equipment protection by encapsulation 'm'*
- AS/NZS 60079.29.2016 *Explosive atmospheres – Part 29.2: Gas detectors – Selection, installation, use and maintenance of detectors for flammable gases and oxygen*
- AS/NZS 3820:2020 *Essential safety requirements for electrical equipment*
- AS/NZS 5601.1:2013 *Gas installations – Part 1: General installations*
- AS/NZS 5601.2:2020 *Gas installations – Part 2: LP Gas installations in caravans and boats for non-propulsive purposes*
- AS 2885.0:2018 *Pipelines – Gas and liquid petroleum Part 0: General requirements*
- AS/NZS 2885.1:2018 *Pipelines – Gas and liquid petroleum – Part 1: Design and construction*
- AS/NZS 2885.2:2020 *Pipelines – Gas and liquid petroleum – Part 2: Welding*
- AS/NZS 2885.3:1997 *Pipelines – Gas and liquid petroleum – Operation and maintenance*
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- AS/NZS 2885.6:2018 *Pipelines – Gas and liquid petroleum – Part 6: Pipeline safety management*
- AS/NZS 4645.1:2018 *Gas distribution networks – Part 1: Network management*
- AS/NZS 4645.2:2018 *Gas distribution networks – Part 2: Steel pipe systems*
- AS/NZS 4645.3:2018 *Gas distribution networks – Part 3: Plastics pipe systems*

5. Next actions

Globally, the pace of transition (powered by the need to meet carbon emission reduction targets) is accelerating. Hydrogen production is an economy of scale and in California, according to the United States Department of Energy, the cost of new hydrogen refuelling stations on a per fuel bowser basis since 2012 has fallen between 77 per cent and 88 per cent at 2020 prices.[17]

Australia is ahead of New Zealand (by at least 3 years) in terms of standards adoptions, capital investment and the development of infrastructure to support their own hydrogen industry and export market to countries such as Japan.

Despite these challenges, New Zealand has a motivated and fully engaged energy sector with the technological requirements to pivot rapidly. But we need to act now. It is time to capitalise on our extensive renewable energy resources to supply high-purity, green hydrogen locally and abroad. If we get our timing right, by 2024/25 New Zealand could be one of the first countries to obtain (through the APEC standards initiative) a globally recognised green credential for hydrogen exports.

Lastly, from a regional perspective, in places like Taranaki and north of Taupo (where Halcyon Power's geothermally powered hydrogen plant is sited), we need to leverage existing international supply chains through the oil and gas industry to support the energy services sector's transition. This stands to create significant new opportunities for New Zealand businesses in the years ahead.

Table 8 – Next actions

Action	Milestone
Regulatory regime Industry is seeking government leadership and clarity on the development of its hydrogen roadmap.[18] The inter-agency **Hydrogen Regulatory Settings Working Group**[19] is working through the complexities in aligning current regulatory settings. However, stakeholder feedback suggests that realigning regulatory settings should not cause further delay to the quick adoption of the good practice international standards outlined in this report	**FY 2022/23 to 2025**
Hydrogen standards implementation strategy In accordance with an agreed multi-year programme of work between Standards New Zealand and WorkSafe New Zealand – Energy Safety (including other regulatory agencies), institute the **hydrogen standards implementation strategy**.	
Stage 1 – Stationary energy and storage	**FY 2022/23**
Stage 2 – Semi-centralised hydrogen distribution	**FY 2023/24**
Stage 3 – Decentralised hydrogen distribution	**FY 2024/25**

17 Koleva and Melaina, 2021.

18 For more information, see https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-strategies-for-new-zealand/hydrogen-in-new-zealand/roadmap-for-hydrogen-in-new-zealand/

19 Participants include MBIE – Energy and Resource Markets Branch, Health & Safety, Building System Performance, Trade & International, Standards New Zealand, Commerce Commission, Energy Efficiency and Conservation Authority, Environmental Protection Agency, Fire and Emergency NZ, Gas Industry Company (GIC), Maritime NZ, Ministry for the Environment, Ministry of Transport, NZ Customs Service, Waka Kotahi/ NZ Transport Agency and WorkSafe New Zealand.

Appendix A – Hydrogen standards review

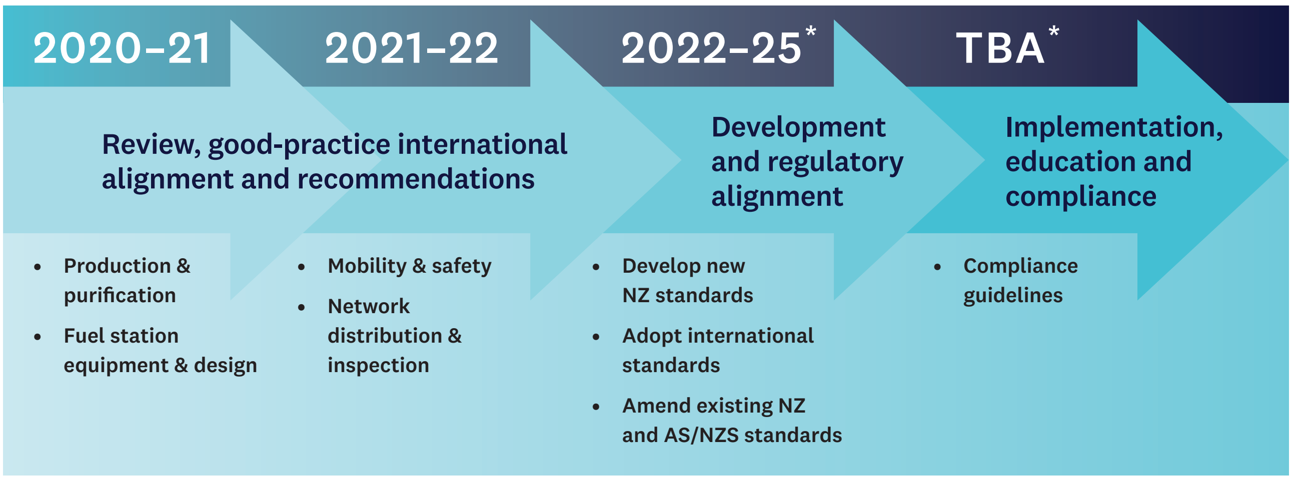
Standards New Zealand held a scoping workshop (promoted as a hydrogen standards forum) in December 2019 to gather feedback from New Zealand's leading gas industry subject matter experts and facilitate cross-government-agency discussions around the advancement of hydrogen from a standards, policy and compliance perspective.

A snapshot of what our OECD partners are doing was identified, and international good practice identified. Valuable insights into the challenges faced by local stakeholders embarking on hydrogen pilot/demonstration projects and the particular lack of a proper regulatory framework that supports the integration of hydrogen as an alternative fuel source were highlighted.

Using stakeholders' feedback and lessons learned from demonstration projects, Standards New Zealand prepared a report for WorkSafe New Zealand – Energy Safety outlining findings and recommending the development of a hydrogen standards draft framework and a 'standards review prioritisation plan' (see Figure A1).

The regulator agreed with the recommendations and the above activities ran in parallel with a broader programme to review regulatory settings, impacted by the integration of hydrogen. This work was led by the Ministry of Business, Innovation and Employment's Energy and Resource Markets team and included other government agencies.

The combination of these activities is characterised in Figure A2, which led to Standards New Zealand developing a hydrogen standards implementation strategy (see section 4).



* Prioritisation plans will be reassessed and agreed upon prior to the end of each financial year.

Figure A1 – Standards review prioritisation plan

Objective

Technical advisory group (TAG) P3652's primary objective was to ensure that chosen standards meet New Zealand's needs for the safe integration of hydrogen across the energy landscape.

The standards under review covered a broad hydrogen ecosystem, which contains many moving parts, from production, through the distribution and transportation of hydrogen in gaseous as well as liquefied states, to on-site production, storage and refuelling facilities.

The intended outcome was to determine which of the reviewed standards would allow for this to occur, resulting in a suite of recommendations for adoption (either directly or with modifications) of good practice international standards.

It was therefore necessary to understand the dynamics of the hydrogen ecosystem and supply chain interdependencies, then use this information as the basis upon which a standards solutions prioritisation plan could be developed (Figure A1), then expanded upon within the standards solutions implementation strategy (outlined in section 4).

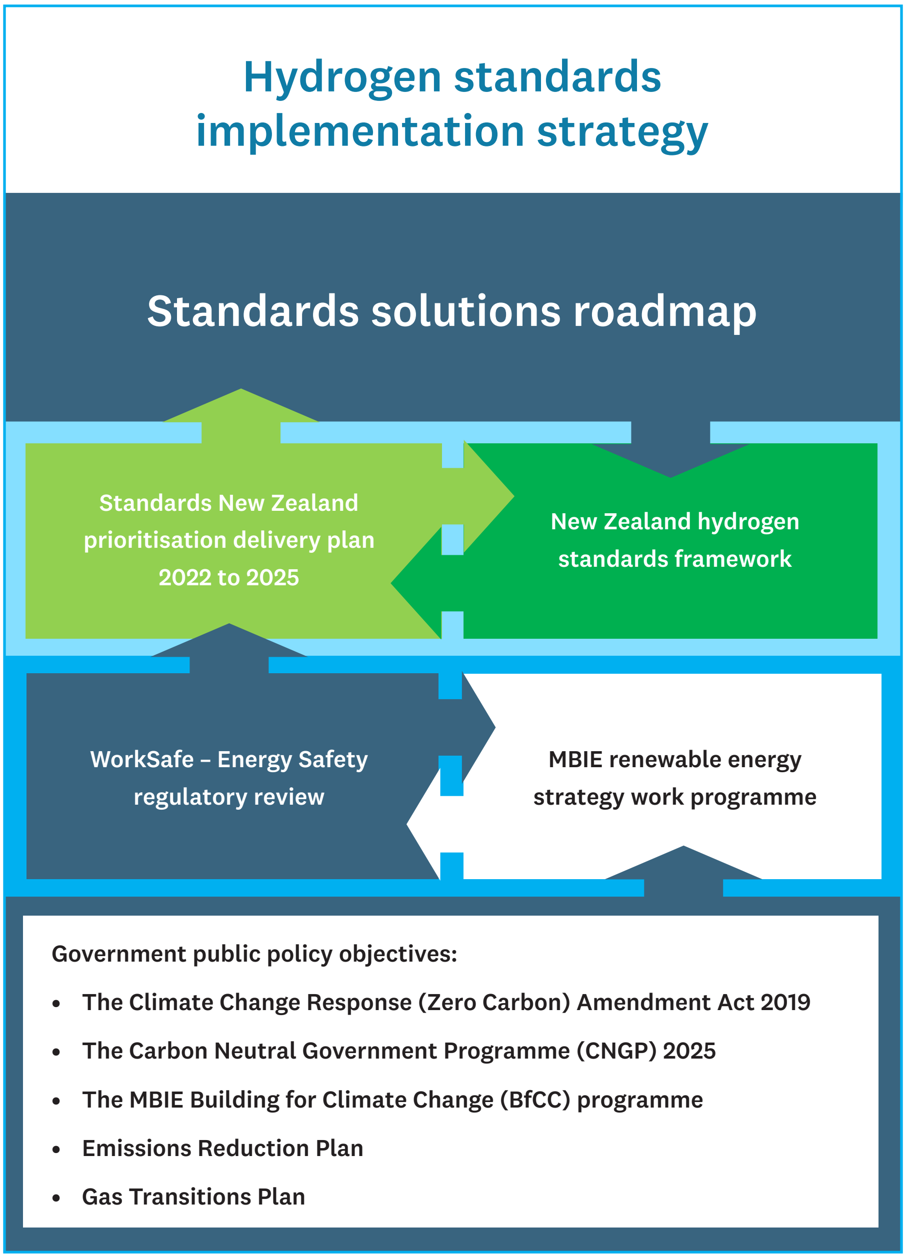


Figure A2 – Hydrogen standards implementation strategy

Scope

Given the large number of standards to be reviewed, a staged approach was agreed. Production & purification, green credentialling, and fuel station equipment & design were covered in 2020/21, followed by mobility & safety and network distribution & inspection in 2021/22. The primary focus concerned international standards for hydrogen relating to industrial and commercial applications.

Project 1: Production & purification and green credentialling

Review of international standards for industrial and commercial applications pertaining to:

- hydrogen generators using water electrolysers and fuel processing technologies
- safety of pressure swing absorption systems for hydrogen separation and purification
- odourisation of hydrogen gas
- green credentialling – for example, reviewing the European Union's (EU) certification scheme (CertifHy), where the Asia-Pacific Economic Cooperation (APEC) is heading, and any other relevant existing or emerging certification schemes.

Project 2: Fuel station equipment & design

Review of international standards for industrial and commercial applications pertaining to:

- design, installation, operation and maintenance for hydrogen refuelling stations
- hydrogen land vehicle refuelling connection devices
- validated refuelling protocols for vehicles
- metering systems, fuel quality control, certification and validation
- on-site hydrogen storage containers and associated devices
- basic considerations for the safety of hydrogen systems, including leakage-detection apparatus for stationary applications.

Project 3: Mobility & safety

Review of local, regional and international standards for industrial and commercial applications pertaining to:

- safety verification of existing gas installations
- essential safety requirements for electrical equipment
- essential requirements for gas equipment – safety and certification
- fuel cell technologies and safety specifications, performance, test methods and installations
- liquid hydrogen fuel tanks and fuel system interfaces
- gaseous hydrogen in fuelling stations, pertaining to fuel quality control
- transportable gas cylinders and transportable gas storage devices
- compressed gaseous hydrogen (CGH2 and hydrogen/natural gas blends fuel systems)
- compressed gaseous fuel measuring systems for vehicles.

Project 4: Network distribution & inspection

Review of international standards for industrial and commercial applications pertaining to:

- gas distribution networks and pipelines, including metrological and technical requirements
- gas measurement
- conformity assessment – requirements for the operation of various types of bodies performing inspection
- hydrogen-fired gas appliances and particular requirements for electrolysers.

Appendix B – Revised New Zealand hydrogen standards framework 2022

Successful implementation of a "hydrogen economy" needs to be underpinned by internationally recognised good practice standards and conformance systems that protect the health, safety and wellbeing of individuals and communities while at the same time facilitating international trade, sustaining industry and supporting innovation.

To ensure that hydrogen can be successfully integrated in a way that is safe, secure and economically viable (through scalability), gaps in cited New Zealand, joint and international standards must be identified. Then a plan to address those gaps can be formulated.

The New Zealand hydrogen standards framework (see Figure B3) focuses on 10 application-specific categories. This framework provides industry a standards point of reference, which is subject to change as good practice, technology and international standards continue to evolve.

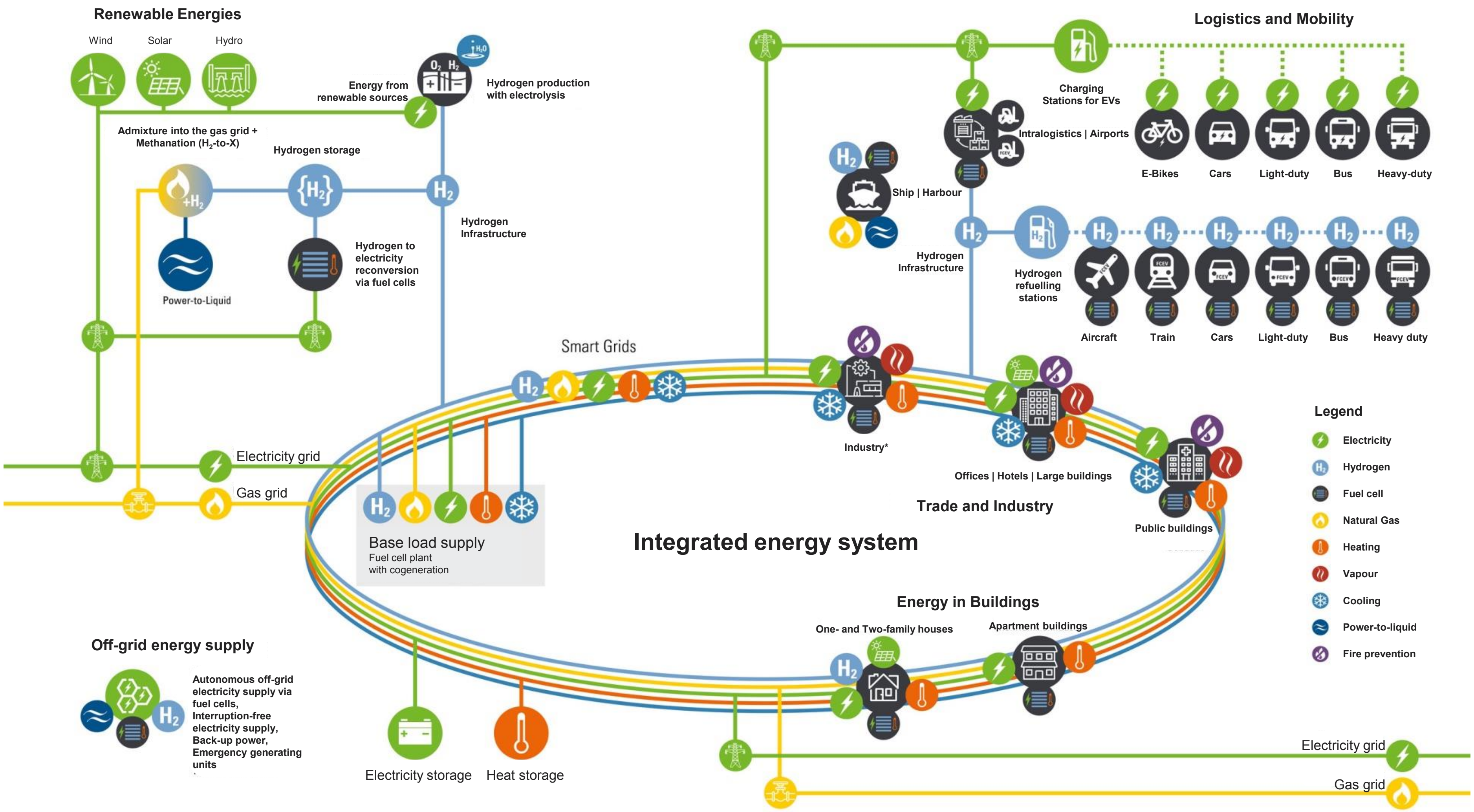


Figure B1 – P2G (power-to-gas) hydrogen supply chain

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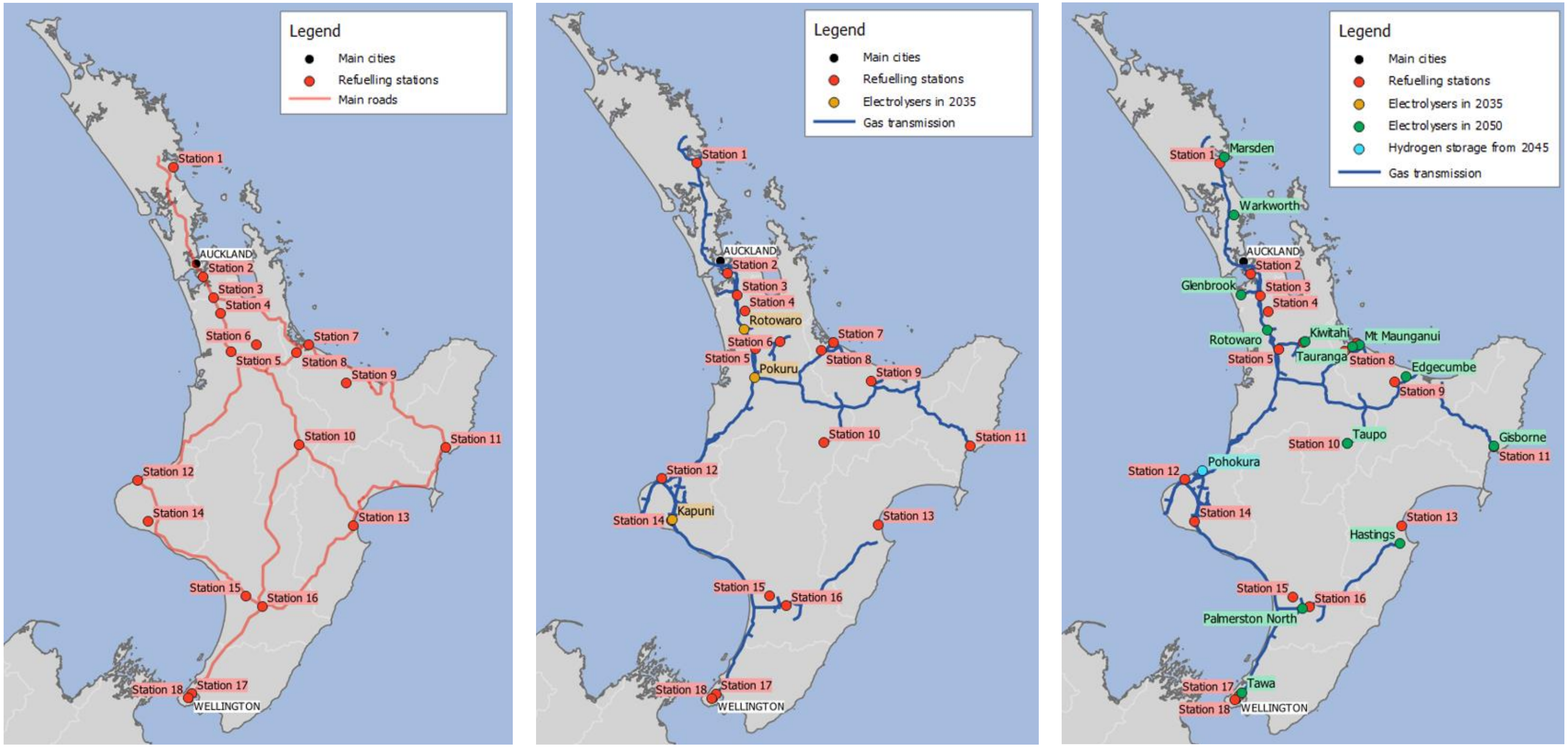
* Industrial applications include ammonia production, hydrocracking to create petroleum, electronics manufacturing, metalworking, welding, medical uses (producing hydrogen peroxide), and food production (turning unsaturated fats into saturated oils and fats, including hydrogenated vegetable oils like margarine).



Refuelling station hub locations: Sites for onsite electrolysers to meet transport demands

Electrolyser locations in 2035: Additional sites for injection of hydrogen into the transmission network (20% by volume) hydrogen blend

Electrolyser and hydrogen storage in 2050: Locations of electrolyser plant and large-scale storage to feed the 100% H2 network

Figure B2 – Hydrogen network infrastructure transition

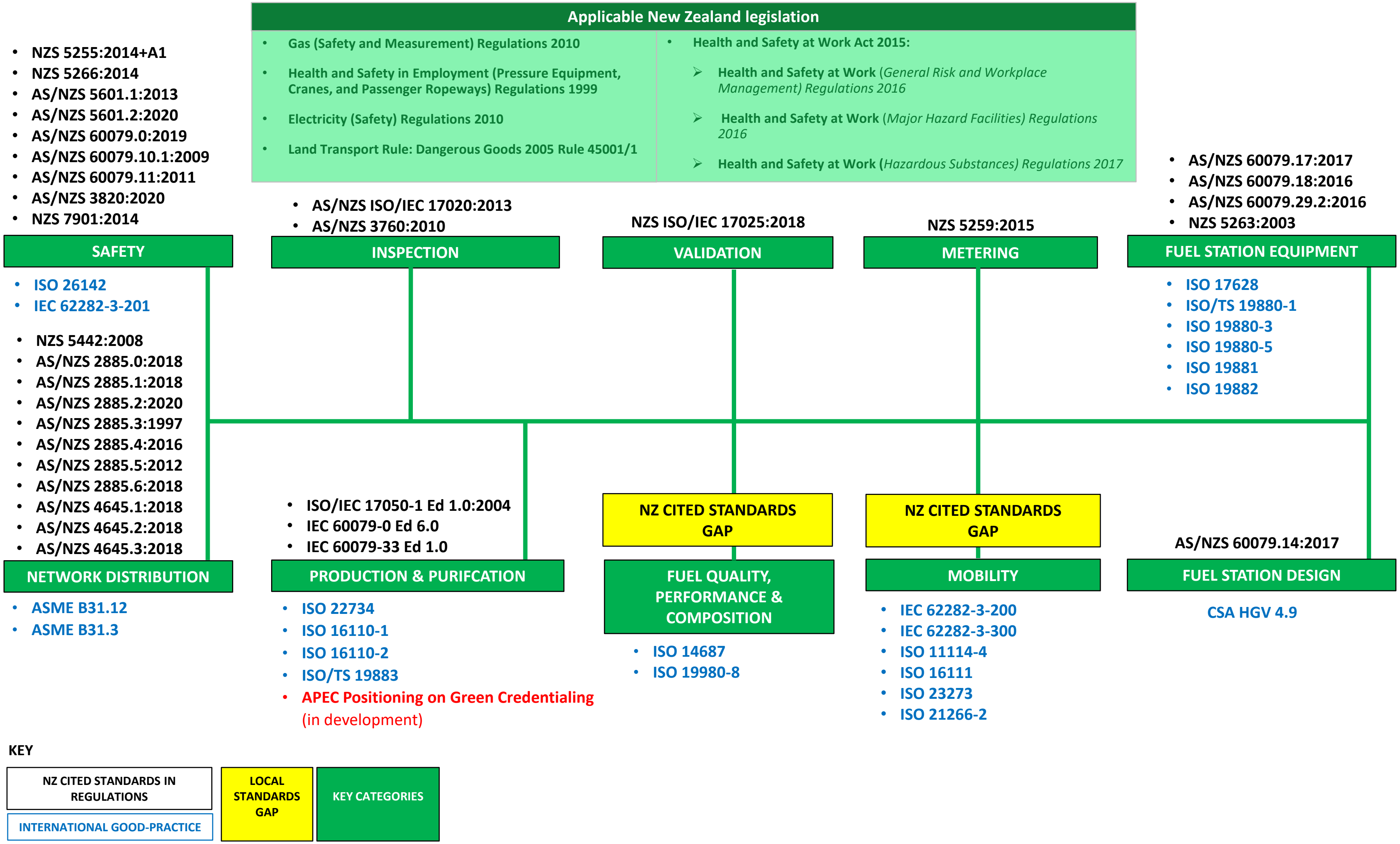
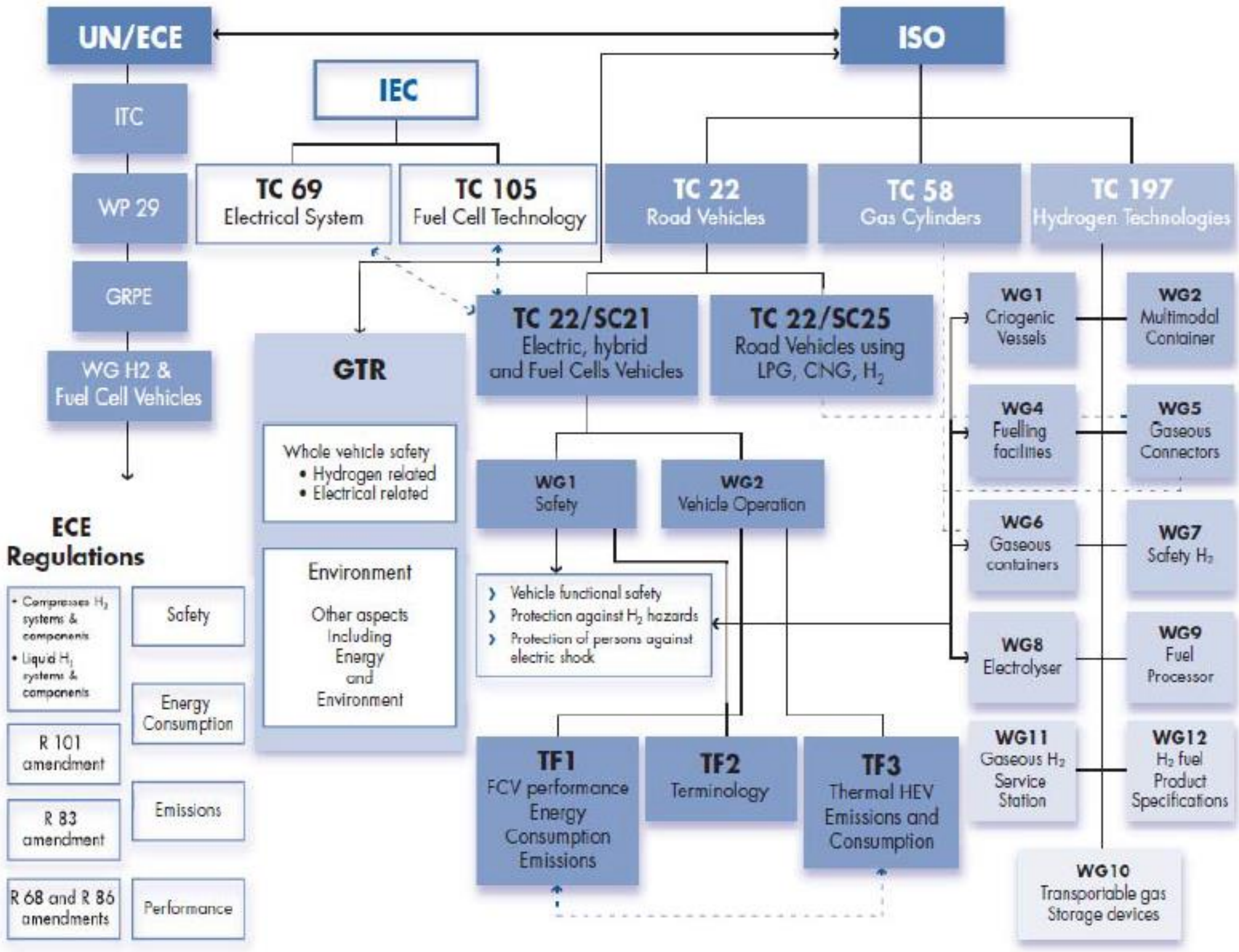


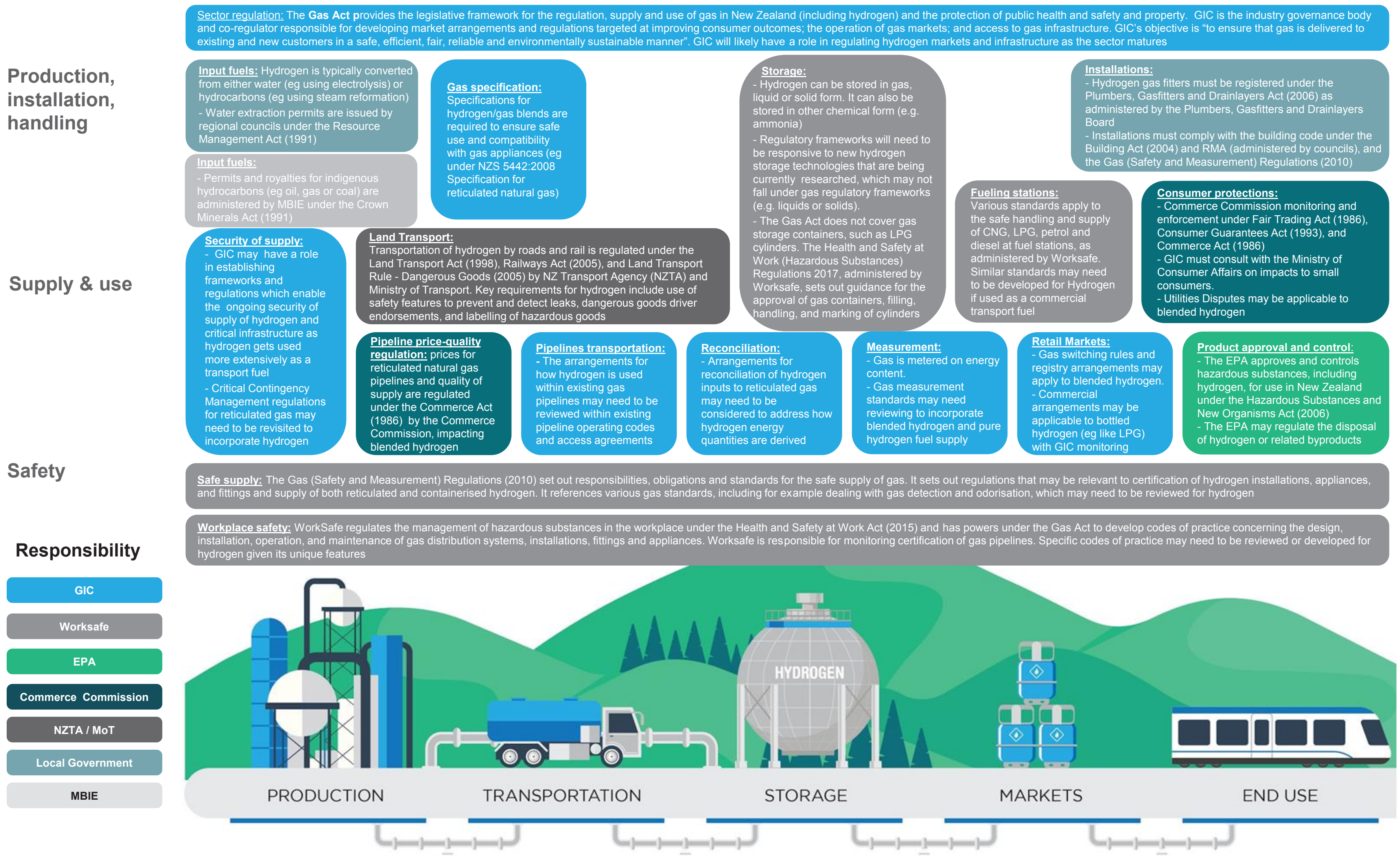
Figure B3 – New Zealand hydrogen standards framework[20]

[20] The New Zealand hydrogen standards draft framework (February 2023) includes the recommended standards solutions outlined in this report.



ABBREVIATIONS
UN – United Nations
ECE – Economic Commission for Europe
H2 – Hydrogen
WG – Working group
WP – Working party
TC – Technical committee
ISO – International Organization for Standardization
GRPE – Group [of] Rapporteurs on Pollution and Energy
GTR – Global Technical Regulations
TF – French Southern Territories

Figure B4 – International standardisation and regulatory bodies in the field of hydrogen, fuel cells and their linkages



Note: 'Blended hydrogen' is hydrogen gas mixed with natural gas

Figure B5 – New Zealand current hydrogen regulatory framework

Appendix C – Standards review commentary

TAG P3652 subgroups reviewed the standards as outlined in the New Zealand hydrogen standards framework. Their final recommendations are outlined in Tables 4, 5 and 6. This section deals with only specific commentary.

Table C1 – Standards review with specific commentary

AS/NZS 3645.1:2012 *Essential requirements for gas equipment – Part 1: Essential safety*

- 2.3.1.13 Note 1. Make provision of other gases
- 2.3.1.14 Note 1. Make provision of other gases
- Note section – add note for test reports, with the results of ISO or EN (European norm) standards
- 2.3.13 New gas could be hydrogen and hydrogen blended, or this could be two classes, pure and blended hydrogen (assuming blends are going to be up to about 25% hydrogen in methane)
- 2.3.13, 2.2.14 A higher operating and maximum overpressure may be appropriate for hydrogen to offset lower energy density. For example, for 100% hydrogen 3–10 kPa operating; 15–20 kPa overpressure maximum
- 1.3.4 would seem to include hydrogen fuel cells once hydrogen is added. Not a problem per se, but may be an unintended consequence
- Generic use of the term 'gas'. Does this need defining given potential for NG/H2 blends – could be through the family descriptors
- 1.2 Does list of reference standards need updating to cover up to pure H2
- 1.3.11 Will need updating for blends (or NZS 5442 will need to include blends)
- 1.3.14 Need further definition of reference gas
- 2.1.5, 2.3.1.13, 2.2.1.14 – Reference to family of gases – need to ensure hydrogen and blends are assigned appropriate family and update this section as required
- 2.3.1.13 Note 1. Make provision of other gases
- 2.3.1.14 Note 1. Make provision of other gases

AS/NZS 3645.2:2012 *Essential requirements for gas equipment – Part 2: Certification*

- 2.1 Add note to make provision of other gases (blended H2 and NG)
- All the standards listed in Appendix A appear to be Australian (mostly AS 455x /456x series). Would these have to be updated for hydrogen and hydrogen-methane blends? Curious to know why no other standards are cited
- 1.3.11 relies on NZS 5442 being updated for NG/H2 blends
- 1.3.13/14/ Table 1 will need gases defined for blends
- B4.8 – is the 5-year time frame still applicable for H2

Table C1 – Standards review with specific commentary *continued*

BS PAS 4444:2020 ***Hydrogen-fired gas appliances. Guide***
• This is only a reference and not a standard. It states that hydrogen should be called 4th family where NZS 5266 and AS/NZS 3645.1 and 2 call it the 1st • Adopt as a reference document to 3645.2 2012 • Focus is on domestic appliances, rather than industrial or process. This is a placeholder before formal standards are adopted by the British Standards Institution (BSI), with many references to generic standards. It should be considered when adopting standards for domestic hydrogen appliances • Will need to confirm that all the referenced standards have been accepted for New Zealand • Agree with comments above. Additionally, need to consider that we could have appliances with mixed fuel gas (e.g. 20% H2 , 80% NG)
IEC 60335-2-108 2008 ***Household and similar electrical appliances – Safety – Particular requirements for electrolysers***
• Section 1: Scope – standard not relevant; applicable only to domestic appliances that "produce low-viscosity, ionised liquids intended for use as detergent-free wash water in appliances for household and similar purposes …" • Section 1: Scope – standard not relevant – specifically excludes appliances for industrial purposes and appliances in areas for explosive atmospheres
NZS 5255:2014 ***Safety verification of existing gas installations***
• 13 (2) Flame visibility observed H2 gas. Where not visible, include as flame abnormality • This standard was reviewed in the last round and disregarded • Foreword – are the referenced standards still relevant and current for hydrogen mixes • This standard is for verification against performance requirements of NZS 5601 parts 1 and 2. Is NZS 5601 appliable for H2? Note, NZS 5601 is for installations downstream of the point of supply only (so production and storage excluded?) • Not sure this standard is applicable – it is only for existing gas installations and appliances • Also, worth noting that hazardous substances regulations state "1.8 Fuel gas (1) These regulations do not apply to any fuel gas that is supplied through a distribution system or is used in a gas installation or gas appliance, within the meaning of the Gas Act 1992" • As H2 is a 2.1.1 gas, need to understand how this would be handled

Table C1 – Standards review with specific commentary *continued*

NZS 5266:2014 *Safety of gas appliances*
• 4.1.6 add new category (c) blended family of gases H2/NG • 4.1.7 Note 1 add blended family of gases H2/NG • Appendix C1.1 add 4th family or blended gases • Appendix C2.2 add blended family of gases H2/NG • Table C2 add Wobbe index and relative density blended NG and H2 gases • C3 will require future update to table on development of H2 test gasses • Add hydrogen as another family of gases with necessary data (as per the six points above) • Consider hydrogen from alternative sources: reformed with CO, CO2 contamination and from electrolysis with O2 and water vapour • Is there any reason other than seismic considerations that this is not a joint Australian/New Zealand standard • Assume NZS 5442 will need review (by this group or others) • 4.1.6 add new category (c) blended family of gases H2/NG
NZS 5259: 2015 *Gas measurement*
• Not applicable for vehicles. Appropriate for utility scale performance-based measurements (for H2 blends). Changes required for blends. Is not appropriate to be modified for 100% H2
ISO 11114-4:2017 *Transportable gas cylinders – Compatibility of cylinder and valve materials with gas contents – Part 4: Test methods for selecting steels resistant to hydrogen embrittlement*
• Consider recognition under relevant regulations in New Zealand
ISO 16111:2018 *Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride*
• Consider recognition under relevant regulations in New Zealand
ISO 13985:2006 *Liquid hydrogen – Land vehicle fuel tanks*
• Standard up to date, but not a priority at this stage
ISO 13984:1999 *Liquid hydrogen – Land vehicle fuelling system interface*
• Standard up to date, but not a priority at this stage
ISO 19880-8:2019 *Gaseous hydrogen – Fuelling stations – Part 8: Fuel quality control*
• Adopted parts 1, 3, and 5 in first round of reviews. Adopt directly (some references may need to be updated)

Table C1 – Standards review with specific commentary *continued*

IEC 62282-3-200:2015 *Fuel cell technologies – Part 3-200: Stationary fuel cell power systems – Performance test methods*
• Some differences may occur between European and Australian versions of IEC 60079 series of standards. Note: Needs to point to the AS/NZ 60079 series of standards
IEC 62282-3-300:2012 *Fuel cell technologies – Part 3-300: Stationary fuel cell power systems – Installation*
• Confirm 7.1.2.1 doesn't contradict distributed generation (DG) regulations in New Zealand. Some differences may occur between European and Australian versions of 60079. Note: Needs to point to AS/NZS 60079 if required in the document
IEC 62282-3-201:2017 *Fuel cell technologies – Part 3-201: Stationary fuel cell power systems – Performance test methods for small fuel cell power systems*
• Some differences may occur between European and Australian versions of 60079. Note: Needs to point to AS/NZ 60079
ISO 17268:2020 *Gaseous hydrogen land vehicle refuelling connection devices*
• Adopt directly (some references may need to be updated)
ISO 23273:2013 *Fuel cell road vehicles – Safety specifications – Protection against hydrogen hazards for vehicles fuelled with compressed hydrogen*
• Good reference document. However, group not familiar enough with New Zealand road vehicle rules to recommend
ISO 21266-2:2018 *Road vehicles – Compressed gaseous hydrogen (CGH2) and hydrogen/natural gas blends fuel systems – Part 2: Test methods*
• Good reference document. However, the group doesn't have the experience in fuelling vehicles with a blend. Group doesn't know many projects of this type
AS 2885 - - - -:2018 *Pipelines – Gas and liquid petroleum* *Part 0: General requirements* *Part 1: Design and construction* *Part 2: Welding* *Part 3: Operation and maintenance* *Part 4: Submarine pipeline systems* *Part 5: Field pressure testing* *Part 6: Pipeline safety management*
• Don't allow any meaningful amounts of hydrogen (update under way in Australia). CoP currently being published (*Hydrogen Pipeline Code of Practice*)

Table C1 – Standards review with specific commentary *continued*

AS/NZS 4645 - - - -:2018 *Gas distribution networks* *Part 1: Network management* *Part 2: Steel pipe systems* *Part 3: Plastics pipe systems*
• Standards allow up to 15% hydrogen already. Consensus within group is that this standard might be appropriate for a number of years, as reaching 20% in distribution networks could be 10 years away
ASME B31.12 – 2019 *Hydrogen piping and pipelines*
• This is the hydrogen pipelines standard. New hydrogen pipelines use this standard
ASME B31.3 – 2020 *Process piping*
• Currently used in New Zealand, so no need to adopt ISO 15649
ISO 15649:2001 *Petroleum and natural gas industries – Piping*
• Upstream standard for designing production facilities. Not appropriate for transmission and distribution. References ASME B31.3 and focuses on natural gas. ASME B31.3 is the standard normally used in New Zealand

Appendix D – Nomenclature

Abbreviations have the following meanings:

APEC	Asia-Pacific Economic Cooperation
CCC	Climate Change Commission
CCS	carbon capture and storage
CCU	carbon capture and utilisation
CGH2	compressed hydrogen gas
CHP	combined heat and power
CoP	code of practice
DC	direct current
DOE	United States Department of Energy
EDB	electricity distribution business
EU	European Union
FC	fuel cell
FCEV	fuel cell electric vehicle
GHG	greenhouse gas
GSMR	gas safety & management regulations
H_2	hydrogen molecule (two atoms)
HDPE	high-density polyethylene
HE	hydrogen embrittlement
HGV	heavy goods vehicle
HHV	higher heating value
HRS	hydrogen refuelling station
HSNO	hazardous substances and new organisms
HSW	health and safety at work
IGC	Industrial Gases Council
kt	kilotonne
kWe	kilowatt (electric)

LFL	lower flammability limit
LH2	liquid hydrogen
LHV	lower heating value
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MAOP	maximum allowable operating pressure
MBIE	Ministry of Business, Innovation and Employment – Hīkina Whakatutuki
MCH	methylcyclohexane
MDPE	medium-density polyethylene
NG	natural gas
NTS	National Transmission System
NZ-ETS	New Zealand Emissions Trading Scheme
O&M	operations & maintenance
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
P2G	power-to-gas
PE	polyethylene
PEM	polymer electrolyte membrane
PJ	petajoule
PSA	pressure swing adsorption
R&D	research & development
RES	renewable energy source
SMR	steam methane reforming
SMS	safety management systems
SOI	statement of intent
TAG	technical advisory group
TOL	toluene
UPS	uninterruptible power supply

Table D1 – Unit conversions

Conversions	Order of magnitude
1 PJ = 277.8 GWh	Peta (P) = 10^{15}
1 PJ = 8.33 kt H2	Tera (T) = 10^{12}
1 TWh = 3.6 PJ	Giga (G) = 10^{9}
1 TWh = 30.03 kt H2	Mega (M) = 10^{6}
1 kg H2 = 120 MJ (LHV)	kilo (k) = 10^{3}
1 kg H2 = 33.33 kWh (LHV)	n/a
1 bar (1.013) = 100 kPa, 14.503 psi = 1 atmosphere @ sea level	n/a

Table D2 – Hydrogen physical properties – Fuel comparator

Property	Hydrogen	Natural gas	Petrol	Diesel
Density (vapour) (at 60°F; 15°C, 1 bar)	0.0841 kg/m^3	0.712 kg/m^3	3.9 kg/m^3	4.5 kg/m^3
Density (liquid) (at 1 bar)	70.7 kg/m^3 (-423.4°F; -253°C)	430.0 kg/m^3 (-259°F; -162°C)	745.0 kg/m^3 (60°F; 15°C)	846.0 kg/m^3 (60°F; 15°C)
Boiling point (liquid to vapour) (at 1 bar)	-253°C	-162°C	95°C	282 – 338°C
Energy per unit of mass (at 32°F or 0°C, 1 bar, LHV)	120.0 MJ/kg (33.33 kWh/kg)	55.0 MJ/kg (15.27 kWh/kg)	44.0 MJ/kg (12.22 kWh/kg)	42.8 MJ/kg (11.88 kWh/kg)
Specific energy density liquefied (at 60°F or 15°C, 1 bar, LHV)	10.0 MJ/L	20.3 MJ/L	32.2 MJ/L	35.7 MJ/L
Ignition range (in air by volume)	4 – 74.2%	3.1 – 15%	1.4 – 7.6%	3.9 – 16.9%
Auto ignition temperature	585°C	482°C	280°C	210°C
Ignition energy	0.011 MJ	0.24 MJ	0.8 MJ	20.0 MJ

Note – kg/m^3 = kilograms per cubic metre; LHV = lower heating value; MJ = megajoule; MJ/kg = megajoules per kilogram; MJ/L = megajoules per litre.

Table D3 – Hydrogen compressibility factor

Pressure (MPa)	Compressibility
0.1013	1
5	1.032
10	1.065
15	1.098
20	1.132
25	1.166
30	1.201
35	1.236
40	1.272
50	1.344
60	1.416
70	1.489
80	1.560
90	1.632
100	1.702

Appendix E – Referenced documents

Reference is made in this document to the following:

New Zealand standards

NZS 5255:2014 + A1	*Safety verification of existing gas installations*
NZS 5258	*Gas distribution networks*
NZS 5259	*Gas measurement*
NZS 5266	*Safety of gas appliances*
NZS 7901	*Electricity and gas industries – Safety management systems for public safety*

Joint Australian/New Zealand standards

AS/NZS 2885.1	*Pipelines – Gas and liquid petroleum – Part 1: Design and construction*
AS/NZS 2885.2	*Pipelines – Gas and liquid petroleum – Part 2: Welding*
AS/NZS 2885.4	*Pipelines – Gas and liquid petroleum – Part 4: Submarine pipelines*
AS/NZS 2885.5	*Pipelines – Gas and liquid petroleum – Part 5: Field pressure testing*
AS/NZS 2885.6	*Pipelines – Gas and liquid petroleum – Part 6: Pipeline safety management*
AS/NZS 3760 + A2	*In-service safety inspection and testing of electrical equipment*
AS/NZS 3820	*Essential safety requirements for electrical equipment*
AS/NZS 4645.1	*Gas distribution networks – Part 1: Network management*
AS/NZS 4645.2	*Gas distribution networks – Part 2: Steel pipe systems*
AS/NZS 4645.3	*Gas distribution networks – Part 3: Plastic pipe systems*
AS/NZS ISO/IEC 17020	*Conformity assessment – Requirements for the operation of various types of bodies performing inspection*
NZS/AS 2885.3	*Pipelines – Gas and liquid petroleum – Operation and maintenance*
NZS/AS 3645.1	*Essential requirements for gas equipment – Part 1: Essential safety*
NZS/AS 3645.2	*Essential requirements for gas equipment – Part 2: Certification*
NZS ISO/CIE 17025	*General requirements for the competence of testing and calibration laboratories*

International standards

ASME B31.12	*Hydrogen piping and pipelines*
ASME B31.3	*Hydrogen piping and pipelines*
BSI PAS 4444	*Hydrogen-fired gas appliances*
ISO 11114-4	*Transportable gas cylinders – Compatibility of cylinder and valve materials with gas contents – Part 4: Test methods for selecting steels resistant to hydrogen embrittlement*
ISO 13984	*Liquid hydrogen – Land vehicle fuelling system interface*
ISO 13985	*Liquid hydrogen – Land vehicle fuel tanks*
ISO TR 15916	*Basic considerations for the safety of hydrogen systems*
ISO 15649	*Petroleum and natural gas industries – Piping*
ISO 1611	*Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride*
ISO 1728	*Gaseous hydrogen land vehicle refuelling connection devices*
ISO 19880 – 8	*Gaseous hydrogen – Fuelling stations – Part 8: Fuel quality control*
ISO 19880 – 8: 2019/DAM-1	*Gaseous hydrogen – Fuelling stations – Part 8: Fuel quality control – Amendment 1*
ISO 21266.2	*Road vehicles – Compressed gaseous hydrogen (CGH2) and hydrogen/natural gas blends fuel systems – Part 2: Test methods*
ISO 23273	*Fuel cell road vehicles – Safety specifications – Protection against hydrogen hazards for vehicles fuelled with compressed hydrogen*
OIML R 117-1	*Dynamic measuring systems for liquids other than water – Part 1: Metrological and technical requirements*
OIML R 139-1	*Compressed gaseous fuel measuring systems for vehicles – Part 1: Metrological and technical requirements*

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New Zealand legislation

The following legislation is applicable to this review:

Electricity (Safety) Regulations 2010

Gas (Safety and Measurement) Regulations 2010

Health and Safety in Employment (Pressure Equipment, Cranes, and Passenger Ropeways) Regulations 1999

Health and Safety at Work Act 2015

Health and Safety at Work (General Risk and Workplace Management) Regulations 2016

Health and Safety at Work (Hazardous Substances) Regulations 2017

Health and Safety at Work (Major Hazard Facilities) Regulations 2016

Land Transport Rule: Dangerous Goods 2005 Rule 45001/1

Websites

www.nzta.govt.nz

www.legislation.govt.nz

www.worksafe.govt.nz

Latest revisions

Users of this report should ensure that their copies of the above-mentioned New Zealand standards are the latest revisions. Amendments to referenced New Zealand and joint Australian/New Zealand standards can be found on the Standards New Zealand website.

MINISTRY OF BUSINESS,
INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

Te Kāwanatanga o Aotearoa
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