

Decarbonising the Built Environment via Green Hydrogen Technologies

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor used artificial intelligence tools or generative artificial intelligence tools (unless it is clearly stated, and referenced, along with the purpose of use), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

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Abstract

The imperative to decarbonize the built environment has intensified as buildings contribute substantially to global greenhouse gas emissions. For countries like New Zealand seeking to meet ambitious climate goals, reducing carbon from building operations is pivotal. Integrating hydrogen technologies shows promise to enable sustainable, low-emission energy services in buildings.

Produced via electrolysis powered by renewables, green hydrogen provides a versatile energy carrier to displace fossil fuel dominance. Applications in heating and power generation can slash building emissions. Fuel cells, boilers and appliances utilizing green hydrogen align with net-zero objectives. Decentralized systems converting surplus solar and wind into storable hydrogen offer resiliency. This empowers buildings to become self-sufficient clean energy hubs. Across heating and power, green hydrogen unlocks potential for the built environment to achieve substantial emissions cuts.

By scrutinizing technical specifications, costs, policies and local nuances, this research seeks insights to guide integration of green hydrogen in New Zealand buildings. The aim is multifaceted - assess feasibility, identify challenges, pinpoint opportunities and uncover pathways forward. Findings can shape decisions, investments and innovations to actualize sustainable, low-carbon built environments nationwide.

Ultimately, the goal is to provide stakeholders - policymakers, industry players, researchers - with evidence and analysis to inform actions that successfully leverage green hydrogen’s versatility. With strategic implementation and cohesive efforts, a future powered by clean hydrogen’s tremendous potential can take form, bringing us closer to a greener Aotearoa.

Chapter 1 – Introduction

Chapter One introduces the imperative for urgent decarbonization and attaining zero net greenhouse gas emissions globally by 2050, aligning with New Zealand’s strategic priority as articulated in the Climate Change Response (Zero Carbon) Amendment Act 2019. The chapter comprehensively addresses the pressing need to transition towards renewable energy sources, with a specific focus on green hydrogen production as a transformative energy vector. It establishes the backdrop of New Zealand’s ambitious targets, emphasizing the pivotal role green hydrogen technologies are expected to play in achieving a sustainable, low-carbon built environment. Additionally, the chapter underscores the significance of these advancements amidst burgeoning energy demands and the critical imperative of environmental sustainability.

1.1 Introduction

Chapter One serves as the foundation of this research, presenting a structured exploration into the critical realm of green hydrogen technologies for achieving a sustainable built environment. It commences by setting the stage, introducing the background and contextualizing the research within the pressing need for decarbonization. Subsequently, the rationale behind this study is delineated, highlighting the urgency and significance of investigating green hydrogen’s potential. The research problem is articulated, emphasizing the existing gaps and underscoring the necessity of this inquiry. Aims and objectives are outlined, precisely identifying the intentions and expected outcomes of this research. Key research questions and hypotheses provide a roadmap for the forthcoming exploration, ensuring a focused and methodical investigation. The theoretical and practical implications are briefly discussed, illuminating the potential contributions and applications of this research. Limitations and assumptions are acknowledged, laying the groundwork for a nuanced and objective interpretation of findings. The chapter concludes by presenting a glimpse into the research’s timeline and offering a synopsis of what lies ahead.

1.2 Background

Decarbonisation and zero net greenhouse gas emissions are the main global goals that are targeted to be reached by 2050 and are becoming a high strategic priority for New Zealand (Climate Change Response (Zero Carbon) Amendment Act 2019). To achieve these targets, scientists on the global scale are working on the solution as to how to commercialise green hydrogen and make it a safe energy vector. Currently, only 4% of all hydrogen types come from renewable energy resources (Karchiyappan, 2019). To support the green concept, the New Zealand Government introduced a hydrogen road map for the development of the long-term green economy model to reduce reliance on fossil fuels (New Zealand Hydrogen Scenarios, 2022).

New Zealand, with its abundant renewable energy and prerequisites for production of green hydrogen, set up a goal to “reach 100% renewable electricity by 2035 and a transition to a clean, green and carbon-neutral economy by 2050” (Gholami 2021; MBIE Green Paper, 2019, p. 4). It seems possible to meet the Government’s current plan considering that the green

hydrogen is produced by splitting water via electrolysis into two elements - hydrogen and oxygen - using the electricity which comes from renewable energy resources such as wind, solar, geothermal and tidal energy (Energy in New Zealand, 2021). This transition is aimed at the heavy-duty transport system supported by the Auckland Council, Auckland Transport and KiwiRail. Apart from enabling the deployment of hydrogen technologies in transport, the Government is planning to focus on the industrial sector and green hydrogen export (Green Paper, 2019).

The production of green hydrogen becomes more affordable due to cost reduction of energy produced from renewable resources, and it has been projected that the cost of production and distribution will hesitate between US\$3.54/kg and US\$5.42/kg in 2025 depending on the production location (NZ Hydrogen Scenarios, 2022). Australia predicts that green hydrogen production cost may reach below A\$3/kg in the nearest future due to the constantly dropping cost of renewable electricity (Longden, 2020). Since the cost of production and storage of renewable sources of energy becomes economically competitive, there is a high possibility for introduction of green hydrogen energy in the New Zealand's built environment based on the development of technologies to allow electrical load flexibility.

Considering strategically that the power demand will continue to grow and the expectations to high quality power has already been set up, decentralisation of large power stations will be required to avoid overloading of the limited electricity capacity and ability to provide automotive energy supply to new infrastructures even in remote areas and off-grid thus protecting environment and providing sustainability.

The main focus of this research is to discuss the transition from the traditional energy to secure, energy efficient, affordable and sustainable green hydrogen energy while decarbonizing the built environment.

As an energy-dependant civilisation, the world's energy consumption has great importance for socio-economic and political aspects. With the world population's continuous growth, the electricity and energy demand have increased respectively. Being heavily dependent on energy, the world population has been producing greenhouse gases with an average carbon footprint of 7 tonnes of CO₂ per person per year. New Zealand, with its well-developed agricultural sector, was one of the sixth countries with the highest Carbon Dioxide per capita at 7.8 tonnes of carbon dioxide equivalent per capita, and 17.2 tonnes of carbon dioxide equivalent of all gases per capita in 2019. In 2020, the energy sector alone contributed 40% of all gross emissions which is 31.5 million tonnes of CO₂ equivalent (Ministry for the Environment, 2022).

To create a more sustainable future, the United Nations agreed to urgently limit global warming to 1.5 degrees Celsius, reduce greenhouse gas emissions by 45% by 2030, reaching net zero emission by 2050 and provide "access to affordable, reliable, sustainable and modern energy for all" as it has been declared in the seventh of the seventeen Sustainable Development Goals of the UN Environment Programme (Kyoto Protocol, 1997; Paris Agreement, 2015; Climate Change, 2022; SDG7, 2015).

New Zealand also contributes to the global target and has introduced the amendment to legislation emphasizing the necessity of a major transition to clean energy (New Zealand Legislation, 2019). The critical role will be played by hydrogen which has already been

introduced to the transportation and industrial sector. For example, a strategic partnership between the NZ Tuaropaki Trust and Japan's Obayashi Corporation has made a decision to launch a project for 1.5-megawatt of green hydrogen production using the geothermal energy from Mokai Power Station in Taupo with a further application in New Zealand and Japan. The hydrogen produced is distributed across NZ for fuelling the vehicles and for industrial needs, but application of green hydrogen in the built environment has not been considered yet.

According to a recent report, residential and commercial buildings consume about 32% and 24% of New Zealand's energy respectively. These indicators are slightly lower than in Europe where the built environment consume 40% of all energy (Maestre, 2021). Almost 32% of the NZ power bill goes towards the cost of electricity production, while 27% goes to the distribution of electricity from the national grid to the final consumer. Reaching the typical household, 27% and 15% of electricity is spent for water and space heating especially during the winter season thus contributing 30% of household emissions in Auckland region alone (Electricity in New Zealand, 2018; Stats NZ, 2021). To minimise energy demand, many actions have been taken in recent years including design improvement, introduction of new building codes and regulations, introduction of renewable sources of energy and energy behavioural modelling, improvement of HVAC systems, installation of photovoltaic systems, introduction of new generation of hot water cylinders and heat pumps. To reduce greenhouse gases emissions released by the old buildings, energy-efficiency measures have been improved through the changes in building envelop design, introduction of new building materials and advanced technologies (Maestre, 2021). Nevertheless, these actions and measurements have not been sufficient enough to achieve the decarbonisation goals and the public is still heavily depending on fossil fuels – oil, coal and gas.

Some of the buildings are connected to the national grid pipeline sourced from the Taranaki region of New Zealand. Several hundred explorations and production wells have been drilled to provide gas to end-users through thousands of kilometres of pipes since 1950 (Gas Statistics, MBIE, 2022). Having a target to become a zero-carbon country by 2050 means that New Zealand may repurpose existing gas infrastructure for hydrogen transportation to public and private customers to provide zero-carbon energy at the point of end-use or even produce the hydrogen energy in-situ on a smaller scale to provide the clean energy to the off-grid users.

Some countries, and in particular the UK, already have begun blending up to 1/5th of hydrogen into the existing gas pipeline aiming at reducing the dependence on natural gas import and input to the global decarbonisation (Hydrogen Blending, 2022, Isaac, 2019).

Currently, in New Zealand, only 2/5th of energy is coming from renewable sources such as hydro, geothermal, wind, solar and 3/5th from oil, gas and coal (Energy in New Zealand, 2020). However, on the global scale more than 4/5th of energy consumed comes from fossil fuels and less than 1/5th from renewables.

The investments made into the fossil energy infrastructure and the high profit interest the investors receive from the fossil fuel sector are the main reasons why almost all global economic activities depend on fossil fuels. Undeniably, the world economic is prosperous today, but the “*hidden cost*” is high and less optimistic.

The “*hidden costs*” of fossil fuels extraction such as climate change, land, water and air pollution should not be neglected. Consequences of fossil fuel extraction are severe and include the extreme weather events caused by climate change; toxins, CO₂ and methane emissions that negatively affect the ecosystem we live in and our health; diseases such as cancer, asthma, heart disease and many other (Union of Concerned Scientists, 2016).

The dependency on fossil fuels has been lasting since the beginning of the industrial revolution, but COVID-19 caused a dramatic decline in global economy activities consequently reducing the energy use worldwide and CO₂ emissions (Hanieh, 2020). However, dependency on fossil fuels in NZ continued during COVID-19 alerts 3 and 4 when the production of natural gas decreased while electricity produced from coal reached the highest indicators since 2013 (MBIE, 2021).

The oil prices dropped dramatically during the pandemic and lockdowns but have escalated in the post COVID-19 global market and have drastically increased recently due to global issues and the Russian invasion of Ukraine. Likely, the prices – actual and “*hidden*” - will continue to grow. So rather than wasting money on energy that brings so many disadvantages to the environment and is harmful to our health, it might be better to reach 100% self-sufficiency by investigating ways of introducing green hydrogen energy and innovative hydrogen technologies.

As an alternative solution, New Zealand has been taking active steps to produce hydro energy which is one of the dominant renewable energy production technologies, albeit not yet quite reliable either due to unforeseen climatic conditions when the precipitation levels can be lower than expected. It means that the pressure to resort to energy from fossil fuels is still very high especially because the processes associated with the production of traditional energy have been well-developed. Some steps have been taken toward solar energy. However, to exclude the return to fossil fuels, consideration needs to be given to green hydrogen particularly for residential and commercial sectors with their constantly increasing electricity demand, especially during daily and seasonal peaks. To date, NZ studies have been focused mainly on hydrogen technologies for transportation and industrial sectors, but no studies have been carried out for hydrogen technologies in the built environment.

Many NZ household power their appliances from electricity generated by solar panels through the government funded pilot programme. This programme is aiming to not only provide affordable energy for local communities and support decarbonisation, but also to introduce innovative technologies for public (SEANZ, 2020). On the contrary, the energy generated by solar panels and consumed by the users is not proportional. The photovoltaics - weather dependent systems – are less effective during the rainy and cloudy days and produce more energy than can be consumed during the sunny days. On both occasions, it causes overloading to the existing electricity grids. However, the same photovoltaic systems in conjunction with hydrogen technologies - hydrogen fuel cells, electrolyser and a storage - can be utilised around the year providing the public with sufficient supply to demand and affordable energy for heating and other needs. This hybrid system brings advantages to the public by reducing overloading from existing electricity grids and avoiding extra cost associated with horizontal infrastructure electrification. It is also energy-efficient and environmentally friendly.

So, the Aotearoa householders and commercial consumers may benefit from hydrogen technologies given the funding available for the introduction of new renewable energy infrastructure, advanced technologies and support from several Government’s Authorities. Also, the NZ economic growth may benefit from healthy society and a recovering environment. Transition must happen exponentially to get ahead of the climate problem we are facing.

1.3 Early implications of Hydrogen Fuel Cells technology

Hydrogen fuel cells are not a new technology. The first fuel cell was invented in 1839 by Welsh Inventor Sir William Grove who combined hydrogen and oxygen molecules to produce electricity. However, the electricity produced was not sufficient for commercial production due to technological constraints, more efforts were put into the development of large-scale electric power stations and despite the works carried out around fuel cells, the interest in them was low until the mid-20th century. The cost associated with hydrogen production was very high and remains high these days.

Since mid of 20th century, there has been a major interest in studying different types of fuel cells. Their work principles and applications have been comprehensively reviewed, described and compared in many studies. For example, Ogawa made a deep analysis of the work of Alkaline Fuel Cells, Solid Oxide Fuel Cells, Polymer Electrolyte Fuel Cells, Phosphoric Acid Fuel Cells and Molten Carbonate Fuel Cells (Ogawa, 2018). The interest in hydrogen fuel cells has gained particular interest after the first launch of spacecraft in 1958. NASA has technically progressed and gained great experience in hydrogen and hydrogen fuel cells which has met aerospace requirements to generate electricity for aerospace applications, such as high efficiency and lightweight. Hydrogen fuel cells with their clean energy have been attracting further investigations and applications.

The aerospace programme opened a door to hydrogen energy and just a decade later from the first space launch, the first hydrogen fuel cells vehicle was introduced and now we face the hydrogen fuel cells evolution in the transport industry. For example, Emirates Team New Zealand launched their first hydrogen boat in March 2022 to contribute toward a zero-emission future.

Great strides have been made in the wide application of hydrogen fuel cells in many countries around the world from small cells that can power cell phones and laptops to much larger ones that can connect electric power grids. In the USA for example, 166 hydrogen fuel cells have been operating since October 2021 using hydrogen gas with a total of 260 megawatts of electricity generation capacity (<https://www.eia.gov/>).

Hydrogen has also found implications in the industrial sector, but future direction and more work need to be done in the introduction of hydrogen technologies in the built environment (Perry & Fuller, 2002).

1.4 Research Rationale

Decarbonizing the building sector is a critical step for countries like New Zealand seeking to meet ambitious climate change targets and transition to low-emission energy systems. Buildings account for over 50% of New Zealand's total energy usage and related greenhouse gas emissions (MBIE, 2019), highlighting the need for sustainable solutions.

Green hydrogen, produced via electrolysis from renewable electricity, offers a compelling pathway as a clean fuel that can displace reliance on natural gas and other fossil fuels used in buildings (Gholami et al., 2021). Hydrogen can provide energy storage to overcome intermittency challenges with renewables and enable emissions-free utilization for thermal and electrical demands in buildings via fuel cells.

While existing hydrogen research has focused predominantly on applications in transportation and industry, potential integration in the built environment requires dedicated analysis. This includes assessing technical feasibility, costs, safety considerations, infrastructure needs, regulatory requirements, and environmental benefits specific to the building sector. An interdisciplinary perspective examining engineering, policy and economic factors is imperative.

By exploring opportunities and challenges associated with deploying green hydrogen systems across residential, commercial and public buildings, this research aims to uncover knowledge integral to national strategies for sustainable and low-carbon built environments. Findings can shape safety regulations, codes, incentives and policies to facilitate adoption.

Overall, this project seeks to provide evidence-based insights to guide government, industry and researchers in leveraging hydrogen's versatility to decarbonize New Zealand's built environment. Successfully transitioning to green hydrogen in buildings will be a pivotal step towards a greener, sustainable Aotearoa.

1.5 Research Significance

This research will have four potential benefits:

1. Economic – less reliance on imported fossil fuels. Currently, the energy industry is dominated by oil and gas on the global stage driven by the world economy. However, New Zealand is targeting to switch to a green hydrogen economy thus contributing to global decarbonisation. To reach this target, New Zealand will need to generate new workplaces since an additional workforce will be required for the production, installation and maintenance of hydrogen technologies.
2. Social – increase the quality of education required for solving the technical problems
3. Environmental and Ecological – reduce the greenhouse gases emission and carbon dioxide footprint
4. Technological – introduce innovative technologies to NZ energy market

This research addresses important problems that modern societies face. The findings of this study will potentially benefit the researcher, academic and broader communities, industry professionals, Government agencies, and the environment on a global scale:

1. The researcher will obtain extended knowledge in hydrogen technologies, become an expert in the studied area, contribute to engineering and the built environment body of knowledge and obtain a PhD Degree which in turn will open new career opportunities for the researcher.
2. The wider community will be educated about advanced hydrogen technologies and potentially benefit from reliable, environmentally friendly and affordable energy, bringing New Zealanders out of fuel poverty by adapting energy efficient practises and obtaining value from green energy in their everyday life in an environmentally friendly way.
3. A broad spectrum of career opportunities will be opened for the public.
4. The environment will benefit from a low or even zero carbon future.
5. The results of the study will contribute towards the regulatory framework formulation, provide guidance to the policy implication and future research recommendation.

1.6 Research Problem

New Zealand has set ambitious climate targets including net zero carbon emissions by 2050. However, the building sector accounts for 20% of the country's total greenhouse gas emissions, primarily due to fossil fuel usage for heating and power generation (MBIE, 2019). Reducing building-related emissions is critical for meeting national climate goals.

Existing policies and measures have not sufficiently decarbonized the sector. Renewable electricity faces intermittency challenges while electrification of heat can be costly and difficult to implement in retrofits. There is a clear need for additional solutions to displace fossil fuel use and related emissions in buildings.

Green hydrogen presents a promising option as a versatile energy carrier that can provide sustainable heat, power, and energy storage by leveraging New Zealand's renewable electricity capacity. However, research focused specifically on realizing green hydrogen's potential to enable built environment decarbonization in the New Zealand context remains limited.

The research problem is the lack of integrated analysis examining the technical, economic and policy aspects of transitioning to green hydrogen systems across residential, commercial and public buildings in New Zealand. Addressing this knowledge gap can help uncover pathways to scale up green hydrogen and accelerate emissions reductions in order to achieve a low-carbon built environment.

1.7 Research Aims

The ultimate goal of this research is to facilitate the decarbonisation of the built environment through the introduction and regulatory support of green hydrogen technologies. To achieve this, the study has the following aims:

Aim 1: To determine the viability of green hydrogen technologies in the built environment by evaluating the economic, technical, environmental, and safety aspects, and to foster broader public acceptance of these technologies.

Aim 2: To develop and propose a regulatory framework that enables the integration of green hydrogen technologies into New Zealand's commercial and residential sectors, ensuring their long-term strategic use as a sustainable energy solution.

The research will conclude by providing strategic recommendations for pilot projects, identifying regulatory trends, policies, and guidance necessary for the widespread adoption of electrolyzers, hydrogen fuel cells, and storage systems in the built environment.

1.8 Research Objectives

1. Conduct a global review of state-of-the-art hydrogen projects to identify safety standards, challenges, and opportunities, with the aim of developing public acceptance of hydrogen technologies by the end of the research period.
2. Identify and analyse the techno-economic performance of hydrogen technologies for the built environment, with the goal of maximising energy outcomes and providing measurable economic benefits, based on the outcome of the data analysis.
3. Develop a comprehensive framework to guide the introduction of hydrogen energy systems in New Zealand, ensuring alignment with social, economic, and environmental security objectives, and public well-being, to be completed by the conclusion of the research study.
4. Formulate detailed hydrogen policy recommendations for the Government, describing safety regulations, codes, and standards, to support the creation of a regulatory framework, by the end of the research, following the completion of the survey and analysis.

1.9 Research Questions

Having reviewed the literature, the following questions can be put together:

1. What specific hydrogen safety requirements need to be addressed to introduce hydrogen technologies to all New Zealand stakeholders?
2. How can hydrogen technologies contribute to decarbonisation of the built environment and how can this be measured?
3. How to accelerate the acceptance of hydrogen technologies by the public to bring New Zealanders out of fuel poverty and to achieve economic growth goals?
4. What factors may influence the Government's decision to accelerate development of new energy vectors and how to provide the Government with confidence to invest in advanced hydrogen technologies?

1.10 Hypotheses

1. New energy vectors may be accepted by the public if hydrogen safety concerns are adequately controlled
2. Transforming to the new energy model may have enough efficient capacity to meet residential and commercial energy demand while improving the environment and ecological footprint
3. A new regulatory framework with a risk-based approach may open new work opportunities and improve the NZ economy
4. The NZ Government may invest in green hydrogen technologies to provide communities with "secure, affordable and sustainable energy".

1.11 Theoretical and Practical Implications

This research will have both theoretical and practical significance, contributing to the body of knowledge on green hydrogen technologies and their role in decarbonizing the built environment. Theoretical significance refers to the advancement of academic understanding, offering insights into challenges, opportunities, and interdisciplinary approaches to hydrogen integration. Practical significance, on the other hand, encompasses the application of research findings to shape policy, modify educational frameworks, and establish safety standards. Through seminars, presentations, and training, the research outcomes will be disseminated to key stakeholders for broad adoption and practical impact.

Theoretical Implications (Anticipated):

1. This study will advance the academic discourse on decarbonizing the built environment, offering new insights into how green hydrogen technologies can be integrated to achieve carbon neutrality.
2. The research will contribute to frameworks that merge knowledge from engineering, environmental science, economics, and policy, offering a comprehensive understanding of hydrogen's role in built environment decarbonization.
3. Findings will help shape regulatory frameworks for green hydrogen technologies, identifying policy gaps and suggesting new strategies to promote its integration into the built environment.

Practical Implications (Anticipated):

1. The research will provide key insights into the technological and infrastructural advancements needed to deploy green hydrogen technologies at scale, offering best practices for system integration.
2. Stakeholders will gain practical guidance on the economic and environmental benefits of adopting green hydrogen solutions, helping to drive investment decisions and policy development.

3. The research will help identify market opportunities, business models, and the financial incentives required to promote green hydrogen adoption.
4. Practical insights will be offered to urban planners and developers for creating energy-efficient, low-carbon infrastructure using hydrogen technologies.
5. The study will evaluate the reductions in greenhouse gases and pollutants through green hydrogen use, offering guidance on its role in climate change mitigation and public health improvement.

1.12 Research Limitations and Assumptions

Limitations represent certain characteristics of the research methodology and design which may influence the research outcomes. To properly interpret the research findings, the following limitations have been identified. The sample size might be insufficient for qualitative and quantitative data collection. The bias of responders, reliability, and adequacy of data obtained, and information collected may not apply in the New Zealand context. The validity of qualitative data obtained from participants during the interviews is subjective as to accuracy. The reliability and consistency of quantitative data received from participants during the survey is subject to interpretation and understanding of the questions. A triangulation approach will assist to check validity and reliability by comparing qualitative data against quantitative data. There is an assumption that contradiction of the findings may occur during the comparison which means that further investigations may be required (Lacey & Luff, 2007).

To ensure that snowball method will not make the research result susceptible to bias, the researcher will diversify the ‘seed’ contacts by deliberately selecting the initial participants and encouraging them to recommend the participation in the research to more than just their closest acquaintances. The ‘seed’ contacts will be properly selected by approaching individuals who are located in different countries, work for different organisations and occupy different hierarchical positions. This method of deliberative participants selection will minimise the bias-associated concerns.

The researcher assumes that the participants will respond accurately, honestly, truthfully and bias-free during the interview and survey phases. This can be achieved by ensuring the participants’ anonymity, confidentiality and voluntary participation in the study, thus maintaining a high level of honesty and truthfulness (Simon, 2011). To avoid bias in the participants’ responses, the researcher will ensure that the language is chosen appropriately and there is no inherent bias in the questions.

Research Aims	Research Objectives	Research Questions	Research Hypotheses
Aim 1 - Identify, analyse and discuss economic, technical, environmental and safety parameters of hydrogen technologies in order to decarbonise the built environment and develop public acceptance	Conduct a global review of state-of-the-art hydrogen projects to identify safety standards, challenges, and opportunities, with the aim of developing public acceptance of hydrogen technologies by the end of the research period.	What specific hydrogen safety requirements need to be addressed to introduce hydrogen technologies to all New Zealand stakeholders?	New energy vectors may be accepted by the public if hydrogen safety concerns are adequately controlled
	Identify and analyse the techno-economic performance of hydrogen technologies for the built environment, with the goal of maximising energy outcomes and providing measurable economic benefits, based on the outcome of the data analysis.	How can hydrogen technologies contribute to decarbonisation of the built environment and how can this be measured?	Transforming to the new energy model may have enough efficient capacity to meet residential and commercial energy demand while improving the environment and ecological footprint

Aim 2 - Develop a regulatory framework for the introduction of green hydrogen technologies into commercial and residential sectors as a new long-term strategic energy opportunity for New Zealand	Develop a comprehensive framework to guide the introduction of hydrogen energy systems in New Zealand, ensuring alignment with social, economic, and environmental security objectives, and public well-being, to be completed by the conclusion of the research study.	How to accelerate the hydrogen technologies acceptance by the public to bring the New Zealanders out of fuel poverty and to achieve the economic growth goals?	New regulatory framework with risk-based approach may open new work opportunities and improve the NZ economy
	Formulate detailed hydrogen policy recommendations for the Government, describing safety regulations, codes, and standards, to support the creation of a regulatory framework, by the end of the research, following the completion of the survey and analysis.	What factors may influence the Government's decision to accelerate development of new energy vectors and how to provide the Government with a confidence to invest to advanced hydrogen technologies?	The NZ Government may invest in green hydrogen technologies to provide communities with "secure, affordable and sustainable energy"

Table 1: Research Framework: Hydrogen Technologies for Decarbonizing the Built Environment

1.13 Research Timeframe

Activity	Timing
Initial literature review	July - October 2022
Developing ethics application	November 2022 – January 2023
Ethics approval	February 2023
PGR9	March 2023
Interviews with the industry professionals	April 2023 – June 2023
Data collection, processing and analysis and survey preparation (NVivo)	June 2023 – August 2023
Ethics Approval for Survey	September 2023
Survey	October 2023 – December 2023
Data analysis and interpretation	January 2024
Thesis writing	February 2024 - May 2024
- Rough draft	February 2024 - March 2024
- Polished draft	March 2024 – April 2024
- Thesis submission	May 2024
The implication of the results	May 2024
Policy recommendation	May 2024
Summary	May 2024
Thesis defence	September 2024

Table 2: Research Timeline

1.14 Synopsis

Chapter 1 (Introduction)

Chapter 2 (Literature Review)

Chapter 3 (Theoretical Framework)

Chapter 4 (Semi-Structured Exploratory Interviews and Literature Review: Report of Findings)

Chapter 5 (Integrating Interview Insights and Literature Review)

Chapter 6 (Survey - Findings)

Chapter 6 (Validation of Key Research Findings)

Chapter 7 (Observations, Data Validation, Discussion and Recommendation)

Chapter 8 (Synthesis of Findings)

Chapter 9 (Conclusions and Recommendations)

1.15 Conclusion

Chapter One has laid a robust foundation for this research, meticulously setting the stage by emphasizing the criticality of decarbonization and achieving net-zero greenhouse gas emissions, aligning with New Zealand's strategic goals. The chapter adeptly highlights the pivotal role green hydrogen technologies can play in transitioning towards a sustainable, low-carbon built environment. It underlines the pressing need to address the energy demand of buildings, a major contributor to greenhouse gas emissions. The research problem is clearly identified: the lack of integrated analysis on transitioning to green hydrogen systems within the built environment. Aimed at resolving this gap, the chapter outlines research objectives, questions, and hypotheses, providing a structured roadmap for the exploration ahead. The theoretical and practical implications underscore the potential contributions of this study to both academic understanding and practical advancements. Acknowledging certain limitations and assumptions, the chapter concludes by affirming the significance of this research in guiding New Zealand towards a sustainable, hydrogen-powered future for its built environment. The subsequent chapter will delve into a comprehensive literature review, critically evaluating the current state of affairs, and utilizing these insights to formulate precise research questions, objectives, and aims.

Chapter 2 - Literature Review

2.1 Introduction

Chapter Two provides an extensive review of critical themes concerning energy, population growth, and sustainability. Beginning with an exploration of the literature landscape, it navigates through the intricate relationship between population growth and escalating energy demands. The chapter delves into the vast spectrum of energy sources, spanning from non-renewable to renewable, emphasizing the safety concerns inherent in their utilization. With a strategic lens, it investigates the transition towards hydrogen, integrating fuel cells and hybrid systems, aiming at enhanced energy efficiency and a balance between economic growth and environmental preservation. Regulatory frameworks and socio-economic concerns, particularly New Zealand's fuel poverty, are also intricately examined to lay a comprehensive foundation for informed deliberations.

2.2 Population Growth and Energy Demand Growth

The energy demand increase is influenced by many factors among which are the energy price fluctuation, economic growth, gross domestic product growth, social development, and population growth (Electricity in NZ, 2018). The global population growth mainly caused by high fertility rate, increased world life expectancy and human longevity (Robine, 2004; Cleland, 2013). The population growth in turn creates the energy demand increase per capita especially in the developed and transitional countries where the gross domestic product per capita is high, and it is expected that this trend will continue to grow (Sheffield, 1999). The global population increased from 2.5 billion in 1950 to 7.9 billion in 2020 and it is projected that the number of people will reach approximately 10.0 billion in 2050 (Hussain, 2018; Lutz, 1997).

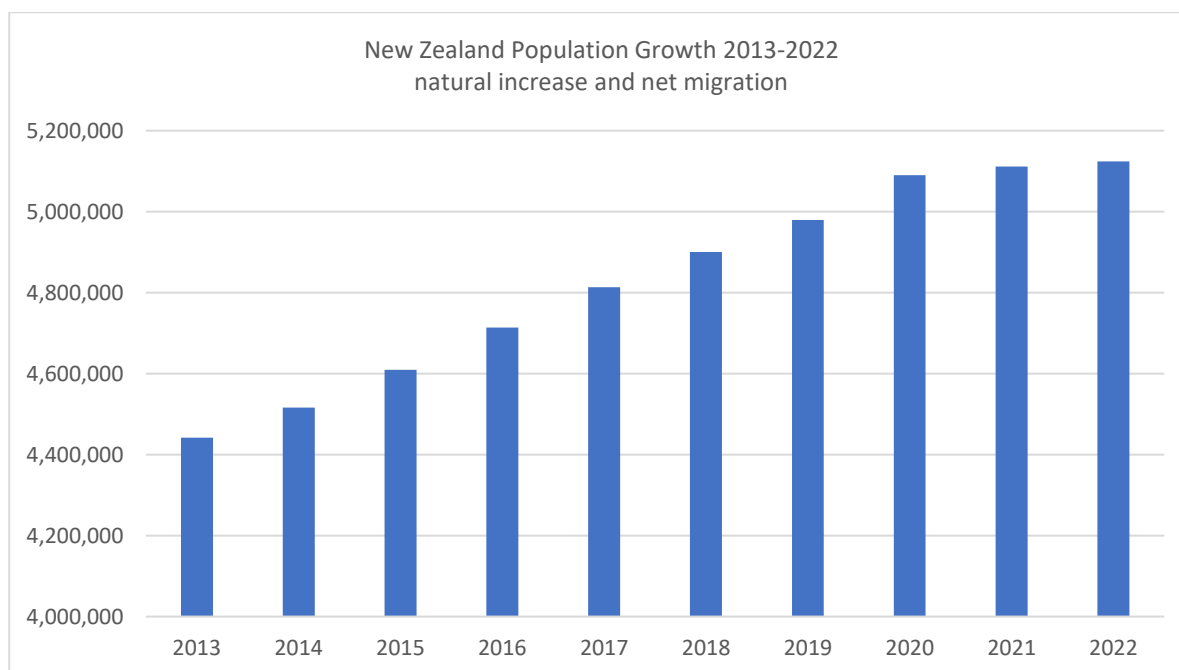


Figure 1: NZ population growth from 2013 to 2022 (Source: Chart prepared based on national population statistics published by Stats NZ on 16th August 2022 www.stats.govt.nz)

According to the data provided by the United Nations Population Division, New Zealand does not have the highest population rate comparing to the rest of the world and ranks number 126 which is equivalent to only 0.06% of the total world population (UN Statistics Division). However, NZ

population continues to grow steadily as it shown in Figure 1. The latest population estimate for New Zealand, as of September 30, 2023, stands at approximately 5,269,200 residents (www.stats.govt.nz).

NZ population has now more than doubled since the mid-20th century growing from 1.9 million in 1950 to 5 million in 2020. Since 1990, NZ population has steady growth at 1.2% per annum and it is projected that the population will continue to increase from 2023 to 2073 as can be seen in Figure 2 (Poot, 2011; Elliot, 2012). Generally, two main streams contribute to NZ population growth - natural increase and net migration. The birth rate is higher than the death rate and the immigrant stream is higher than the number of people leaving the country. However, during the unprecedented COVID-19 borders closure, the migrant arrivals decreased significantly by 40% while migrant departure increased by 3% (www.stats.govt.nz). Nevertheless, the index shows that overall NZ population growth has an increasing trend.

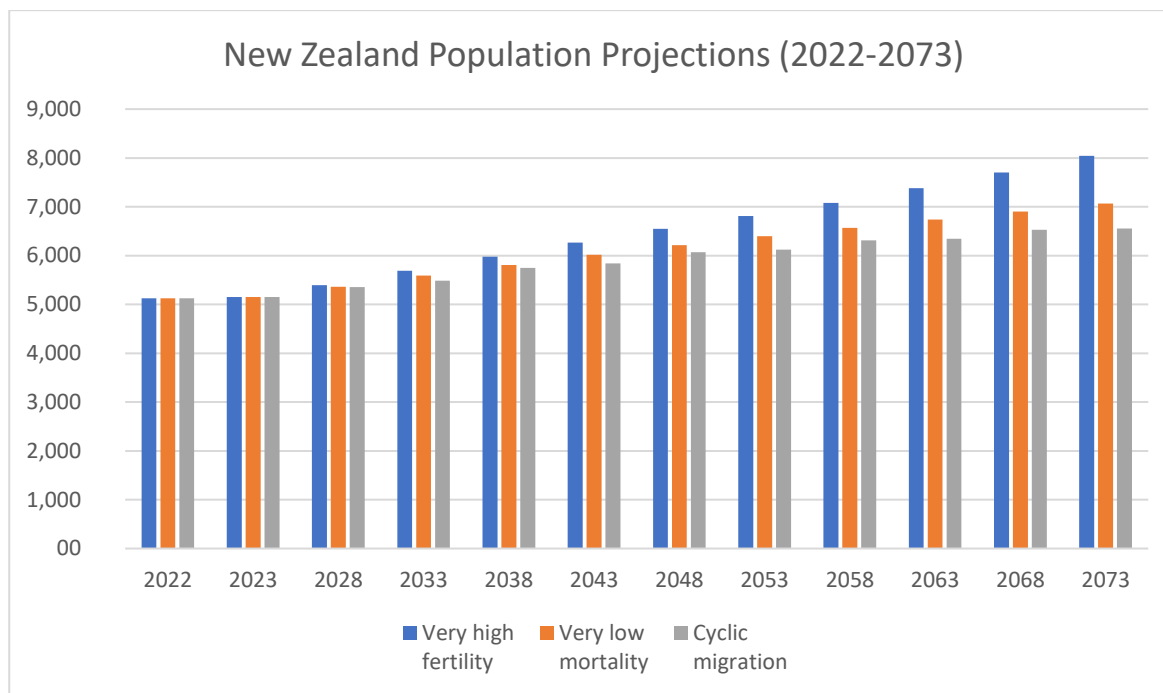


Figure 2: NZ population projection (Chart prepared based on national population projections statistics published by Stats NZ on 27th July 2022 www.stats.govt.nz)

The same growing pattern can be seen in Figure 3 which identifies a strong correlation between the population growth and domestic electricity consumption growth.

Since population growth is the main contributing factor to residential energy consumption, the steady trend can indicate that energy demand will increase proportionally to population growth (Elliot, 2012). Based on NZ population projections where population variables correlated to electricity consumption, a linear energy consumption model may forecast the increase in energy demand in the long term (Mohamed & Bodger, 2005).

Constantly growing population, constantly produce and consume more energy to meet their needs thus creating environmental problems (Dincer, 1999). The interdependence between population, energy and economic growth unfortunately leads to environmental degradation, increase in fossil fuel consumption and carbon dioxide emissions (Ozcan, 2020). The emissions contributed by the energy sector increased from 23.9 million tonnes in 1990 to 31.5 million tonnes of carbon dioxide equivalent in 2020 (Ministry for the Environment, 2022). Thus, the overall uptrend can be drawn as the following: the environmental degradation is caused by population and economy growth, increased energy consumption, fossil fuels and CO₂ emission.

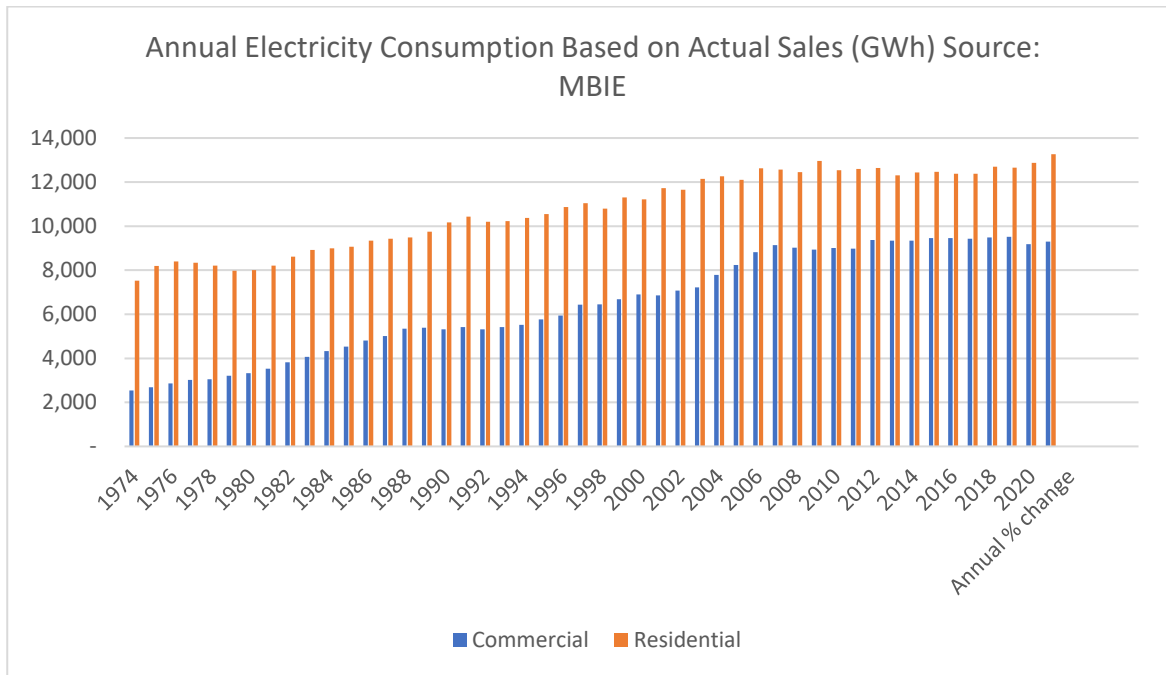


Figure 3: Annual electricity consumption in GWh from 1974 to 2020 (Source: Chart prepared based on MBIE Energy Statistics [Energy in New Zealand | Ministry of Business, Innovation & Employment \(mbie.govt.nz\)](https://www.mbie.govt.nz/energy-in-new-zealand))

It means that dynamic growth of both - population and energy – will impact the increase of carbon footprint and continue to increase global warming. While it is against humanity to control the population growth, the ecological footprint can and must be controlled through effective government policies, transitioning back to renewable energy and improving energy efficiency in the short term while improving the environmental and life quality in the long term (Khan, 2021).

On the other hand, Yunez-Cano suggests that transition to renewable energy and hydrogen in particular can contribute to reduction of fossil fuel dependency and pollution emissions. It can change the uptrend direction. In other words, the interdependence between population, energy and economic growth will continue go up, while consumption of fossil fuels and pollution emissions will go down (Yunez-Cano, 2016).

It has been estimated that if the growing population will continue to rely on fossil fuels to meet the energy demand, it will continue increase the temperature on the Earth. However, if fossil fuels will be replaced by green hydrogen, the overall trend will be reversed and the temperature will be stabilised (Veziroglu, 1989).

Sheffield in his study measures the energy value per capita and analyses the interconnection between population growth due to high fertility rates and energy demand growth. He projects that fossil resources will meet energy demand; however, due to global-warming concerns, Sheffield recommends restricting usage of fossil fuel and increasing carbon sequestration. Also, he suggests increasing usage of sustainable renewable energy sources to replace fossil fuels and increase energy efficiency “*to minimise energy demand*”. According to Sheffield, one of the possible solutions to meet energy demand is to introduce hydrogen energy via hydrogen fuel cells for “*static and mobile applications*” (Sheffield, 1999, p. 379). Thus, a strong interrelation between population growth, energy demand growth and environmental degradation has been identified; however, do all energy sources contribute to global greenhouse gases and carbon dioxide emissions? Is there an energy source that may solve a pressing problem?

2.3 Energy Sources

Primarily, global energy comes from fuels – conventional and alternative – liquids, solids and gases. All fuels can be classified as three major groups of energy sources – fossil, renewable and nuclear (Forsberg, 2009). Nuclear and fossil fuels can be categorised as conventional fuels. While nuclear fuels generate energy through the chain reaction of fission, fossil fuels generate energy via process of combustion releasing the carbon dioxide into the atmosphere. Oil, coal and natural gas are three main fossil fuels and the world's dominant energy resources (Dincer & Zamfirescu, 2011).

According to the world statistics, 84.3% of world energy comes from fossil fuels while only 16% comes from nuclear and renewable energy including solar, wind, biofuels and hydropower.

Last year, 33.1%, 27% and 24.3% of global energy came from oil, coal and gas, respectively. The energy produced through burning of fossil fuels, contributed $\frac{3}{4}$ of global greenhouse gases emissions and increased level of CO₂ emissions in the last decade (Ritchie & Roser, 2021). The most effective ways of reducing greenhouse gases and carbon dioxide emissions are improvement of energy efficiency and transitioning to a hydrogen strategy which will be discussed later. But now let us look at NZ energy sources and what they bring to the New Zealanders.

Similar to the rest of the world, New Zealand has been heavily dependent on fossil fuels especially oil. However, in contrast to the global energy map, the second source of energy in NZ is hydropower followed by gas, coal, renewables and wind. Solar is one of the major renewable energy sources, but still contributes only around 3% to the global energy sector and approximately 1% in the generation of energy in NZ.

Noticeably, in mid-20th century, NZ energy was 100% green with 94% of hydro energy and 6% of geothermal. The NZ power infrastructure was built with a capacity to meet energy demand of less than 2 million people. However, in the beginning of the 21st century, the population has increased significantly and the carrying power capacity of national power grids could not meet the constantly increasing energy demand. That is when the fossils have become dominant fuels contributing to global warming and climate change ever since (Nair & Zhang, 2009).

2.4 Non-Renewable Sources of Energy

Almost two thirds of NZ's energy consumption originates from non-renewable sources of energy, being oil, gas and coal (Walmsley et al., 2018). In spite of their limited availability, oil and gas remain the main sources of energy in NZ and also the main contributing sources of greenhouse gas, toxic and polluting emissions. Energy extraction from burning fossil fuels contributes to sulfur dioxide and nitrogen oxides being released, driving climate change and creating harm to both the environment and our health. Coal mining alone contributes toward respiratory diseases such as pneumoconiosis, silicosis, lung cancer and tuberculosis (Perret, 2020; Hendryx et al., 2020). Furthermore, coal extraction pollutes surface and groundwater systems increasing their toxic metal content (Ali, 2017). Considering the dramatic outcomes associated with fossil fuel extraction, the NZ Government has banned new extraction of gas, oil and coal and have ceased granting licences and permits for any new fossil fuel exploration (Lazarus et al., 2018). Although some argue that a new ban will have an insignificant direct impact on emissions reduction, the detrimental impact on the NZ economy could be NZ\$40 billion by mid this century. It can be rationalised that extracted fossil fuels have been exported and burned overseas. The ban will result in a reduction of fossil fuels which will affect the NZ economy, while the burned fossil fuels will continue to pollute the atmosphere, albeit not in New Zealand but globally. Nevertheless, the ban will facilitate advancement of renewable sources of energy and cutting-edge technologies to produce electricity. It can be assumed that hydrogen and

hydrogen technologies would be a reasonable alternative to reform the fossil fuel economy (NZ Parliament, 2018).

2.5 Nuclear Power

Nuclear power is considered as non-renewable yet recyclable and sustainable energy. Many countries accepted nuclear power as a source of emissions-free electricity due to its low level of emissions. On the one hand, it offers an alternative source of clean energy, but on the other hand, it associates with catastrophes and disasters (Brain, 2000). There is a public concern around potential nuclear power accidents, as associated with the tragic events that occurred at the Chernobyl nuclear reactor in Ukraine in 1986, and at the Fukushima Daiichi nuclear power plant in Japan in 2011. Nevertheless, the UN report ‘Chernobyl Panel’ has shown that the nuclear accident at Chernobyl caused 59 total deaths to date, nine of which could have been avoided. In contrast, the oil industry has caused 10,273 deaths in less than a quarter century in the period from 1970 to 1992 (Smith, 2008).

Nuclear power is banned in NZ under the New Zealand Nuclear Free Zone, Disarmament, and Arms Control Act 1987. However, Smith argues that nuclear power should be considered as a main energy source for NZ because nuclear power is one of the safest and environmentally friendly energies. According to Smith, radioactive elements can be found in NZ rocks and soil which are used for industrial purposes, while radioactive isotopes are widely utilised in NZ medical institutions. Nuclear waste, after finishing its lifecycle, is stored in the Christchurch nuclear waste dump, so NZ is not as “nuclear free” as it would seem. Smith brings to the discussion that Australia, as well as NZ, are also a part of the 1985 South Pacific Nuclear Free Zone Treaty but nevertheless Australia produces medical isotopes utilised by NZ medical institutions. He criticises a law banning nuclear ships approaching NZ territorial waters, testifying that it has been an error of judgment. He condemns NZ in that they “would be foolish” if they will not adopt energy technologies that have both economic and environmental reliability (Smith, 2008).

Nonetheless, nuclear power cannot be considered as an energy option for NZ. Even though “clean power” does not produce as much carbon as fossil fuels while producing the highest energy efficiency compared to other sources of energy, Capex of a nuclear plant is very high. The safety aspect is an issue for both people and environment due to the risk of potential explosion and high-level of nuclear waste (McLeish, 2008; Cvetkovic, 2021).

Considering Smith’s statement about the adoption of the economically and environmentally reliable energy, hydrogen falls under this category.

2.6 Renewable Sources of Energy

2.6.1 Hydropower

Even though hydropower has been one of the main renewable energy sources in NZ for many decades, it remains an unreliable source of energy due to unpredictable dry seasons which may lead to energy shortages during the dry years and small-scale hydro power plants with limited reservoirs (Suomalainen, 2015). The crisis situation associated with drought anomalies may require resorting to oil and gas in short term, but it is not a desirable outcome due to the targeted objectives of the net zero emissions strategy. Assuming that NZ will continue to use local gas, the local gas capacity will not be sufficient to meet the NZ energy demand. In the worst-case scenario when multiple dry seasons result in prolonged dry years, NZ will be forced to import oil, gas and coal to cover the energy shortage thus compromising the environmental concern and low electricity tariffs for the public. In case NZ experience a reoccurrence of the power crisis happening in 1992 and 2021, the electricity

consumers will face power restrictions if renewable and reliable sources of energy will not be introduced to the public (Electricity Supply & Demand, 2015).

Apart from the climatic challenges relating to dry years, hydropower faces several other obstacles against wider development, including the typically geographically remote location of hydro power stations in relation to target customers. For example, the biggest hydroelectric plant, Manapōuri, is located in the South Island while the main electricity consumers are in the North Island. The generated electricity must be delivered to the end user via under ocean high voltage DC cables which require sufficient funds for the development, operation and maintenance of the horizontal hydropower infrastructure. That said, the availability of hydroelectricity during dry seasons still remains the main challenge of hydropower (Kelly, 2011).

2.6.2 Geothermal Energy

Another source of renewable energy utilised in NZ is geothermal power, which in contrast to hydro, wind and solar power does not depend on weather conditions since it is extracted from the earth in the form of heat, hot water and steam. Reliable geothermal energy is a direct source for electricity generation and heat application in both residential and industrial sectors. The first NZ geothermal plant, Wairakei, was built in 1958 and was the second geothermal plant in the world. Since then, several other plants have been put into operation; however, the overall contribution of geothermal energy into the total NZ energy market is only 17%.

Even though there is potential for geothermal energy development, the government rigorously restricted uncontrolled geothermal energy extraction. The almost unregulated extraction in the mid-80s largely led to drying up of geysers and hot springs, which were the main attractions for tourists. Unfortunately, geothermal energy development at Orakeikorako region, for example, has been negatively affected by the development of hydroelectric plants in proximity to the geothermal sources which has caused thermal quenching in geysers and flooding of hot springs. It also has led to land subsidence due to underground water withdrawal. As a consequence of these environmental degradations, geothermal energy extraction has been reduced by almost three times (Kelly, 2011). Finally, “as a matter of national importance”, any further geothermal energy development cannot proceed without consultation with Māori communities due to their natural resource management rights and “cultural and spiritual values” associated with water and land in order to avoid any potential conflicts (Tutua-Nathan, 1988, p.287-289).

2.6.3 Wind Energy

In contrast to nuclear power, the NZ public has been more positive and receptive to wind power. Nevertheless, the introduction of wind turbines is not supported widely by the communities. As one of the case studies show, the NZ public accept wind power as an alternative source of energy, but they oppose it when it comes to the specific development of wind farms (Graham, 2009).

Geographical location, natural conditions and exposure to winds from the ocean have created prerequisites for wind power in New Zealand. Compared to other countries, NZ has one of the highest capacity factors to produce this energy. However, despite the high capacity, wind power growth is slow due to many factors including protection of natural landscapes, cultural heritage and Maori interests. Apart from this, wind farms may have adverse ecological and environmental effects. For example, many people have raised their concerns that construction of large-scale wind turbines may negatively impact the landscape, farms, nature and ecosystem. While overall, wind energy produced via wind farms may technically meet energy demand and facilitate the zero emissions targets, the public opposition will inhibit the construction of large-scale wind turbines in NZ (Graham, 2009).

Although, large- and small-scale wind turbines have not met local support, micro-generation has been met more positively and potentially can be utilised for hydrogen production (Zhang, 2022).

2.6.4 Solar Energy

To encourage and stimulate usage of solar energy, the Governments of some countries pay solar energy consumers for the electricity excess produced by their private PV cells and back feeding the grid. However, the customers who are located off-grid and only have seasonal energy excess, may face energy shortages during unsuitable seasonal production of solar energy. Sheffield, with the reference to Johansson and Socolow, assumes that solar energy may cover all global energy needs and there is a high possibility to use solar seasonal excess energy for hydrogen production which can be used later during the seasonal patterns (Sheffield, 1999).

Solar energy in NZ is used for residential and commercial buildings for water-heating systems and photovoltaic technologies to convert sunlight into electricity. While PV cells use renewable energy and are environmentally friendly, they still have disadvantages such as capital cost. However, the main drawback of solar energy is its unreliability and high weather dependency to generate power (Kuwahara, 2022). Generation production is greater in summer and significantly reduced in winter. On average, NZ households consume around 22 kWh per day. To produce this amount of electricity, PV panels are able to convert around 15% of available 4 kWh of raw solar energy per day per m² of PV cells. It has been estimated that this meets daily electricity demand under certain weather conditions (Meduna, 2006). While this energy is sufficient to cover spring and autumn daily electricity patterns, and even the energy surplus can be generated for hydrogen production for example, there is still demand for more energy in winter seasons. To meet the seasonal energy demand either the size of PV cells or a number of cells must be increased (Leva, 2009). However, many NZ buildings will not be able to accommodate the additional number of PV cells due to the limited roofs area.

That is where an energy produced from a hybrid system – combination of PV cells, electrolyser, Hydrogen Fuel Cells and storage will help to meet the energy demand requirements while responding gently to the environment and increasing energy efficiency in residential and commercial buildings on a pair with the Government’s vision for “affordable, secure and sustainable energy system that provide for New Zealanders’ wellbeing in a low emission world” (MBIE, 2022).

2.6.5 Hydrogen

Hydrogen is not available in elemental form, but it can be produced in various methods from both – fossil and renewables (Dufour et al., 2012; Navarro et al., 2007; Acar & Dincer, 2014). There are 24 ways of sustainable hydrogen production that have been counted to date (Dincer & Zamfirescu, 2012; Turner, J). Green hydrogen can be obtained from water (via electrolysis, thermolysis and photolysis); biomass (via gasification and pyrolysis); black, grey and brown hydrogen are produced from fossil fuels (via natural gas oxidation, coal gasification and methane steam reforming) and even from municipal waste (Dincer & Zamfirescu, 2012; Hosseini & Wahid, 2016; Ourya & Abderafi, 2022;).

The method of production of hydrogen from natural gas is called steam methane reforming and it produces more than 95% of today’s hydrogen (Maestre, 2021). Natural gas – methane - processed with high temperatures produces hydrogen and either carbon dioxide which can be “pumped into saline aquifers” at least 1km below the ocean bed, or solid black carbon which can be utilised for rubber applications and in metallurgical and auto industry (Socolow, 1997; Abbas & Daud, 2010). Thus, natural gas after some chemical processes becomes clean energy without CO₂ emissions released into the atmosphere. Carbon capturing minimises CO₂ emissions thus creating blue

hydrogen. While, the distribution of black carbon partially returns the cost of hydrogen production, the sequestration of methane may have a detrimental effect on the environment (Gaudernack, 1998). However, hydrogen produced from fuels is not considered as green and must not be adopted by NZ (MBIE, 2020).

Another way to generate hydrogen is by electrolysis of fresh and even seawater, with application of renewable energy, either solar or wind which is an environmentally friendly solution (Chi & Yu, 2018). Hydrogen generated by methane decomposition and from water electrolysis can be used for hydrogen fuel cells. However, green hydrogen produced from water does not release CO₂ into the atmosphere, completes the water cycle and is the clearest option for hydrogen fuel cells. Furthermore, the possibility to use seawater instead of fresh water does not go against three waters reform vision. Besides, hydrogen produced and stored in-situ can help to meet seasonal electricity demand while decentralising energy systems and supplying energy for remote locations.

The main hydrogen classifications based on source of energy required for hydrogen production is presented in the table below.

Hydrogen classifications based on production and sources of energy		
Hydrogen Classification based on source of energy required to produce Hydrogen	Source of Energy Required for Hydrogen Production	Hydrogen classification based on carbon intensity
Black Hydrogen	Bituminous Coal	High Carbon Hydrogen
Grey Hydrogen	Natural Gas or Methane	
Brown Hydrogen	Brown Coal (Lignite)	
Blue Hydrogen	Natural Gas or Methane with Carbon Capture and Storage	Low Carbon Hydrogen
Green Hydrogen	Electrolysis powered by renewable energy	
Pink Hydrogen	Electrolysis powered by nuclear energy	

Table 3: Hydrogen classifications based on production and sources of energy. Source: Greening the grid <https://www.nrel.gov/docs/fy22osti/82554.pdf> (www.greeningthegrid.org)

Thus, this paper will focus on energy produced from green hydrogen since this energy starts and finishes with water, environmentally friendly, sustainable and aligns with water reform. However, safety concern is a main challenge associated with hydrogen production, storage and utilization.

2.7 Safety Concerns

Safety, in some studies, has been considered as a challenge that can be outcome with proper controls in place (Srisiriwat & Pirom, 2017). A concern associated with hydrogen safety based on the tragic historical events. Hydrogen combustibility and flammability caused the catastrophe of Hindenburg airship on 6th May 1937 when 35 people were killed (Waibel, 2013).

Due to hydrogen chemical characteristics such as odourless, colourless, “*low explosive limits*”, leaked gas may lead to explosion hazards (Najjar, 2013, p. 10724).

Hydrogen has a significantly higher flame velocity level and greater flammability range compared to other gases, and it can burn at a higher temperature than natural gas (Sanchez & Williams, 2014).

This means that due to these combustion characteristics, the engineers may face challenges in the application, optimisation and accommodation of hydrogen in the built environment.

Ng & Lee in their study recommend resolving all hazards and safety associated issues prior to achieving public acceptance. Nevertheless, they recognise that currently the explosive situations can be controlled with proper safety measurements including proper ventilation and avoiding contamination of hydrogen storages (Ng & Lee, 2008). Ventilation optimisation is also supported by MacIntyre who recommends analysing risks and optimizing design for achieving hydrogen safety (MacIntyre, 2007). Najjar in turn suggests that the sensor detectors must be used to identify the leakage and eliminate the hazard in order to deploy a hydrogen economy. He also listed several causes which may lead to the unwanted hazardous events one of which is human error. However, the catastrophic events can be prevented once hydrogen properties and well-understood and safety regulations are established (Najjar, 2013). It has been also advised that previous accidents must be properly investigated to avoid reoccurrence in the future (MacIntyre, 2007).

On the other hand, hydrogen is a non-toxic gas, and the risk of CO poisoning is zero. Hydrogen has been used in the industrial sector for many decades already, and special safety requirements have been set up. Residential and commercial sectors also can establish a set of regulations and standards once hydrogen is introduced to them.

In many countries, hydrogen safety programmes have already been initiated. For example, Canada established a set of policies, regulation and guidelines to protect the Canadian hydrogen communities (MacIntyre, 2007). Australia also contributed to a hydrogen safety strategy by introducing a Hydrogen Safety Code of Practice in 2022. Having said that, New Zealand can adopt the international standards and develop safety regulations to introduce hydrogen technologies to all New Zealand stakeholders as a part of the decarbonisation strategy.

Thus, the **first objective** of this thesis can be outlined as the following:

Objective 1:

Conduct a global review of state-of-the-art hydrogen projects to identify safety standards, challenges, and opportunities, with the aim of developing public acceptance of hydrogen technologies by the end of the research period.

The discussion around safety could help to formulate the **first research question**:

Question 1:

What specific hydrogen safety requirements need to be addressed to introduce hydrogen technologies to all New Zealand stakeholders?

2.8 Transition to Hydrogen Strategy

Decarbonisation is a long-term goal aiming at creating a carbon free era, where hydrogen strategy plays the main role. The future prospect for hydrogen is to be integrated into a global economy and become the main energy vector in industrial, manufacturing, transportation and buildings sectors. To reduce carbon dioxide emissions associated with production and consumption of fossil, fossil fuels must go through decarbonisation - a process of separating the energy from “the carbon content of fuels” by transformation of the primary fuels into the secondary ones (Socolow, 1997, p. 12).

While there have been many debates related to decarbonisation in Europe and NZ, the first steps towards a zero-carbon future have been made in Asia, Japan, Korea and the USA where hydrogen and hydrogen fuel cells found strong support and have been commercialised.

Dodds criticises the European countries for being focused on a limited “range of technological options” and neglecting hydrogen and hydrogen fuel cells. In his study, he argues that the countries with already well-developed gas infrastructure have done little or no examination for hydrogen fuel cells. He strongly recommends analysing hydrogen and hydrogen fuel cells technologies for policymakers to contribute to a zero-carbon future (Dodds, 2015, p. 2065).

The idea of a hydrogen energy strategy is greatly supported by Socolow who discusses multiple benefits from switching to a hydrogen world economy. He emphasises the significance of hydrogen as a fuel for hydrogen fuel cells is not only to replace the fossil fuels but also to reduce carbon dioxide thus assisting in the fight that is the climate crisis (Socolow, 1997). Johansson also supports the hydrogen strategy projecting that transitioning to hydrogen from fossil fuels will reduce to 75 percent of global carbon dioxide by 2050 (Johansson, 1993).

The significance of transitioning to “reliable, environmentally friendly and affordable energy” is strongly supported by Yunez-Cano and other authors who believe that a hydrogen strategy is the way to decarbonisation. In their study, the authors suggest that hydrogen technologies have a significant impact on fossil fuels and pollution emission reduction. They recommend reconsidering current energy supply chain from energy production to energy consumption (Yunez-Cano, 2016, p. 19539). Najjar believes that being “an ideal fuel”, hydrogen with its properties - cleanliness, energy-efficiency and convenience - will facilitate the hydrogen economy to gain “independency from foreign control” (Najjar, 2013, p. 10717).

2.9 Hydrogen Fuel Cells and Hybrid Systems

Hydrogen fuel cells are energy-reliable systems that can be used in facilities such as hospitals where the electrical supply and heat are critical and needs to be constant and uninterrupted (Mat Isa, 2016). They can also be used in remote off-grid locations (Gracia, 2018). Hydrogen fuel cells do not need to be recharged and can operate as long as hydrogen is supplied; they do not self-discharge, are noiseless in operation, do not contain toxic components, are highly energy-efficient due to the ability produce combined heat and power (Verbecke & Vesey, 2013). Hydrogen fuel cells produce electricity by converting hydrogen into energy namely converting chemical energy into electrical energy. The clean energy produced by hydrogen does not contaminate the environment due to the electricity production through chemistry rather than combustion and has higher efficiency compared to the traditional source of energy. Hydrogen fuel cells are quiet in operation because there are no movable parts, are durable and have low-to-zero emissions because hydrogen is derived from renewable sources of energy and emit only water vapour (<https://www.fchea.org/fuelcells>). The importance of hydrogen and hydrogen fuel cells for “better environment and sustainability” has been emphasised by Dincer (Dincer, 2006).

A considerable amount of literature has been published recently in relation to green hydrogen energy for the industrial sector and hydrogen fuel cells in the transportation sector in particular for heavy vehicles. In a wide spectrum, hydrogen is used in chemical, agricultural, metallurgical and aerospace industries where clean combustion is required due to the flammable characteristics of hydrogen. An industrial application of hydrogen has been broadly described by Ramachandran & Menon who recognise that implications of hydrogen fuel cells in the built environment are just in progress and there has been relatively little literature published about hydrogen fuel cells (Ramachandran & Menon, 1998). This view is supported by Tsay who also acknowledges that the industrial sector focuses on hydrogen as a source of heat and power while the built environment is still to be investigated for their hydrogen fuel cells adoption (Tsay, 2003).

Several studies have considered the application of hybrid hydrogen system for off-grid households to decentralise power dependency and gain more autonomy. For example, Knosala discusses hydrogen

fuel cells' energy and economic benefits in remote locations to uncover self-sufficient building energy potential. He raises the safety concerns associated with hydrogen storage and emphasises the necessity of controlling systems. However, neither safety measures nor monitoring systems have been included in the study (Knosala, 2021).

Ghenai and Bettayeb are very positive about this hybrid power system – a combination of photovoltaic and hydrogen fuel cells. This is evidenced by their study where they evaluated a photovoltaic / hydrogen fuel cells / battery / generator hybrid power system in a commercial building (Administration building at the University of Sharjah, UAE) as an alternative to a diesel generator. They discussed the technical, economic and energy performance of the hybrid system; however, safety control measures, design and environmental benefits have not been carried out during this research either (Ghenai and Bettayeb, 2017).

It has been demonstrated that hybrid technologies can be applied in residential projects. The first sustainable pilot project Phi Suea House development in Chiang Mai, Thailand has been powered by a hybrid system of photovoltaic and fuel cells. The system consists of several components - photovoltaic panels, electrolyser, hydrogen energy storage and a battery.

During the daytime, the solar panels generate the electricity required for electrolyser splitting hydrogen and oxygen from purified rainwater or seawater. The DC voltage from photovoltaic cells is used for electrolysis. While dry and pure hydrogen produced on-site under 35 bar pressure via an anion exchange membrane electrolyser is stored in a tank and does not have an expiration date, oxygen is released in the air. At night, cloudy or rainy days solar energy cannot be used and that is when a converter converts hydrogen into electricity.

The main feature of an anion exchange membrane electrolyser is a lower cost due to the semipermeable membrane produced from steel. It makes anion exchange membrane a more affordable system compared to the proton exchange membrane which is made up of titanium. The average daily power production is 326.8kWh (Cowan, 2016; Dissara, 2020). That would be sufficient to cover the electricity needs of one average New Zealand house whose average electricity consumption is equal to about 7,000kWh consumption in a year.

Srisiriwat and Pirom support the hybrid systems. They are convinced that solar photovoltaic cells are effective only in conjunction with hydrogen fuel cells and hydrogen storage since the solar energy cannot be utilised under certain weather conditions, gloomy days and at nights. They demonstrate the performance of a hybrid power system in remote and coastal areas and its ability to utilise electrolyser to split seawater to produce hydrogen. Both authors are confident that this system is reliable and secure. The ability to produce energy off-grid through seawater electrolysis is strongly believed to be a more advanced technique than freshwater electrolysis. Furthermore, they investigated that abundant concentration of sodium chloride in seawater increases production of hydrogen with less renewable energy input. The authors discussed the economic, ecological and energy security performance observed in Phi Suea House project where the first hybrid system has been implemented (Srisiriwat & Pirom, 2017).

The detailed explanation and effectiveness of the hybrid system is provided by Bidi who is very positive about integration of hydrogen energy into micro-grids, remote locations and islands. The author testifies that being weather dependant, photovoltaics are "*intermittent and random*". However, once combined with hydrogen fuel cells, storage and electrolyser, they become an efficient energy system (Bidi, 2021, p. 1).

This view is supported by many authors, who argue that alone the PV system, especially off-grid, cannot cover the energy demand but is very effective when it is connected to hydrogen storage, hydrogen fuel cells and electrolyser. As evidence, Avril examines the site of La Nouvelle in the cirque de Mafate located on a remote island in the Indian Ocean. The study shows that efficiency of the

hybrid system is higher than utilisation of PV cells alone. Apart from techno-economic aspects, the author highlights environmental and ecological benefits of hybrid system for off-grid locations (Avril, 2010).

Despite the environmental benefits, where hydrogen energy has found a sustainable application, an economic challenge needs to be achieved since hydrogen production, storage and hydrogen fuel cells remain quite expensive. However, the advanced hydrogen technologies have been modified combining electrolyser and hydrogen fuel cells into one single unit making the system more compact, energy efficient and commercially viable.

Green hydrogen can be produced at low and high temperatures (Yilanci, 2009). However, when it is produced at high temperature, the waste heat energy released by the electrolyser can be turned into a significant advantage by connecting the cells' waste heat for heating applications. In fact, the ability to produce both - electricity and heat – may be a provision of thermal to electric ratio in the buildings, especially during the wintertime. It means that hydrogen applied for heating may ease electrical pressure on infrastructure during the cold seasons and become a winter energy vector (Knosala, 2021). In one of the studies, Knosala advanced further and analysed hydrogen technologies for self-sufficient homes. He found out that hybrid systems can achieve energy autonomy and high energy efficiency due to simultaneous supplying of electricity and heat in contrast to electricity-only supplied by the centralised grids. According to Knosala's estimations, the hybrid systems will reduce the total annual energy cost by 80% aligning this system with one of the NZ Government's goals of “*energy trilemma*” – affordability (Knosala, 2021).

However, little or no research has been made on powering and heating residential and commercial buildings since hydrogen has not been produced in large quantities yet and sufficient investigations are required about hydrogen performance (Ronge, 2021).

Hydrogen implication in the built environment is in a nascent stage and some may argue that hydrogen technologies are commercially unviable. However, to “*accelerate the transition to Hydrogen Era*” the strategic framework and systems approach must be established (Edwards, 2008).

The New Zealand Government in turn released a Green Paper encouraging the researchers to provide their feedback as per how to produce and utilise hydrogen while measuring the decarbonisation in New Zealand since there is a gap in the Government hydrogen safety and regulatory policy platforms (Green Paper, 2019).

Since the gap has been identified, the **second research objective and the second research question** can be formulated as the following:

Objective 2:

Identify and analyse the techno-economic performance of hydrogen technologies for the built environment, with the goal of maximising energy outcomes and providing measurable economic benefits, based on the outcome of the data analysis.

Question 2

How can hydrogen technologies contribute into decarbonisation of the built environment and how can this be measured?

2.10 Energy Efficiency, Economic Growth and Environmental Protection

The New Zealand economy and almost all daily activities largely depend on energy and particularly on electricity. Enhancing the NZ economy can be achieved in different ways and one of them is improvement of energy efficiency. The advantages of energy efficiency improvement are countless

including but not limited to significant financial savings, the increased productivity, environmental security and a reduction in reliance on imported oil, gas and coal supplies (Hirst, 1991).

NZ has implemented Energy Efficiency and Conservation Strategy through the set of the policies and objectives aimed at achieving the transition to net zero carbon emission by 2050. Three main objectives emphasised in the policy by Hon Judith Collins - the minister of Energy and Resources - are to generate renewable energy, implement it within the different sectors and maximise the value obtained from energy (MBIE, 2017).

Achieving energy efficiency goals brings multiple benefits for individuals and society and may bring multiple benefits to New Zealand. Low energy cost means affordability for low-cost householders. It improves their thermal comfort, health and wellbeing and increase productivity (Grosche, 2010). The productivity increase leads to overall economic security through competitiveness and gross domestic product growth. This, in turn, reduces dependence on local and imported fossils, reduces emissions, improves the ecological footprint, and benefits for the environment (MBIE, 2017; Campbell, 2015).

Hydrogen strategy, in turn, may also benefit energy efficiency, economic growth and environmental protection. Hydrogen technologies have great energy potential. Green hydrogen produced from water electrolysis is one of the more environmentally friendly sources of energy which does not harm the environment, can be stored in long-term energy stores and used later not only during daily but also during seasonal variations. In contrast, solar energy can be produced only under certain weather conditions and stored in short term batteries. The batteries have their pros and cons. They can accumulate energy, but they are not suitable for long-term storage, they self-discharge if they have not been charged regularly and their operative ability does not last indefinitely (Yilanci, 2009). Wind and tidal energy also have storage limitations once captured. Some authors do not recommend relying solely on solar and wind energy due to their instability, high weather condition dependency and technical limitations (Knosala, 2021; Leo, 2019).

With the introduction of photovoltaic systems to the public as an alternative to fossil fuels, more and more people have invested into photovoltaic systems. The energy injected into the grid during the summer days when energy production is higher than energy consumption can lead to the grid overloading and to detrimental consequences such as damaging appliances due to voltage problems (Yang, 2014). On the other hand, surplus power can be used for hydrogen production through water electrolysis thus releasing pressure off the grid. Compressed green hydrogen produced can be stored in hydrogen vessels generating energy through the hydrogen fuel cells when solar energy cannot be obtained (Shiroudi et al., 2013). Thus, one of the hydrogen energy efficiency performances is the ability to be stored in long-term storages and being weather independent (Conibeer, 2007; Baykara, 2018).

In this context, hydrogen technologies in conjunction with PV systems would be a reliable hybrid energy system that could power the built environment and off-grid communities and become the alternative to the traditional electricity vectors (Maestre, 2021).

Another advantageous energy efficiency characteristic of hydrogen technology is an ability to supply energy and heat simultaneously. One study compared the hybrid system with the standalone solar system in south-east Australia. The result of the study demonstrated that the hybrid system met 95% of the annual hot water demand while the solar system alone could cover just 54% (Assaf, 2016). This indicates that hydrogen technologies are more energy secured than solar systems and would bring benefits to NZ shores once introduced.

In another study, it has been examined that high energy efficiency can be achieved through application of hydrogen fuel cells for power and water heating in the built environment; however, the author accentuated that more time must be allocated for making hydrogen as “a national energy supply source” (Kuwahara, 2022, p. 13).

Apart from energy security performance and flexibility, green hydrogen produced from solar energy is eco- and environmentally friendly, sustainable and clean energy carrier (Baykara, 2018). Green hydrogen production has positive impact on the environment. It can be said that the “greener” the method of hydrogen production, the lesser the environmental impact factor (Dincer & Acar, 2015).

Hydrogen energy can be used in all industries – metallurgical, agricultural and chemical - displacing fossil fuels thus protecting the environment from polluting emissions (Najjar, 2013). But it is yet to be identified what hydrogen will open for a variety of industries and public in terms of new occupational opportunities.

While hydrogen benefits have been discussed in many studies, very little has been said about the education, skills and training required for these new opportunities. The hydrogen economic growth will require adaption of new skills and qualifications, training and educational programmes. Bezdek in his research suggests that sufficient training will be required to support and grow a hydrogen economy and hydrogen technologies such as hydrogen fuel cells. He, with reference to the U.S. Department of Energy, emphasises that a broad spectrum of career opportunities will be opened for a variety of engineers – mechanical, electrical and industrial, installers, maintenance staff, operators, manufacturers and educators. The study identifies that hydrogen market will require around “one million new jobs in the USA by 2030”. Also, the study highlights that the hydrogen industry will require “highly educated workers with masters and doctoral degrees” and will offer salaries higher than average. For this purpose, educational institutions and universities may need to review their curriculum to provide the students with necessary knowledge required for a hydrogen economy (Bezdek, 2019). It means that NZ may face significant advantages from the introduction of hydrogen technologies into the NZ market.

It is therefore can be concluded that green hydrogen and hydrogen technologies are beneficial for a low or even zero carbon future and can bring social, economic and environmental benefits, but they have not been introduced to NZ yet. It can be assumed that the public has low awareness of cutting-edge hydrogen technologies which will benefit communities and the environment, and the cost of hydrogen technologies has not been evaluated in the NZ market yet.

While the policy makers have already accepted the hydrogen vision, the public is yet to be educated and convinced about the safety of hydrogen technologies, sustainability and financial benefit. Thus, the **third objective** of this thesis can be outlined as the following:

Objective 3

Develop a comprehensive framework to guide the introduction of hydrogen energy systems in New Zealand, ensuring alignment with social, economic, and environmental security objectives, and public well-being, to be completed by the conclusion of the research study.

2.11 NZ Fuel Poverty

Undeniably, energy efficiency must be achieved without compromising the energy security, affordability and sustainability.

At the end of the last century, the gas and electricity tariffs in NZ were relatively cheap comparing to the world standards with average c0.06 and c2.3 per kWh respectively depending on the region (Saha, 1980). Many householders used gas for water heating, but the majority of all NZ household’s appliances have been electric including ovens and hot water cylinders in contrast to the European countries where residential and commercial stoves and boilers fuelled with natural gas (Vries, 2020).

Currently, NZ electricity costs vary depending on the region and the provider with average tariff at c30.22 per kWh. The majority of New Zealanders live in the North Island while the main energy

production is located in the South Island. It means that the high cost of electricity includes not only production cost but the cost of the energy distribution to the end costumers through electricity grid infrastructure. Although, the bills might not be noticeable during the summertime when the days are long and warm so less electricity is required for lighting and cooling, the bills in winter, however, cannot be absorbed by every New Zealander with low- or no income.

While the commercial energy consumption has decreased during the Covid quarantines, the residential energy consumption was significantly higher than during the “normal”. People spent more time at their homes cooking and keeping their spaces comfortably warm. However, those who lost their workplaces were forced to change their energy consumption behaviour by switching their appliances off. Financial difficulties lead to energy conservation which is not a smart form of energy efficiency and may lead to health issues.

In 2012, almost 25% of NZ households have been assessed in “fuel poverty” due to lack of heating, water heating systems and thermal insulation. According to Howden-Chapman, “fuel poverty” and low indoor temperature compared to the world standards, are considered as main contribution factors to the NZ seasonal mortality rate (Howden-Chapman, 2012; Isaacs, 1993).

With the average energy consumption of 7000kWh per year, the average NZ family needs to pay more than 10% of their income for electricity which according to Boardman’s definition is considered as “fuel poverty” (Boardman, 1991).

To find a way to address “fuel poverty”, many New Zealanders, Māori and Pasifika families share their accommodation with others. They try to adapt their energy behaviour which vary from simple actions such as closing the curtains when it is cold and windy, installation of double-glazing and insulating water cylinders to more advanced steps like the installation of solar panels (Miroso, 2010). Besides, New Zealanders received government support through the subsidised government programme “The Warm Up New Zealand: Heat Smart” programme aimed at insulating houses and installing clean heating appliances. The programme not only targeted health improvement and energy cost reduction, but also creating new workplaces for those involved in production and installation of heaters and insulation (Howden-Chapman, 2012).

To continue supporting their people, the NZ Government has developed an Aotearoa New Zealand Energy Strategy planning to achieve the trilemma of energy “security, affordability and sustainability” (MBIE, 2022).

The unfortunate situation around NZ fuel poverty creates the **third question** of this thesis:

Question 3:

How to accelerate the hydrogen technologies acceptance by the public to bring the New Zealanders out of fuel poverty and to achieve the economic growth goals?

2.12 Regulatory Framework

The Government agencies, such as the Ministry of Business and Innovation (MBIE), are in the process of reviewing the regulatory framework to support the future of a green hydrogen economy. For this purpose, the MBIE have engaged industry professionals, in particular a consultancy organisation PwC, to investigate if the hydrogen roadmap and existing regulatory reform for the application of hydrogen in the industrial and transportation sectors are up to standards and viable for other sectors including residential and commercial buildings. PwC have advised the Government to develop a clearly formulated strategy, legislative framework and safety regulations.

The NZ Government has given consideration to regulations, policies and the development of standards to support the green hydrogen strategy and new hydrogen technologies; however, no major movement has developed to date since the existing regulatory systems have been set up for traditional hydrogen applications in the industrial and agricultural sectors.

For the safe introduction of green hydrogen and hydrogen technologies to the residential and commercial sectors, the Government is seeking the recommendations and support from industry stakeholders to develop and implement hydrogen regulations in order to evaluate against the existing international standards and their compliance with the New Zealand regulations with the resulting implication once approved (Hydrogen in New Zealand, MBIE, 2022).

30 countries have already published and implemented their hydrogen strategies through policies and regulations and industry stakeholders' support. For example, Japan and Australia, with whom NZ maintains a strong political and economic relationship, have not only implemented the regulatory framework, but have also started to produce and export hydrogen and implement it within these sectors. Japan is one of the countries that published their hydrogen strategy and the strategic roadmap globally. Safety is one of the major concerns so new standards, guidelines and regulations with a risk-based approach have been developed to allow the industry to manage the safety risks.

New Zealand's regulatory agencies have started to explore the ways of meeting the legislative framework in order to introduce novel hydrogen technologies as a strategic part of a hydrogen economy. Currently, none of the existing regulatory frameworks, including but not limited to safety, infrastructure, market and so on, are fit for hydrogen purpose due to lack of flexibility in the existing regulatory regime. Nevertheless, the lack of flexibility can be substituted by the risk management-based approach developed in Japan (New Zealand's hydrogen regulatory pathway, 2022).

Currently, New Zealand does not have a clear national policy strategy or regulatory framework. However, in order to incorporate hydrogen technologies within the NZ market, the improvement of flexibility around the regulatory system and adaptation of international standards will be required in the short term. Thus, the discussion around regulatory framework outlines the fourth research objective and the fourth research question:

Objective 4:

Formulate detailed hydrogen policy recommendations for the Government, describing safety regulations, codes, and standards, to support the creation of a regulatory framework, by the end of the research, following the completion of the survey and analysis.

Question 4:

What factors may influence the Government's decision to accelerate development of new energy vector and how to provide the Government with a confidence to invest into advanced hydrogen technologies?

2.13 Conclusion

Chapter Two has provided a comprehensive review of the literature, establishing a strong basis for the research framework. It has identified the critical challenges associated with escalating global energy demand, driven by factors like economic growth, population increase, and social development, and the pressing need for a shift towards renewable energy sources, notably green hydrogen, to mitigate environmental and societal impacts. New Zealand's energy dynamics, historical transitions, and the potential for integrating hydrogen technologies have been highlighted. The research objectives and questions are designed to delve deeper into these aspects, aiming to contribute meaningful insights into the effective integration of hydrogen technologies within New Zealand's

energy landscape. The subsequent chapter will build upon this foundation to outline the research methodology, aligning with the identified research objectives and questions.

Chapter 3 - Theoretical Framework

3.1 Introduction

Chapter Three presents a comprehensive exploration of the research methodology that underpins this study. It begins by establishing the theoretical framework, delving into various research types, and delineating the research strategy. The philosophical foundations and interpretive frameworks are critically examined, providing a basis for understanding the philosophical assumptions guiding this research. Key components of the research methodology, including approaches such as qualitative, quantitative, and mixed methods, are elucidated. Triangulation, validity, reliability, deduction, induction, research design, and various data collection methods like snowball, interviews, and questionnaires are meticulously discussed. The chapter also sheds light on data analysis, literature review methodology, and the adoption of multimethodology. The philosophical stance and environmental ethics influencing this research are highlighted, underscoring the study's commitment to ethical considerations in the pursuit of knowledge.

3.2 Research and Research Types

Research can be defined as an “*academic activity*” which is aiming at “*search of knowledge*” to contribute towards the existing knowledge and can be referred as “*the systematic method consisting of enunciating the problem, formulating a hypothesis, collecting the facts or data, analysing the facts and reaching certain conclusions either in the form of solutions towards the concerned problem or in certain generalisations for some theoretical formulation*”. Kothari describes research as “*a voyage of discovery*” and “*a movement from the known to the unknown*” which leads researchers of different professions through certain processes to discover new information and facts achieving research objectives and aims. Purpose of each research is to receive answers to questions via the application of certain scientific methods and techniques (Kothari, 2004).

Depending on discipline, research problems, aims, questions and objectives, researchers define what **type of research** they are going to use and what methodology to adopt. There are many different types of research such as fundamental and applied, explanatory and exploratory, descriptive and analytical, diagnostic and hypothesis-testing research. While some research study characteristics of individuals and groups, others aiming at testing a hypothesis of “*relationship between variables*”.

Fundamental research, for instance, focuses on expanding knowledge in existing areas, generalisation and a theory formulation. In opposition to fundamental research, **applied research** looks for a solution to immediate problem organisation and/or society experience.

Both these research types have a purpose to find particular information using a variety of methods. However, fundamental research, with its inductive nature, develops new theories, whereas applied research uses deductive nature to conduct research based on existing theories (Kothari, 2004).

Descriptive research uses surveys as a tool for collecting information to describe the state of affairs in the form in which they currently exist. This type of research does not control variables and only deliver the facts. **Analytical research**, in contrast, aiming at analysing facts and critically evaluating information to discover and examine relationship of causes and effects (Kothari, 2004).

Explanatory research focuses on causes and effects relationship and researchers analyse and explain which cause produced certain effect. In contrast, **exploratory research** investigates problems which are not concretely defined and/or have limitations to understand the nature of these problems through identification of casual relationship with variables (Yin, 2003). Typically, explanatory research uses

a quantitative approach to collect and analyse data, whereas exploratory research resorts to a qualitative approach gathering information via interviews and literature review.

Kothari (2004) and Yin (2003) in their books, discussed main research types and their characteristics. Based on the comparative review of the main research types, the following table has been created to highlight the main features of the research types which includes the purpose, the main methods, application and characteristics of each research type.

Research Types	Fundamental	Applied	Descriptive	Analytical	Explanatory	Exploratory
Purpose	Formulation a theory, generalisation, create new or expand current knowledge	Find a solution for an immediate problem society or an organisation facing, policies formulation	Description of the state of affairs as it exists at present, report data, conduct comparison, get the participants' understanding and opinions about a phenomenon	Analyse facts and available information, critical evaluation of the materials, discover and examine cause and effect	Define and explain causes and effects relationship of a certain problem or phenomenon ; solve a problem	Explore and investigate a problem which has not been previously studied and/or clearly defined
Methods	Internal Validity, Generalizability, examination, verifications, induction	External validity, deduction	Surveys, data collection and analysis via different techniques	Data	Secondary resources analysis to gather the data, in-depth interviews, literature review, focus group interviews	Data collection through questionnaire and survey, observations
Application	Human Behaviour, Mathematics	Social, economic and political science	Social science, demographic questionnaire, companies' questionnaire, consumers' research	Social science	Case studies	Pilot Projects
Main Characteristics	self-initiated,	set by a sponsor	no control over the variables	quantitative, variables are uninfluenced and uncontrolled	structured, relationship based, successor of exploratory research	non-structured, discovery based, predecessor of explanatory research
Questions	What?	How to solve?	What's happening?	What and why happening?	Why?	How?

Table 4: Classification of Research Types and Characteristics

The understanding of the main research features has determined the decision to combine different research types together in this study due to the novelty and uniqueness of the research topic. Since green hydrogen is a new energy vector and hydrogen technologies are yet to be introduced to the

public, the research is going to explore the NZ market and the ways of green hydrogen deployment by seeking the answers to the exploratory question “*how?*”, applied question “*how to solve?*” and fundamental “*what?*”. To obtain the answers to the questions, the research strategy, philosophy, design and methodology will be discussed later in the study.

3.3 Research Strategy

The strategy for research is determined by many factors including the researchers’ experience, the complicity of research problems, philosophical views and the audience to whom the research will be addressed. There are many research strategies such as case study, ethnography, experimental strategies, surveys and others (Creswell, 2013 & 2014).

The combination of six research types discussed earlier will be combined into a survey research strategy to conduct this research in several stages and answer the research questions – why, what, how, when, who, how much and how many.

For instance:

- How can hydrogen technologies contribute into decarbonisation of the built environment and how can this be measured?
- How to accelerate the hydrogen technologies acceptance by the public to bring the New Zealanders out of fuel poverty and to achieve the economic growth goals?
- What specific hydrogen safety requirements need to be addressed to introduce hydrogen technologies to all New Zealand stakeholders?
- What factors may influence the Government’s decision to accelerate development of new energy vector and how to provide the Government with a confidence to invest into advanced hydrogen technologies?

Other research types and strategies will not fit into the research design and will unlikely meet the research requirements. For example, this research cannot be a historical one because of the novelty and uniqueness of the topic and rather than studying the historical archives, the researcher will be studying the most recent experience and how to apply it in the future in different conditions and situations. On the same basis, ethnography, which studies humans and their culture, cannot be utilised for this study either (Creswell, 2013 & 2014).

Research strategy needs to be supported by research philosophy which will be discussed in the next section.

3.4 Research Philosophy and Philosophical Assumptions

Each research is looking for answers to different problems bringing significance to the businesses, societies and science as well as to the researchers. The researchers bring their experience, knowledge, philosophical assumptions, abstract ideas and beliefs into their research to test existing or develop new theories, accept or reject hypothesis, and analyse the data and reasons (Killam, 2013).

The beliefs researchers bring to their research have been named in different ways. For example, Crotty calls them epistemologies, ontologies and philosophical assumptions, while Lincoln calls them paradigms and Neuman uses the term of research. These beliefs, let’s call them philosophical assumptions, can be classified into four categories: ontology, epistemology, axiology and methodology (Creswell, 2014).

Question	Quantitative	Qualitative
Ontology - What is the nature of reality?	Reality is objective and singular, apart from the researcher	Reality is subjective and multiple as seen by participants in a study
Epistemology - What is the relationship of the researcher to that being researched?	Researcher is independent from that being researched	Researcher interacts with that being researched
Methodology - What is the process of research?	Deductive process: cause and effect	Inductive process: mutual simultaneous shaping of factors

Table 5: Differences in Research Approaches: Quantitative vs. Qualitative

Ontology, or ontological assumption, in a broader term, can be called “*the nature of reality*”, “*the nature of knowledge*” or “*study of being*” (Creswell, 2014; Hudson & Ozanne, 1988). Smith explains that philosophers and researchers use a term “*metaphysics*” as a synonym to ontology and associates it with reality (Smith, 2003). When the researchers are carrying out their research, they are embracing multiple and subjective realities and views of various people. Different realities can be differently perceived by different people. This perception is quite useful for qualitative research since it helps to understand how reality is viewed (Groat, 2013).

However, it does not mean that ontological assumption does not find application in quantitative research. By asking a question: “*What is the nature of reality?*” the quantitative researchers looking at singular and subjective reality which is perceived separately from researchers, while qualitative researchers study multiple and objective realities (Groat, 2013).

Epistemology can be defined as “*a study of how people or systems of people know things and how they think they know things*”, or “*how reality is known by the researcher*”. Epistemology relates to nature of knowledge, or how the knowledge is known, and what is the connection between researchers and studied objects (Ryan, 2006; Alharahsheh, 2020).

When it comes to qualitative research, **epistemology**, as well as ontology, can be adopted by researchers. Researchers spend as much time as they can with the participants, so epistemology facilitates a very close connection between researchers and the studied objects (participants). This is a very important part of studying called “*field study*” or ethnography. Researchers collect the information, subjective knowledge and evidence directly from the participants and understand the context of their experience with the following speculative philosophical discussion in the research. However, instead of understanding “*the nature of reality*”, researchers are seeking the answer to the question: “*How reality is known?*” (Creswell, 2014).

In contrary, in quantitative approach, epistemology separates researchers from the studied objects to develop a truth accurately (Park, 2020).

While both – ontology and epistemology – can be used for qualitative research, they still have different concerns. Ontology is trying to find answers to questions such as: “What is true and real?” and “What is the nature of reality?”, whereas epistemology is concerned about a variety of methods of getting the knowledge by asking the questions like: “What and how do we know?” about something. So, by understanding what and how this research will come to the result and add value to the research.

Axiological and **methodological** are another form of assumptions which characterise qualitative research. While **axiology** brings the researchers’ personal role of values into studies, methodological beliefs help researchers to collect and analyse information obtained to develop their research. The uniqueness of **methodological assumption** is that researchers start their research having little or no

knowledge related to their topic, changing the research questions during the research development, and gradually yet steadily improving and increasing their knowledge while explaining how the research has been conducted (Creswell, 2014).

Methodological assumption helps researchers do determine what research methods, procedures and techniques to use for data collecting and analysing and with overall design process for the research conducting (Hudson & Ozanne, 1988).

Considering the reviewed philosophical assumptions and the nature of this study, it can be concluded that a combination of ontological, epistemological, axiological and methodological assumptions will be applied into this study. For example, ontological assumption will be a tool for measuring realities subjectively and objectively, while axiology will find an application through a prism of the researcher's personal values and linked with methodology through the journey of the knowledge accumulation and expansion.

Apart from that, subjectivity is seen as a socially constructed by human reality. In other words, the environmental degradation and climate change problems we are facing today is a reality created by humans. On the other hand, objectivity shows that reality can be perceived as a concrete structure when contextual information goes through concrete processes. This can be speculatively said that humans as a responding mechanism and adaptive agent can respond to the existing problems by processing information and fostering environmental values (Groat, 2013).

Overall, the combination of all discussed earlier philosophical assumption will be seen in this study; however, some of them will be noticeable while others will be hidden from the audience. This research will be framed based on methodological beliefs, thus both quantitative and qualitative approaches for data collection will be used during this research. Epistemological beliefs will be linked with this research to speculate about deductive and inductive reasonings and analyse subjective and objective evidence received from participants. Ontological believes will reflect what will be useful with practical application and how it can be achieved in reality. Axiological beliefs will be reflected through the "researcher's and participants' views" and knowledge. Methodological believes are an essential part of interpretive pragmatic framework to collect both – qualitative and quantitative data with the following analysis and interpretation (Creswell, 2014).

3.5 Philosophical Interpretive Framework and Categorisations

In some research, philosophical assumptions can be hidden from readers or be visible from the first to the last page; however, quite often research have a separate chapter where philosophical assumptions are discussed in detail to frame interpretive framework as a theoretical part of study. Interpretive frameworks consist of numerous categorisations including positivism, post-positivism, constructivism, interpretivism, pragmatism, multi-paradigm and myriads of others.

The **positivism paradigm**, from ontological point of view, speculates about nature of reality where a single reality exists, and such a reality can be measured.

Positivism believes that causes determine effects, accepts singular and objective reality, and require thorough validity a theory testing thus making this framework suitable for quantitative research. Positivism can be characterised as scientific, deductive, material, certain, objective, factual and absolute philosophical theory.

Positivism has a reliance on hypothetico-deductive method for hypothesis verifications and based on quantitative research method. Hypothetico-deductive model helps researchers to formulate a hypothesis that can be tested to develop empirical knowledge, and to accept or reject the hypothesis. Studies use dependent and independent variables to support the casual relationship between them.

Dependent variables can be measured whereas independent variables can be manipulated. Consequently, one of the main purposes of positivism is to keep variables isolated and controlled from the researchers' bias using internal validity.

To understand nature of knowledge, positivists should develop knowledge truly, objectively, unbiasedly and values-free in line with epistemological views. Researchers and participants must be entirely separated. This can be achieved by operating dualism and objectivity. Dualism supports participants – researchers' separation for the bias free result supported by objectivity (Park & Konge & Artino, 2020).

Contrary to positivism, **post-positivism** holds a position that causes may or may not determine effects, there are multiple subjective realities and created hypotheses may be either accepted or rejected. As a consequence, such a philosophical assumption has found its application in qualitative research and adherents of post-positivism assume that "*truth can never be found*" (Groat, 2013; Creswell, 2013).

Post-positivism is defined as humanistic, inductive, interpretive, probable, subjective and critical philosophical view. That's why positivism is more applicable for science, mathematics, engineering and statistics, while post-positivism has a better application in social, political behavioural and psychological science. This approach, in contrast to positivism, connect researchers and participants.

Post-positivists ask open-ended questions opening interpretive dialogues having a purpose to set up a problem and create complicated questions rather than solve the problem, so research adopt exploratory character. Post-positivism is widely adopted in qualitative method, but positivism uses quantitative method (Ryan, 2006).

Interpretivism paradigm focuses on human beliefs, their views and what motivates them. Interpretivists seek the understanding of how different humans perceive the same reality and why people behave differently experiencing the same situation; they use a variety of qualitative approach methods and interpretive techniques, such as observations and interviews, to obtain the information sought. Interpretivism do not test hypothesis but make attempts to understand the sense of reality (Creswell, 2013).

Interpretivism has a subjective focus, in other words, interpretivists consider human beings in a different way to physical phenomenon and assume that "humans cannot be divided from their knowledge". The reality is subjective and can vary depending on different individuals; the information received from individuals cannot be generalised due to different point of views and opinions. The high-level of validity must be presented since researchers can be biased depending on the personal researchers' beliefs, interests and experience (Hudson & Ozanne, 1988).

Interpretivists are in close connection to their objects of study and participants. Interviews have a two-way communication rather than collection of information participants have a collaborative nature. Interpretivism is applicable for qualitative approaches based on the described qualities (Miles & Huberman, 1994).

Constructivism, similarly to **interpretivism**, has the same ontology and beliefs that multiple realities exist and different people can experience and perceive the same reality differently based on their own reality. Constructivists try to understand the complexity of individuals' realities and how these realities have been socially constructed, while interpretivists are interested in how the individuals' realities were individually experienced by the individuals in terms of perception and feelings. Thus, in constructivism individuals narrate about their experience, whereas in interpretivism individuals speculate about their perception of their individual reality.

Constructivists collect the views of the participants about the research topic by asking open-ended questions and encouraging participants to "talk" while researchers "listen" carefully. The qualitative

information obtained is not narrowed down as it commonly happens while other philosophical worldviews are applied. Vice versa, researchers try to make their research more complex and multiplex creating “pattern of meaning” (Creswell, 2014).

Pragmatism focuses on research problems, research purposes, aims and needs. What distinguishes pragmatism from other philosophical frameworks is that pragmatists do not create boundaries between qualitative and quantitative approaches such as interpretivists and positivists but interconnect the approaches instead. That’s why pragmatists use mixed methods for their research, combining different approaches and different philosophical assumptions, theoretical and practical knowledge into a unified paradigm. Pragmatists believe that all philosophical concepts must be verified through scientific experiments to get their practical value, otherwise they will not be valid (Creswell, 2014).

Multi-paradigm moves even further by developing and implementing multi-strategy, multiple approaches and multimethodology. While some criticise multi-paradigm saying that a researcher must be committed to epistemology while conducting challenging multi-paradigm research; however, Knight argues that despite some challenges, “*no single methodology can ever provide a complete picture of the project*”, and that multi-paradigm is a useful tool for complex studies. He suggests that multi-paradigm must be adopted by the researchers who conduct their studies in construction management and the built environment because “*it is always wise to utilise a variety of approaches*” to gain richer insights and a more complete understanding of “*social phenomena*” instead of “*adopting a particular paradigm*” with its narrow vision (Knight, 2008; p.p. 10-11).

The review of philosophical interpretive framework and categorisation has led to the following summary. In this study, based on positivism with its reliance on hypothetico-deductive method, some casual relationships can be identified. For example, population growth and energy demand, energy growth and fossil fuel consumption increase, fossil fuel consumption increase and environmental degradation. As it will be analysed and discussed later, some of these variables would possibly be measured while others could be manipulated with application of the positivism paradigm.

Besides, multi-paradigm will be taken as a basis for this study. A particular interest will have “*an interpretive framework based on pragmatism*” emphasised by Creswell who believes that researchers who use this worldview should “*focus on the outcomes*” and be free to adopt multiple methods, approaches and techniques to collect and analyse data for the best research outcome with the following practical implication.

Consequently, this research will connect theory and practice under one umbrella; values, knowledge, expertise and beliefs the participants bring to the study will have a significance for the existing reality from axiological perspective. Some characteristics of both - positivism and post-positivism will be reflected in this study.

To achieve a logical conclusion based on a research problem, a multi-paradigm researcher uses a wide range of approaches thoughtfully planning several directions and following the procedures to collect, analyse and interpret the data. For this purpose, researchers use research approaches, design and methods which all together form research methodology (Creswell, 2014).

3.6 Key Components of Research Methodology

Methodology is an overall strategy that includes the ways of conducting research. To develop research with a logical conclusion, researchers prepare a plan as per how they are going to conduct their research addressing the research problem to the audience based on researchers’ philosophical assumptions, nature of research problem, researchers’ experience and their worldview perception. The plan includes detailed steps and methods of how researchers are planning to collect, analyse and

interpret data (Creswell, 2014). This plan, with all procedures, can be defined as research methodology. The research methodology consists of three main key components - research approach, research design and research method which will be discussed in the next sections.

3.7 Research Approach – Qualitative, Quantitative and Mixed Methods

Research approach can be described as a plan and set of procedures required from researchers to accomplish their research. Research approach starts from broad philosophical assumption and leads researchers through detailed methods – data collection, analysis and interpretation - to the research conclusion. Each researcher develops their research approaches depending on area of knowledge, a research topic and a research problem.

Primarily, there are three research approaches - qualitative and quantitative and mixed method.

Qualitative approach starts with assumptions and moves from broader definitions and theoretical frameworks to more narrow and specific document examinations and participant interviewing. Researchers using this approach, usually move from the “bottom up” and “back and forth” between topics and data involving participants into establishment of the fundamental research matter. This complexity requires from researchers certain inductive-deductive skills for the entire research duration.

Qualitative approach analyses and interprets narratives, perceptions, opinions and detailed data collected during in-depth open-ended interviews to explore and understand “how things work” with the following categorisations of the information analysed. The analysis and results of received descriptive information can be used to accept new and/or improve existing knowledge, write new policies and guidance.

Qualitative inquiry can help to understand all kinds of phenomenon, identify the consequences of these phenomenon, understand how systems function, and identify patterns in case studies, as well as carry out subjective evaluation of information obtained from participants.

From a philosophical point of view, a qualitative approach can be described as an activity of world observation, interpretation of information obtained from different participants or multiple subjective realities. These interpretations are addressed to the audience in the written report with no certain structure which means that researcher has flexibility in ways of presenting the findings.

Flexibility will find its practical application in this research and will assist the researcher with the research complexity by modification of the research processes, changing the ways of extensive data collection and even altering the research questions for the best research outcome and detailed understanding the research problem (Creswell, 2013 & 2014).

Quantitative approach, in contrast to qualitative research, is based on statistical theories and systematic investigation of objective, quantifiable and statistical data collecting through closed-ended questions and analysing the data received (Watson, 2015). Quantitative approach uses deduction to carry out quantitative analysis and quantify relationship between variables. If two variables are involved in the research, one of the variables will be independent variable while another will be dependent.

In contrast to qualitative approach, quantitative approach uses probability sampling and large sample sizes and study relationships between independent and dependent variables (Khalid, 2012).

Qualitative approach, from philosophical perspective, makes ontological assumptions that reality is subjective, whereas in quantitative approach reality is objective and singular, and exists independently of the researchers. Epistemology makes an assumption that researchers interact with

the research subjects in qualitative approach, but in quantitative research researchers are independent and subjects studied must be measurable. Through axiology, researchers in qualitative approach are biased and bring their values, but in quantitative approach vice versa, researchers are bias-free and are detached from objects studied. Methodological assumption in qualitative approach guides researchers towards data verification and accuracy through inductive processes, whereas in quantitative approach, generalisation and deductive processes dominate (Baban, 2009). Qualitative approach focuses on paradigm of constructivism and interpretivism while quantitative approach has a focus on positivism and post-positivism.

Mixed method can be described as a combination of qualitative and quantitative approaches. Usually, quantitative data is collected through closed-ended questions, questionnaire and statistics, while qualitative data is obtained via open-ended questions and personal experience. This concept of different data collection is the main attribute of mixed-method approach where both kinds of data are required for accomplished research.

Mixed method approach working with pragmatism paradigm integrating thematic and statistics, narratives and numeric, exploratory and explanatory research purposes benefit research by combining both approaches – qualitative and quantitative (Creswell, 2013). The model of mixed method identified by structure of pragmatism and multi-paradigm through hypothetico-deductive and inductive logic lens.

To conclude the discussion above in this section, quantitative research will examine several variables and their relationship. For example, population growth can be considered as “predictor”, in other words, independent variable, so the energy growth can be expressed as “criterion”. i.e. dependent variable. However, not only quantitative but also qualitative approach will find its implementation in this study.

What is meaningful about qualitative research and will be adopted for this study, is that the researcher will be constantly focused on obtaining diverse knowledge, explanations and subjective views from participants about the research problem. Considering that there is little, or no knowledge related to the research topic and research problem, this tandem researcher – participants will collaboratively contribute to the research and reflect “an interpretive framework based on pragmatism” with the focus on the best research outcome. And that’s where different multiple subjective realities will be combined into one research based ontological assumption. Phenomenological characteristic of qualitative research will be highlighted through understanding the participants experience with hydrogen technologies, what challenges did they face, what safety measures have been adopted.

Quantitative and qualitative approaches combined under entire mixed method approach, will be used in this study; however, due to the necessity of obtaining excessive and valuable qualitative data, triangulation research method, the main characteristics of which are to be discussed in the next section, will be also adopted.

3.8 Triangulation

Triangulation is a research method similar to mixed method. The difference is that mixed method combines qualitative and quantitative research methods, while triangulation represents a combination of several more comprehensive and advanced qualitative methods and theoretical approaches (Flick, 2019).

What makes triangulation is an attractive method for this research is that triangulation is the most useful tool for researchers when they are uncertain of what method might fit to their studies. Previously, triangulation was used as a data validation strategy, but later it has been accepted as a research method. Flick, with the reference to Cook, calls triangulation as the most useful and

promising methodology and suggests using concept of “*multiplism*” in occasions when researchers do not have clear understanding of what approach must be adopted for their studies.

In this research, triangulation will play a significant role because of combination of qualitative and quantitative approaches, and triangulation will be used for data validation for both approaches (Miles & Huberman, 1994).

Triangulation aims at checking qualitative data against quantitative which assists researchers with capturing of different types of data. Qualitative approach can provide information where quantitative approach fails and vice versa but, in a combination, they complement each other, and this characteristic will be irreplaceable for this research (Flick, 2019).

Thus, qualitative approach will be required for the unlimited phenomena exploration, problems discovery and hypotheses development on the first research stage with several waves of qualitative interviews. It is a required precondition for adequate data collection and analysis, causes, reasons and effects and revealing of any possible connections between variables. Quantitative approach will be positioned on the next research stage (Flick, 2019).

The next step will be an adaptation of “*concurrent triangulation*” or a mixed method approach depending on the information gathered, analysed and interpreted. This transformative multi-phase design – a combination of qualitative, quantitative and mixed-methods – will integrate different approaches for a purpose of giving a weight to the study. Qualitative data will be transferred into quantitative while quantitative data will be analysed in quantitative logic way for a quality research assessment (Miles & Huberman, 1994).

Also, triangulation facilitates an adaptation of several qualitative approaches and removes the boundaries between qualitative and quantitative approach which is undeniably a good strategy to be adopted for this study because philosophical assumption and theoretical frameworks can be interconnected to address the research problem (Flick, 2019).

Some may argue that when researchers mix qualitative and quantitative approaches, they do not allocate sufficient time into “*fundamental discussion*” and “*theoretical foundation*”, and question accuracy and consistency. However, systematic, comprehensive triangulation can perform when a combination of various qualitative approaches, as well as combination of qualitative and quantitative approaches, take place within one study; and when theoretical, methodological and epistemological backgrounds are considered as a combination; and when validity and reliability, which will be discussed next, are applied (Flick, 2019).

3.9 Validity and Reliability

Validity and reliability are fundamental to research because validity refers to the accuracy of the research measured whereas reliability refers to consistency of the research measured. In other words, researchers by using validity and reliability strategies ensure how accurately and consistently their findings are.

Validity of the qualitative data will be achieved by sending the transcripts back to the participants and requesting them to review and comment on the accuracy of the recorded responses. In the same way, the validation of the responses’ interpretation can be achieved (Lacey & Luff, 2007).

Triangulation, discussed earlier, is one of the most appropriate strategies to check the validity and reliability of quantitative and qualitative data. For example, reliability can be achieved by ensuring that the transcripts are error-free, while validity is addressed by “*trustworthiness, authenticity and credibility*”.

Triangulation strategy will be applied to this research where qualitative findings will be transformed into quantitative to measure the reliability and validity (Creswell, 2014).

3.10 Deduction and Induction

Both deduction and induction are conclusion-oriented approaches, so any research can adopt a deductive or inductive approach. The main distinction between them is that deduction uses “*top down*” approach or “*from general to specific*” while induction is completely opposite and uses a “*bottom up*” approach and goes “*from specific to general*” (Khalid, 2012).

Deduction starts with an idea and moves from generalisation to specific observation, collecting and analysing data to accept or reject hypothesis. In contrast, induction begins from specific observation and gradually moves to generalisations through observation, forming observations’ patterns, and finally, developing a theory.

Deduction > theory > hypothesis > observation > confirmation

Induction > observation > pattern > hypothesis > theory

The main characteristic of deduction is that deductive research cannot be conducted without existing theory. Contrary, inductive research developing a theory from scratch having little or no data (Khalid, 2012).

This research will use both research approaches as part of a multi-paradigm strategy. For example, deduction may start with a hypothesis that if green hydrogen will replace fossil fuels, it may help reach the zero-emissions targets, decarbonisation goal and may lead to environmental recovery. It can be followed by observation of the pilot projects where green hydrogen technologies have been used in the built environment and confirmed by the industry professionals who have used them.

On the other hand, induction may observe that green hydrogen technologies do not release harmful emissions into atmosphere, so they may contribute to global decarbonisation and environment recovery thus leading us to generalisation which can be confirmed by a theory that all hydrogen technologies may have a positive impact on the environment.

Overall, deduction and induction are an integral part of the research methodology on a par with research methods and research design which will be discussed in the following sections.

3.11 Research Design

Research design can be described as a key component of the research methodology and an overall research structure, strategy, or a plan of investigations prepared by researchers to answer the research questions (Tan, 2002).

Research design is often called a strategy of inquiry since researchers not only select a method of conducting their research, but also determine procedures and choose directions in order to proceed with research (Creswell, 2013).

Preliminary design stage starts with broad assumptions, problem statement, literature review, hypotheses/questions, data collection/analysis, results, report and discussion (Creswell, 2014). Typically, each stage is followed by another in certain order. However, in this research, these stages will be interconnected and not separated. In contrast to quantitative research design, qualitative research design has more flexible and less rigid structure which will be adopted into this research.

All research have several phases and start with concepts during the first phase; paradigms, theories, perspectives, philosophical and theoretical framework during the second phase, consideration of

research strategies during the third phase; application of a variety of data collection and analysis methods at the penultimate phase; followed by interpretation and evaluation at the final phase (Denzin & Lincoln, 2011).

Due to complexity of the topic, this research will be less structured and more flexible. It has started with introduction and literature review which assisted with the problem statement, the establishment of the research aims, objectives, questions and the hypotheses formulation. It has included theoretical and conceptual phases to understand the methodological research requirements. There will be several research phases – interviews, data collection, data analysis, survey preparation, analyse of the data obtained from the survey, interpretation of the data analysed, thesis preparation and discussion, and finally, the result of the study will be addressed to an academic audience, the industry professionals, policy makers and public.

3.12 Research method – Snowball, Interview Methods, Questionnaire Survey, and Sample Size

Research method is another component of research methodology which can be defined as procedures that are required for collecting and analysing data (Hudson & Ozanne, 1988). Researchers, depending on the nature of the problem and nature of their research, adopt more suitable methods for their studies to collect the necessary evidence. Particularly for this research, the data will be collected primarily via interviews with participants, survey and an extensive literature review.

The collection of the data will be staged. Although, the initial literature review has already been conducted, it will be reviewed regularly throughout the study and added as needed. In parallel, the interview method will be applied. The series of semi-structured interviews with exploratory characteristics will be carried out with multiple and diverse participants who will be subjectively selected using a snowball method.

Snowball method or snowball sampling is a method of selecting the participants for qualitative research. The snowball method is also called “*chain-referral sampling*” when the participants recruited in stages or waves - wave one is followed by wave two, and this expansion growth like a snowball “*rolling down a hill*”. This snowball method was developed by Coleman and Goodman in the middle of the last century as a nonprobability approach for qualitative research (Heckathorn, 2015).

Since this study will have fragments of qualitative research, the snowball sampling method will be used for identification of quality participants as a starting point for qualitative and empirical data collection. The quality participants – professionals who have knowledge related to the research topic - will be initial or “*seeds*” contacts. These participants will not only share their knowledge but also recommend further quality contacts who may benefit for the research in both ways – data collection and other contacts recommendations for interviews and survey participation. Thus, by using the professional network, the link to quality information and quality participants will be established. The participants recruiting process stops when geometric sequence brings adequate number of participants to the study and sufficient information is received (Parker, 2019).

The participants can be selected in two ways – either through application of probabilistic or non-probabilistic sampling approaches. **Probabilistic approach** selects participants randomly which is not a suitable option for this study since limited number of people may have required knowledge related to the research topic. Therefore, **non-probabilistic approach** will be the best option for selecting the participants who may have the knowledge required for the research. The **non-probabilistic sampling** – participants with certain characteristics determined by the research requirements - will be selectively chosen for this study.

The non-probabilistic sampling is called “*deliberate sampling*” because the participants are deliberately selected for the study. However, researchers must be careful using this selection method and remain unbiased and impartial to get the bias-free result.

The **sample size** – the number of participants – must have an optimum size to avoid “*sampling errors*”, when the sample size is too small, and to control “*systematic bias*”, when the sample size is too large, but it must be sufficient for the evaluation parameters (Kothari, 2004).

Marshall specifies that a sample size of 30 is an optimum sample size for qualitative research since a sample size of 20 is rather too small while a sample size of 40 is rather too large (Marshall, 2013). Creswell, in turn, suggests that a recommended sampling size for qualitative research must be between 20 and 30 depending on the research scope (Creswell, 2013). The same sample size of 30 has been suggested by Boddy who believes that research must develop “*a depth of understanding rather than a breadth*”.

According to Marshall, qualitative researchers do not pay enough attention to the sample size. Boddy, on the other hand, cites Onwuegbuzie and Leech in support of his argument that since qualitative research does not aim to make statistical generalisations, “*sample size is not an issue*” (Boddy, 2016). Thus, this research will have a sample size of 30 and the selected participants will be interviewed for a purpose of getting empirical knowledge required for the study. However, the interview sample size can be less than 30 depending on the achievement of “*thematic saturation*” when “*no new concepts emerge from subsequent interviews*” (Patton, 2002, as cited in Vasileiou, 2018).

The sample size for the survey will be approximately 155. According to statistics from Engineering New Zealand, there are approximately 50,000 engineers in New Zealand across all disciplines (Stats NZ; NZRAB; Engineering NZ). Estimating that 5% or 2,500 are involved in the energy sector, and 10% of those or 250 are specialized in hydrogen technologies gives a population size of $N = 250$ industry experts.

Using a 95% confidence level and 5% margin of error, the sample size can be calculated using the following formula:

$$n = N \times ((N-1)E^2 + x)$$

Where:

n = sample size

N = population size

E = margin of error

Plugging in the values:

$$n = 250 \times ((250-1)(0.05)^2 + 250)$$

$$n = 250 \times ((249)(0.0025) + 250)$$

$$n = 250 \times (0.6225) + 250$$

$$n = 402/0.6225$$

$$n = 155$$

Therefore, the estimated sample size for the survey is 155 industry professionals involved with hydrogen technologies in New Zealand.

This provides a 95% confidence level with a 5% margin of error, which are typical values used in research. The sample size can be adjusted based on factors like desired confidence level, available

survey resources, expected response rates, etc. But this provides an initial sound estimate. Let me know if you need any clarification or have additional considerations for estimating the sample size (Cochran, 1977; Creswell, 2014; Nardi, 2018).

The **interview method** has been chosen to collect empirical data through personal interviews in structured, semi-structured or unstructured ways. Intensive interviews may start with pre-determined questions to investigate the participants' knowledge around the research topic. The information obtained will be recorded.

Researchers-interviewers ask prepared questions which can be modified depending on the answers received from the participants-interviewees for a purpose of intensive investigation.

For this study, the interview method will be used to get more in-depth information via flexible unstructured interviews to get answers to all queries thus keeping non-response rate on a very low level (Kothari, 2004). Empirical quality data collected will be analysed and used for the questionnaire preparation.

Questionnaires can be described a process of data collecting from a number of respondents by asking them the same "*set of questions*". Questionnaire survey is an instrument for quantitative data collection when each participant is requested to provide the responses to the same questions in the pre-arranged order (De Vaus, 2013). Akinci and Saunders believe that questionnaire survey is one of the most efficient tools of quantitative, descriptive and explanatory data collection in easy and flexible way. Questionnaires can be either self-completed when the respondents complete the questionnaires on their own, or interviewer-completed when the researcher records the participants answers during the interviews (Akinci & Saunders, 2015).

Questionnaire surveys, as a part of triangulation, are designed to collect secondary quantitative data to validate primary qualitative data. On the one hand, questionnaires are used by positivist and post-positivists to reflect epistemological assumption, determine reliability and validity for generalisation. On the other hand, questionnaires are used by pragmatists in conjunction with qualitative approaches and mixed method research.

The sample size for the questionnaire will not be large since the hydrogen industry has not been developed properly in New Zealand yet. The convenient sampling size for the survey stage will be based on the size of the industry professional population rather than on the size of general population due to peculiarity of the research topic.

Considering that the survey will be conducted among the New Zealand industry professionals, the estimated size identified through Qualtrics sample size calculator is 80 with confidence level of 95% and margin of error of 5%. Based on data extracted from the Public Service Commission and the PwC Report, the total NZ population was around 5.3m in 2022; approximately 2.4m make up the New Zealand's total workforce and about 77,000 are engineers for each industry which is around 3% of the NZ workforce (Public Service, 2022; PWC Report 2021).

A number of potential participants for the survey have been identified across the sector including New Zealand Green Building Council, New Zealand Institute of Architects, Energy Efficiency and Conservation Authority, Ministry of Business, Innovation and Employment, Hydrogen Council, Energy Efficiency and Conservation Authority, Environmental Protection Authority, Standards New Zealand, engineering, environmental and sustainable energy consulting organisations such as WSP, GHD, AECOM and BECA, several power providers including Contact Energy, Meridian energy and Nova Energy, FirstGas, Sustainability Trust and Tuaropaki Trust (developer of geothermal and hydrogen energy production), New Zealand Green Investment Finance, solar energy company Solar Zero, WorkSafe New Zealand, H2H Energy.

Overall, 100 potential participants have been identified which will form the professional population size. This means that the survey sample size of 80 participants will be a targeted population.

To identify if a relationship in the professional sample exists and can be generalised to the professional population, it is assumed that the probability of findings will be .05 or less, and such a relationship will achieve a statistical significance. However, if the probability of findings will be more than .05, it will mean that no relationship in the professional population exists and a statistically non-significant relationship will be drawn.

On some occasions, there can be a case where “*a relationship exists when it does not exist*” and it is known as “*a Type I Error*”, and it is possible with larger samples. Also, there is a possibility that it can be shown that “*a relationship does not exist when it exists*”; this is known as “*a Type II Error*” and is associated with smaller samples (Cramer, 2003).

To get higher-responses rates, the interviewer-completed questionnaires can be offered to the participants to assist in answering the research questions (Akinici & Saunders, 2015).

On the basis of the research method discussed, it can be summarised that for this study, narrative and numerical data will be collected in multi stages through the application of the interview method via snowball sampling and the subsequent questionnaire survey method.

3.13 Data Analysis

The qualitative data obtained during the interviews will be stored and analysed by using NVivo software, while the quantitative data received from the survey will be managed via Statistical Package for the Social Science - SPSS software. The usage of the software packages helps to store and analyse large amount of data securely, code and re-code the data using a “*top down approach*” which is helpful for the further regulatory framework formulation and policy recommendation (Lacey & Luff, 2007, p.35).

The narrative data collected during the online interviews will be recorder and transcribed. The transcripts will be transferred into Word or PDF formats and uploaded into NVivo for further coding or indexing, identification of themes, re-coding, developing of categories, exploration of relationship between categories, testing the hypotheses against the analysed data and/or developing a new theory based on analytical techniques (Lacey & Luff, 2007).

Lacey and Luff suggest using three main techniques of qualitative analysis. The first one is to count how many times a particular word or concept have occurred during the narrative data collection. The second technique is to give a certain code to the unit of data such as sentence or paragraph to examine them at the more detailed level. For example, a unit of thematic data can refer to safety concerns, so all data with the reference to this unit will be coded and analysed. Finally, the third technique theoretically analyses the data in an inductive and deductive ways to accept or reject the hypotheses and develop a new theory (Lacey & Luff, 2007).

Due to the exploratory nature of the research, the qualitative data collected during the interviews will be analysed by using a combination of word-based and code-based data analysis. The qualitative data analysis will start with the code-based analysis of the transcribed interview content to generate main themes, develop the categories and identify the relationships between concepts. This will be followed by the word-based analysis to identify how many times the interviewees were referring to the specific theme and counting the frequency of particular words used.

A number of codes needs to be sufficient enough to provide a trustworthy result but not so overwhelming as to overcomplicate the analytical process. Through the process of synthesis, the codes will be grouped, summarised and categorised (Busetto, 2020).

The coding for this study will use deductive and inductive approaches, so the deductive coding will have an investigative purpose, while inductive coding will generate categories from the transcripts (Bernard, 2000).

The qualitative data will be measured in quantitative way in regard to frequency, proportion and /or percentage. The categories, variables and relationships identified during qualitative analysis will be quantified during the survey phase and coded with a set of different numbers which will represent different categories. The number of cases within the categories will be counted and expressed in percentage (Cramer, 2003).

The reports generated by the software packages after the data is analysed will be used by the researcher in the thesis to demonstrate the analytical processes.

Analysis of the qualitative data will assist with preparation of the questions for the quantitative data collection to reflect the research questions as well as contribute towards potential pathway for the NZ regulatory framework. Based on the data gathered from the interview stage, the questionnaire will be prepared, and the survey will be conducted through the online survey tool “Qualtrics”. The quantitative data obtained from the survey will be coded, transferred to and analysed via SPSS software package.

For survey analysis, a Likert-type response scale will provide a structured way for participants to express opinions or judgements on the construct being measured (Sullivan & Artino, 2013). The common scale applied uses 5 to 7 points with numeric and verbal labels anchoring each option (e.g. 1 = Strongly Agree, 5 = Strongly Disagree). Using at least 5 points balances discrimination validity with reliability (Hinkin, 1998), whereas a 3-point scale limits granularity of measurement (Lehman et al., 2011). The survey questions will be aligned with conventional 3 to 5-point scale design.

The process of quantitative data analysis will include several steps. At the beginning, the data will be edited in order to identify any errors and missing data, such as unanswered questions. Once the errors and missing data are identified, the data will be cleaned having a purpose to enhance data accuracy and eliminate the gaps in the analysis. The missed data will be replaced with the mean value of all other numbers of a one particular variable to avoid bias results. The mean value must not exceed 15%. Finally, the variables will be measured, and normality of the variables will be assessed (George, 2003).

The quantitative data will be analysed by using descriptive and inferential statistics techniques. Descriptive statistics are used for the analysis of the respondents’ responses via mean, median, mode and standard deviation techniques, whereas inferential statistics are used for population sampling size examination for making generalisation.

Furthermore, to analyse the quantitative data in a more logic way, the exploratory factor analysis, which consists of a number of statistical techniques, will be adopted for this study to “*simplify a complex sets of data*”.

3.14 Literature Review Methodology

Literature review is one of the essential and fundamental parts of the doctoral study process. It provides researchers with relevant and comprehensive information conducted by other researchers and the industry experts for critical evaluation, analysis and interpretation (Tranfield et al., 2003). The literature review process can be described as “*a data collection tool*” that aims at obtaining information to form an empirical body of knowledge related to the topic (Onwuegbuzie, 2016).

The literature review stands as an indispensable component within academic endeavours, forming a bedrock for the progression of knowledge. It serves a vital purpose by meticulously examining prior

relevant literature, offering a comprehensive understanding of existing scholarship. This process not only identifies prevailing gaps but also aids in shaping the research problem, framing pertinent questions, and defining clear aims and objectives (Webster & Watson, 2002; Kilston & Straus, 2010).

The literature review methodology consists of several activities including but not limited to data identification, understanding of data found, recording, meaning-making and transmitting information related to the research topic (Onwuegbuzie, 2016). A comprehensive literature review uses a mixed-method approach as a tool for collecting quantitative and qualitative data relevant to the topic.

Onwuegbuzie suggests using a seven steps technique for comprehensive literature review which includes the topics exploration via media, observations, documents, experts in the field and secondary data resources; initiation, storage and organization of data, selection/deselection, expansion and critical evaluation of data, analysis/synthesis and presentation of information. He advises to critically examine, organise, reflect and evaluate each of the seven steps (Onwuegbuzie, 2016).

The literature review is an important process because the researchers are given an opportunity to familiarise themselves with the previous findings done by other researchers having an aim to identify the gap in the existing literature. Once the gap is identified, the researchers start to explore the missed or under-researched area to contribute to the existing or formation of a new body of knowledge (Ridley, 2012).

The literature review has a purpose of exploring a topic, getting an extended knowledge in the area of studying and comprehensive understanding about the topic. On the other hand, the lack of literature opens more perspectives for the researcher to explore their topic. During the exploration process, the researchers collect, interpret, summarise, analyse, evaluate and synthesise the data identified (Ridley, 2012; Onwuegbuzie, 2016; Booth et al., 2021).

Each of these processes have different purposes and objectives. For example, when researchers proceed with summarising, they passively review the information without proper understanding, in other words they just receive the information. In contrast, when they analyse the information, on this occasion the researchers actively participate in the literature review process, thus responding to the process. Through the evaluation process, researchers assess and value the data received, trying to justify each piece of information. And finally, researchers organise information accommodating it in their reports while comparing, categorising, contrasting and interpreting the findings via synthesis process (Ridley, 2012; Onwuegbuzie, 2016; Booth et al., 2021; Bandara et al., 2015).

These processes are influenced by the researchers' beliefs, values and philosophical assumptions and begins with a broader topic exploration gradually narrowing it down. Every single piece of found information brings new concepts and ideas, aggregates the found results through all research stages and not only during the first, initial phase (Onwuegbuzie, 2016).

3.15 Multimethodology for this Study

The nature of the problem has outlined the following research multimethodology. This empirical, conclusion-oriented study, with features of exploratory and explanatory research, will be carried out based on the triangulation and mixed method approaches. The research process will consist of a number of steps required for the qualitative and quantitative data collection for the effective and successful research completion and for achieving the desired outcomes. The research design will have several phases and look at the problem from different philosophical point of views.

The multimethodology is an important multi-staged strategy adopted for this study in order to achieve the research objectives. For this purpose, the multimethodology will combine subjectivity and objectivity, qualitative and quantitative approaches, ontology and epistemology, interpretive framework of multiple paradigms and assumptions, and mixed methods. Qualitative approaches

through the positivist paradigm prism will be interconnected with quantitative approach and reflection of interpretative paradigm. Mixed method and triangulation will be a reflection of induction and deduction through multi-paradigm prism.

The problems societies are facing today are complex and require the in-depth analysis. For this purpose, multimethodological research design, with its problem-focused orientation, will be a better fit to this study rather than a traditional generic research design (Knight, 2008).

The **initial first stage** starts with conceptual model to introduce the topic. The topic exploration begins with the literature review to identify the presented gaps, refine and narrow down the topic selected, identify the problem and highlight the research significance (Knopf, 2006).

Comprehensive literature review will be conducted with the application of mixed-use method approach and mixed research techniques through collecting quantitative and qualitative information via searching of information on the AUT online library catalogues and databases and browsing on Google Scholar. The search starts with exploration phase during which the researcher asks questions or uses a combination of keywords relevant to the topic in the search window. For example, the search can start with keywords such as “*green hydrogen*”, “*production of green hydrogen*”, “*green hydrogen – safety*”, “*green hydrogen fuel cells*”, etc. By changing the keywords, the research results will improve.

Furthermore, the data will be collected through grey literature review which includes the Government and industry electronic publications – government reports and policies, conference articles and research reports, statistical reports and working papers from research groups. These publications can be found by searching the Government and organisation websites (Mahood et al., 2013; Paez, 2017).

Once the appropriate data is identified, it must be critically evaluated regarding its application to the research. Skim reading techniques helps the researcher to consider whether the found paper and the authors’ logical arguments support the research questions and objectives. The researcher uses skim reading to read the abstract, conclusion and the first sentences of the paragraphs or the first paragraphs of each chapter to eliminate the information not relevant to the research. The researcher will select what information will be used in the study and deselect the information which will not find application in the research.

After the relevant source of information is identified, it will be critically evaluated regarding its application in the research; the data found will be organised and kept in the database, properly annotated and sited in the bibliography. The findings and interpretations will make sense to other readers, so other researchers can use the same data in the future.

The literature review will form a part of the report on a par with theoretical framework, methodology, research aims, objectives, questions and hypotheses.

Empirical sources are studied to verify the validity of information and to make an assumption with the following hypotheses formulation. The data will be described and explained in a synopsis. Based on the data collected, the open- and close-ended questions will be prepared and asked during the series of interviews (Research Method, 2007).

During the second phase, a series of interviews in person and online will be conducted with the deliberately selected key informants – experts in the field of green hydrogen and hydrogen technologies and involved in the Government strategy for reducing carbon emissions. Information will be collected from the specialists, policy makers and researchers working on similar topics and problems locally and worldwide using professional platforms like LinkedIn. Professional connections will be done with the hydrogen technologies engineers, researchers and manufacturers to collect technical information, as well as contact details of potential participants for both – interviews and survey. The policy makers will be approached via professional network connections. The interviews

will be conducted in accordance with ethical principles. Prior to the interviews, the ethics approval has been formulated and submitted to Auckland University of Technology Ethics Committee. The approval has been obtained.

The participants will be recruited by using a snowball sampling technique to conduct a series of interviews in order to obtain primary data and professional contacts of other potential participants for interviews and survey. Having limited knowledge about the research topic, the initial interviews with wave one participants will start with more generic questions. The questions will be modified after the first round of interviews based on the qualitative data received. The researcher may re-interview the participants from wave one depending on qualitative information received from wave two and/or three.

The participants recruiting process will occur via a LinkedIn professional network platform. The professionals will be found through the search window on the LinkedIn page by using the key words such as green hydrogen, hydrogen technologies, hydrogen fuel cells, connecting green hydrogen etc. After the required groups or organisations are identified, the researcher will go through the list of people who work for this organisation with the job titles – hydrogen expert, CEOs, directors, engineers, founders, inventors, technical advisors, policymakers etc. The LinkedIn pages of these candidates will be viewed in order to gain a better understanding of their qualifications as well as their work experience related to green hydrogen and hydrogen technologies. Once the right potential participant is identified, the request for connection will be sent to them as soon as possible.

After the hydrogen expert accepts the request for connection, the researcher will respond with an introduction message that will include greetings and thanks for accepting the request for connection, with the following explanation about the researcher and the purpose for the connection. As part of the recruitment process, it may be necessary to conduct an initial introduction call.

If necessary, the initial call will be held via Teams application so that the researcher can introduce herself to the potential participant, explain why the professional connection was done, gain an understanding of their experience related to green hydrogen and green hydrogen technologies, as well as introduce the research topic, objectives, and aims.

The potential participants will be asked about their willingness to participate in the research and share their professional knowledge which will help to complete the research. If the potential participants agree to participate, they will be asked for their professional email addresses, and all supporting information including the consent form, participant information sheet, indicative questions and the project brief will be forwarded to the potential participant before the interview process. During the recruiting process, the potential participants will be asked who in their opinion would be another potential participant for the study and the contact details of another potential participant can be obtained.

There is a possibility that the potential participant may decline the invitation to participate in the research and the opportunity to be interviewed in such a case, the researcher will thank the potential participant respectfully and conclude the Teams call.

The recruiting process will continue via LinkedIn until the right candidates express their willingness to participate in the study and to be interviewed for the purpose of getting their professional knowledge related to the research topic. The recruitment process stops once the right sample size is reached and the interview process with the participants has begun.

Semi-structured or even unstructured interviews will be conducted face-to-face or via Teams application depending on physical location of the participants and their time availability. The questions might be modified during the interview process and the knowledge and experience the interviewees possess; and depending on situation, some questions can be omitted, and the sequence

of questions can be changed. This flexibility is useful for the exploratory research nature (Kothari, 2004).

The researcher will remain honest and impartial and will record the responses accurately, carefully and completely; the researcher's approach will be friendly and unbiased; the interviews direction will remain focused, and any irrelevant discussions will be avoided to keep the interviewees focused (Kothari, 2004).

The interviews will start with *"friendly greetings in accordance with the cultural pattern"*. The atmosphere will be friendly, informal and relaxed so the participants will be willing to share their knowledge with the researcher, who will be disciplined and intelligent (Kothari, 2004).

The interviews will be conducted in good faith, so that the main participants will feel honoured and appreciated. The primary researcher will demonstrate good attitude towards the participants, respect and interest to their answers, so the participants will be encouraged to provide the professional information required for the research. Besides, the primary researcher will emphasise the participants' contribution into the research so the participants will see the significance and benefit from their participating in the research.

All documentation required for the interviews to be conducted, such as consent forms, information sheets with preliminary indicative questions, will be prepared and shared with the interviewees at least one week prior the interviews.

The interviewees will be encouraged to provide accurate responses, the unclear questions will be clarified or rephrased, the responses will be recorded, and sent to the participants for their review and comments. Collection of qualitative data ends when "saturation" is reached.

The second phase is an important part of the research aiming at understanding what information must be gathered for preparation of the third research phase – survey - as well as answering research questions, meeting research objectives and identifying the right candidates for the survey. During **the second phase**, interviews will be semi-structured to conduct intensive investigation.

Data from qualitative, semi-structured interviews, numeric and narrative data collected will be processed, analysed and interpreted in order to address the research questions and objectives. The data will be categorised and utilised for the questionnaire survey preparation. The survey will validate the data received from interviewees.

It may be required to contact the interviewees more than one time via mobile phone calls or via emails to get more data or clarifications.

The participants will be asked to provide their feedback on the interviews and the interview questions in order to make the appropriate improvements since the participants, with their different backgrounds, views and opinions may see the same processes differently and perceive the questions in different ways. Their feedback will help the researchers to identify and eliminate any present issues with the interview processes as well as understand how the participants interpret the same questions in different ways. The feedback may assist with generating of new data (Lacey & Luff, 2007).

The qualitative data received will be coded via NVivo software to identify the variables which will form categories and exploratory data will be analysed to create quantitative measures for the next research phase. The data will be analysed through the process of coding to identify similarities and differences in the interviewees' responses with the following creation of categories. The process will continue until no new *"theoretical saturation"*, or new categories are generated. Credibility of the data will be achieved by presenting the data to participants for their revision and confirmation. To become familiar with the software, the researcher has taken the online NVivo trainings provided by AUT.

Based on data received, coded, analysed and interpreted, the questionnaires will be prepared, and the survey will be conducted during **the third study phase**. Questionnaire surveys will have a form of opened and closed questions. Open questions will require the respondent to provide an answer, while closed questions will ask to choose an answer from a list of offered options, or a listed wording scale from “*strongly agree*” to “*strongly disagree*”. The wording scale can be coded for future measuring (Akinci & Saunders, 2015).

The questions will be thoroughly and carefully considered and placed in the certain and logical order to ensure a consistency of data collected, validity and reliability of the answers. The questions will be prepared in a way so they can be easily understood by the participants. In the same way, the participants must respond in a way understandable by the researcher (Akinci & Saunders, 2015).

The questions in the questionnaire survey will be effectively prepared in sequence starting from easiest to more complex; they will be impartial and biased-free. The first several questions will play a significant role because they will help participants to create a right attitude and motivate them for cooperation, but overall, the questions will be simple and easily understood. The participants will not be limited in time answering the questions, so their responses will be mindful and thoughtful (Kothari, 2004).

The survey will be carried out by using an online survey software Qualtrics. The numerical data from the survey will be processed and analysed using SPSS software.

There will be a combination of open-ended questions, “*dichotomous*” questions with “yes” or “no” answers, and closed questions with multiple choice and/or alternative answers (Kothari, 2004).

The purpose of the study will be explained to the participants in the beginning of each phase. They will be provided with clear explanation as to what information is required from them in order to conduct the research. All questions will be purposely formulated to get reliable and comprehensive information to add value to the study.

The qualitative information obtained during semi-structured interviews will be used for the survey to obtain quantitative data. The results from both – interviews (qualitative data) and survey (quantitative data) – will be validated (Flick, 2019).

In other words, qualitative data is to be obtained during the first exploration phase; quantitative data is to be gathered during the second questionnaire phase, and finally qualitative data will be deepened to assess the results during the third phase (Miles & Huberman, 1994).

In both cases – interviews and surveys with the hydrogen experts – anonymity and confidentiality will be guaranteed and the researcher will act ethically (Akinci & Saunders, 2015).

During **the fourth phase** of the research, the qualitative and quantitative data will be combined to carry out the final data validation. The final validation is important not only for qualitative and quantitative data checking, but also for understanding whether the findings will be applied in the future or not.

Literature review and interviews will be carried out simultaneously. Both - primary and secondary data will be collected. Primary data will be obtained via an unstructured interview method for intensive investigation (Daniel, 2011). Secondary data will be collected through published resources including technical journals, reports prepared by research scholars and organisations connected to the industry, statistics and other published documents (Kothari, 2004). Methodology will include both - descriptive and analytical methods. The descriptive method will cover the information collected during the interviews and surveys with the following report drafting in the thesis, while the analytical method applied in this research will analyse the facts and critically evaluate the information obtained from other studies in an orderly and consistent manner (Kothari, 2004).

Following the data collection, the analysis of data will be required. For this purpose, the data collected – narrative and numerical – will be edited, sorted, examined, coded, categorised, classified, evaluated and analysed by using different tools and techniques in order to answer the research questions (Kothari, 2004).

For example, through the data sorting and analysis, the similarities in responses will be identified, relationships between variables will be linked, patterns will be identified which will help to generalise the formed patterns and formalise the body of knowledge (Miles & Huberman, 1994).

Data will go through the reduction process during which the notes from in person interviews and transcriptions from online interviews will be simplified and transformed with the following graphical display and interpretation in the final report (Miles & Huberman, 1994).

After the interpretation of the information and the report drafting, the final presentation will be presented, and a formal conclusion reached. The report will consist of an introduction, summary of information obtained, main report and conclusion. The report will be prepared in a logical and explanatory way.

Following the discussed multimethodology, this research will answer the identified and defined research questions, and achieve the research aims and objectives. Also, the proposed multimethodology through the philosophical framework will try to find “*a solution for an immediate problem*” New Zealand and global society face now and accept or reject the formulated hypotheses.

3.16 Philosophy of this Research

Taking as a basis of post-positivism, we can say that the problems we face today, such as climate change and environmental degradation, caused by consequences of human activities and technological revolution. Having said that, philosophy of technology intersects with environmental philosophy.

Poel, with reference to Winner, speculates that technologies are the human products and are “*shaped by human interests and values, and open to human choice*” (Poel, 2020). He stresses that “*the impact of technology on society is deterministic*” and that this impact can be either techno-pessimistic or techno-optimistic. The parallel of Poel’s assumption and constructivist approach can be drawn in this research.

Consumerism and human actions have caused environmental degradation, pollution and climate change. To protect and recover the environment, achieving decarbonisation and sustainability goals, humans may need put environmental philosophy in place. As emphasised by Poel, humans can “*shape new technologies by their interests and values*”. New technologies have already started to be shaped by humans. If humans align the innovative technologies with revised “*values, needs and expectations*”, the environmental concern, as an effect, will be addressed.

Introduction of new technologies may affect existing and create new realities and moral problems which may require reviewing of existing moral values, obligations and standards (Poel, 2020).

On the basis of philosophical frameworks, literature review and statistical display, cause and effect pattern can be drawn as follows:

Population growth > cause > energy demand > effect

Energy demand > cause > increase in fossil fuel consumption > effect > fuel poverty > effect

Fuel poverty > cause > health deterioration and productivity decrease > effect

Increase in fossil fuel consumption > cause > environmental degradation > effect

In other words, causes have determined effects. In terms of variables, the following relationships of variables can be formulated:

1. Population growth – independent variable (predictor) – Energy demand – dependent variable (criterion).
2. Energy demand - independent variable (predictor) – Fossil fuel consumption increase - dependent variable (criterion)
3. Fossil fuels consumption increase - independent variable (predictor) – environmental concern increase - dependent variable (criterion)

Cause / Independent Variable / Predictor	Effect / Dependent Variable / Criterion
Population growth	Energy demand and economic growth
Energy demand and economic growth	Fossil fuel consumption increase
Fossil fuel consumption increase	Environmental concern increase

Table 6: Causal Relationships: Population Growth, Energy Demand, and Environmental Concern

Variable Interactions in the Context of Energy Demand and Environmental Impact

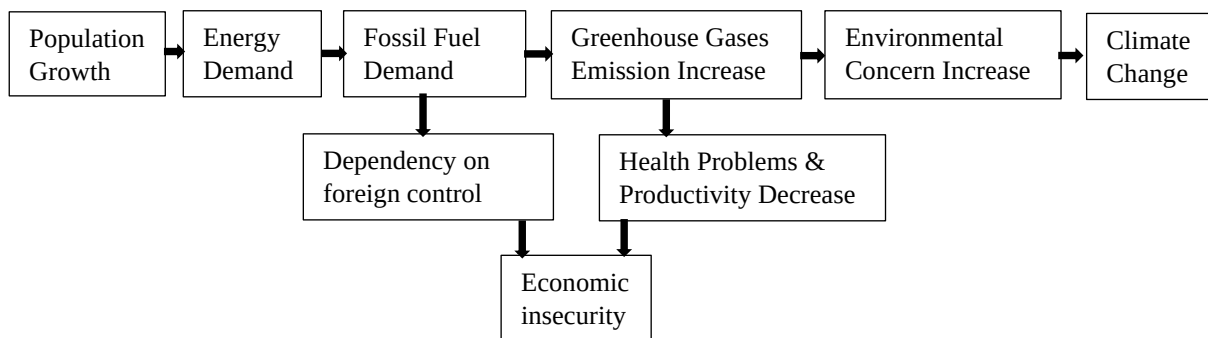


Figure 4: Variable Interactions in the Context of Energy Demand and Environmental Impact

Hypothesis – if the patterns of variables will be reformulated to the following dependencies, the environmental concern will be decreased:

1. Population growth – independent variable (predictor) – Energy demand – dependent variable (criterion).
2. Energy demand increase – independent variable (predictor) – Introduction of sustainable renewable energy sources (Green hydrogen and hydrogen technologies) increase – dependent variable (criterion)
3. Green hydrogen production and hydrogen technologies implementation increase, (consequently, quality of education increase, energy efficiency increase, fuel poverty decrease, productivity increase) – independent variable (predictor) – fossil fuel consumption decrease – dependent variable (criterion)
4. Fossil fuel consumption decrease – independent variable (predictor) – environmental concern decrease – dependent variable (criterion)

Cause / independent variable / predictor	Effect / dependent variable / criterion
Population growth	Energy demand & Economic Growth
Energy demand & Economic Growth	Sustainable energy resources increase

Sustainable energy resources increase	Fossil fuel consumption reduction
Fossil fuel consumption reduction	Environmental concern decrease/ Environmental recovery

Table 7: Causal Relationships between Population Growth, Energy Demand, and Environmental Impact

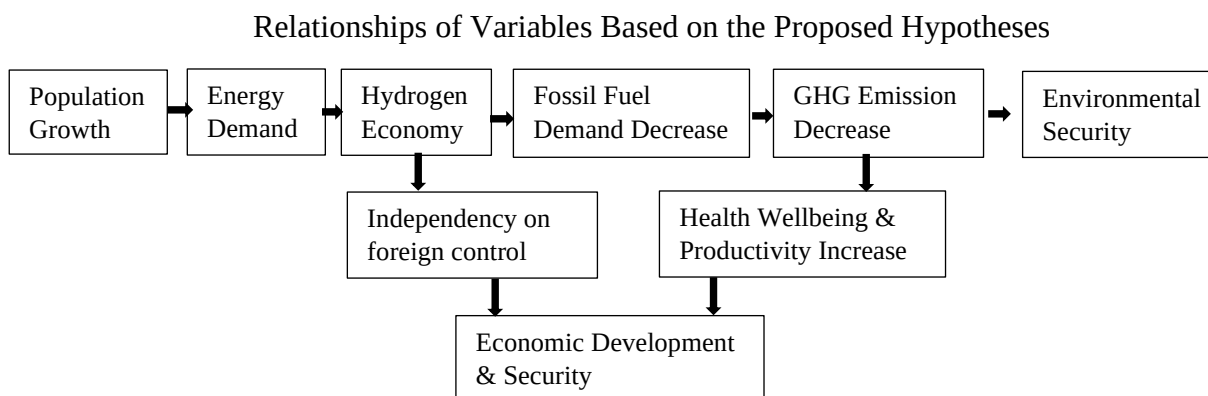


Figure 5: Relationships of Variables Based on the Proposed Hypotheses

We live in reality where energy has a great impact on socio-economic and political aspects, where humans constantly consume energy. The more population growth, the more energy they consume. Two variables – population growth and energy demand - are interconnected. However, population growth as an independent variable has several other dependent variables and the following casual relationships can be created: population growth – fossil fuel consumption, population growth – environmental degradation. However, if the input variable such as new energy resource will be introduced, it may change the casual relationship in the following way: population growth – energy demand, population growth – sustainable energy demand, population growth - environmental recovery. Population growth is considered as a cause and all other variables as effect of this cause.

Based on the conceptual framework and continuum of research paradigms adapted by Groat and Wang from Mugerauer, 1995; Guba and Lincoln, 1998; Teddlie and Tashakorri, 2009; and Mertens, 2010, the theoretical framework for this study can be outlined as the following:

Positivist traditions can find their application in this study where multiple variables can be objectively measured to practically reflect the reality. At the same time, constructivists find their manifestation in subjective epistemology where researchers and participants cooperatively come up with understanding of the researched problem and knowledge which can find practical application for solving the problem (Groat & Wang, 2013).

Objective ←-----→ Subjective

	Positivism/Post-Positivism		Intersubjective	Constructivism	
Epistemology	Knowledge distinct from object of inquiry	Knowing through distance from object	Knowledge framed by understanding sociocultural engagement	Knowledge co-constructed with participants	Knowledge perpetually provisional
Ontology	Assumes objective reality	External reality revealed probabilistically	Diverse realities situated in sociocultural context	Multiple constructed realities	Infinite realities

Table 8: Continuum of research paradigms. Adapted from Mugerauer, 1995; Guba and Lincoln, 1998; Teddlie and Tashakorri, 2009; and Mertens, 2010 (Groat & Wang, 2013)

Undeniably, environmental degradation and population growth cannot be considered as separate issues. On the one hand, high fertility rate, longevity, low mortality rate and overall improvement of health sector have contributed into population growth. It can be treated as a positive aspect for the economic development especially in developed countries where parents invest in their children's education – "*human capital*". Becker is confident that the modern approach of investment in human capital and new technologies is a fundamental aspect for developed countries and new economic models (Becker, 1992). On the other hand, population growth causing the increase in energy production and consumption negatively affecting the natural resources and environment (Ray, 2011).

The environmental problems and climate change, in turn, cause health problems which may have negative impact on socio-economic and political situations globally (Ray, 2011; Pimentel, 2007).

Some sceptics may argue that in order to protect the environment and natural resources, the population planned programs should be implemented (Qu, 1982). However, putting measures to control population growth, will this be morally admissible? Asking this abstract question, we should not forget about environmental and ecological philosophical principles either. Being a human means that we have ethical and moral obligations to protect environment we live in, and environmental ethics emphasise these principles (Desjardins, 2013).

3.17 Environmental Ethics and Environmental Philosophy

While environmental ethics focuses on nature and relationship of human being with this nature, the environmental philosophy focuses on the broader concepts of the environment (Brennan, 2002).

Brennan, with references to O'Neil and Jamieson, accentuates human responsibilities and "*moral duties*" to protect the nature. Traditional anthropocentrists may disagree since they proclaim human over the nature and believe that whatever is for "*the sake of man*" should be justified; the nature is the merely the instrumental means for human goals.

However, nonanthropocentrists and weak anthropocentrists criticise and discouraging this position (Norton, 1984). They find consumerism as an "*ecologically destructive and unsustainable*" problem, which diverts humans from nature. They encourage humans to re-establish their connection with nature in order to achieve sustainability and address current environmental problems. It can be outlined that connection with the sustainable environment is an essential factor for future human beings (Emerald, 2004).

Environmental ethics, as a novel discipline of environmental philosophy, has posed a challenge to anthropocentric's views by emphasizing human obligations towards nature to treat the environment in a way as humans treat themselves. Positivists have an optimistic view on the human – nature relationship; animists remove boundaries between human and nature claiming that the "*living nature*" should be associated not only with humans, flora and fauna but with water, land, bushes and mountains (Emerald, 2004).

The analogy between environmental philosophy, animistic framework and Māori cultural can be drawn. The environmentalists aspirations align with Māori's values about the nature protection. Māori do have a very strong connection with the nature and the land demonstrating their concern for the environment, since the land is the source of life, and the sustenance thus must be protected. Lockhart, referring to Challenger, accents the Māori's spiritual connection with Mother Earth as a

basis of life for human existence, and draws the parallel between healthy environment and human “*spiritual welfare*” and well-being (Lockhart, 2019).

The significance of this passage lies in its exploration of how different philosophical and ethical frameworks influence human relationships with the environment. By contrasting anthropocentric views with non-anthropocentric and animistic perspectives, the discussion emphasizes the moral obligations humans have toward nature. This is particularly relevant in addressing modern environmental challenges, as it critiques consumerism and encourages a reconnection with nature to achieve sustainability. The parallel drawn between environmental philosophy and Māori cultural values further highlights the importance of integrating indigenous knowledge and spiritual connections to the land in fostering sustainable practices. Ultimately, the passage underscores the need for a shift in ethical and cultural perspectives to ensure a healthy environment for future generations.

3.18 Conclusion

Chapter Three is a cornerstone in establishing the research’s foundational framework. It intricately weaves together various essential elements of the research process, showcasing a robust theoretical framework aligned with specific research types, strategies, and philosophies. The interpretive nature of the research takes centre stage, underpinned by a multimethodological approach that seamlessly integrates qualitative, quantitative, and mixed methods. The discussion delves into vital components of research methodology, including triangulation, validity, reliability, deduction, and induction, ensuring a comprehensive and robust approach. Research design and methods, such as snowball sampling, interviews, and questionnaire surveys, are carefully addressed. Additionally, the chapter sheds light on the methodology adopted for the literature review, paying heed to the philosophical underpinnings and ethical considerations. This chapter sets the stage for the subsequent unveiling of findings derived from semi-structured exploratory interviews and an extensive literature review.

In essence, this chapter strategically navigates through the theoretical foundations, aligning them with the unique demands of this research. The need for a multi-methodology approach is underscored, reflecting the study’s complexity and the multifaceted nature of green hydrogen integration into New Zealand’s built environment. The careful blend of theoretical and practical knowledge within an ethical and ecological framework echoes the research’s holistic aims. By seamlessly incorporating diverse paradigms and methodologies, this study is poised to uncover nuanced insights vital for a sustainable, zero-emissions future.

Chapter 4 - Semi-Structured Exploratory Interviews and Literature Review: Report of Findings

4.1 Introduction

Chapter Four embarks on an insightful exploration of the research findings derived from semi-structured exploratory interviews and an extensive literature review. The methodology employed is carefully outlined, providing a strategic approach to understanding the perspectives and motivations of industry professionals regarding green hydrogen technologies in the built environment. Through a systematic breakdown of various interviews conducted globally, this chapter uncovers a rich tapestry of insights, weaving through the diverse views and backgrounds of participants. It delves into the intricate details of different geographical contexts, offering a nuanced understanding of how various regions perceive and approach the integration of green hydrogen. Additionally, the chapter synthesizes a comprehensive review of literature, presenting a thorough analysis of pivotal aspects such as decarbonization, environmental sustainability, government policies, technological advancements, challenges, and cost considerations in the realm of green hydrogen technologies. The subsequent sections delve into the findings and variations in viewpoints, setting the stage for a comprehensive conclusion that consolidates the essence of these discoveries.

4.2 Methodology

Research Design - This chapter elucidates the methodological approach undertaken to investigate the multifaceted landscape of green hydrogen and hydrogen technologies within the purview of the built environment and other sectors. A qualitative research design was meticulously crafted to probe into the nuanced dimensions of this emerging field. In pursuit of comprehensive insights, a diverse cohort of 16 deliberately selected participants hailing from distinct countries was engaged. These participants were deemed apt for the research's purpose, offering a panoramic view of global perspectives on hydrogen-related matters.

Data Collection - Semi-structured interviews were employed as the primary data collection method, facilitated by a set of open-ended questions meticulously designed to encompass a wide array of facets associated with green hydrogen and its manifold applications. The interviews navigated through themes including hydrogen technologies, their application within the built environment and other sectors, their role in decarbonization, safety considerations, the inception of the hydrogen economy, regulatory frameworks, standards, government support, public perceptions, requisite skills and knowledge for the burgeoning hydrogen industry, the economic implications of hydrogen technologies, and the spectrum of green and low-carbon hydrogen.

Data Analysis - The qualitative data harvested from the interviews underwent a systematic analytical process. NVivo, a robust qualitative data analysis software, was harnessed to facilitate data management, sorting, coding, and categorization. Through an iterative approach, the data was meticulously scrutinized, enabling the identification of recurring themes, patterns, and subtle variations across participants' perspectives. The thematic analysis framework was judiciously employed, underpinning the systematic exploration of the data's underlying structures.

Emergence of Themes - The thematic analysis revealed a rich tapestry of participant responses. Consistent threads of consensus emerged on certain issues, wherein participants converged in their viewpoints. Simultaneously, intriguing divergences surfaced, encapsulating the diversity of perspectives harboured by participants from different countries and professional backgrounds.

Research Rigor - The research's robustness was ensured through several strategies. The participants' diversity, originating from varied countries, was instrumental in enriching the depth and breadth of insights. The open-ended nature of the questions facilitated a comprehensive exploration of the research landscape. Triangulation was employed by cross-referencing participant responses against established literature and extant knowledge. This multi-pronged approach engendered data validity and credibility.

Contribution to Research and Future Directions - This chapter's findings constitute a pivotal stepping stone in addressing the research's overarching questions, objectives, and aims. The qualitative data amassed has not only illuminated the current contours of hydrogen-related perspectives but has also paved the way for the impending quantitative phase. The insights garnered from this qualitative phase will be instrumental in shaping the survey questions for the subsequent research stage, thereby fortifying the research's holistic approach and bridging qualitative and quantitative paradigms.

Conclusion - This chapter elucidated the intricacies of the research's methodological underpinning, illuminating the rationale, design, and execution of the qualitative phase. The diverse participant cohort, in conjunction with the thematic analysis approach, has culminated in an expansive panorama of perspectives on green hydrogen and hydrogen technologies. This foundational phase provides a robust groundwork for the forthcoming quantitative phase, amplifying the research's comprehensive exploration of hydrogen's multifarious facets.

4.3 Interviews with the Industry Professionals

This chapter presents the results obtained from a combination of comprehensive literature review and exploratory semi-structured interviews conducted with professionals in the hydrogen industry. Since the hydrogen industry, with its potential to contribute to decarbonization efforts and transition to a sustainable energy future, has gained significant attention globally, including New Zealand, there has been a need to explore the viewpoints of industry professionals to gain deeper insights into the challenges, opportunities, and key factors that influence the successful implementation and advancement of hydrogen technologies.

Semi-structured exploratory interviews have been selected as one of the primary research methods for this study due to their flexibility in capturing rich and nuanced information while allowing for an exploratory approach. This research methodology offered the opportunity to engage directly with hydrogen industry professionals, including key stakeholders, experts, and decision-makers, to gain first-hand knowledge and perspectives on the current state and future prospects of the hydrogen industry.

By conducting exploratory semi-structured interviews, this research stage has addressed several research objectives. First, it has helped to understand the current status of hydrogen technologies and initiatives in the industry, including the state of research and development, commercial applications, and policy frameworks. Second, it has identified the main drivers and barriers influencing the adoption and integration of hydrogen technologies in New Zealand as a whole and in the New Zealand built environment in particular. Third, it has explored the role of various stakeholders, such as government agencies, industry players, and research institutions, in shaping the hydrogen industry landscape and driving its growth. Finally, the experts' opinions on potential strategies and pathways for the future development and deployment of hydrogen technologies in the New Zealand region have been gathered.

To ensure a comprehensive and diverse perspective, a purposive sampling technique have been utilized to select participants for the semi-structured interviews. This involved targeting professionals

with significant experience and expertise in the hydrogen industry, representing various sectors including government, industry, research institutions, and non-governmental organizations. The inclusion of multiple stakeholders has enabled a holistic understanding of the challenges and opportunities surrounding hydrogen technology adoption and provided a well-rounded analysis for this PhD research.

The findings from these semi-structured interviews have been analysed using thematic analysis techniques, allowing for the identification of recurring patterns, key themes, and critical insights within the data. The results of this research will contribute to the existing body of knowledge on the hydrogen industry, providing valuable insights for policymakers, industry practitioners, researchers, and other stakeholders interested in the development and advancement of hydrogen technologies.

Several interviews were conducted with professionals in the field of green hydrogen technologies to gather insights and gain a deeper understanding of the decarbonization potential of the built environment through the utilization of green hydrogen. These interviews proved to be instrumental in acquiring valuable information and industry perspectives that enriched the study.

The interviewed green hydrogen professionals generously shared their expertise and provided a wealth of information pertaining to various aspects of the study. Their insights encompassed topics such as hydrogen production technologies, storage and distribution systems, policy frameworks, and the integration of green hydrogen within the built environment. The discussions shed light on the technical, economic, and environmental considerations of implementing green hydrogen technologies in decarbonizing the built environment.

Furthermore, the professionals recommended additional resources, such as research papers, industry reports, and relevant publications, which proved to be invaluable for further expanding the knowledge base of the study. These resources were thoroughly studied, analysed, and incorporated into the report to enhance the comprehensiveness and depth of the research findings.

The interviews and the subsequent exploration of the recommended resources allowed for a comprehensive examination of the challenges, opportunities, and potential pathways for achieving decarbonization goals through the utilization of green hydrogen technologies in the built environment.

The contribution of the interviewed professionals and the insights gained from their expertise played a crucial role in shaping the analysis and recommendations presented in this report. Their valuable inputs served as a foundation for further investigation and synthesis of information, ultimately strengthening the overall quality and relevance of the research.

4.4 Interviewees' Inspiration, Motivation and Vision

The interviewees who work within the green hydrogen industry showcased a deep passion and inspiration for their chosen career path. Their motivations, visions, and diverse backgrounds have played a significant role in driving their commitment to advancing green hydrogen technologies and utilizing them as a means to address the challenges of decarbonization in the built environment.

The interviewees expressed various factors that sparked their interest and inspired them to work within the green hydrogen industry. Some highlighted the urgency of addressing climate change and the desire to contribute to sustainable solutions as the driving force behind their career choice. Others shared personal experiences, such as witnessing the environmental impacts of traditional energy sources or being involved in renewable energy research, which ignited their passion for green hydrogen.

Motivations varied among the interviewees but commonly revolved around the potential of green hydrogen to revolutionize the energy landscape and foster a cleaner, more sustainable future. They

emphasized the need to reduce carbon emissions, mitigate environmental degradation, and ensure energy security for future generations. Many interviewees expressed a strong belief in the transformative power of green hydrogen and its ability to reshape the energy sector and contribute to a more sustainable built environment.

The interviewees' diverse backgrounds brought valuable perspectives to their work within the green hydrogen industry. They hailed from a range of disciplines including engineering, environmental science, policy, and economics. This multidisciplinary background provided them with a holistic understanding of the technical, economic, and policy dimensions of green hydrogen, enabling them to approach challenges and opportunities from different angles.

Their educational and professional backgrounds equipped them with the necessary knowledge and skills to navigate the complexities of the green hydrogen industry. Moreover, their experiences in related fields, such as renewable energy, sustainability, or energy policy, have contributed to their expertise and provided a solid foundation for their work in advancing green hydrogen technologies.

The interviewees shared a common vision for the future, envisioning a world where green hydrogen plays a pivotal role in the decarbonization of the built environment. They expressed a strong belief in the potential of green hydrogen to provide a sustainable and reliable energy solution, reduce greenhouse gas emissions, and foster economic growth. Their collective vision serves as a driving force in their daily endeavours to promote, develop, and implement green hydrogen technologies.

Understanding the inspiration, motivations, visions, and backgrounds of the interviewees provides valuable insights into the personal journeys and perspectives of professionals within the green hydrogen industry. It highlights the deep commitment and dedication they bring to their work, and it underscores the significance of their contributions to the advancement of green hydrogen technologies in the context of decarbonizing the built environment.

Participant	Background - Education	Person	Place
DA	Energy Sector	Male	Korea
EEF	Mechanical Engineering	Male	Costa Rica
JH	Engineering	Male	New Zealand
JAGR	Chemical Engineering	Male	Mexico
KQ	Engineering	Female	The USA (California)
MR	Chemical Engineering	Female	Italy
MS	Telecommunication / Mobile Network	Male	Indonesia
PL	Energy Sector	Male	France
RH	Engineering	Male	New Zealand
RGJA	Energy Sector	Male	Colombia
SGJA	Mechanical Engineering	Male	Mexico
SJS	Business Owner	Male	Germany
TW	Engineering	Male	New Zealand
TN	Business Development	Male	Japan/ New Zealand

VG	Energy Sector	Male	Saudi Arabia
ZJ	Chemical Engineering	Male	The UK

Table 9: Participants Demographics

4.5 Participants' Background and Insights on Hydrogen Technologies

In the discussions with participants from various perspectives, a unified consensus emerges regarding the immense potential of hydrogen as a transformative and sustainable energy carrier, particularly within the manufacturing and energy sectors. The role of hydrogen in providing a stable energy supply for manufacturing processes is underscored, with a keen focus on the benefits of using renewable energy sources for hydrogen production. This aligns with the versatile nature of hydrogen, as its application spans from powering vehicles to fuelling industrial operations, highlighting its adaptability across diverse sectors. The significance of sustainable hydrogen production methods, particularly electrolysis powered by renewable energy, garners unanimous acknowledgment. While proton exchange membrane (PEM) fuel cells are recognized for their role, participants also recognize their limitations in certain scenarios due to efficiency concerns. The potential of alkaline fuel cells is discussed, with optimism surrounding ongoing advancements that promise improved efficiency and flexibility.

The dialogues delve into the cost-effectiveness of hydrogen solutions, especially in residential settings. Comparative evaluations against battery technologies reveal intriguing insights into hydrogen's resource-intensive nature. Yet, a consensus emerges that hydrogen could find its place, especially in emergency backup power scenarios. The global perspective on hydrogen adoption is also touched upon, citing Japan's enthusiasm for hydrogen technologies. Challenges surrounding language barriers are acknowledged, which limit direct communication on the matter. Despite challenges, participants express optimism about the scalability of hydrogen production and storage, envisioning a role for hydrogen in balancing seasonal energy demands.

Amid the technological optimism, the participants highlight the early stage of hydrogen technology development. Skill enhancement and digitalization are identified as crucial to ensuring the sustainability of green hydrogen production. Environmental concerns pertaining to resource extraction for hydrogen production are also addressed. The importance of hydrogen fuel cells in diverse applications, including larger buildings, industries, and even dairy farms, is recognized. Participants concur that evolving codes and standards facilitate the safe integration of hydrogen solutions.

Technological advancements are spotlighted, with a shared belief in the rapid evolution of hydrogen technologies. The modular design of anion exchange membrane (AEM) electrolyzers, exemplified by companies like Enapter, is highlighted for its potential to enhance efficiency, scalability, and cost-effectiveness. Yet, conversations underscore the importance of considering the holistic efficiency and cost of entire systems, beyond individual components.

Throughout the discussions, the versatility of hydrogen as a clean energy carrier takes centre stage. Green hydrogen, produced through renewable energy sources, emerges as a critical driver in making hydrogen solutions truly sustainable. Participants emphasize the necessity for seamless system integration, interconnectivity between technologies, and collaborative efforts across various sectors and industries.

The participants stress the significance of a reliable energy supply, and they see hydrogen as a pivotal solution for achieving this, especially in terms of energy carriers. They view hydrogen as a novel and

versatile gas, essential for decarbonization efforts. Despite being a new technology, its potential to create fuel from water and emit only water upon usage is seen as a game-changer.

Collectively, the conversations resonate with the pivotal role of hydrogen in the transition to a sustainable energy future. Challenges and debates notwithstanding, the potential for hydrogen to reshape industries, accelerate decarbonization, and revolutionize the energy landscape stands as a common thread. The trajectory of technology, collaboration across sectors, and alignment with sustainability goals are underscored as the keys to unlocking hydrogen's full potential. The participants believe that hydrogen holds the promise to be a key enabling technology for the future due to its workable nature and its potential to revolutionize energy systems:

"I think it's the magic of hydrogen. The magic of creating a fuel from water" (JAGR)

"It's a new technology. It's a new space. It is a kind of versatile gas that can be used anywhere" (DA)

"I think it has future" (RGJA)

4.5.1 DA - Korea

In this semi-structured interview, the participant, identified as DA, shared valuable insights into his background and expertise in hydrogen technologies. With a background in the energy sector and a focus on refining processes, DA's experience at GCS Energy, a major Korean oil refinery, provided direct exposure to hydrogen's critical role within the industry. DA's current role at Intralinks involves overseeing hydrogen projects, where they have engaged with a variety of hydrogen technologies, including reforming, electrolysis, and fuel cell technologies. This hands-on involvement extends to collaborating with fuel cell coating companies and exploring different types of bipolar plates.

DA's views on hydrogen and its technologies seem to be practical and informed, recognizing the value of green hydrogen while considering the complexities. Given Korea's challenges in adopting traditional renewable energy sources, DA recognizes hydrogen and fuel cells as a promising solution for stable energy supply and decarbonization, making Korea a leader in fuel cell production and power plant installations.

DA highlighted the significance of hydrogen in the decarbonization of the built environment, particularly in countries like Korea, where stable energy supply is crucial for its manufacturing-based economy. He emphasized the potential of fuel cells for residential and commercial buildings, offering a practical solution to meet the energy needs of these sectors while reducing their ecological footprint.

DA's opinion is that the manufacturing realm critically hinges on a consistent and dependable energy supply, precisely where hydrogen emerges as a game-changing prospect. This novel technology, as per DA's assessment, operates within a fresh domain, centred on the extraction of hydrogen through environmentally friendly means, particularly by harnessing renewable energy sources. According to DA, the potential for hydrogen as an energy carrier is vast and versatile, spanning diverse applications like vehicular use and industrial processes. As an adaptable gas, in DA's view, its utility knows no bounds. It's important to note, as DA points out, that the pure hydrogen-based PEM fuel cell, often discussed, excels in applications necessitating frequent on-off cycling, such as automobiles. However, DA emphasizes that it's not a sustainable choice for static systems like buildings or uninterruptible power supplies.

As DA sees it, for these applications, the sourcing of hydrogen or renewable energy through fuel cells stands as the sole viable option. This perspective, according to DA, underscores the immense potential of fuel cells in both commercial and residential structures. Among these, DA highlights that the PEM fuel cell, deemed a sophisticated electrolysis system, demonstrates an efficiency of around 80 to 85%.

Following suit, as noted by DA, alkaline fuel cells emerge as the next-tier technology, exhibiting efficiencies of approximately 70 to 75%. DA observes that a plethora of companies are actively engaged in the advancement of various hydrogen production technologies.

According to DA's insights, the current focus extends beyond the production of solely green hydrogen, emphasizing accessibility to a wide spectrum of hydrogen variants for public consumption. This impetus, as highlighted by DA, is why significant investments are being channelled into fuel cell technologies. In essence, DA's opinion is that hydrogen's potential to provide a consistent, adaptable, and environmentally conscious energy source positions it as a transformational force in the manufacturing landscape.

DA discussed the potential for utilizing hydrogen technologies for domestic and commercial applications. Regarding fuel cells for buildings, he stated:

"The only way of decarbonizing the built environment is through a fuel cells. So that's the only way that's left for carrier for countries like Korea, Japan and Taiwan where the land is quite restricted" (DA).

He believes that fuel cells could play an important role in helping countries like Korea meet regulations requiring a portion of buildings' electricity to come from renewable sources, since options like solar and wind are limited.

DA noted that key challenges remain for wide adoption of hydrogen, particularly around the transportation and storage of hydrogen. However, he saw potential benefits if these issues could be overcome:

"If we find a way of generating hydrogen using relatively cheap renewable energy. And then we have a solution to decarbonize not only the built environment, but everything that uses energy basically" (DA).

While progress is being made, DA estimated it could take decades for green hydrogen to fully replace fossil fuels in some hard-to-abate sectors.

When discussing the challenges of hydrogen technologies, DA addressed issues such as the cost and efficiency of production, transportation, and storage. He stressed the importance of scaling up hydrogen production to drive down costs and make it more accessible. Additionally, safety considerations were acknowledged, recognizing the need for stringent regulations and public awareness campaigns to dispel misconceptions and build confidence in hydrogen as a safe energy source.

DA also highlighted the role of government support in promoting hydrogen adoption, providing subsidies to incentivize the development of hydrogen infrastructure and encourage the use of hydrogen-powered vehicles.

As for the future of green hydrogen, DA expressed optimism about its potential to revolutionize the energy landscape. He predicted that while complete replacement of fossil fuels may take several decades, scaling up hydrogen production and efficient delivery mechanisms could be achieved in the shorter term.

One particularly noteworthy point made by DA was the importance of addressing the energy trilemma of affordability, energy security, and sustainability. He believed that hydrogen technologies could play a vital role in striking a balance between these three key factors, especially in regions like Korea, where sustainable energy sources are limited.

In conclusion, this interview with DA shed light on the current state and prospects of hydrogen technologies, particularly in the context of domestic and commercial applications. DA's expertise

and experiences in the field provided valuable insights for understanding the challenges and opportunities in realizing the full potential of hydrogen as a clean and sustainable energy solution for diverse sectors, paving the way towards a greener and more energy-efficient future. DA's perspective highlights the promise of hydrogen technologies for decarbonizing the domestic and commercial sectors through fuel cells, but also significant barriers still exist that must be addressed for truly wide-scale implementation.

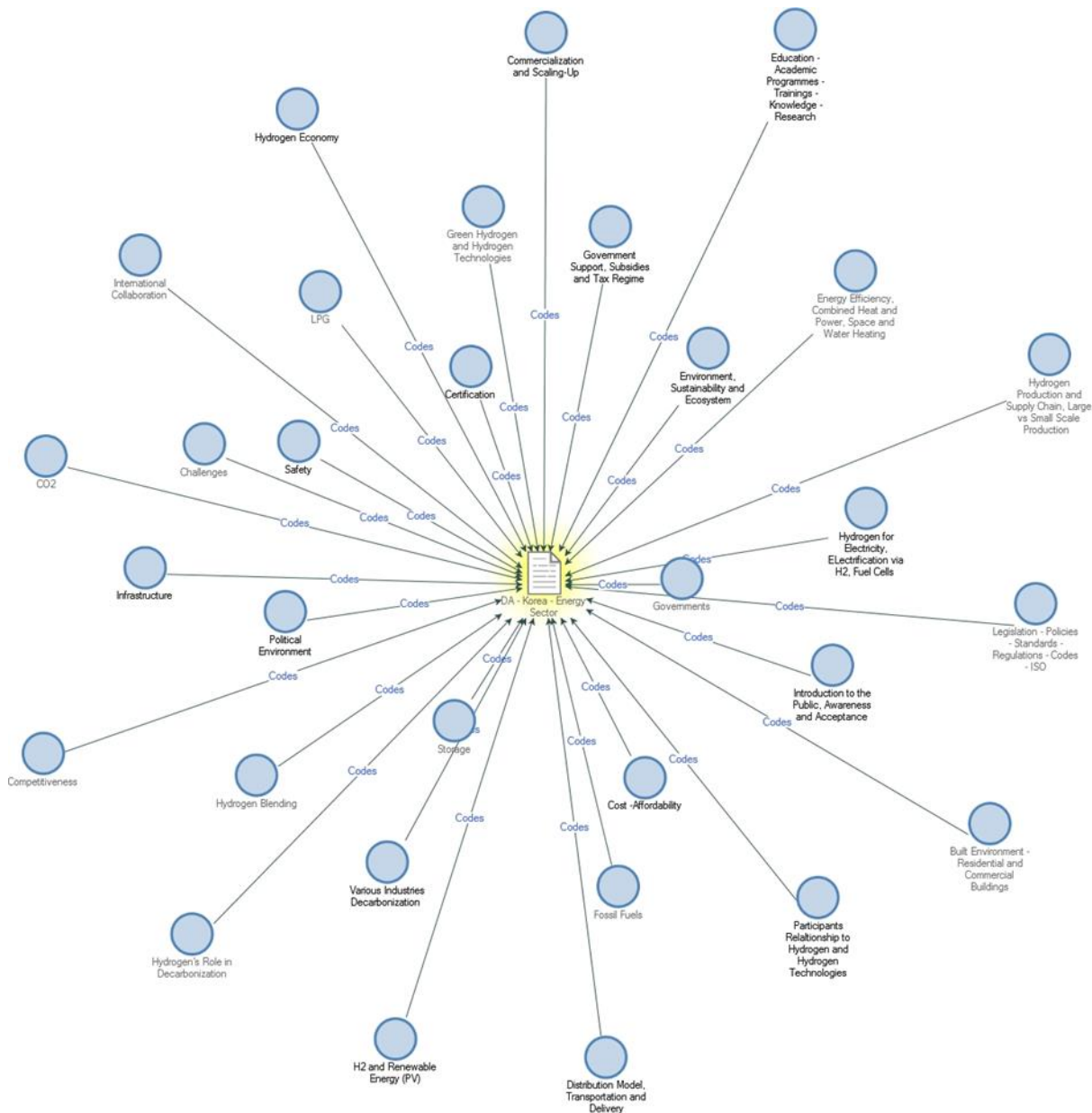


Diagram 1: DA - Thematic Interview Summary Diagram

4.5.2 EEF – Costa Rica

EEF has been deeply involved in hydrogen technologies since his post-graduate studies and has since played a vital role in Costa Rica's hydrogen endeavours. His journey into the world of hydrogen began after completing a master's degree, when he joined Astra Rocket Company, founded by a Costa Rican astronaut. His association with this visionary figure and the appealing prospect of hydrogen technology garnered interest from stakeholders in Costa Rica. EEF played a pivotal role as a mechanical engineer in a team of five that successfully established the country's first hydrogen generation, storage, and dispensing plant. This achievement encompassed fuelling Toyota Mirai

vehicles and an Airbus hydrogen fuel cell bus. EEF's commitment extended beyond pilot projects, as he pursued sustainable implementation of hydrogen technologies in Costa Rica. His endeavours included shaping the Costa Rican national hydrogen strategy and collaborating with the United Nations Environmental Program to develop Panama's hydrogen strategy. EEF's ongoing contributions extend to assisting private companies with their hydrogen projects and coordinating the Alliance for Hydrogen in Costa Rica, which unites various players across the hydrogen supply chain. His expertise extends from mechanical engineering to sustainable innovation, working on national hydrogen strategies and private sector projects. EEF envisions hydrogen as a versatile solution to decarbonize various sectors and believes in its potential for green, CO₂-free energy generation and storage.

EEF's perspective, as expressed, is that hydrogen functions much like a battery, offering comparable energy storage in a more compact manner. EEF notes that while weight is a concern in transportation, it becomes less pertinent in other applications. Moreover, EEF highlights that hydrogen boasts nearly triple the efficiency, making it an appealing contender. However, as EEF points out, the intricacies of a system involving an electrolyser, tank, and fuel cell interlinked by pipes and pressure add a layer of complexity beyond the simplicity of batteries.

EEF suggests that a scenario wherein only a fuel cell, tank, and centralized hydrogen were needed for recharging clients could be feasible if numerically viable. EEF acknowledges that transportation of hydrogen, if cost-effective, could transform the equation. Nevertheless, EEF recognizes that the puzzle of seamlessly integrating hydrogen into this realm persists, as the present landscape indicates that alternative pathways might yield better results.

According to EEF's observations, the current focus is on generating hydrogen to meet pre-existing demands, particularly in the production of ammonia and fertilizers. EEF notes that the potential to produce excess hydrogen offers a tantalizing proposition. EEF speculates that an over-scaled electrolyser could unlock a trove of available hydrogen gas, paving the way for diverse applications, from cars to backup power generation.

While acknowledging the complexity of materials required for these technologies, EEF believes that their absence does not diminish their potential. EEF underscores the urgency to decarbonize, emphasizing the indispensability of these innovative solutions. EEF points out that while many of these technologies have roots in the past, their significance in today's context is unparalleled.

Indeed, as EEF sees it, hydrogen's allure lies not only in its scientific marvel of water conversion but also in its potential to revolutionize diverse sectors. EEF believes that its ability to merge with our energy landscape, much like a Trojan horse, awaits a future where numbers align, propelling us toward a greener horizon.

Regarding the decarbonization of the built environment, EEF highlights hydrogen's ability to generate heat and electricity with only water as emissions. He sees hydrogen as an ideal candidate for decarbonizing economies, especially in countries with abundant renewable energy sources like Costa Rica. While electricity generation is already largely decarbonized, transportation and industrial sectors remain challenging areas to tackle, making hydrogen a compelling solution.

EEF stresses the importance of baseline assessment and measuring the impact of hydrogen technologies on decarbonization. Evaluating CO₂ emissions reduction based on technology displacement is crucial to understand the environmental benefits fully. Furthermore, he emphasizes the need for subsidies or concessional funding to drive the adoption of hydrogen technologies, especially in countries with limited financial resources.

In the context of introducing hydrogen technologies to the international market, EEF emphasizes that safety concerns can be addressed through existing norms and regulations for handling gases. While

hydrogen does face challenges with its supply chain and production costs, EEF sees it as a promising technology with the potential to lower carbon emissions in various sectors. He believes that continued investment, government mandates, and increased opportunity costs for alternative fossil fuels can drive wider adoption of hydrogen technologies.

When asked about using hydrogen in buildings, EEF was sceptical about deploying fuel cells in homes. He felt batteries would be a better fit given their higher efficiency and lower complexity versus having an electrolyser, storage tanks and fuel cell system. However, EEF thought hydrogen could play a role for heating in some geographies. As he stated:

“I understand that it’s part of the inefficiency of a fuel cell goes in heat. So if you’re using that heater, that is fantastic”.

He also saw potential for hydrogen in industrial settings.

EEF acknowledges that hydrogen can play a significant role in decarbonizing energy consumption, especially in the industrial and agricultural sectors. He encourages a focus on finding demand-driven applications, such as using hydrogen for producing green fertilizers. Moreover, EEF emphasizes the need to consider life cycle analysis and sustainability when developing hydrogen technologies, ensuring that the supply chain and materials are environmentally friendly and recyclable.

EEF emphasized the high upfront costs of hydrogen technology as the biggest barrier to adoption. In his view, government mandates and subsidies will be critical to drive deployment. As EEF argued, many companies will not adopt hydrogen *“if it’s less expensive it will happen I think. I’ve seen many projects that just don’t happen because of that, like people are not going to pay more if they don’t have a good reason”*.

In summary, EEF’s insights emphasize the importance of addressing safety concerns, providing financial support, and establishing government mandates to drive the acceptance of hydrogen technologies. He envisions hydrogen as a powerful means to decarbonize the built environment, stressing that it can bring about a cleaner, greener future. Fuel cells for buildings hold the potential for efficient power generation, while reducing CO₂ emissions and promoting sustainability. As hydrogen technologies continue to mature, they offer a compelling solution to the global challenge of decarbonization across various sectors.

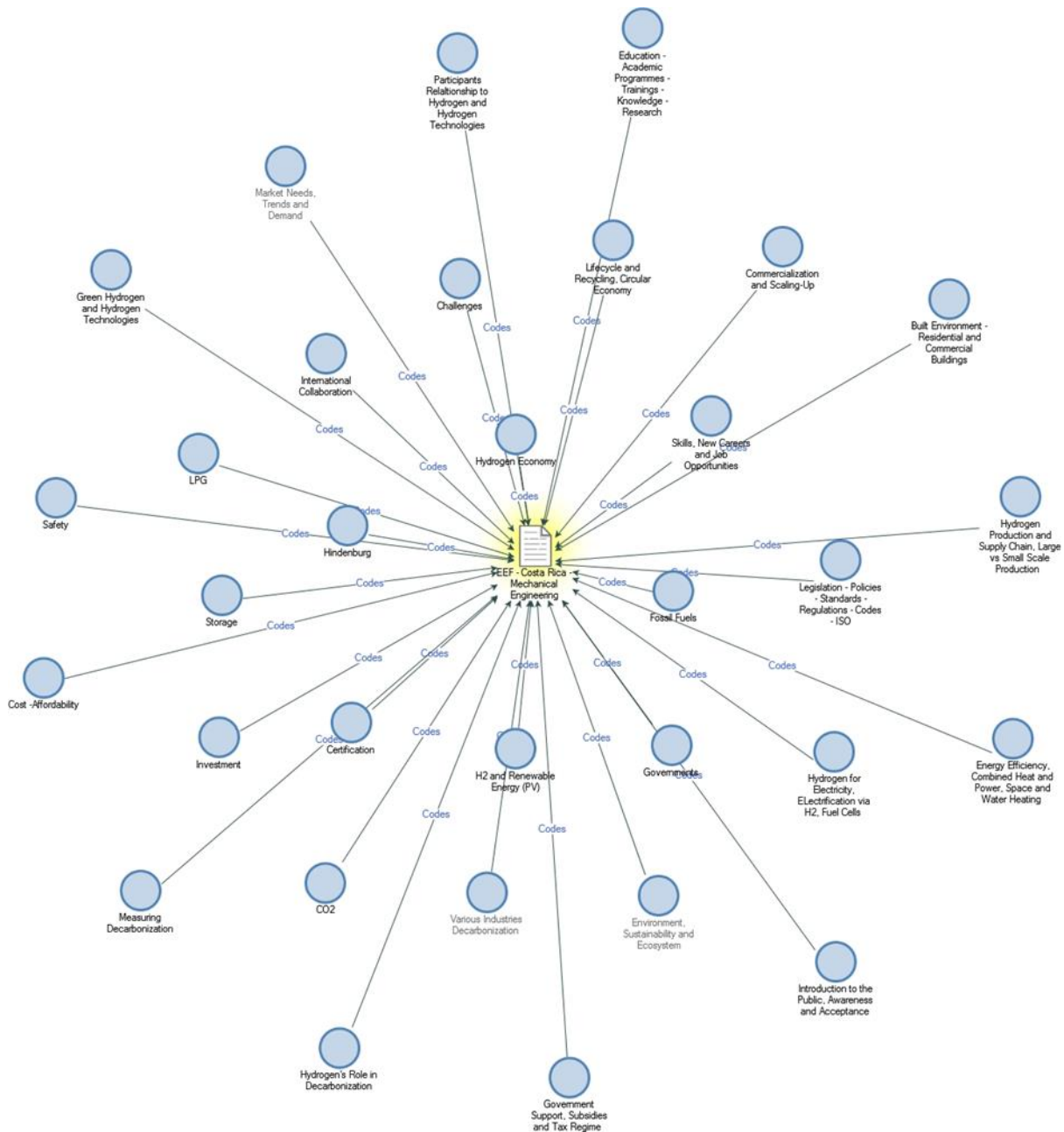


Diagram 2: EEF - Thematic Interview Summary Diagram

4.5.3 SGJA - Mexico

Participant's SGJA journey into hydrogen began with a mechanical engineering background followed by a master's in energy engineering, which laid the foundation for understanding renewable hydrogen. With a strong desire to contribute to climate change mitigation, the participant delved into renewable energy projects, specializing in wind and solar development for around four years. Joining the United Nations program focused on supporting energy transition in Mexico, the participant became a technical advisor for policymakers, initiating their involvement in the hydrogen domain. The SGJA's work involves creating technical documents about green hydrogen, detailing production, costs, and competitiveness against other alternatives. This effort has garnered industry interest, enabling networking with Mexican and German companies. Collaborations extend to subnational governments where policy advisement fosters hydrogen initiatives. The program operates iteratively, with interested companies submitting applications to Germany for approval. Successful proposals lead to cooperative efforts in realizing hydrogen projects. In his work, SGJA collaborates with the German government agencies to promote hydrogen adoption in Mexico. His organization facilitates public-

private partnerships, providing technical assistance to private companies interested in hydrogen projects. They aim to fill knowledge gaps and develop studies to support the adoption of green hydrogen. The projects range from ammonia production to other applications in various industries. His interest in climate change and renewable energy led him to work as a project developer in wind and solar energy for several years before joining an international cooperation organization. SGJA is currently working as a technical advisor for policymakers, specifically focusing on hydrogen projects in Mexico.

SGJA holds the view that diversified suppliers of green hydrogen are singularly dedicated to the production of green hydrogen. In his opinion, these suppliers are exclusively focused on the creation of environmentally friendly hydrogen, emphasizing a commitment to sustainability and clean energy. This perspective highlights the dedication and specialization of such suppliers in contributing to the advancement of green hydrogen technologies and its potential in addressing global energy and climate challenges.

Regarding the environmental impact of hydrogen technologies, SGJA emphasizes that as long as hydrogen is produced using renewable energy or biogas without associated emissions, it can be considered environmentally friendly. SGJA believes that:

“As long as it is produced from renewable energy or from biogas for example and there are no emissions associated to this production and then you can say it is environmentally friendly”.

He believes that hydrogen can contribute significantly to the decarbonization of the built environment, especially in energy-intensive industries like cement and steel.

However, SGJA mentions that one of the challenges in Mexico is the political stance on fossil fuels, which hinders the rapid transition to green hydrogen. SGJA mentions that:

“Currently we do have the revelation to promote renewable energies. It’s just that the current party in power has this regressive vision of how of energy and this concept of energy security that dates back to the 70s”.

He hopes that with future administrations, the focus will shift back to renewable energy, as it was before 2018 when Mexico was making significant strides in the renewable energy sector.

Overall, SGJA’s insights highlight the potential of green hydrogen in replacing fossil fuels for energy production and decarbonizing energy-intensive industries. However, political will and regulatory support are critical to accelerating the adoption of green hydrogen technologies. The challenges faced in Mexico serve as a reminder of the importance of policy alignment and support from government agencies to promote sustainable energy solutions. While SGJA is involved in promoting large-scale green hydrogen production in Mexico, distributed hydrogen applications for buildings currently face regulatory and policy hurdles. However, SGJA sees huge potential for hydrogen technologies to contribute to the decarbonization of various sectors in the coming decades through the replacement of fossil fuels.

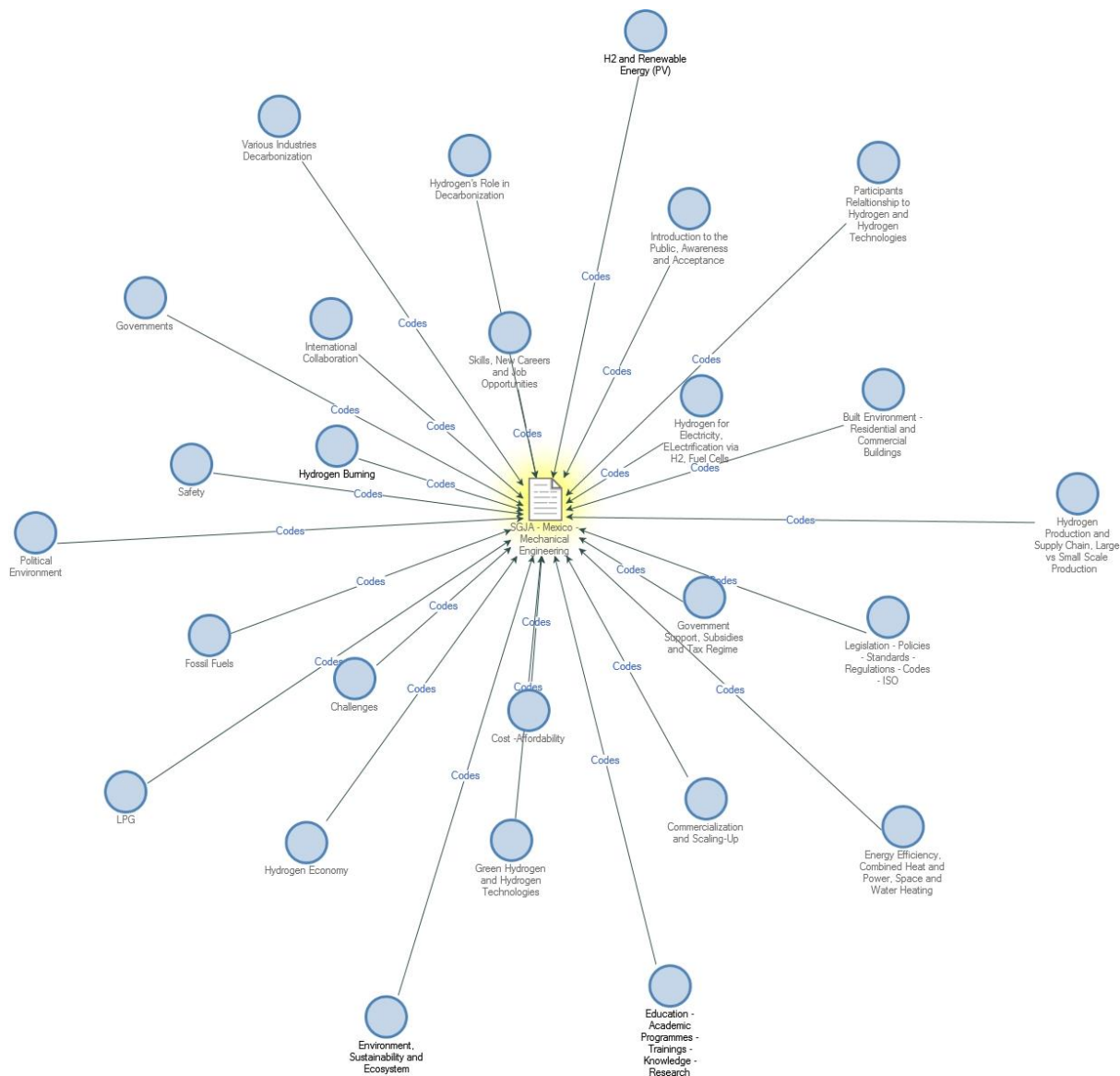


Diagram 3: SGJA - Thematic Interview Summary Diagram

4.5.4 JH - NZ

Participant JH's journey began with a strong desire for constructive contributions, leading him to pursue engineering. His initial experience in extractive industries and mineral processing research sparked an interest in sustainability. Transitioning into renewables, he obtained a PhD and worked extensively in solar thermal. Over the years, his interest in hydrogen and its value proposition grew, with about two decades of involvement in exploring hydrogen technologies and its production. This diverse background underscores his multidimensional perspective on green hydrogen and its potential role in addressing energy and environmental challenges.

JH envisions a future where New Zealand rooftops are adorned with solar panels, and households host the gentle hum of an electrolyser. This scenario reflects JH's belief in the synergy between solar energy generation and hydrogen production at a local level, contributing to a sustainable and decentralized energy landscape. However, the practicality of this setup hinges on cost-effectiveness. The task at hand involves selecting technologies wisely, attuned to the resource intensity that different options entail. JH notes that there is an allure in seeking silver bullet solutions - technological wonders capable of rectifying systemic challenges. This tendency to embrace gleaming solutions stems from our innate inclination as humans to champion technologies that promise panaceas.

JH suggests that if renewable energy serves as the wellspring, hydrogen gains an edge over batteries due to resource considerations. JH points out that there is a presumption that the PEM variant ought to excel in terms of current efficiency and flexibility. Comparatively, JH highlights that alkaline options offer a slight edge in terms of cost and development, exerting a lighter demand on electrode materials. Moreover, JH observes that alkaline systems have evolved to display newfound flexibility.

When examining the canvas of applications, JH finds that the hydrogen and fuel cells program unfurls intriguing dimensions. For instance, JH contemplates instances like providing emergency power to the army and hospitals, where the merits of hydrogen materialize as an emergency backup solution, seamlessly woven into infrastructure.

In certain realms, such as low-temperature applications, mysteries remain. JH points out that here, a delicate balance must be struck, navigating the potential challenges of hydrogen crossover due to its diminutive nature. However, in the realm of high temperatures, JH sees opportunities flourishing. JH envisions that ceramic membranes and mobile oxygen could engender an efficient and robust fuel cell. JH also finds the prospect of hydrogen oxidation and ammonia utilization intriguing.

Embarking on this journey, JH finds it heartening to acknowledge the presence of functional technologies. JH recalls whispers of 100% efficient electrolyzers, like “Lavo”. Yet, JH acknowledges grappling with nuances, such as the distinction between thermoneutral voltage and thermodynamic efficiency.

Reflecting on the global stage, JH points out that Japan emerges as a beacon of progress. JH highlights that Japan’s landscape features residential fuel cells dating back to the early 2010s. Notably, JH emphasizes that Japan wields significant intellectual property sway, fostering a vested interest in orchestrating large-scale demonstrations and comprehending the intricacies of hydrogen’s potential.

In the interview, JH expressed a cautious perspective on the role of hydrogen in the decarbonization of the built environment, particularly for direct use in buildings. He believed that while hydrogen technologies can play a valuable role in decarbonizing difficult sectors such as steelmaking and transportation, direct use of hydrogen for building heating or power generation may not be the most efficient solution.

JH highlighted the importance of prioritizing resource utilization and focusing on the overall efficiency of energy systems rather than seeking “*magic bullet*” technologies. He suggested that better management of building envelopes, adoption of electric heat pumps, and improvements in thermal storage could be more effective strategies for reducing carbon emissions in the built environment compared to hydrogen-based solutions. JH states:

“I think the role of hydrogen is more in the really hard to decarbonize areas and possibly it will come down to like a utilization of resources thing as well... I think electric heat pumps are like a really nice way of providing me the right refrigerants, a really nice way of heating houses and there’s a lot more to be gained out of managing building envelopes and making them more efficient than looking for magic bullets and things that can you know our technological fix to kind of a systemic problem” (JH).

When discussing the challenges and obstacles facing hydrogen technologies, JH emphasized the need for standards, regulations, and safety guidelines to ensure safe and reliable implementation saying that “*standards and regulations are currently lacking*”. He also stressed the importance of education and communication to dispel misconceptions and increase public awareness about hydrogen technologies. He believes that there is a “*need to develop that human capital*” because “*hydrogen is very possibly one of the keys enabling technology of the future*”.

While acknowledging that hydrogen may have a role for reliable emergency backup power in hospitals and critical facilities, JH believes:

“Direct use of electricity and thermal storage and better management of building envelopes is actually better than saying well hydrogen’s gonna fix everything”.

He cites the high cycle efficiency losses and resource intensity of distributed hydrogen systems compared to electrification options.

Regarding the potential application of hydrogen in remote locations and off-grid areas, JH saw promise in such scenarios, where hydrogen could offer a viable solution for power generation and energy storage. However, he acknowledged that the cost of producing hydrogen would be a critical factor in determining its widespread adoption.

Throughout the interview, JH questioned the cost-effectiveness of hydrogen in the built environment compared to other alternatives, such as direct electrification and better building management. He suggested that hydrogen’s role should be focused on the decarbonization of challenging industries and long-distance transport.

In conclusion, JH offered valuable considerations for the potential use of hydrogen technologies in the built environment. While JH is involved in promoting hydrogen technologies in other sectors, he is sceptical that hydrogen fuel cells will play a major role in decarbonizing the built environment due to their inefficiency and high costs compared to electrification solutions like heat pumps and energy storage. However, he recognizes potential niche applications for reliable emergency backup power and distributed generation with cogeneration of heat. His cautious approach and emphasis on efficiency and resource utilization present critical aspects to be addressed in the development of hydrogen-based solutions for a sustainable future.

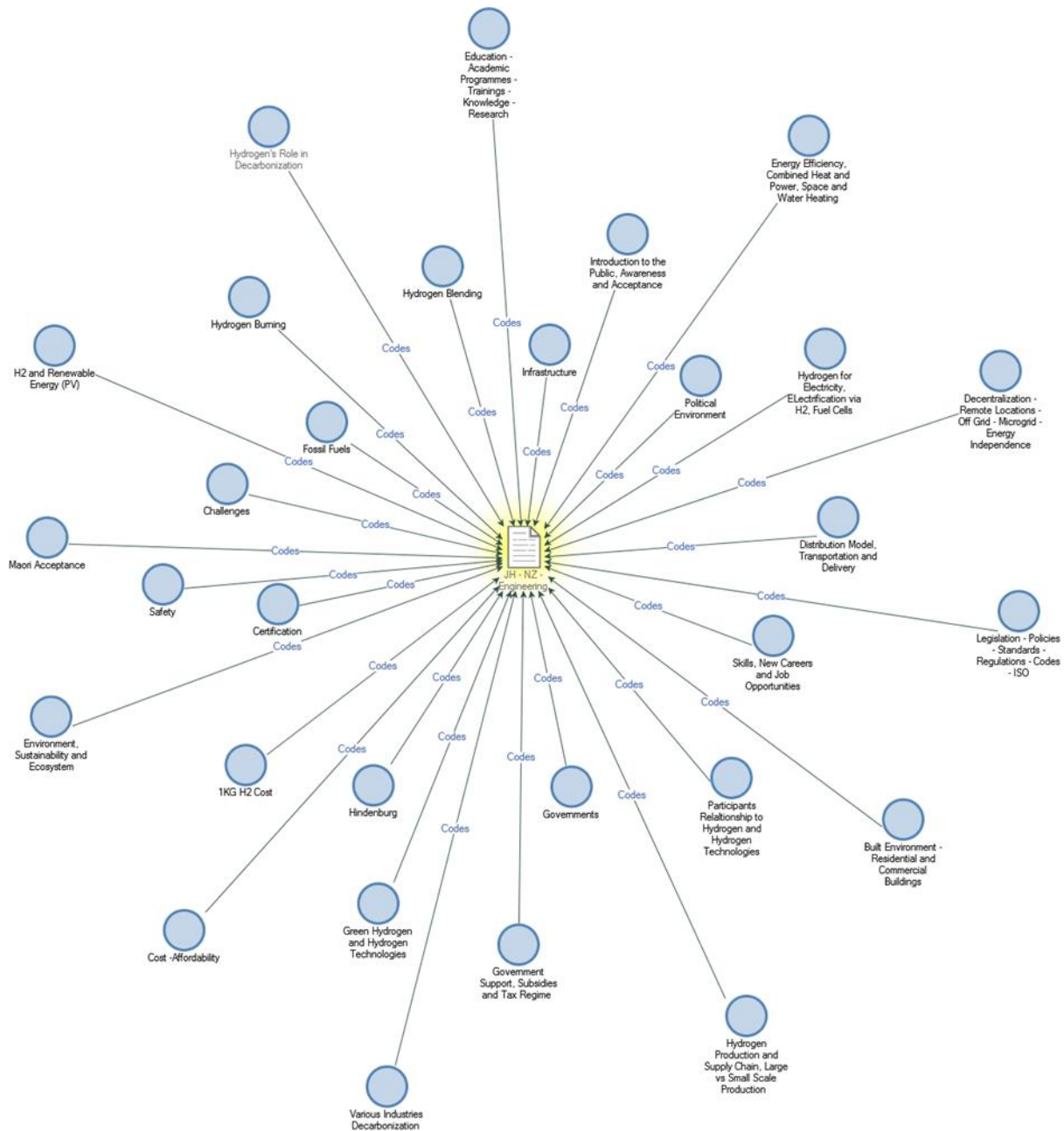


Diagram 4: JH - Thematic Interview Summary Diagram

4.5.5 RGJA - Colombia

In this academic interview, RGJA, a professional with a background in power generation and renewables, shares valuable insights into the world of green hydrogen and hydrogen technologies. RGJA's journey in this field began with a master's degree in renewable energy, where the potential of green hydrogen piqued his interest. He later got involved in projects with the German International Cooperation Agency and the Colombian government to implement hydrogen strategies.

RGJA's journey into the energy sector began in power generation, focusing on conventional technologies such as boilers and engines. A transition into renewable energy, particularly photovoltaics, ignited his passion for sustainable solutions. In 2020, while pursuing a master's degree in renewable energy, he delved into the realm of green hydrogen. In 2021, JR engaged with Colombia's government-driven commitment to green hydrogen by joining the German International Cooperation Agency. Collaborating closely with the Ministry of Mines and Energy, he has been

instrumental in advancing Colombia's hydrogen implementation strategy. His experience spans from conventional power to renewables, culminating in a pivotal role in Colombia's green hydrogen initiatives.

RGJA expresses optimism about the future of hydrogen technology, highlighting its potential to drive a decarbonized economy in the long term. He acknowledges that the technology is in its nascent stages, requiring substantial investments from the public sector for further development. Comparing it to established technologies like PEM and alkaline electrolyzers, RGJA recognizes the current limitations of the technology. He also suggests hydrogen's use as a backup fuel and for emergency situations, underscoring its versatility and potential applications.

The focus of the interview revolves around the utilization of hydrogen technologies for the decarbonization of the built environment, particularly residential and commercial buildings. RGJA highlights the opportunities in residential and industrial heating, cooking stoves, and emergency power for buildings, demonstrating how hydrogen can contribute to electrification and energy security.

Addressing the challenges of public acceptance and economic growth, RGJA emphasizes the need for social acceptance, safety education, and community-driven energy solutions to bring green hydrogen to the masses. He also highlights the importance of government support through subsidies and incentives to make green hydrogen projects financially viable and encourage investment. RGJA believes governments need to *"create a very special tax regime"* and provide long-term policy stability to truly accelerate the adoption of hydrogen technologies.

Safety concerns are discussed, particularly regarding explosion risks in domestic applications. RGJA suggests using specialized instrumentation for hydrogen detection to mitigate potential hazards.

The interview delves into the cost and energy efficiency of green hydrogen production, acknowledging the current high costs and the potential to lower them through economies of scale. RGJA discusses the role of solar energy and the efficiency of green hydrogen production, underlining the importance of optimizing the process to improve affordability.

RGJA emphasizes the necessity of education and training for installers to work with hydrogen technologies and suggests the development of new educational programs to create a skilled workforce.

Regarding international standards and codes, RGJA highlights the existence of industrial standards but emphasizes the need for specific residential codes to ensure safe hydrogen installations in buildings.

Lastly, the interview touches on the importance of government support in Colombia, including financial incentives and legal security for private investors, to foster the growth of hydrogen technologies.

In conclusion, RGJA's highlighted the immense potential of green hydrogen and hydrogen technologies to revolutionize the built environment. From energy-efficient heating and power generation to decarbonization, hydrogen emerges as a promising solution for a sustainable and environmentally friendly future. However, to realize this potential, governments must play a pivotal role by providing support, incentives, and a stable policy framework to promote widespread adoption of hydrogen technologies in the residential and commercial sectors.

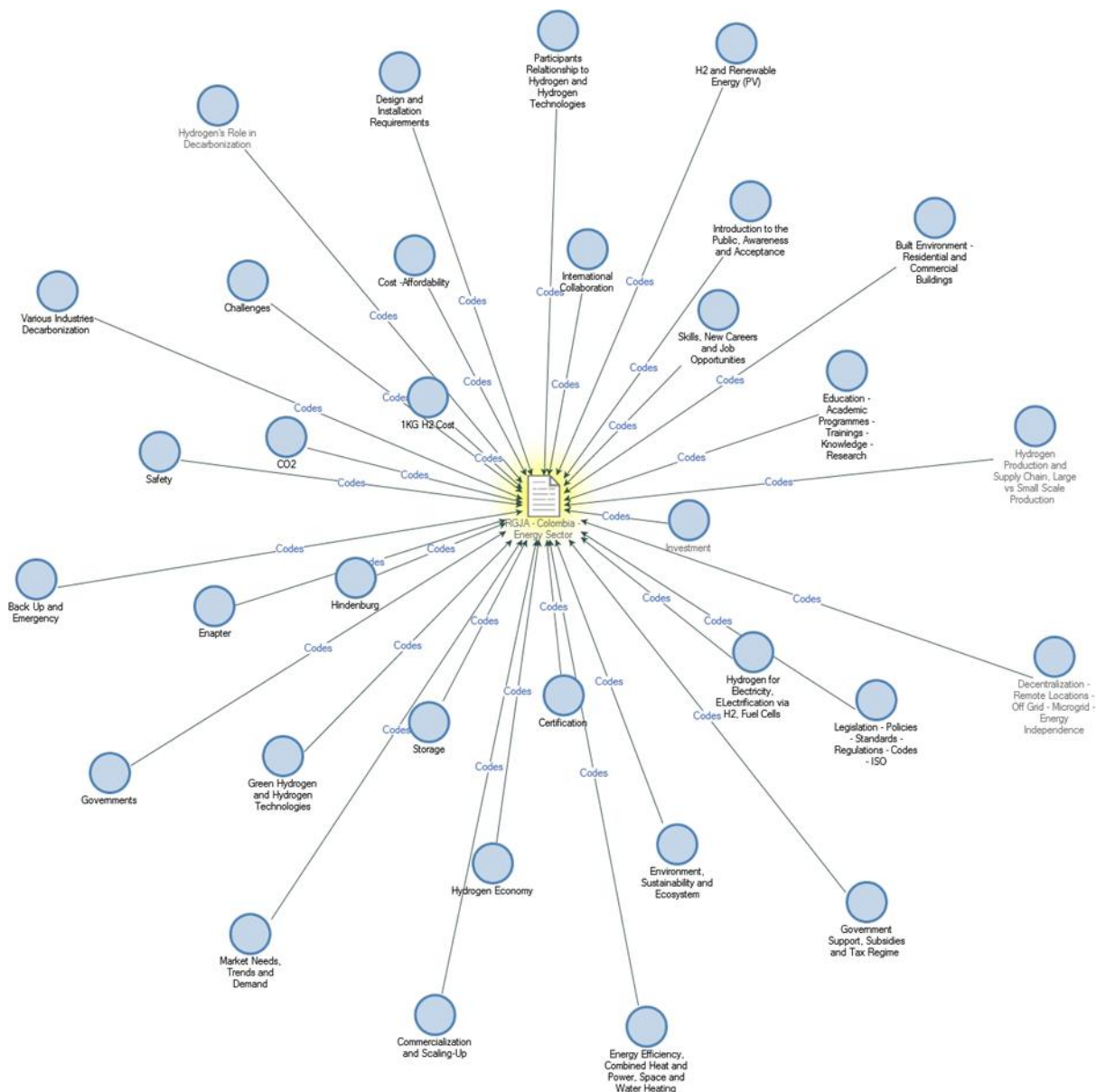


Diagram 5: RGJA - Thematic Interview Summary Diagram

4.5.6 JAGR – Mexico

JAGR's immersion into hydrogen exploration traces back to his collegiate days in 2012, where he embarked on a modest academic endeavour centred on constructing a miniature fuel cell. This experience ignited his fascination with hydrogen's potential as a fuel source. Subsequently, as a chemical engineer, he transitioned to a Swiss electrolyser firm specializing in laboratory electrolyzers for analytical applications. Later, in 2014, he ventured into consultancy, joining HINICIO, a European consultancy firm focusing on hydrogen projects. Through various consultancy endeavours across Latin America, including Colombia's Ecopetrol hydrogen initiative and Costa Rica's national hydrogen strategy, JAGR honed his expertise in the field. His unwavering dedication to hydrogen stems from its transformative capability to convert water into fuel and his belief in its capacity to revolutionize the energy landscape expeditiously, contrasting the protracted process of oil formation. His trajectory exemplifies the convergence of his energy sector interest, chemical engineering background, and hydrogen's transformative allure.

JAGR perceives hydrogen's allure in its technologically mature landscape, albeit with latent revelations. He views it as a complex dualism, combining technical viability and economic feasibility. On one facet, he illustrates technical viability through a prototype incorporating solar panels, an

electrolyser, a fuel cell, and smart energy management within a mobile office setting. This prototype harnesses solar or hydrogen energy adaptively, contingent upon availability. However, JAGR contends that financial viability poses a significant obstacle, presently hindering economic feasibility.

Looking ahead, JAGR envisions large-scale hydrogen production leveraging economies of scale to propel affordability. This vision contrasts favourably with other energy storage alternatives, particularly in accommodating regions with variable energy demands. Yet, economic considerations steer the discourse toward pragmatic solutions, as per JAGR's perspective.

However, JAGR acknowledges the nascent maturity of hydrogen technology, recognizing both traditional assembly methods and emerging digital pathways. He underscores digitalization's role in ensuring hydrogen's environmental sustainability and aligning with emissions reduction objectives.

Despite hydrogen's green aspirations, JAGR underscores the enduring role of metals in its production, as it straddles artificial and impactful realms. He views hydrogen as a response to humanity's artificial challenges, poised to reshape infrastructure and seek a novel equilibrium.

JAGR posits that hydrogen's allure transcends definition, embodying a captivating fusion of science, technology, economics, and philosophy. It heralds a future where energy is both harnessed and harmonized, transcending known boundaries and paving the way for undiscovered horizons.

Regarding hydrogen technologies' potential for decarbonizing the built environment, JAGR expresses reservations about their applicability, particularly in mild climates. He notes the efficiency and cost-effectiveness of existing solar thermal boilers in equatorial regions like Mexico, rendering hydrogen solutions less appealing. Nonetheless, he acknowledges active exploration and advocacy for hydrogen-based applications in countries such as Japan.

Despite challenges, JAGR emphasizes the imperative of establishing a hydrogen infrastructure, citing environmental benefits and economic opportunities. He underscores the need for comprehensive safety regulations and technological advancements to enhance efficiency and drive down costs.

Ultimately, JAGR's insights illuminate the opportunities and challenges surrounding hydrogen technologies' deployment, underscoring the importance of policy support, investment, and technological innovation to accelerate their integration and contribute to a cleaner, more sustainable energy landscape.

in hydrogen systems. Presently, hydrogen systems offer distinct advantages, partly attributed to the small size of hydrogen molecules. Notably, the origin of a green hydrogen molecule becomes inconsequential once it's produced, emphasizing its role as an energy carrier similar to electricity.

The discussion revolves around the utilization of hydrogen in both domestic and commercial settings. KQ highlights several areas where hydrogen technologies have found application, such as passenger vehicles, heavy-duty trucks, forklifts in warehouses, and power supply for critical facilities like banks and hospitals. Of note is the interest in blending hydrogen with natural gas to reduce emissions, which presents a promising avenue for reducing carbon footprints in the built environment.

Regarding decarbonization of the built environment, KQ identifies hydrogen fuel cells as a key solution for reducing emissions from natural gas appliances. The integration of hydrogen in building systems, particularly for larger buildings like industrial complexes, apartment buildings, and dairy farms, has the potential to drive decarbonization efforts effectively. However, the challenge lies in overcoming infrastructure limitations, such as adapting existing pipelines and appliances to accommodate hydrogen safely and efficiently. KQ stated:

“So if you have a photovoltaic on your roof and but you are grid connected so I’m happy. But the few homes I know that are powered by hydrogen and are in fact off grid...They maintain their own hydrogen storage. They maintain their own solar wind energy production”.

While acknowledging such distributed applications, KQ saw grid integration as key:

“Even if 15%, in five years 15% of the grid is powered by renewable energy that can grow... But just getting the first part of it on, there is a big deal”.

Regarding fuel cells specifically for buildings, KQ pointed out that:

“The true changes there have to be incremental...we have to start with where we are to get to where we’re going”.

Overall, while recognizing the benefits hydrogen technologies could bring through efficiency and reliability, KQ saw infrastructure and standards as crucial first steps for wide-scale adoption, highlighting the need for international cooperation in these areas.

The interview emphasizes the importance of standardization and international collaboration in advancing hydrogen technologies. KQ emphasizes the need for product and system standards to be international, while recognizing that local codes and regulations may need to be tailored to individual countries or regions. KQ's mention of ISO TC 197 (Hydrogen Technologies) and IEC/TC 105 (Fuel Cell Technologies) underscores the significance of these international bodies in shaping the future of hydrogen technologies.

While discussing the adoption of hydrogen in different countries, KQ highlights the role of advocacy groups and the significance of policy support from governments. Countries like the United States, particularly California, have demonstrated a strong commitment to hydrogen technologies as part of their strategy to reduce emissions and enhance energy security. However, KQ acknowledges that the pace of adoption varies depending on available resources and priorities in different regions.

Furthermore, the interview touches on the cost-effectiveness of hydrogen production, which can vary based on the scale, location, and transportation methods used. The potential for using hydrogen to store excess renewable energy and enable greater use of renewables on the grid is recognized as an important strategy for enhancing energy sustainability.

In conclusion, KQ's insights shed light on the current state and future potential of hydrogen technologies for decarbonizing the built environment. Fuel cells emerge as a key technology to address emissions from natural gas appliances, while blending hydrogen with natural gas presents an

accessible step towards reducing carbon footprints. However, the transition to widespread adoption faces challenges related to infrastructure, safety, and the need for incremental changes. International collaboration and standardization efforts play a vital role in driving progress in the field of hydrogen technologies.

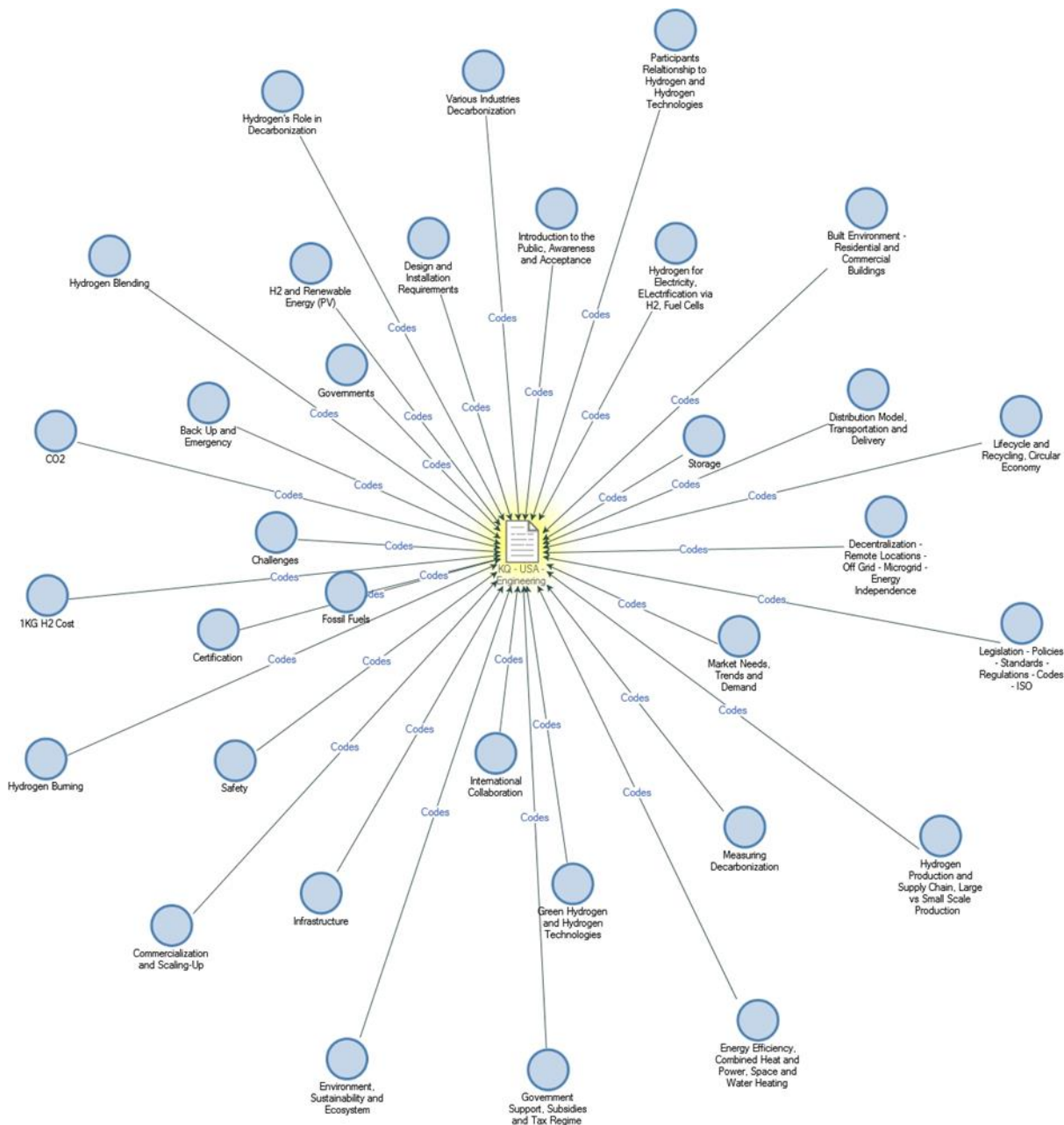


Diagram 7: KQ - Thematic Interview Summary Diagram

4.5.8 MR – Italy

MR's journey began in chemical engineering, which gradually sparked his interest in the energy sector. As she pursued his master's degree, her focus sharpened on addressing the challenges of energy transition. She delved deeper into the subject during a doctoral program at TU Delft, immersing herself in the study of green hydrogen and its role in the transition. Her pivotal experience with a consortium of companies exploring hydrogen as a shipping fuel further solidified her path. Attending conferences provided her with valuable insights into the technical aspects and potential applications of hydrogen technologies. This journey reflects her dedication to contributing to the advancement of green hydrogen and its applications.

In this interview, the discussion revolved around the use of hydrogen for domestic and commercial applications. MR's experience in the field, including involvement in a project exploring hydrogen as a shipping fuel, provided valuable insights into the challenges and potential of hydrogen technologies.

MR believes that hydrogen's minute molecular size renders it a potential substitute for various gases, as MR highlighted. Its compactness presents both a promise and a challenge, according to MR's perspective. MR opines that the key to its widespread adoption lies in cost reduction, where technologies can bridge the gap between green hydrogen and alternative fuels, making it a feasible solution. In this equation, MR asserts that the private sector plays a pivotal role, offering functional solutions that interlock seamlessly.

However, MR recognizes that the puzzle demands a complete picture. According to MR, the presence of multiple small companies, each specializing in a specific aspect of hydrogen technology, risks creating disjointed progress. MR suggests that the synergy between these pieces is orchestrated by technology. Once all aspects align, MR believes that governments can orchestrate infrastructure development with confidence.

MR acknowledges that no technology is a universal panacea, emphasizing that transparency about strengths, weaknesses, and uncertainties is paramount, in MR's opinion. This transparency, as she sees it, fosters a foundation of trust upon which governments can build investments.

MR points out that hydrogen's significance extends beyond energy, permeating the chemical industry. According to MR, its green credentials hinge on 100% green energy input and efficient application. The link between green electricity and hydrogen is vital, she believes, presenting an opportunity to harmonize our energy landscape.

MR sees optimization and customization as key trajectories. In her view, fine-tuning electrolyzers to suit different applications, pressures, and temperatures ensures efficiency and affordability. She mentions that the medium-term goal is to stabilize and scale up these technologies.

Different technologies vie for supremacy, each with its merits, according to MR's perspective. She notes that the Enapter technology stands out for its reduced rare earth metals consumption and practical pressure output. However, MR emphasizes that context is crucial, as application-specific variables sway technology preferences.

Depending on the application, hydrogen's role can be multifaceted – from storage to electricity generation, she believes. MR states that the technology required is already within reach, waiting to be harnessed for a greener future.

MR emphasized the importance of safety considerations when working with hydrogen, particularly due to its explosive nature and the need for proper containment and infrastructure adaptations. Despite the safety challenges, MR expressed confidence in existing knowledge and experience from other gas industries that could be applied to ensure safe hydrogen utilization.

Regarding domestic applications, MR proposed the adoption of green hydrogen for heating, where it can replace other gases like methane in boilers. However, MR also acknowledged the need to achieve the same efficiency levels as pure hydrogen, which could be a challenge. The focus on energy efficiency was reiterated, emphasizing the importance of optimizing electrolyzers for hydrogen production. While acknowledging potential benefits through *"efficiency and reliability"*, MR emphasized *"infrastructure and standards as crucial first steps for wide-scale adoption"*.

On decarbonizing the built environment with hydrogen, MR noted:

"For heating, I would rather go with electrification for homes...For bigger complexes and industries then I will go for gas and hydrogen fired boilers".

By-products like heat from hydrogen production could be used *“to keep the building warm in winter”*. Yet MR stressed starting with *“pilot projects, for example selecting a community to install a system to heat up buildings with hydrogen”*, to gain confidence in technologies.

When it came to commercial and larger-scale applications, MR pointed out the potential of hydrogen to transform the energy sector and decarbonize various industries. As a fundamental molecule for the chemical industry, hydrogen presents opportunities for both energy and industrial transitions. MR argued that green hydrogen, produced with 100% renewable energy, could play a crucial role in addressing the trilemma of affordability, energy security, and sustainability.

Despite the promise of hydrogen technologies, MR highlighted that there are still obstacles to overcome, such as the cost of production and the need for better infrastructure. Moreover, it was stressed that transparency and honesty about the technology’s strengths and weaknesses are essential to gain government and public confidence for investment and adoption.

The interview also touched upon the importance of international collaboration in setting hydrogen standards and regulations. MR advocated for standardized protocols to enable a smoother exchange of technologies and products among countries.

In terms of workforce development, MR recommended updating educational curricula to include hydrogen technologies and attract more skilled professionals to the field. As the industry advances, expertise in digitalization and automation would be crucial.

Overall, while seeing hydrogen as a potential *“democratic way of distributing energy”* by enabling off-grid communities, MR cautioned that technologies *“cannot be everything already perfect”*. Governments evaluating hydrogen options should *“be open about strengths and weaknesses and the open questions”*. Indeed, for MR, hydrogen technologies can be considered *“green”* only when *“the input energy...is green for real”* and applied *“in an efficient way, not going blindly to hydrogen”*.

In conclusion, MR’s interview sheds light on the potential of hydrogen technologies for domestic and commercial utilization, particularly in decarbonizing the energy sector. MR’s insights highlight the need for pragmatic, targeted applications of hydrogen - starting small and building confidence - to decarbonize the built environment, while managing costs, efficiency and safety requirements through proper standards and regulation. While acknowledging the challenges, MR emphasizes the importance of safe implementation, optimization, and international collaboration to make hydrogen a viable and environmentally friendly energy solution.

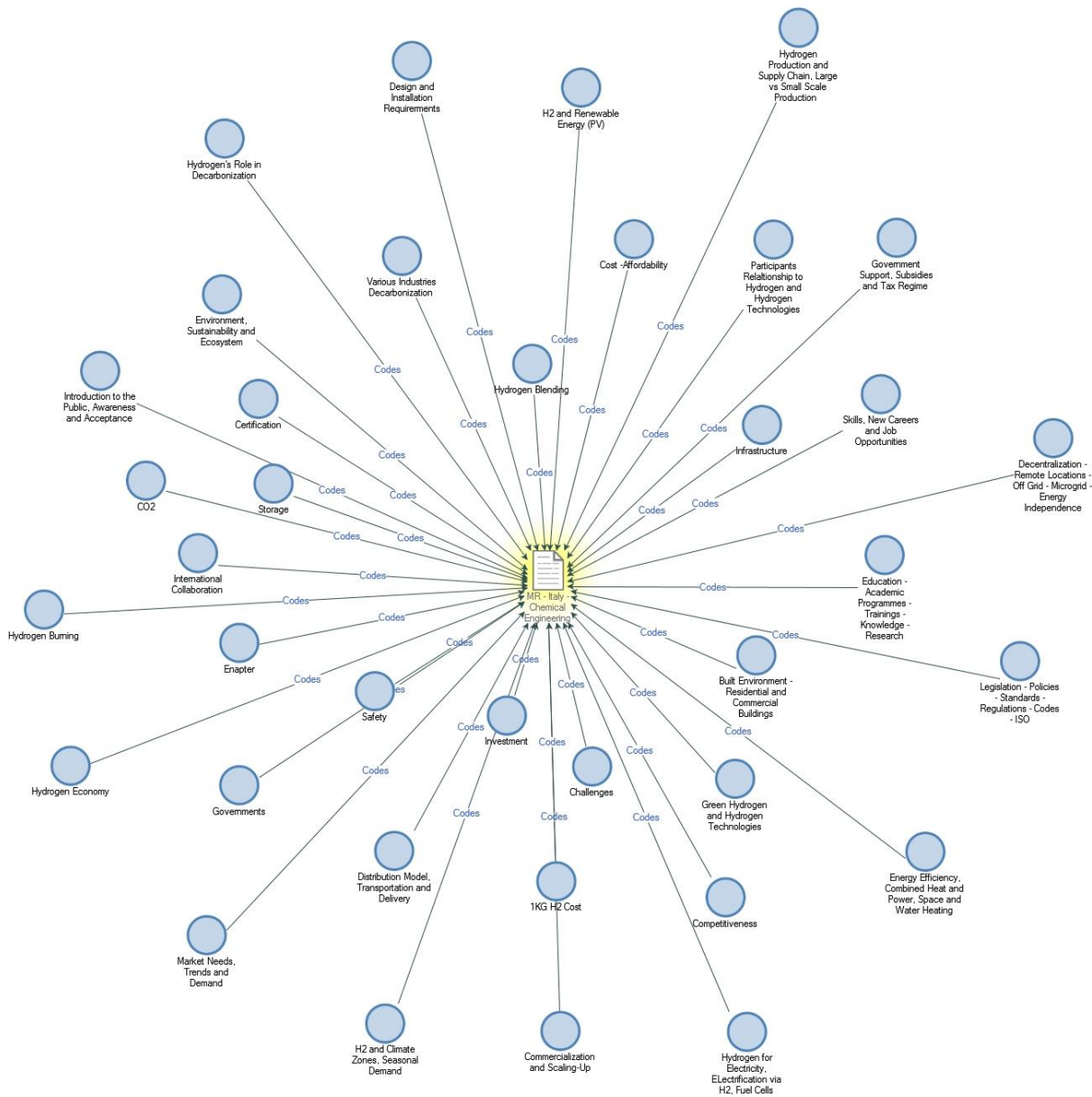


Diagram 8: MR - Thematic Interview Summary Diagram

4.5.9 MS – Indonesia

In this interview with MS, an expert with significant experience and knowledge in the field of hydrogen technologies, various aspects related to the adoption and implementation of green hydrogen solutions for domestic and commercial utilization were discussed. MS's background and expertise make him a credible source to provide insights into the challenges, benefits, and potential of hydrogen technologies.

MS, a former professional in the mobile telecoms industry, has transitioned into the realm of hydrogen technologies with a keen focus on “*self-refuelling fuel cells*” (SRFC). Drawing from his experience in addressing power supply challenges faced by mobile networks in remote areas, MS conceived the idea of using hydrogen fuel cells backed by grid or renewable energy sources to ensure reliable power supply for base stations.

MS's journey into the world of green hydrogen began with a focus on modular hydrogen production units. His company specializes in developing these units and partnering with others to customize and deploy them based on specific production needs. Notably, he was engaged in a substantial project in Malaysia aimed at producing 22 metric tons of hydrogen daily for a power station. To meet this

industrial-scale demand, alkaline electrolysis proved to be the optimal choice. MS's involvement in such projects underscores his active role in advancing the implementation of hydrogen technologies for large-scale applications and showcases his commitment to the growth of the green hydrogen industry.

MS envisions the evolution of hydrogen technology mirroring the progression from mainframes to modular PCs, drawing an analogy to highlight the shift towards modularized electrolyzers. According to MS's perspective, these systems effectively scale by centralizing key components for cost efficiency and enhanced performance, similar to how networking PCs transformed the computing landscape and replaced mainframes.

In this context, just as networking many PCs became impractical at a certain scale, MS sees modularization transforming hydrogen production. Electrolyzer components are consolidated, resembling computer servers, which, as MS suggests, drives down component costs due to mass production techniques.

Consider a box generating 500 litres of hydrogen per hour, consuming 2.4 kilowatts of energy, with a consumption of 0.4 litres per kilowatt-hour. Various electrolyzer technologies exist, including alkaline and PEM, all demanding electrical energy for water splitting. However, efficiency becomes the differentiator, as MS points out. For instance, producing 1 kilogram of hydrogen requires 53.3 kilowatt-hours of electricity, with a lower heating value of approximately 60 kilowatt-hours. According to MS, electrolyzer efficiency typically reaches around 63.3%. Yet, different manufacturers might focus on stack efficiency rather than overall system efficiency.

As MS sees it, the transition to hydrogen offers a chance to replace fossil fuels, with electrification being a key approach to reducing emissions from carbon-based sources. The integration of hydrogen in buildings, with fuel cells playing a crucial role, is gaining momentum, according to his observation. Notably, fuel cells not only convert hydrogen into electricity but also produce heat, which MS believes can be harnessed for building heating, yielding an impressive overall efficiency of around 83%.

In terms of household integration, MS envisions a future where hydrogen modules are as ubiquitous as microwave ovens within two decades. However, MS acknowledges that for hydrogen to have substantial impacts, it must penetrate industrial sectors and scale up on an industry-wide level.

Regarding storage, MS notes that alternatives to high-pressure gas storage are being explored. According to MS, innovative solutions like an oil substance capable of absorbing and releasing hydrogen are being developed, offering transport convenience and efficiency.

Regarding the lifespan and recycling of hydrogen technologies, MS highlights the importance of considering the longevity of electrolyzers and fuel cells, which undergo chemical reactions and require periodic replacement of certain components. While some recycling of materials is possible, the overall feasibility of recycling may vary depending on the specific components and technological advancements over time.

As for the longevity of electrolyzers and fuel cells, MS recognizes that their operational lifespans vary based on manufacturer, application, and runtime. MS points out that electrolyzers might operate for around 35,000 hours, while fuel cells could function for 20,000 to 30,000 hours, often exceeding 10 to 15 years. MS highlights the cost-effectiveness of Anion Exchange Membrane technology and its compatibility with renewable energy sources as a favourable choice. Additionally, MS is aware of ongoing research to develop electrolyzers that can operate directly with seawater, potentially addressing water scarcity challenges associated with widespread hydrogen production.

One of the notable deployments of this concept was witnessed in Thailand's Phi Suea housing project, where an independent microgrid efficiently managed its energy resources using solar panels,

batteries, and SRFCs, demonstrating the potential for off-grid energy solutions. MS's current affiliation with the company Enapter is dedicated to building modular hydrogen production systems, allowing flexible capacity deployment to match energy demand in diverse applications.

MS emphasizes the importance of demonstrating economic viability in hydrogen technologies, urging the consideration of total cost of ownership, capital expenses, and operational expenses. Governments can play a crucial role in accelerating adoption by providing subsidies or incentives, making the transition financially attractive for users. MS emphasized the primacy of economics:

“Users will do changes if they see a benefit...If I have a particular way of doing things, I look at my total cost of ownership... People are not going to move to something that's more expensive unless there's a reason, a fact a financial reason, a benefit again overall”.

Thus, government incentives - from subsidies to import tax exemptions - may help accelerate the transition by offsetting higher initial costs.

For buildings seeking decarbonization, MS advocates on-site hydrogen production through solar panels and fuel cell integration, effectively reducing dependency on fossil fuels. Also, he advocates that:

“The alternative is to have hydrogen on site and to have a fuel cell to convert that hydrogen into electricity, but also to use the fuel cells heat generated to provide heat for the building”.

MS argued efficiency and scale are both important:

“If I produce [hydrogen] here and then I have to transport it there, there's a cost in doing that. But if I need it here and I can make it here, then I save that transportation cost”.

Yet producing hydrogen “where you need it and when you need it gives you more control” and flexibility. MS also provides valuable insights into the factors influencing the adoption of hydrogen technologies for residential and commercial buildings. The focus on outdoor cabinets for hydrogen storage helps simplify safety requirements and ensures a practical approach for implementing hydrogen technologies.

In his vision, successful decarbonization lies in substituting traditional energy sources with clean hydrogen, leading to a measurable reduction in carbon emissions. However, practicality and economic benefits must be prioritized to encourage widespread acceptance and implementation of hydrogen technologies, leading to a significant impact on the built environment and fuel poverty. By embracing innovative solutions and incentivizing the shift to cleaner energy options, hydrogen technologies can revolutionize energy consumption and contribute to a greener, sustainable future.

One of the key points highlighted by MS is the importance of decarbonizing various sectors, including the energy sector, to meet global CO₂ emission reduction goals. Many governments, including those in Asia, have committed to reducing carbon emissions collectively, driving the need for accelerated development of new energy vectors, such as green hydrogen. However, this poses a challenge for countries heavily dependent on oil and gas exports while striving to balance economic interests with CO₂ reduction targets.

Regarding the safety requirements for introducing hydrogen technologies, MS emphasizes the need to address safety concerns and provide informative guidelines for stakeholders, especially fire departments and relevant authorities. While some progress has been made in establishing safety protocols, a common international standard is yet to be established. However, MS cautioned:

“It's more about putting in the making everybody happy... hydrogen is no more dangerous than say, LPG...[but] at very, very high pressures, that's a safety and security comes into play”.

The interview also delves into the potential of green hydrogen as a replacement for fossil fuels. MS believes that it is inevitable for hydrogen to play a significant role in the future energy landscape due to its abundance. Already, industries like shipping and transportation are making strides in adopting hydrogen technologies. However, the widespread adoption of hydrogen will require addressing challenges related to large-scale storage and transportation, and this may take around 20 to 30 years to become commonplace.

The discussion extends to the use of seawater as a potential source for hydrogen production. While the physics of hydrogen production remains constant regardless of the water source, the challenges lie in removing salination from seawater or desalinating water before electrolysis. The cost-effectiveness of hydrogen production from seawater depends on the overall balance of plant and the price of electricity.

In terms of convincing customers and government agencies about the benefits of hydrogen technologies, MS stresses the importance of demonstrating financial viability. For remote areas and communities heavily reliant on diesel generators, a hydrogen-based system can offer cost savings over time, making it an attractive option for sustainable power generation.

Lastly, MS explains that their company partners with various manufacturers to assemble customized hydrogen systems based on specific requirements. The cost of installing a hybrid hydrogen system, including photovoltaics, electrolyzers, storage, and hydrogen fuel cells, would vary depending on the scale and energy needs of the project. In areas where grid connection is not feasible or economically viable, hydrogen systems offer a promising alternative.

Overall, this interview with MS provides valuable insights into the potential of green hydrogen technologies for residential and commercial applications, the challenges faced in adoption, and the prospects of decarbonizing various sectors through hydrogen-based solutions. MS highlights that targeted, small-scale hydrogen production - collocated with end users - can efficiently decarbonize parts of the built environment. Yet economic viability, infrastructure and public acceptance remain key barriers, necessitating pragmatic policy support to catalyse a transition to hydrogen.

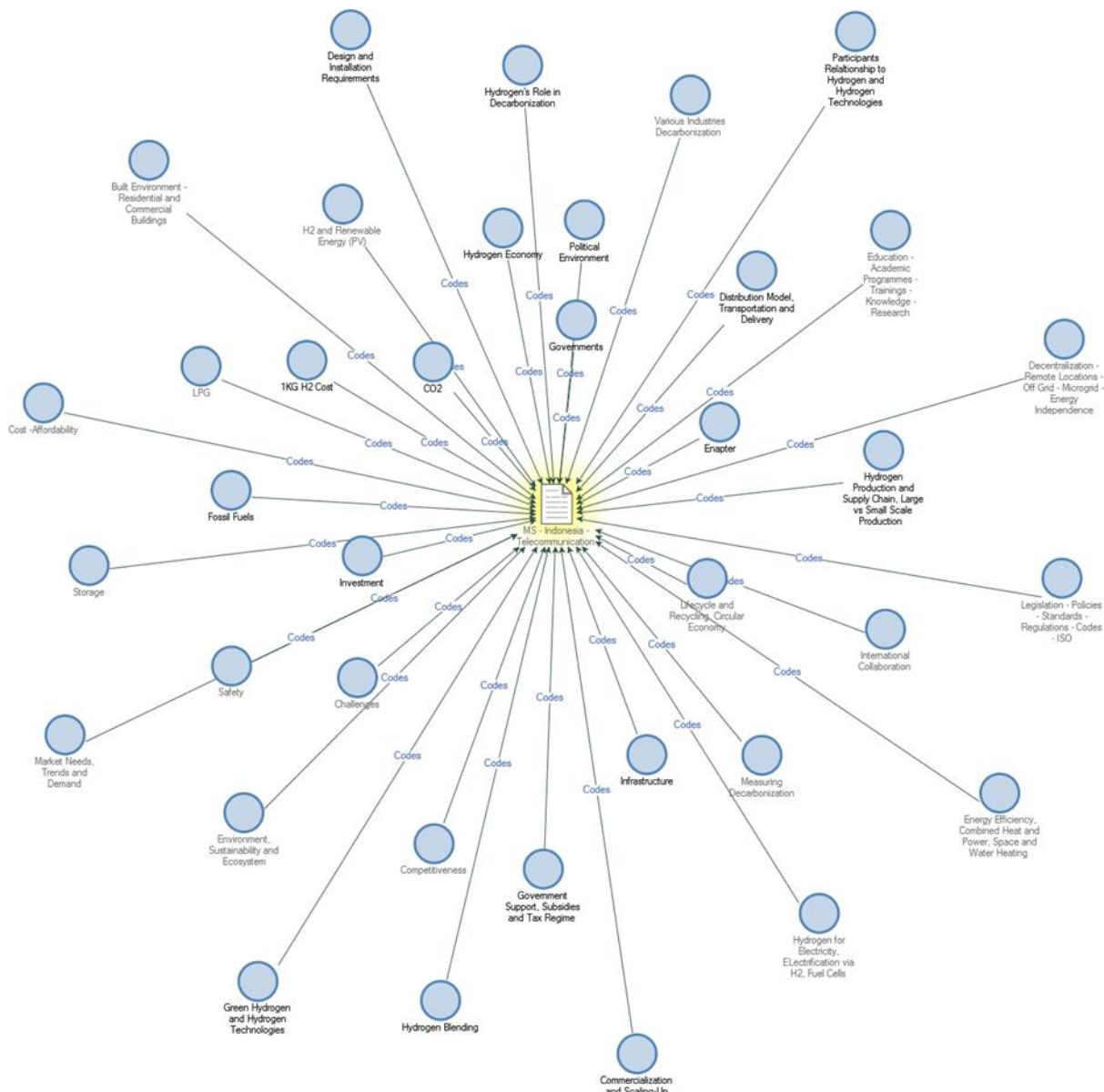


Diagram 9: MS - Thematic Interview Summary Diagram

4.5.10 PL – France

PL, a prominent figure in hydrogen research and a respected participant in the hydrogen community for over two decades, has been deeply involved in various aspects of hydrogen technologies. His journey began as the Program Manager of the Non-Fuel Set Program Research at a renowned Research Institute in 2000. While PL's early motivation stemmed from managing and contributing to a new program, he soon found himself engaged at the national, European, and international levels.

PL has been involved in the field of hydrogen for over two decades, primarily through his work at a Research Institute. He has held various positions, starting as a program manager in a fuel cell and hydrogen program, later becoming program director for different energy programs. His dedication to hydrogen technology is evident in his involvement at national, European, and international levels. He played a significant role in the European fuel cell and hydrogen joint undertaking, contributing to research, innovation, and demonstration projects. PL's influence extended to international partnerships, such as the International Partnership for the Hydrogen Economy (IPHE), where he participated as a signature member. He also chaired a Technology Collaboration Program (TCP) focused on energy topics, demonstrating his commitment to fostering collaboration and advancement

in the hydrogen field. Despite his diverse roles, PL's impact on hydrogen technology and research remains substantial.

PL is deeply entrenched in advancing technologies, particularly in electrolysis, as he collaborates extensively with industry partners to supply these technologies. Alongside this, PL conducts techno-economic analyses with a significant focus on achieving competitiveness in energy systems. Factors like grid connectivity and load factors are vital considerations. For instance, connecting to a wind or PV farm with a load factor of 20% to 30% might impact electrolyser cost due to capital expenses, according to PL's perspective.

In PL's view, the IEA's net-zero scenario and the annual Global Hydrogen Review yield valuable insights into hydrogen's role in decarbonization. These reports offer evaluations of the projected production of green or low-carbon hydrogen by 2050, contributing around 15-20% to total decarbonization efforts. PL also notes the significance of IRENA, an agency focusing on various low-carbon technologies, including renewable hydrogen, which is poised to play a substantial role in global production.

PL's expertise in green hydrogen and hydrogen fuel cells has led him to explore a wide range of applications, including the decarbonization of the built environment. He delves into the potential of hydrogen technologies in the realm of sustainability, drawing attention to hydrogen's role in various decarbonization scenarios. His insights shed light on the significance of renewable hydrogen and low-carbon hydrogen, emphasizing the need for international frameworks to define and certify these types of hydrogen.

PL acknowledges that the term "*green hydrogen*" is evolving, giving way to terms like "*low-carbon hydrogen*" and "*renewable hydrogen*". These terms better reflect the diverse production methods and technologies involved, which encompass not just electrolysis but also deriving hydrogen from biomass or other renewable sources.

In PL's perspective, the future entails assessing hydrogen's sustainability based on specific criteria. He sees promise in a reversible fuel cell combined with an electrolyser, particularly for residential settings and larger buildings, offering energy autonomy and addressing hydrogen intermittency.

In terms of hydrogen's potential in commercial and residential settings, PL draws attention to projects combining hydrogen production with renewable sources like wind and photovoltaic energy. He highlights the development of solid oxide electrolysers for large-scale hydrogen production, while also mentioning reversible electrolysers for more localized applications.

Regarding electrolyser technologies, PL highlights a recent comparison between PEM and alkaline electrolysers. While acknowledging PEM's compactness, PL underscores the robustness and operational costs of alkaline electrolysers. Additionally, PL notes the emergence of contenders like AEM, proton exchange, and high-temperature solid oxide electrolysers, potentially challenging the dominance of PEM and alkaline technologies.

When discussing the production of green hydrogen, PL emphasizes the importance of considering the complete life cycle, evaluating factors such as carbon content, land use, and water usage. He acknowledges the relevance of various hydrogen technologies, including proton exchange membrane (PEM) and anion exchange membrane (AEM) electrolysers, highlighting the ongoing debate between their advantages.

PL points out a noteworthy player in this field, a joint venture in France focused on solid oxide electrolysers for large-scale hydrogen production. They have set their sights on maturing the technology over the next five years. Furthermore, PL mentions another technology offering a small-scale, high-temperature reversible electrolyser.

Hydrogen's rich century-spanning history in the industry is not lost on PL, and while the technologies are evolving, he believes that the fundamental understanding of hydrogen remains unchanged.

PL's knowledge extends to hydrogen safety requirements, particularly in the context of mobility applications, where public awareness plays a crucial role. He underscores the necessity for international safety standards to ensure the widespread acceptance of hydrogen technologies. While recognizing the importance of international standards, PL acknowledges that some aspects, such as regulations concerning the installation of production units, may differ across countries based on their specific circumstances.

Regarding small-scale hydrogen production for commercial and residential use, PL suggests that it can be addressed through national frameworks and regulations, as long as there is no impact on international trade. He advocates for mutual recognition platforms for certification schemes to facilitate international trade of hydrogen-based products.

PL's profound knowledge and insights provide a comprehensive overview of hydrogen technologies, their potential applications in various sectors, and the critical role they play in the decarbonization of the built environment. His expertise in green hydrogen, hydrogen fuel cells, and related technologies offers valuable contributions to the ongoing global efforts to transition towards a sustainable energy future.

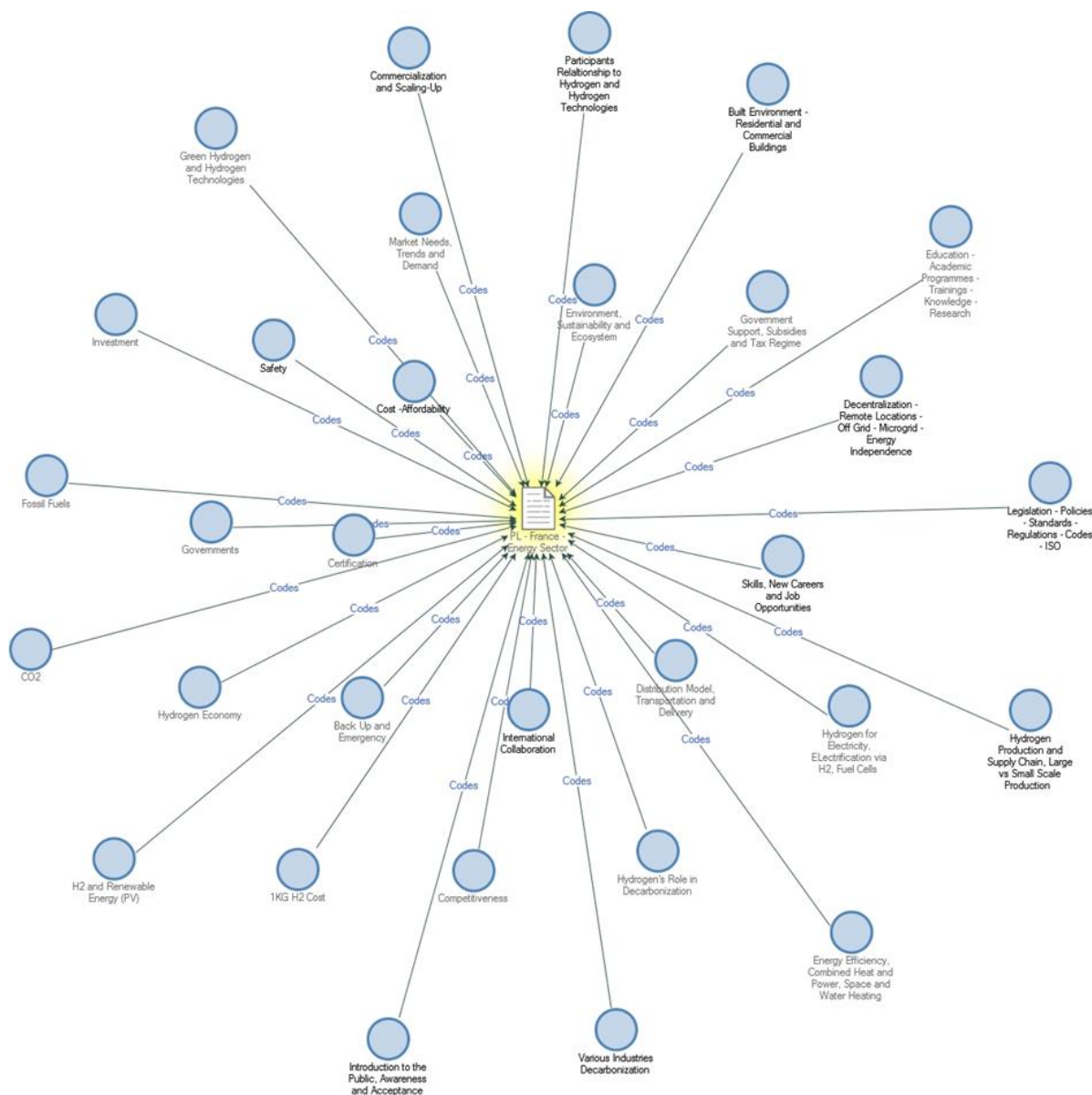


Diagram 10: PL - Thematic Interview Summary Diagram

4.5.11 RH – NZ

In this interview with RH, an expert in hydrogen technologies and a key figure in New Zealand's hydrogen-related standards development, the focus was on green hydrogen and its potential applications in decarbonizing the built environment, particularly in domestic and commercial sectors. RH's involvement in hydrogen technology is rooted in innovation and a deep understanding of the field. As a part of a team that pioneered advancements in hydrogen technology, his perspective is shaped by hands-on experience and a clear bias towards innovation. While initially exploring fuel cell technology, RH and his team transitioned to combustion processes due to practicality and economic considerations. RH's authority in the field is evident as he actively participates in both international and national hydrogen standardization efforts. His active engagement in shaping hydrogen standards highlights his commitment to driving progress and ensuring safe and effective integration of hydrogen technologies.

Considering efficiency, RH emphasizes that small-scale hydrogen-to-electricity conversion faces challenges in surpassing 50%, while hydrogen combustion boasts about 85% efficiency, potentially scaling up to 90%. Within New Zealand's energy landscape, targeting the 71% allocated to cooking, hot water, and space heating through hydrogen combustion emerges as a compelling energy-efficient and cost-effective avenue. This strategy could involve a circulating hot water system, effectively optimizing hydrogen usage for these applications and potentially justifying the capital investment in fuel cells.

Though RH's expertise as the inventor of hirelings skews practical bias towards smaller fuel cells, such as a 500-Watt iteration, the utility of these cells for emergency power is underscored, ensuring essential devices remain operational during critical times.

In RH's vision, a fusion of solar-powered electrolysis and hydrogen combustion for heating emerges as an energy-efficient and economically viable alternative, potentially outpacing the efficiency of small-scale hydrogen-to-electricity conversion. Additionally, the concept supports emergency fuel cells for crucial energy needs. Solar panels power an electrolyser, initiating the water-splitting process into hydrogen and oxygen. The resulting hydrogen is then utilized in an instant water heater, effectively replacing the carbon-intensive gas heating method and significantly reducing the carbon footprint.

Notably, an Australian endeavour led by Lavo showcases a hydrogen battery, essentially a reversible fuel cell, offering substantial 40 kWh storage capacity. However, RH acknowledges that the cost might limit its viability to specific use cases, necessitating careful economic evaluation.

From a sustainability standpoint, RH's approach embraces water utilization and the avoidance of fossil fuels, ultimately nurturing a circular hydrogen energy economy. This ecological cycle ensures the water used in the process returns as water vapor to the environment, upholding the natural water cycle and bolstering overall sustainability.

Regarding electrolyser technologies, RH identifies three main contenders. The physical membrane approach is deemed the simplest and most cost-effective, albeit with potential trade-offs in hydrogen quality and reliability. Meanwhile, the proton exchange membrane demonstrates impressive electrochemical efficiencies, but grapples with platinum usage challenges. Notably, Enapter's anion exchange membrane technology shines for its efficiency, even though considerations over OH ion movement's impact on electrochemical performance arise.

Efficiency, reliability, and cost emerge as pivotal factors in RH's perspective when selecting suitable technology. While catalyst-based systems can degrade due to catalyst poisoning over time, PEM systems might face efficiency decay without leading to complete failure.

Hydrogen's energy density in comparison to methane raises considerations within gas mixtures. The lower density of hydrogen could disrupt equipment requiring specific energy ranges, thereby influencing combustion in heaters. RH introduces the concept of the Hobby Lobby index, pertaining to gas quality standards essential for equipment functionality.

As for hybrid networks featuring hydrogen and natural gas, limitations arise due to energy density disparities. A pure hydrogen network might necessitate burner modifications, while integrating hydrogen alongside other gases would likely entail adapting burners to accommodate both fuels.

During the interview, RH discussed his focus on remote areas in relation to renewable power generation, storage, and usage, particularly in the context of using hydrogen as an alternative to LPG. He emphasized the significance of this approach for remote locations, aiming to provide power, facilitate business growth, and offer technical solutions. RH described a project that originated as research, addressing challenges associated with off-the-grid renewable energy systems and the synchronization of energy supply and demand. He underlined the benefit of using hydrogen as a storage medium due to its density and storage longevity.

The project involved an identity polyethylene pipe for storing hydrogen underground, designed to last a century, in contrast to lead-acid batteries with shorter lifespans. The focus was on thermal power rather than electrical, with hot water heaters and burners as key components. RH pointed out that the system's efficiency surpassed that of fuel cells, despite the latter's usefulness. He showcased installations and prototypes, highlighting the practicality and adaptability of the system in remote settings. He further discussed the cost implications and potential for a hydrogen-fuelled fuel cell system.

RH touched on the environmental advantages, such as negligible CO₂ emissions compared to LPG, and his work to obtain exemptions under the Gas Act for the projects. He acknowledged challenges with local councils and discussed ongoing efforts to update gas standards to incorporate hydrogen safely. He emphasized the technical feasibility of burning hydrogen, even if regulatory and commercial challenges exist for blending it with natural gas. Overall, RH presented an innovative approach to providing sustainable power solutions for remote areas using hydrogen technology.

RH's vision champions enhanced sustainability through a circular hydrogen energy economy utilizing abundant water resources. Different electrolyser technologies, with their varying efficiencies and considerations, are assessed. RH also delves into the compatibility of hydrogen within mixed gas networks, where burner adjustments are vital for optimal performance.

RH discussed various aspects of hydrogen technologies, particularly focusing on their potential in New Zealand and their role in decarbonization efforts. RH emphasized that hydrogen, as a clean fuel, could have applications in sectors such as transport, industrial processes, and heating. He mentioned that blending hydrogen with natural gas could be a viable solution for decarbonizing existing infrastructure and achieving emission reductions without major modifications. RH expressed optimism about the feasibility of using hydrogen for heating and cooking applications, particularly in remote locations.

Regarding safety concerns, RH explained that hydrogen's unique properties, such as its wide flammability range and near-invisibility of the flame in daylight, pose challenges for detection and awareness. He discussed the importance of safety measures, such as using sensors to detect hydrogen leaks, solenoid valves to isolate the gas in case of leakage and utilizing flame-controlling devices to address flame visibility issues.

RH touched upon the challenges of scaling up hydrogen technologies, especially in terms of cost and infrastructure. He highlighted the potential of hydrogen technologies for energy storage, particularly in grid-scale applications, where excess renewable energy could be converted to hydrogen and stored

for later use. He also discussed hydrogen's potential in hard-to-convert industrial processes and as a fuel source for aviation and clean steel production.

In terms of public acceptance and government involvement, RH suggested that demonstrating the value and practicality of hydrogen technologies through sound business cases and real-world applications would be crucial. He mentioned that the New Zealand government, led by the Minister for Energy, Megan Woods, has shown interest in hydrogen technologies. However, RH emphasized the need for clear and accurate communication to address public perceptions and concerns, particularly around safety and feasibility.

RH highlighted the significance of using hydrogen technologies to replace fossil fuels for hot water heating in buildings. By employing an electrolyser powered by solar panels to produce hydrogen from water, and subsequently burning the hydrogen in an instant water heater, the operating fuel of gas appliances can be completely decarbonized, leading to substantial carbon dioxide emissions savings. RH shared valuable insights on the design requirements, qualifications, and standards associated with hydrogen technology installation in residential and commercial buildings.

To accelerate the acceptance of hydrogen technologies by the public, RH emphasized the importance of ensuring proper certification and safety measures. Based on research, RH found that public confidence in hydrogen technologies increases significantly when certified by recognized New Zealand authorities. Hence, establishing a clear pathway for certification and providing public information about the safety measures in place could drive acceptance.

RH also discussed the relevance of measuring the impact of hydrogen technologies in terms of decarbonization. Instead of presenting complex carbon dioxide metrics, RH suggested expressing the benefits in terms of tangible services or savings that people can understand and relate to, such as the equivalent of kilometres driven or units of gas used. Additionally, addressing the economic aspect is crucial. To make hydrogen technologies economically viable, RH proposed aggressively driving down the upfront costs and potentially implementing carbon pricing to encourage adoption.

Regarding safety requirements for introducing hydrogen technologies to stakeholders, RH highlighted the importance of detection and monitoring systems. For domestic use, implementing hydrogen sensors at the highest point of the building, alongside solenoid valves to control hydrogen flow, can ensure safety. Industrial-scale applications would require sophisticated gas sensors, flame detection systems, and pressure measurements to detect and prevent leaks effectively.

When considering the government's role in accelerating hydrogen technology development, RH suggested providing regulatory support rather than driving the process directly. Government regulations and incentives, coupled with collaborative efforts with private companies already investing in hydrogen technology, can promote the adoption of advanced hydrogen solutions.

Discussing different hydrogen electrolyser technologies, RH compared proton exchange membrane (PEM), anion exchange membrane (AEM), and alkaline electrolyzers. PEM was recognized as the most mature and efficient option but could face challenges with platinum usage and potential poisoning. AEM and alkaline electrolyzers, on the other hand, offer their advantages in simplicity and potential longer life.

The summary highlighted RH's perspective on the potential of green hydrogen in solving energy-related challenges, including affordability, energy security, and sustainability. The circular hydrogen economy, utilizing water as a readily available resource, contributes to sustainability. RH also emphasized the need to manage oxides of nitrogen (NO_x) emissions to ensure decarbonization remains effective.

In terms of cost, RH mentioned that the price of producing one kilogram of green hydrogen varies widely, with some estimates as low as \$5 per kilogram. However, further advancements and economies of scale could potentially bring the cost down to around \$1 to \$1.5 per kilogram.

Regarding design requirements, RH emphasized the significance of material selection, especially for low-pressure applications inside the house. He highlighted the need to prevent static discharge as hydrogen is more prone to ignition due to its lower ignition energy compared to methane. However, with proper grounding and design considerations, these challenges can be addressed.

In terms of qualifications, RH suggested that professionals already possessing skills in gas fitting can easily transition to hydrogen technologies with just a small additional training, akin to obtaining a hydrogen endorsement. While specific hydrogen-related knowledge is necessary, most existing gas fitting skills are transferable, making the transition relatively smooth.

Discussing standards, RH indicated the complexity of hydrogen-related standards, which require careful consideration in various areas such as transmission, appliances, and transportation. While he acknowledged the importance of having hydrogen standards, he did not believe a single international standard would suffice for all countries. Instead, he advocated for national adaptations of international standards to suit the specific needs of each country, while also ensuring safe and efficient hydrogen utilization.

Regarding the potential of using hydrogen for residential self-sufficiency through solar energy, RH recognized the technical feasibility of such projects but highlighted the economic challenges. He expressed reservations about the cost-effectiveness of using hydrogen for individual residential projects due to the inefficiencies involved. Instead, he suggested focusing on off-grid applications, where hydrogen can serve as a valuable fuel gas, particularly for process heat.

When it comes to the acceptance of a hydrogen economy in New Zealand, RH clarified that it is not a matter of acceptance but rather a lack of compelling use cases for widespread hydrogen utilization. He acknowledged some promising use cases, such as Huanga's ammonia production using green hydrogen and certain off-grid applications, but felt that the residential sector, in particular, lacks a strong business case for widespread hydrogen adoption. He emphasized the importance of considering both the environmental impact and cost-effectiveness when evaluating the potential of hydrogen applications.

RH also discussed the advantages of hydrogen for certain applications, particularly in decarbonizing the transportation sector. He cited the example of a company that successfully incorporated hydrogen alongside diesel to partially decarbonize their operations. However, he highlighted that subsidies should not be the sole driving force behind hydrogen adoption, but rather a combination of market demand and commercial viability.

In conclusion, RH's expertise and in-depth knowledge of hydrogen technologies shed light on the challenges and opportunities in utilizing hydrogen for residential and commercial purposes. While certain off-grid applications show promise, widespread adoption in the residential sector faces economic hurdles. His insights underscore the importance of evaluating each use case carefully to determine the feasibility and potential benefits of integrating hydrogen technologies in various sectors. Overall, RH's insights provide valuable perspectives on the usage of hydrogen for domestic and commercial utilization, the challenges in decarbonizing the built environment, and the potential benefits of green hydrogen technologies. His expertise in the field of hydrogen technologies enriches the discussion, making it relevant and engaging for the audience. Overall, RH expressed optimism about the potential of hydrogen technologies in New Zealand's energy landscape and highlighted various areas where hydrogen could contribute to achieving energy sustainability and decarbonization goals.

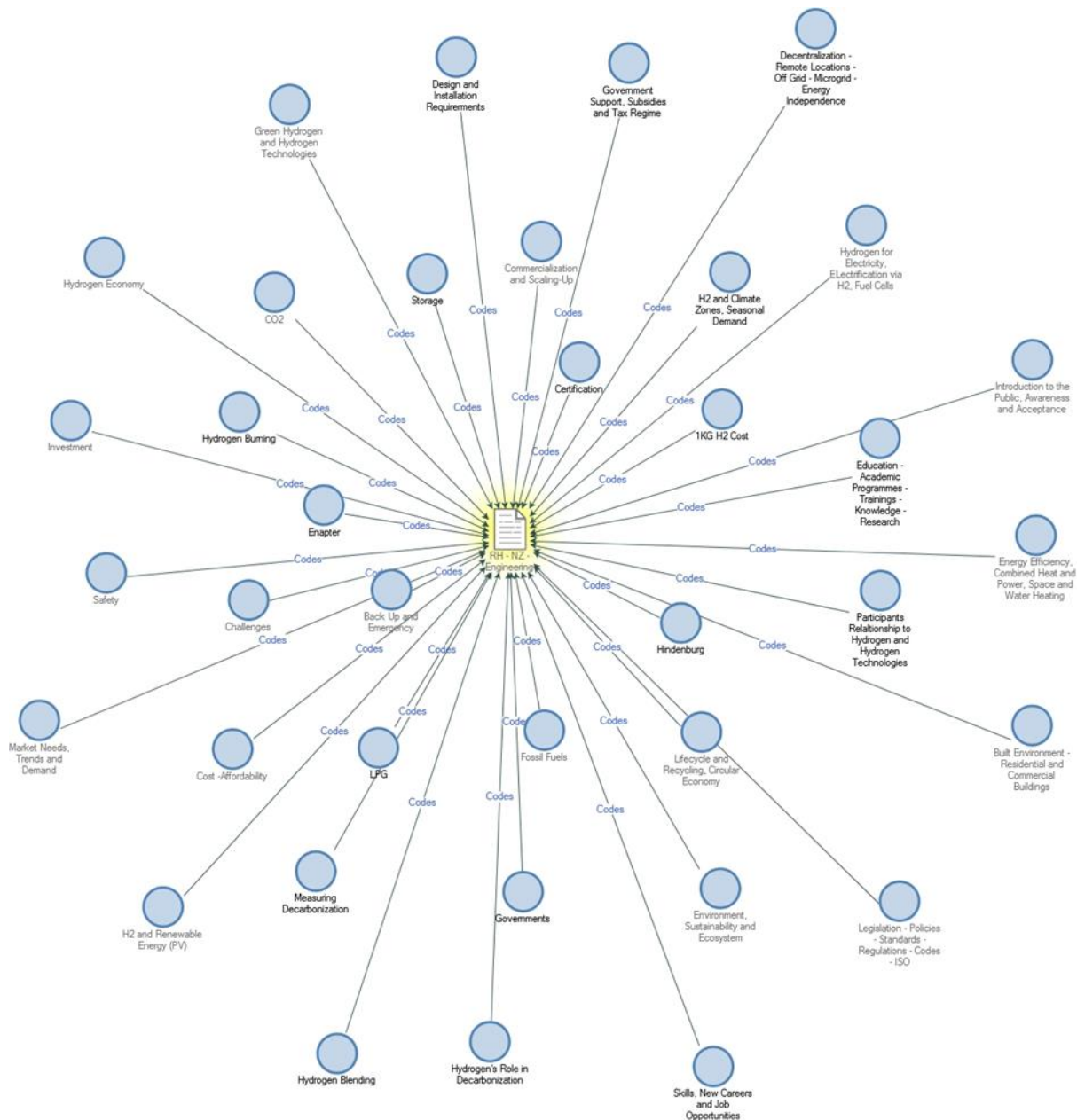


Diagram 11: RH - Thematic Interview Summary Diagram

4.5.12 SJS – Germany

The participant, SJS, is a prominent figure in the hydrogen technology field with a background in software, hardware, and electrochemistry. The interviewee, SJS, has a strong background and expertise in hydrogen technologies, particularly in the development of AEM (Anion Exchange Membrane) electrolyzers. SJS is the founder of a company that manufactures and sells AEM electrolyzers globally. His interest in green hydrogen and hydrogen technologies began when he sought to make his private home in northern Thailand completely off-grid and sustainable. However, he faced challenges with seasonal energy storage due to the rainy season, which led him to explore hydrogen as a potential solution. After experimenting with a small electrolyser in his home, he recognized the potential of hydrogen as an energy storage medium and decided to invest in the technology. Due to his personal interest in sustainable off-grid solutions for his home in Southeast Asia, SJS initially became involved with small-scale hydrogen electrolyzers. After taking over a struggling electrolyser company in 2017, he envisions that producing low-cost electrolyzers at large scale could enable hydrogen to become cheaper than fossil fuels, thereby facilitating the transition to clean energy.

SJS's journey into hydrogen technology began with a personal goal of creating an off-grid and sustainable home in northern Thailand. Recognizing the limitations of battery storage during extended rainy seasons, he ventured into hydrogen technology as a means of overcoming energy storage challenges. After discovering a small electrolyser company at an exhibition in Singapore, SJS implemented their technology in his home, demonstrating its viability even when sceptics doubted its success. When the company faced bankruptcy, he and his son stepped in, drawing from their combined expertise in electrochemistry, software, hardware, and mechanical engineering. Their company's mission expanded beyond personal use to tackling global climate change by revolutionizing hydrogen production to make it more affordable than fossil fuels. The realization that traditional energy sources must be replaced with sustainable alternatives drove SJS to innovate and mass-produce electrolysers, envisioning hydrogen as a vital component in the transition to a cleaner energy future.

Within the realm of innovative technologies, SJS underscores the continuous effort of evaluating and experimenting with various ideas and claims about high-efficiency solutions. Expert evaluation is essential to determine the viability and practicality of these concepts. It is acknowledged that not all ideas materialize into successful products, necessitating substantial development and validation for concepts to transition into functional products.

However, while hydrogen's potential as an energy carrier garners optimism, SJS points out that challenges persist. These challenges encompass not only the technology itself but also infrastructure, technology readiness, and public perception. The transition from fossil fuels would require substantial shifts in subsidies and policies to create an equitable environment for hydrogen to compete with established energy sources.

SJS further emphasizes the importance of technological readiness, drawing parallels with successful applications in industries like automotive and solar panel production. The journey from conceptualization to practical implementation is crucial to ensure that ideas evolve into feasible and impactful solutions.

Hydrogen's versatility and potential across various sectors are acknowledged by SJS, but they also emphasize the significance of market dynamics, industry acceptance, and policy support. Collaboration, research, and technological advancement are identified as pivotal factors in shaping a sustainable energy future, as different industries navigate the transition towards cleaner energy sources.

SJS's company focuses on producing hydrogen electrolysers for various applications, including refilling stations, industrial use, and even aviation. The main goal is to produce hydrogen more efficiently and cost-effectively to make it a viable alternative to fossil fuels, thereby contributing to the decarbonization of the built environment.

To accelerate the acceptance of hydrogen technologies, SJS emphasizes the need for public awareness and education. He believes that the government's support is crucial, but it should focus on promoting renewable energy sources, which will lead to increased interest in hydrogen. However, he highlights that governments often favour fossil fuel industries, which hinders the widespread adoption of hydrogen technologies. The government's support and favourable policies are critical to encouraging the widespread adoption of hydrogen technologies in various sectors. On the challenges of deploying hydrogen at scale, SJS observes:

“As long as there is so much money...from oil and gas companies...then you understand how big the influence of these kind of companies is”.

He advocates shifting government subsidies away from fossil fuels to allow fair competition between hydrogen and conventional energy sources. Yet government policies often continue to favour

centralized systems, hampering decentralization through technologies like distributed solar generation and hydrogen production. He argues that producing affordable green hydrogen requires both very low-cost renewable electricity and efficient electrolyzers. Technological advancements could bring electrolyser costs below €300 per kW in the next five years, according to SJS.

Despite the potential benefits of hydrogen, there are still misconceptions about its safety and feasibility. SJS points out that these misconceptions are often propagated by vested interests in the fossil fuel industry, which creates barriers to acceptance. Overcoming these challenges requires public awareness campaigns to dispel myths and showcase successful implementations of hydrogen technologies.

Regarding the decarbonization of the built environment, SJS emphasizes the need to transition from fossil fuels to hydrogen as a clean energy source. He believes that wherever fossil fuels are used today, hydrogen can be a viable and cleaner alternative.

“Everywhere where you have today fossil fuel, you could use hydrogen and you should and you will not use hydrogen if hydrogen is cheaper than fossil fuel”.

SJS also stresses the importance of decentralization in energy systems. By encouraging the use of distributed energy sources like solar panels and wind farms, governments can reduce the reliance on centralized energy production and distribution. This shift would lead to a more resilient and sustainable energy infrastructure.

In the discussion about the benefits of hydrogen technologies, SJS highlighted the positive impact of green hydrogen in providing sustainable and almost grid-independent power solutions. He mentioned that his company’s hydrogen-based home power solutions are gaining popularity, offering customers almost self-sustained homes with minimal grid connectivity. However, the challenge lies in the cost of the systems, which is still relatively high. SJS stressed the importance of governments supporting the hydrogen industry without creating unnecessary hurdles, enabling faster progress in this crucial sector.

Regarding the sustainability of hydrogen technologies, SJS affirmed that the systems are recyclable at the end of their life cycle. He mentioned that his company considers environmental aspects in their product development and uses recyclable materials wherever possible. SJS also discussed the importance of widespread adoption of green hydrogen, which requires collaboration between countries and a flexible approach to standards to allow for innovation and development.

In terms of safety, SJS expressed confidence in the existing safety requirements for hydrogen production and storage. He mentioned that the hydrogen industry has advanced safety measures in place, and there is no immediate need for additional regulations.

When discussing the scale of hydrogen production, SJS explained that the decision on whether to produce green hydrogen on a large or small scale depends on the use case. Large-scale production can be cost-effective for energy-intensive industries, while small-scale systems may be more suitable for remote areas or individual households.

SJS also stressed the importance of education and training in the hydrogen industry. He advocated for including more electrochemistry courses in educational curriculums and offering workshops to spread knowledge about hydrogen technologies. He mentioned that his company is working on establishing learning hubs in different countries to support skill development in this field.

In conclusion, SJS’s expertise and experience in the hydrogen technology sector make him a valuable voice in the quest for a cleaner and more sustainable energy future. His company’s efforts to produce efficient and affordable hydrogen electrolyzers are a step forward in the decarbonization of the built environment. However, he acknowledges the challenges posed by vested interests and government

policies that favour fossil fuels. Overcoming these barriers will require widespread public awareness, education, and government support for renewable energy sources and hydrogen technologies. SJS's expertise and experience in hydrogen technologies make him a valuable source of knowledge for the development and acceptance of hydrogen solutions. His company's AEM electrolyzers offer promising possibilities for domestic and commercial utilization of green hydrogen, contributing to the decarbonization of various sectors. SJS's insights shed light on the challenges and potential of green hydrogen, making it an exciting prospect for a sustainable energy transition.

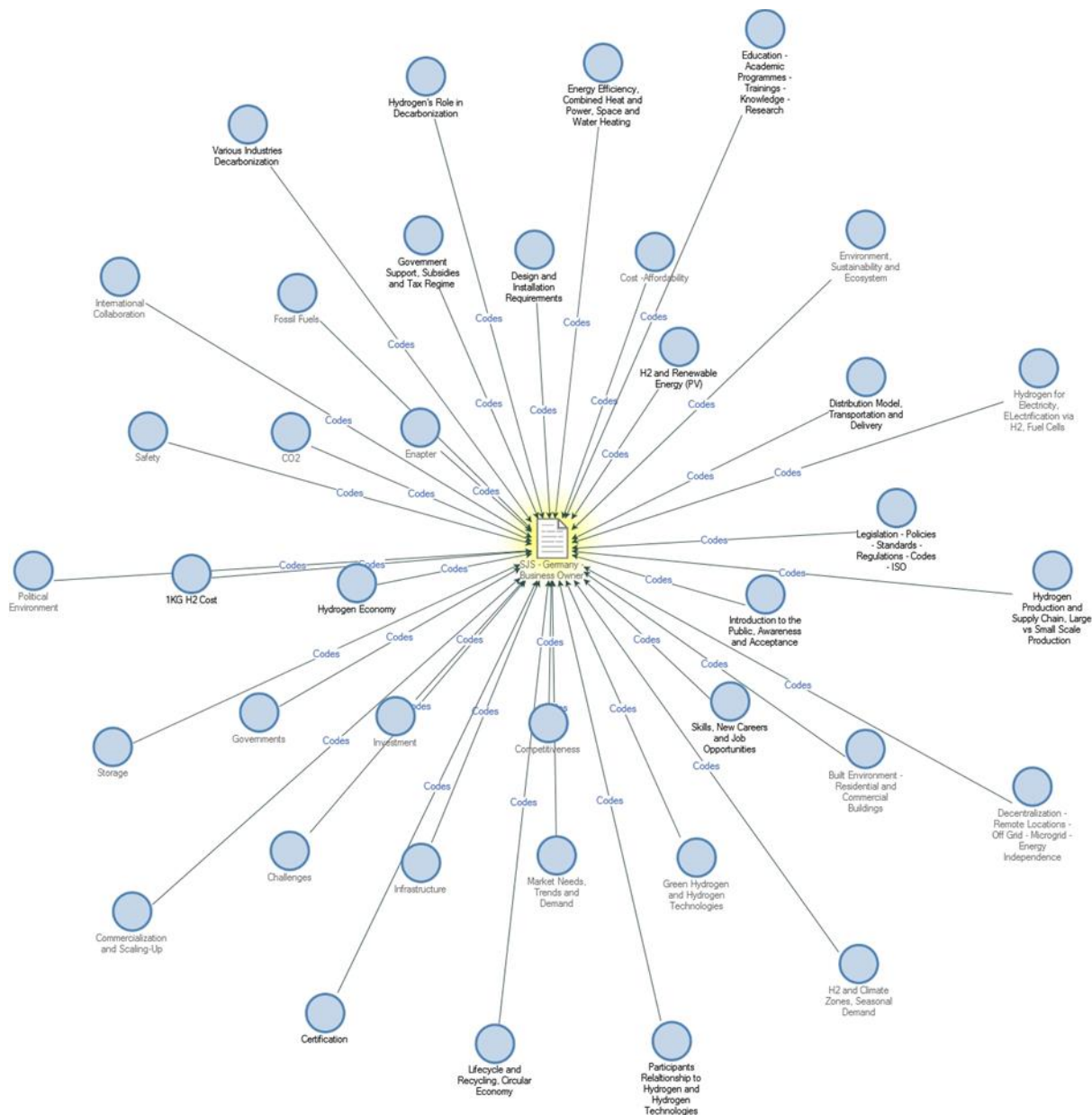


Diagram 12: SJS - Thematic Interview Summary Diagram

4.5.13 TW – NZ

TW's journey in the realm of hydrogen technology began with Venture Taranaki's initiative, Vincent Taranaki 2050, following the announcement of an oil and gas ban. Leading a team of 45 in TIS, a company entrenched in the oil and gas sector, TW recognized the need to adapt and embrace the hydrogen transition. Through workshops and research, TW and his team explored hydrogen's potential, procured various technologies, and conducted trials to gain hands-on knowledge. Focusing on sizing systems and identifying opportunities to replace gas appliances with hydrogen,

TW aimed to enhance efficiency for high-end loads like cooking, hot water, and space heating, supplementing solar and battery-powered solutions for lighter loads. In his role as operations manager, TW not only oversees TIS's operations but also leverages his expertise to facilitate the hydrogen sector's growth, building networks, understanding challenges, and providing tailored solutions to propel the shift toward green hydrogen technologies.

The developmental trajectory of implementing hydrogen technology involves practical trials, scalability considerations, and efficiency enhancements. A company, represented by TW, initiated a trial setup within their workshop to gain first-hand experience before advancing towards commercialization. The primary objective revolves around fine-tuning the system's dimensions, longevity, and efficiency to render hydrogen production economically feasible.

Efficiency-wise, the company operates its electrolyser systems at approximately 70% efficiency. This translates to a requirement of approximately 43 kilowatts of energy to produce 1 kilogram of hydrogen, equivalent to 33 kilowatt-hours of stored energy. The hydrogen generated is stored akin to a battery, holding the potential to release the stored energy as needed.

In terms of pricing, the integration of hydrogen batteries and solar systems for residential purposes currently incurs an expense of approximately NZD70,000. Nonetheless, TW's company is actively observing industry peers like Lavo, who employ innovative storage methods that could potentially lead to significant cost reductions.

A challenge encountered pertains to the delicate balance between promoting hydrogen's potential while acknowledging its limitations. TW underscores the importance of avoiding overstatement, recognizing that while hydrogen holds the potential to address numerous energy challenges, it is essential to remain realistic about its capabilities. The company shows particular interest in utilizing hydrogen for thermal applications, envisioning its use in hydrogen boilers and cooking hobs to eliminate carbon emissions completely.

The development path pursued by the company involves substantiating technology feasibility, showcasing effective control mechanisms, and customizing systems to align with community or microgrid requirements. Their vision entails self-contained containers capable of producing and storing hydrogen, with potential applications spanning community energy supply and refuelling stations.

Collaboration with appliance manufacturers is another focal point, aiming to develop appliances that can utilize hydrogen as a fuel source. This endeavour involves navigating regulatory complexities and securing exemptions for appliances designed for hydrogen use.

Considering electrolyzers, distinct types demand diverse prerequisites. For example, alkaline electrolyzers depend on conductive water, while other systems might necessitate exceptionally pure water. Exploration into solar panel-powered seawater electrolysis is also underway within the industry.

TW's current projects involve concepting and understanding market entry points for hydrogen products, aiming to assist people in implementing hydrogen solutions. He has experience working with Enapter, a supplier of anion exchange membrane electrolyzers, which offers scalability and maintenance-friendly features.

In terms of affordability, TW explains that the cost of producing 1 kilogram of green hydrogen is around \$9 to \$11. However, he believes the cost will significantly drop in the near future due to Enapter's mass production facility coming online.

TW sees distributed hydrogen production as the more cost-effective and energy-efficient option for residential and commercial utilization. He envisions a scenario where hydrogen systems work in

parallel with batteries, allowing for energy self-sufficiency and improved efficiency in high-load applications like cooking, hot water, and space heating.

When it comes to safety, TW asserts that choosing the right products and material selection is crucial for hydrogen technology installations. Hydrogen is perceived to be dangerous, but he argues that it can disperse quickly, making it safer in certain situations compared to natural gas.

As for government support, TW mentions the need for more clarity and a focus on energy independence and resilience. He believes that enabling energy self-sufficiency through domestic solar and hydrogen utilization will provide greater value to the community.

Regarding education, TW emphasizes the importance of educating professionals, particularly in the regulatory and architectural space, to understand hydrogen safety and efficiency. He also suggests the adoption of micro-credentials to certify professionals working with hydrogen systems.

TW emphasizes the importance of creating a supportive regulatory framework to drive the adoption of hydrogen technologies. While New Zealand has not yet implemented green certificates to incentivize low or zero-carbon energy sources, TW believes that such a system would be beneficial to encourage the uptake of hydrogen-based solutions.

Regarding the installation of hydrogen systems for residential developments, TW highlights the need for thorough compliance with existing regulations. He acknowledges the complexities of navigating through the approval processes with local councils but remains optimistic about the potential for exemptions and proper safety measures.

TW showcases the practicality and viability of hydrogen technologies for off-grid and microgrid applications. He envisions small communities becoming self-sufficient through micro hubs of energy, offering energy independence and resilience to extreme weather events.

The expert also emphasizes the environmental benefits of hydrogen technologies, as they produce zero or near-zero emissions when used as a fuel source. He points out that hydrogen can displace carbon in existing fuels, making it a cleaner and more sustainable alternative.

While TW acknowledges the challenges of implementing hydrogen technologies on a larger scale, he highlights the role of pilot projects in demonstrating the safety and efficiency of such systems. By collaborating with architects, engineers, and developers, he aims to showcase the potential of hydrogen solutions and pave the way for broader adoption.

TW's expertise and passion for hydrogen technologies demonstrate the potential of green hydrogen in New Zealand's built environment. By advocating for a supportive regulatory environment and promoting pilot projects, he envisions a future where hydrogen plays a significant role in decarbonizing the energy sector and fostering sustainable and resilient communities.

In conclusion, TW's insights reveal a promising future for hydrogen technologies, especially in the domestic and commercial sectors. His vision of using distributed hydrogen production in conjunction with renewables provides a pathway for New Zealand to address the trilemma of affordability, sustainability, and reliability while contributing to decarbonization efforts. However, to fully realize this potential, clear regulations, government support, and well-informed professionals are crucial components of the equation.

that the key challenge that persists is the cost factor, which is viewed as a significant barrier to achieving widespread adoption. However, there is a prevailing expectation that as technology progresses and economies of scale are achieved, the cost hurdle will gradually diminish.

TN points out one of the primary advantages of hydrogen technology - its remarkably clean emissions profile, emitting only water as a by-product. This aspect makes hydrogen an attractive choice for decarbonization efforts, particularly in sectors where other methods might struggle to eliminate the last remnants of emissions.

The role of hydrogen within New Zealand's energy landscape is multifaceted. While hydrogen production through electrolysis holds the potential to emit no CO₂, the overall environmental impact hinges on the energy source used for electrolysis. If the energy derives from the grid, which still carries a carbon footprint in New Zealand due to its energy mix, the emissions reduction might not be as substantial. This underscores the crucial necessity of ensuring the renewable nature of the energy used for hydrogen production.

The potential applications of hydrogen span a wide spectrum, encompassing factories, residential areas, commercial buildings, and even remote islands isolated from the grid. The feasibility of integrating hydrogen in these scenarios is often contingent upon the local infrastructure and energy demands. In certain instances, it might prove more economically viable to generate and utilize hydrogen locally rather than pursuing grid connectivity.

TN highlights the potential repurposing of existing infrastructure, such as legacy Olympic facilities, for hydrogen-related activities, showcasing the adaptability of hydrogen technology within pre-existing structures.

When it comes to technology providers, choices are influenced by factors like adherence to local regulations and standards. TN underscores that companies like Enapter offer promising technology, but challenges such as obtaining local compliance in New Zealand can impact their adoption in specific regions. This illustrates the broader truth that while the technology might hold global relevance, regional compliance and adaptation are pivotal for successful implementation.

TM discussed the challenges and opportunities of implementing green hydrogen in various sectors, particularly in construction sites. He highlighted the difficulty in locating hydrogen cylinders due to safety concerns and space limitations. However, he also mentioned the potential of small-scale electrolyzers connected to photovoltaic systems for domestic and remote locations, which could offer a decentralized and sustainable energy solution.

The interviewee shared examples of hydrogen projects in Japan, such as a town in Fukushima powered by green hydrogen, emphasizing the importance of raising awareness and dispelling safety misconceptions about hydrogen. He advocated for a clear government roadmap and support through subsidies and incentives to accelerate the adoption of hydrogen technologies.

Regarding the cost of green hydrogen production, TM acknowledged its high current cost but expressed hope for future reductions through mass production. He also emphasized the need for collaboration between government and industry to drive advancements in hydrogen technologies.

Safety considerations for hydrogen technologies were discussed, and TM mentioned the importance of proper design, location, and distance regulations to ensure safety during production, storage, and use of hydrogen.

The conversation touched on the challenges of obtaining permissions and navigating current regulations for introducing hydrogen technologies in New Zealand. TM suggested approaching high-level government officials to champion hydrogen adoption and overcome bureaucratic hurdles.

Overall, TM underscored the potential of green hydrogen and hydrogen technologies to address energy affordability, security, and sustainability. He highlighted the need for collaboration, clear regulations, and public awareness campaigns to create a hydrogen-based energy landscape that can contribute significantly to decarbonizing the built environment and advancing a greener future for New Zealand. The prevailing optimism regarding hydrogen technology's environmental advantages and its potential to play a significant role in a low-carbon energy future is balanced by practical considerations, particularly cost and localized infrastructure nuances. In this pursuit, collaborative efforts among technology providers, policymakers, and industry stakeholders will be indispensable in fully realizing the extensive potential of hydrogen as a pivotal energy carrier.

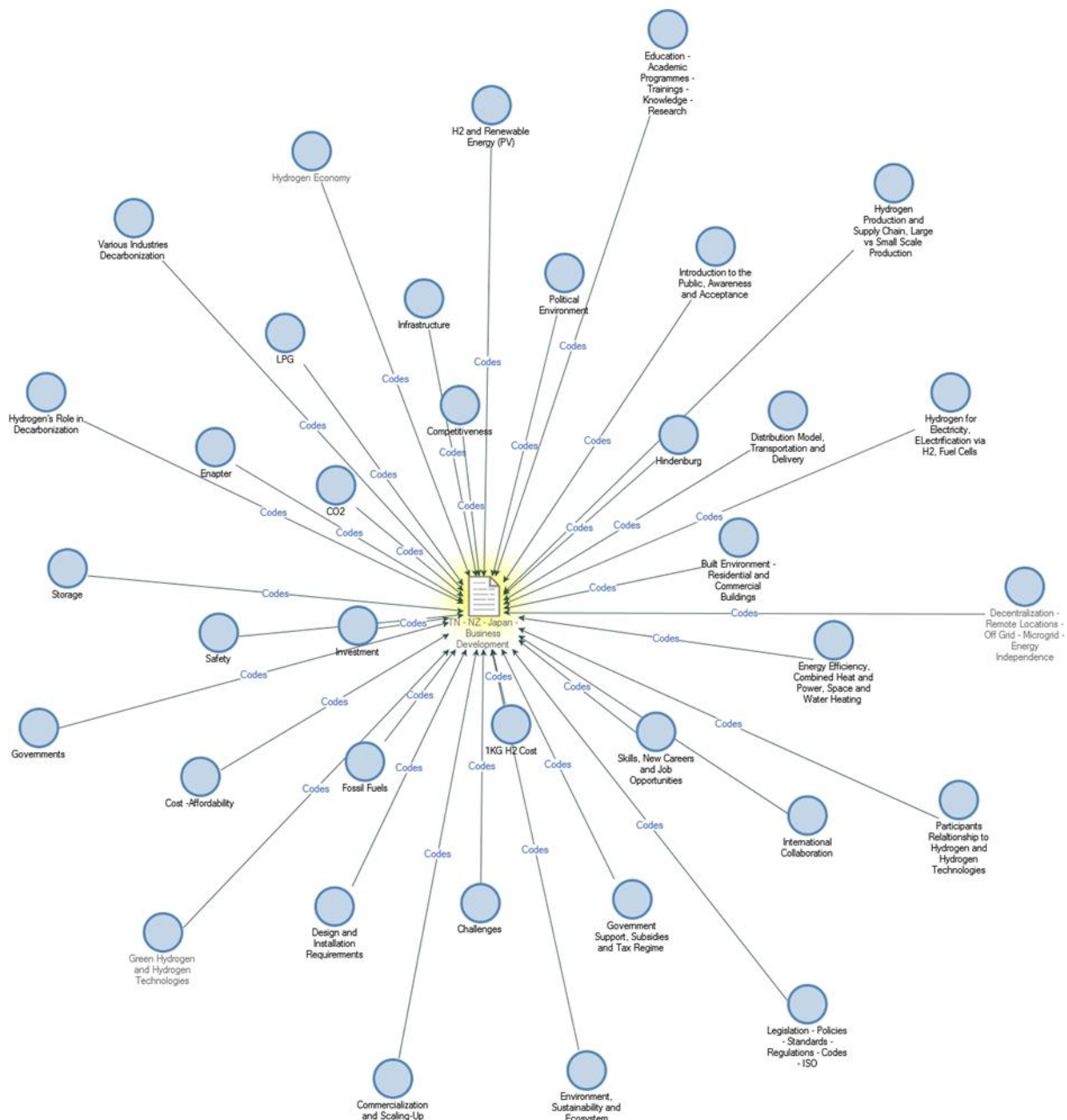


Diagram 14: TN - Thematic Interview Summary Diagram

4.5.15 VG – Saudi Arabia / Germany

VG's experience in the energy sector, coupled with his interest in renewable energies, led him to join the hydrogen team at Neom. The project aims to harness renewable energies, such as wind and solar power, to produce hydrogen, which will be used for export, industrial applications, and transportation, including hydrogen mobility.

VG's journey encompasses a transition from energy trading in Germany to a dynamic role within the hydrogen team at Neom, a pioneering megaproject in Saudi Arabia. With a background in renewable energies, VG has embraced the compelling potential of hydrogen. As part of Neom's ambitious endeavours, VG contributes to the utility company Neom, which seeks to establish a comprehensive hydrogen ecosystem. This vision encompasses a 2.2 GW electrolyser project, transportation infrastructure, local use cases for mobility and industrial applications, as well as hydrogen export. Neom's overarching mission aligns with Saudi Arabia's goal to diversify its economy beyond oil dependency, positioning the country as a global leader in sustainable technology, circular economy practices, smart city solutions, and more. VG's engagement in developing hydrogen mobility and refuelling infrastructure within the vast Neom region underscores his pivotal role in this monumental project.

Public perception and acceptance of hydrogen as an environmentally friendly technology can play a crucial role in its deployment and adoption. VG emphasizes that in Germany, there is a prevailing positive sentiment towards hydrogen and its potential to drive clean energy production. This strong public support can significantly propel policies and initiatives that encourage the widespread use of hydrogen across various sectors.

VG underscores the importance of evaluating the environmental impact of hydrogen throughout its entire lifecycle, encompassing the production process. While hydrogen-based systems operate without emissions, it is essential to account for the upstream emissions linked to equipment manufacturing and electricity generation for electrolysis. Nonetheless, VG notes that these emissions are often markedly lower when compared to alternatives rooted in fossil fuels.

The establishment of standards and regulations to define "*green hydrogen*" varies among different countries and regions. VG highlights the criteria in Europe, which include utilizing freshly constructed renewable energy sources and producing hydrogen concurrently with renewable energy generation. These stringent standards ensure that the hydrogen produced adheres to elevated environmental benchmarks.

VG also accentuates the need to elucidate the role of hydrogen as both an energy carrier and a storage medium. Hydrogen, in itself, does not function as an energy source; rather, it serves as a conduit for energy storage and transportation. The conversion of electricity into hydrogen through electrolysis essentially encapsulates electrical energy in a chemical form. The efficiency of this conversion process, as well as the subsequent utilization of hydrogen through combustion or fuel cells, significantly influences the overall energy efficiency of the entire system.

One key topic discussed during the interview is the potential use of hydrogen in the built environment, particularly in residential and commercial buildings. VG points out that hydrogen heating, while a use case for buildings, may not be the most efficient option. Compared to using a heat pump directly powered by electricity, hydrogen-based heating involves significant energy losses, making it less environmentally friendly and more expensive. VG noted that while "*heating for us is not a big thing*" in Saudi Arabia, in countries like Germany with cold winters "*if the energy will be produced, let's say by hydrogen*", this could contribute to decarbonization of the domestic sector. However, VG was "*quite against hydrogen for heating*" due to efficiency losses, stating:

“If you want to heat up a building, by renewable energy, you have basically two options...The heat pump has an efficiency of I don't know 80-90%. So for every renewable kWh you produce 80% of that you can use as a heating energy for your building. If you go via hydrogen, you have an efficiency overall of 30%. So you practically waste 2/3 of your precious renewable energy”.

Nevertheless, VG acknowledges that waste-to-energy systems, which utilize small-scale electrolyzers and hydrogen storage, could be a viable solution for certain scenarios.

The interview further explores the challenges of introducing hydrogen technologies into society. VG highlights that public acceptance is essential, and countering safety concerns, such as the association with past accidents, can be a daunting task. To gain public confidence, showcasing successful hydrogen implementations in different countries, including Germany, where hydrogen is embraced, might help dispel misconceptions.

VG emphasizes the importance of adhering to international standards rather than creating localized ones to streamline hydrogen technology adoption globally. He also mentions that attracting private investors can play a vital role in accelerating the development of advanced hydrogen technologies, with some countries offering incentives and subsidies to attract investments.

The potential of hydrogen technologies in sustainability, energy security, and affordability is discussed, with VG pointing out that hydrogen can play a significant role in decarbonization efforts, especially in industries like cement production and transportation.

Regarding the Neom project, VG highlights the massive scale of the endeavour, with plans to build a full hydrogen ecosystem that includes large-scale electrolyzers and hydrogen refuelling infrastructure for heavy-duty vehicles, trucks, and buses. The project aims to support Saudi Arabia's transition away from oil dependency and establish a sustainable future for the country.

VG felt that for the majority of hydrogen jobs, workers with general industry skills could transition into the hydrogen sector, with only around 10% requiring deeper technical knowledge. Regarding the prospects of his project in Saudi Arabia to develop a green hydrogen ecosystem, VG highlighted the support from the government and ability to *“build everything on a green field”* as advantages in overcoming the technological challenges of high costs and energy losses associated with hydrogen production and use.

VG's insights provide valuable information about the challenges and opportunities associated with hydrogen technologies, emphasizing the importance of international cooperation, public acceptance, and technological advancements to drive the adoption of green hydrogen and its potential contribution to the decarbonization of various sectors, particularly the built environment.

In summation, the favourable public perception of hydrogen, coupled with the implementation of rigorous standards and regulations to ensure its environmental advantages, contributes substantially to establishing hydrogen's credibility as a clean energy solution. As technological advancements and infrastructure continue to evolve, VG envisions hydrogen playing a pivotal role in shaping a more sustainable and low-carbon energy future.

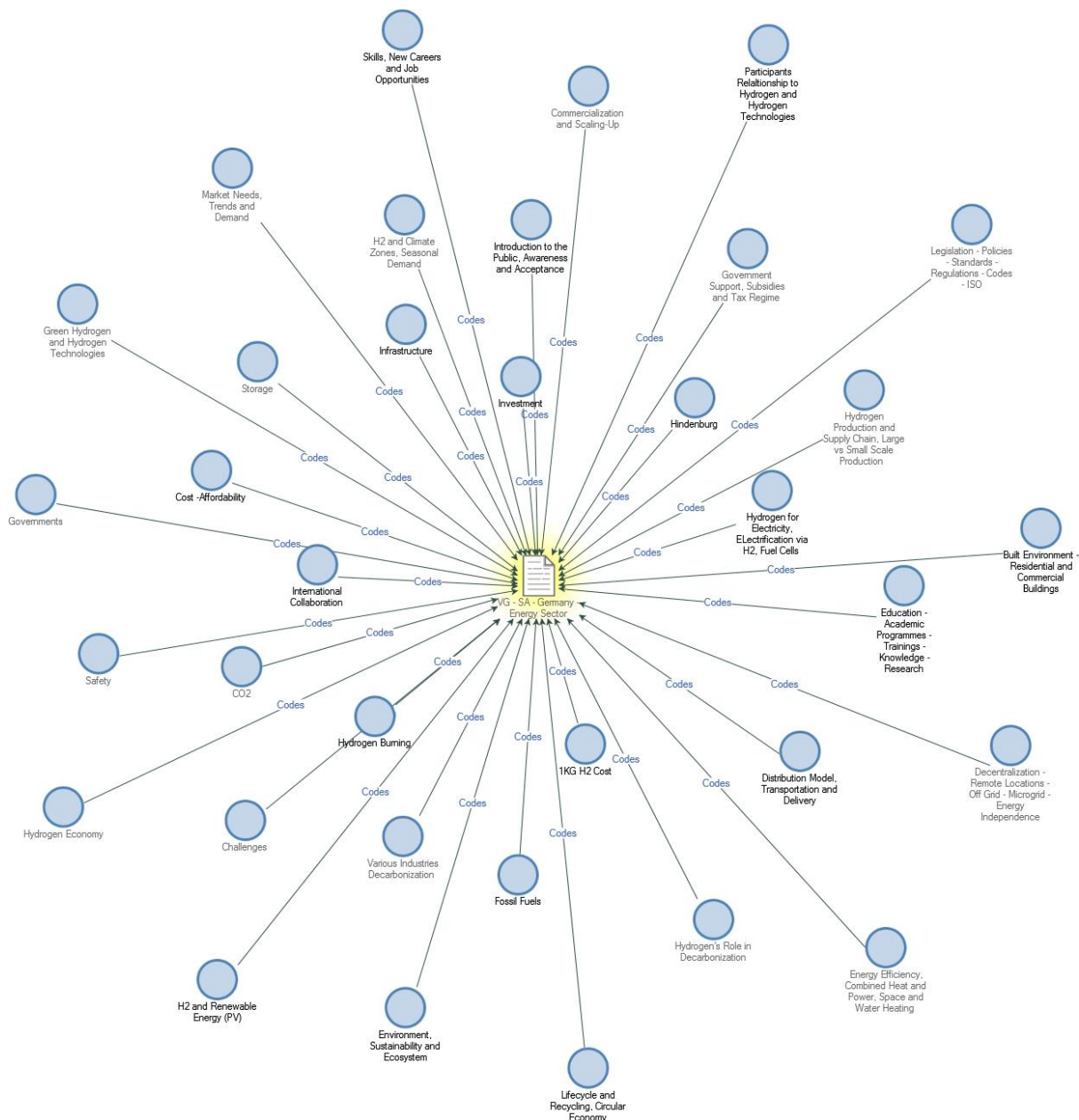


Diagram 15: VG - Thematic Interview Summary Diagram

4.5.16 ZJ – the UK

ZJ's journey through chemical engineering led to a profound involvement with hydrogen-related technologies. His initial exposure during his undergraduate studies ignited a fascination for sustainable energy systems. This interest evolved as he pursued a master's and PhD, delving into various aspects of hydrogen applications, particularly fuel cells and their potential for residential usage. With a background firmly rooted in the hydrogen fuel cell domain, ZJ's career has expanded to encompass energy policy, specifically focused on hydrogen storage and strategies within the UK. His work involves collaboration with industries, offering professional advice and contributing to the development of roadmaps and research papers. ZJ also underscores the crucial role of universities in upskilling professionals through training courses, thereby promoting hydrogen expertise for the future.

In his master's and PhD research, ZJ. concentrated on hydrogen fuel cells, specifically looking at residential Combined Heat and Power (CHP) units. He believes that hydrogen technologies can be considered environmentally friendly due to the potential for low carbon emission production, especially with the adoption of carbon capture and utilization storage technologies. Additionally, the

use of renewable electricity for water electrolysis to produce hydrogen further enhances its environmental benefits.

ZJ mentioned that the UK holds an optimistic perspective on hydrogen's role in the future energy landscape, especially for residential-scale hydrogen production and utilization. While technically feasible to generate electricity through PEM fuel cells, the cost factor remains a challenge due to the expenses associated with electrolyzers, fuel cells, and system integration. The overall lifespan of the system ranges from 15 to 20 years, though the individual PEM fuel cell stacks typically last between 5 to 7 years, with a maximum of around 10 years. Key materials such as platinum, palladium, and nickel play pivotal roles in fuel cell technology. Efforts are underway to recycle elements like nickel oxide from waste high-temperature fuel cells for stack fabrication, particularly for catalysts. The UK government emphasizes green and blue hydrogen production, with encouragement for carbon capture technologies. In this context, techno-economic assessments play a crucial role in evaluating the feasibility and viability of these hydrogen technologies.

ZJ believes hydrogen fuel cells can help decarbonize the built environment through several means. Blending hydrogen into the natural gas grid at scales of 20% or more could immediately reduce carbon emissions from gas heating systems. He states that "blending 20% of hydrogen into the national gas grid...could completely remove that 20% of carbon emissions" produced by natural gas. High temperature fuel cells in CHP units have the potential to achieve up to 90% efficiency for supplying heat and power to buildings, far exceeding the 50-60% efficiency of current gas CHP technologies. For domestic and commercial utilization of hydrogen, ZJ mentions several issues that must be addressed. Hydrogen storage and distribution infrastructure would need upgrades for large scale deployment, especially if the existing natural gas grid is fully replaced. Safety requirements around hydrogen leakage and venting also present challenges for both compressed and liquid hydrogen storage. While small scale onsite hydrogen production using electrolyzers is possible, the overall system costs remain high for residential applications at present.

However, ZJ acknowledges the challenges in reducing carbon emissions through hydrogen technologies. Key hurdles include the high cost of technology, such as electrolyzers and fuel cells, and the need for government policy support to make hydrogen adoption economically feasible. He also points out infrastructure challenges, such as modifying existing gas pipelines for hydrogen distribution and deciding on the best form of hydrogen storage, be it compressed gas, liquefied, or new technologies.

When discussing the safety requirements, ZJ emphasizes the importance of preventing hydrogen leakage, especially during production, storage, and transportation. He suggests that small-scale electrolyzers, particularly when powered by solar energy, could be a viable option for residential hydrogen production. However, affordability remains a concern for these small-scale applications.

In the context of the energy trilemma (affordability, energy security, and sustainability), ZJ sees green hydrogen as a promising solution. It can store large amounts of renewable energy and contribute to energy security by reducing reliance on imported energy sources. Hydrogen's potential to decarbonize the built environment is evident through projects like the Coney Islands in Scotland, where renewable energy is used to produce and supply hydrogen to the local energy system.

While ZJ believes hydrogen technologies have a significant role in decarbonization efforts, he acknowledges the need for continued research and development to overcome challenges and drawbacks. The limited lifespan of fuel cell stacks and the reliance on materials like platinum and nickel call for improved recycling processes to ensure sustainability.

In the interview, ZJ highlighted the potential of hydrogen for domestic and commercial utilization. He discussed the use of fuel cells in buildings, emphasizing the benefits of hydrogen as a clean and efficient energy source. He also emphasized the importance of policy support from governments to

drive the adoption of hydrogen technologies, particularly in the initial stages where the costs may be relatively higher.

ZJ addressed the challenge of capturing CO₂ emissions during hydrogen production, emphasizing the use of absorption beds to capture and store CO₂. He also highlighted the need for international standards for hydrogen technologies, while acknowledging that countries may need to adapt certain aspects to suit their unique energy infrastructures.

Regarding the UK's efforts, ZJ praised the government's hydrogen strategy and financial support for feasibility and demonstration projects. He emphasized the need for collaboration between academia, industry, and the government to educate the public about hydrogen's safety and benefits.

In the context of New Zealand, ZJ recommended a thorough consultation program with stakeholders and national energy providers to integrate hydrogen technologies into the existing energy system. He suggested considering the country's energy infrastructure and potential import options to facilitate a smooth transition to green hydrogen.

ZJ's insights demonstrate the importance of multi-disciplinary skills for professionals working in hydrogen technologies. Engineers with backgrounds in chemical, mechanical, and electrical engineering are well-suited for roles in hydrogen production, distribution, and storage. He emphasized the need for training courses and higher degrees to upscale the skills of professionals in this rapidly evolving field.

ZJ recommends a comprehensive approach involving government consultation, techno-economic assessments, and stakeholder engagement to introduce hydrogen in new markets like New Zealand. Proper monitoring and safety measures around hydrogen leakage must also be put in place. Educational institutions have an important role to play in upskilling professionals with the range of engineering knowledge required for the hydrogen sector.

In conclusion, ZJ's expertise and passion for hydrogen technologies make him a valuable asset in promoting the adoption of green hydrogen for domestic and commercial applications. His insights shed light on the challenges and opportunities in the sector and underscore the importance of government support, technical advancements, and public engagement to drive the hydrogen revolution forward and on the importance of policy support, technology advancement, and safety considerations to realize the full potential of green hydrogen in achieving a sustainable energy future.

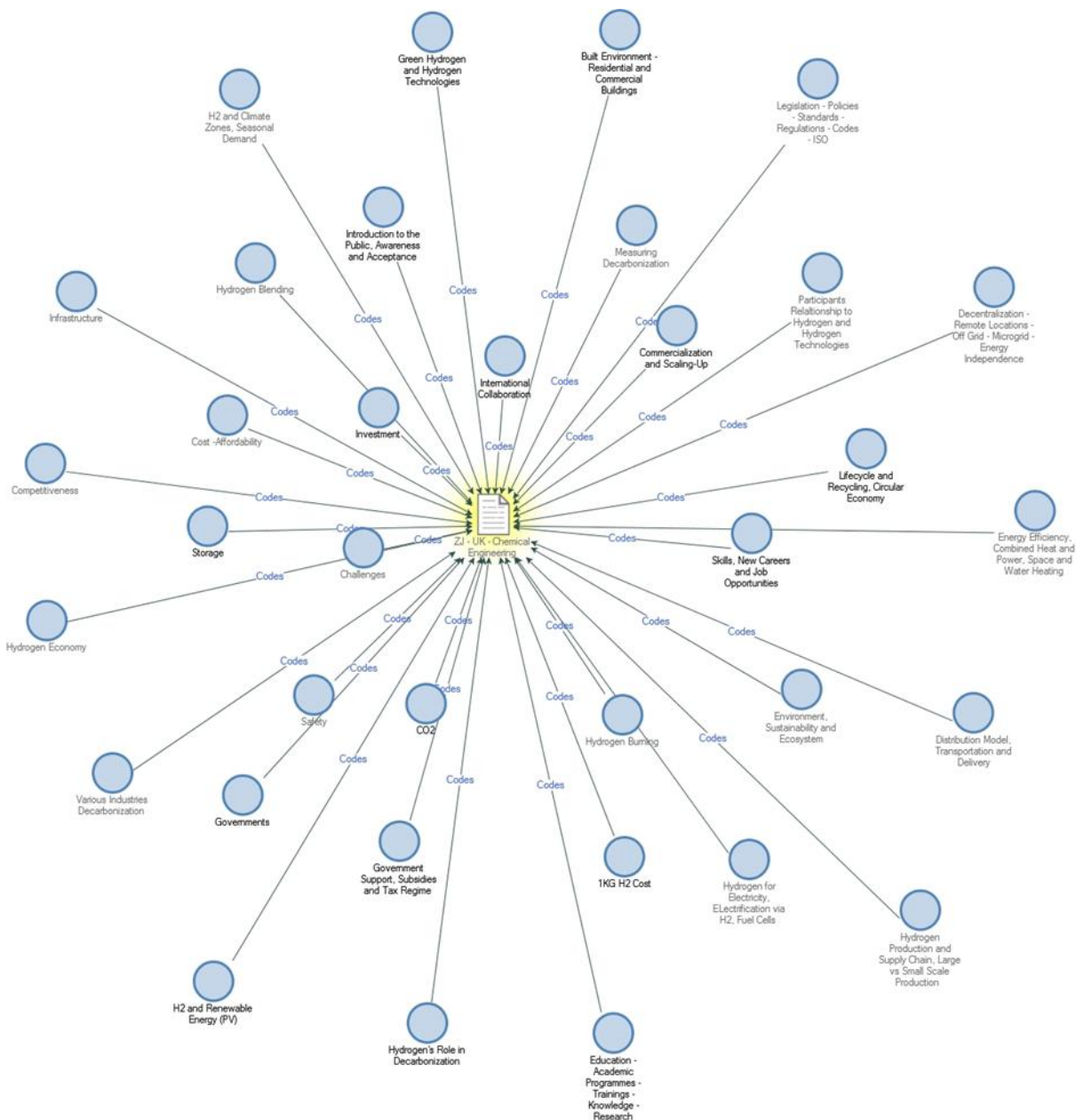


Diagram 16: ZJ - Thematic Interview Summary Diagram

4.6 Common Views

The participants hail from diverse professional backgrounds, spanning engineering disciplines, project management, business development, and research. However, some common threads emerge. Many embarked on their hydrogen journey from a foundation in mechanical, chemical or renewable energy engineering, which provided requisite technical grounding. Several worked with companies specializing in fuel cells, electrolyzers, and related hydrogen technologies. This allowed hands-on experience from prototype development to commercialization.

Most participants now play multifaceted strategic roles, exemplified by DA overseeing projects and TW leading operations while also facilitating sector growth. Many evolved into advisory positions, like RGJA, SGJA and ZJ guiding government policymaking. The prominence of engineers transitioning into advisory roles that leverage technical strengths while considering real-world nuances is noticeable.

Access to first-hand technical knowledge, even for non-engineers like TN, empowers well-informed assessments. However, a key differentiator is the ability to translate this knowledge into practical

insights on implementation, as RH and MS demonstrate. Experience spanning personal projects, commercial facilities, and international initiatives provides a multi-layered perspective.

Several common focus areas emerge, including renewable integration, electrification, decarbonization, and sustainability. Regional circumstances and resources play an important role, as evidenced across diverse geographies from New Zealand to Saudi Arabia. However, the overarching commitment to advancing hydrogen technologies safely and efficiently is consistent.

The built environment repeatedly arises as an application domain. Experts like JH and TW envision fuel cells as enablers of self-sufficient buildings and resilient community energy hubs. But contextual factors, from infrastructure compatibility to public acceptance, require consideration, as KQ highlights. This underscores the importance of strategic localized demonstration projects.

The participants indicated that green hydrogen has potential to decarbonize built environment through fuel cells and blending with natural gas grid. However, experts recognize that efficiency losses make direct electrification a more attractive option for heating, while niche applications like backup power and combined heat and power (CHP) systems show significant potential.

Despite the promise of hydrogen, there are several challenges that need to be addressed for widespread adoption such as high upfront costs, lack of infrastructure and safety concerns. Experts emphasized the need to address these obstacles to facilitate the broader acceptance of hydrogen solutions.

Government policies and subsidies are critical to accelerate acceptance and commercialization of hydrogen. Establishing robust standards and regulations is equally important to ensure safe and efficient implementation. Experts called for targeted policy interventions to promote hydrogen adoption and level the playing field with traditional energy sources.

International collaboration is key to developing common safety standards, certification schemes, and sharing technological advancements through technology transfer. Experts recognized the significance of international collaboration and knowledge-sharing in the development of hydrogen technologies. They emphasized the importance of aligning safety standards, certification schemes, and technology transfer to foster global acceptance of hydrogen solutions.

Technological advancements in efficiency, storage and cost reduction are still needed to make hydrogen economically viable. Experts discussed the need for improving efficiency, storage solutions, and cost reduction in order to make green hydrogen competitive with conventional energy sources.

The economic viability of hydrogen technologies was a recurring topic. Experts discussed the importance of demonstrating cost-effectiveness and long-term benefits to encourage the transition to hydrogen-based solutions.

Experts discussed the potential of niche applications of hydrogen technologies, such as off-grid and remote applications, where it can offer unique advantages. They recommended targeted approaches that focus on specific use cases to maximize the benefits of hydrogen solutions.

Education and public campaigns are crucial to build confidence in hydrogen and address misconceptions. Building public awareness and addressing misconceptions about hydrogen technologies were considered essential to gain public acceptance and support. Experts highlighted the need for education and informative campaigns to dispel myths and showcase successful hydrogen implementations.

4.7 Differences in Views

Some participants expressed reservations about the efficiency of hydrogen for heating in residential buildings, citing efficiency losses compared to direct electrification. They highlighted that in certain climates or regions where alternative heating options are available, hydrogen may not be the most efficient solution. On the other hand, other participants saw potential for hydrogen heating, especially in off-grid or remote areas where decarbonization is challenging and direct electrification may not be feasible.

There were differing views on the scale of adoption for hydrogen technologies. Some participants advocated for targeting niche applications where hydrogen provides clear economic and environmental benefits, while others saw wider potential for hydrogen to replace fossil fuels in various sectors, including transportation, industry, and residential buildings.

Participants from different countries had varying perspectives on government policies and priorities. In some countries, there was a strong focus on renewable energy sources and promoting green hydrogen to utilize excess renewable electricity, while others faced challenges due to vested interests in the fossil fuel industry and policies that favoured centralized energy systems.

While safety concerns were acknowledged by all participants, views on the need for additional regulations and standards differed. Some experts stressed the importance of establishing common safety standards through international collaboration, while others believed that existing safety measures are sufficient and emphasized the need for public awareness campaigns to dispel misconceptions.

Also, the participants' opinions were different around the scalability of hydrogen production. Some experts believed that small-scale, distributed hydrogen production could be more suitable for specific applications and areas, while others saw the potential for large-scale hydrogen production to cater to energy-intensive industries and contribute to the broader energy transition.

Participants discussed the economic viability of hydrogen technologies, emphasizing the importance of cost reduction through technological advancements. Some experts believed that government subsidies and supportive policies are crucial to accelerate hydrogen adoption and level the playing field against established fossil fuel industries.

While all participants recognized the importance of public acceptance, opinions varied on the best approach to build confidence in hydrogen technologies. Some stressed the need for public education and awareness campaigns to address misconceptions, while others emphasized the role of successful implementations and visible benefits to gain public support.

4.8 Summary

Overall, the participants' blend of technical knowledge and practical experience allows for balanced yet optimistic assessments of hydrogen's potential across sectors. The combination of engineering skills, commercial awareness, policy engagement and on-ground implementation exposure positions these participants as leaders guiding the built environment's transition towards hydrogen-based solutions. Their diverse voices provide a well-rounded perspective on harnessing hydrogen technologies to drive decarbonization and sustainability within the built environment. Although experts acknowledged the challenges and limitations of hydrogen technologies, and the differences in opinions among the participants highlight the complexity and multi-faceted nature of hydrogen technologies, the great potential for green hydrogen to revolutionize the energy landscape and decarbonize various sectors has been recognised. However, a pragmatic, targeted approach - starting

with niche applications - is recommended to maximize benefits based on environmental, economic and social factors in each context. In order to fully realize this potential, strong government support, technological advancements, safety standards, public confidence and international cooperation will be critical to facilitate the transition towards a hydrogen economy.

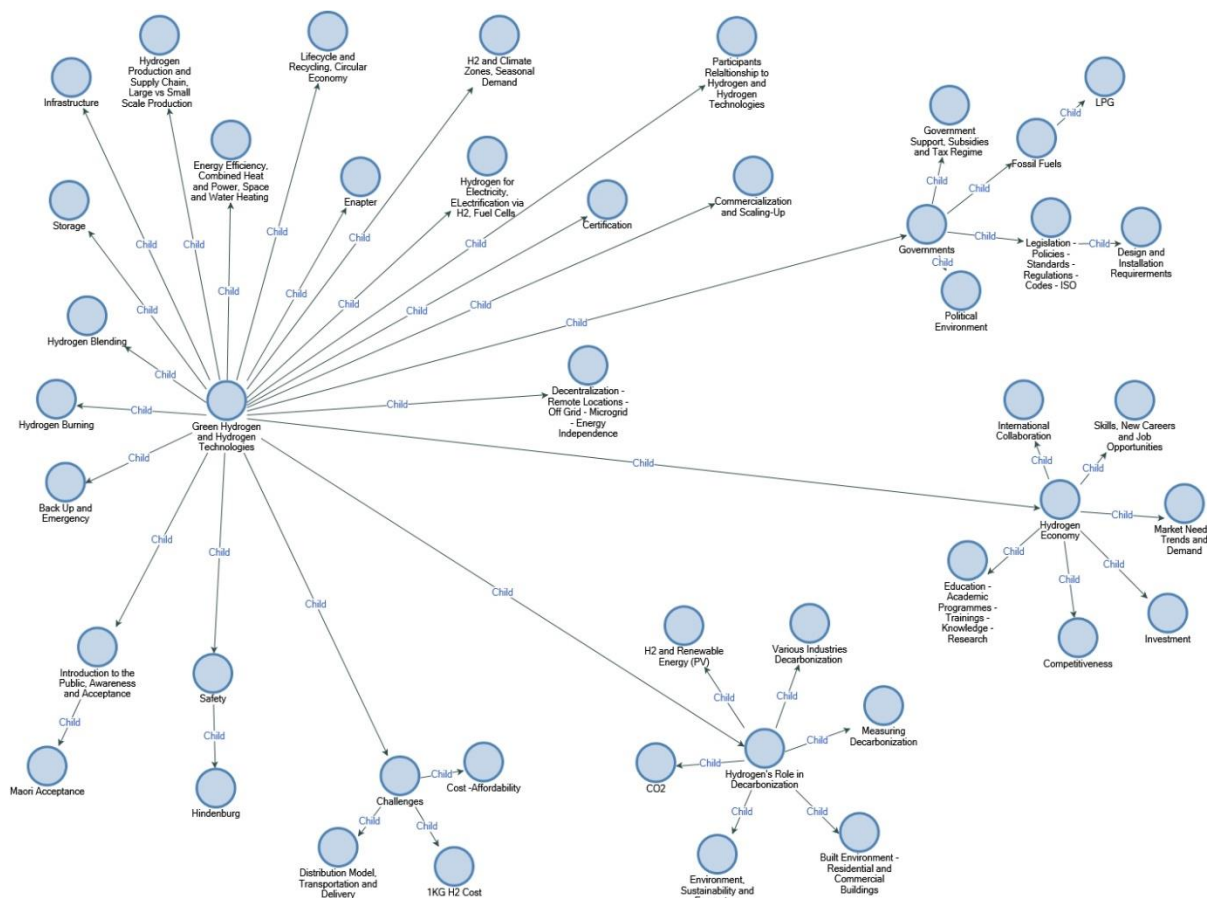


Diagram 17: Composite Thematic Interview Diagram

4.9 Nodes NVivo Hydrogen Role in Decarbonization

The participants' opinions about the role of hydrogen in decarbonization reflect a diverse range of perspectives. While some participants emphasize hydrogen's potential to decarbonize various sectors, including hard-to-abate industries like steel and cement, others remain sceptical about its direct use in the built environment. The consensus is that hydrogen can play a crucial role in decarbonizing challenging sectors, such as heavy transportation and industrial processes, where other alternatives might be less viable. However, the feasibility of hydrogen adoption varies by region, with factors like renewable energy availability, resource utilization, and economic considerations influencing its potential. The participants also highlight the importance of considering the entire hydrogen value chain's impact on the environment and the need for strong government policies, carbon pricing, and global cooperation to drive sustainable hydrogen adoption.

DA's opinions highlight the multifaceted role of hydrogen in decarbonization. He acknowledges hydrogen's significance in industries such as oil refineries and its potential as a versatile energy carrier for various applications. He emphasizes the importance of extracting hydrogen cleanly through renewable energy sources. While advocating for decarbonization, he explores challenges faced by countries like Korea due to limited land for renewable installations, noise concerns from wind farms, and the need for stable electricity supply. He underscores the potential of fuel cells for Korea's energy

needs and stresses the importance of blue hydrogen generation with low emissions. DA envisions hydrogen's transformative potential in various sectors, including the built environment, and highlights its role in long-term sustainability and cost reduction. He also acknowledges that certain sectors like steel and cement might require more time to transition to blue hydrogen and emphasizes the necessity of scaling up hydrogen production for broader economic impact and effective delivery to end users. While government prioritizes scaling, sustainability remains crucial for the economy's complete decarbonization:

EEF highlights hydrogen's remarkable potential to revolutionize decarbonization efforts across various sectors. With its capacity to generate both heat and electricity while emitting only water as a by-product, hydrogen stands as a versatile solution capable of driving industrial processes and fuelling transportation. EEF underscores the importance of green hydrogen, produced through renewable energy and water, as an ideal candidate for achieving sustainable economies. In Costa Rica, where renewable energy makes up a substantial portion of the grid, the challenge lies in extending this decarbonization to the transportation and industrial sectors. Despite significant progress in electric vehicle adoption, limitations in battery technology for certain applications, such as trucks and heavy-duty vehicles, create an opening for hydrogen-based solutions.

To measure decarbonization, EEF emphasizes establishing a baseline and calculating CO₂ emissions reduction through technology displacement. The focus is on quantifying the benefits of hydrogen adoption, like the project involving Toyota Mirai vehicles at the Costa Rica airport. EEF acknowledges the importance of not merely adding vehicles but converting existing ones through retrofits to expedite the decarbonization process. Additionally, EEF highlights the environmental concerns posed by excessive fertilizer use, a significant challenge in Costa Rica due to its terrain and heavy rainfall. By pressuring external providers to adopt sustainable practices, hydrogen can play a pivotal role in minimizing carbon emissions and fostering cleaner air.

EEF envisions a comprehensive hydrogen economy as the key to widespread decarbonization. By aligning hydrogen production with renewable sources, companies can tout their operations as CO₂-free or reduced, offering tangible environmental benefits. While emphasizing the potential for cleaner air, EEF also stresses that hydrogen's potential extends beyond niche applications, advocating for its adoption on a larger scale to address global carbon emissions. Through concerted efforts, EEF envisions a future where hydrogen catalyses a transformative shift toward sustainable economies while factoring in regional needs and climate considerations.

SGJA emphasizes the environmental friendliness of hydrogen when produced through renewable energy or biogas, with no associated emissions. Notably, in Mexico's industrial landscape, industries such as cement and steel, which demand significant thermal energy, can benefit from hydrogen adoption to replace coal or natural gas for high-temperature processes. While hydrogen's integration into sectors like construction and plastics may take time, SGJA envisions substantial decarbonization potential by 2040-2050.

In Mexico, the cost competitiveness of renewable energy is evident, with solar energy reaching prices as low as \$20 per Megawatt hour in recent auctions. Projects like the one involving green ammonia production with wind and solar inputs underscore the growing interest in hydrogen, with plans to initiate construction by 2025.

While acknowledging the current limited application of green hydrogen in the built environment, SGJA anticipates its expansion through the integration of solar and wind energy for hydrogen production. The collaboration between hydrogen projects and solar/wind developers exemplifies their dedication to a sustainable future. Overall, SGJA's perspective underscores the pivotal role of green hydrogen in the decarbonization journey, offering a pathway to cleaner industries and energy systems.

JH's perspective offers a critical take on the viability of hydrogen's integration within the built environment for decarbonization purposes. JH expresses scepticism regarding the direct utilization of hydrogen in most building-related applications. Instead, the focus is directed towards the potential of hydrogen to address the challenges of decarbonization in industries with more limited alternatives, such as steelmaking.

The viewpoint emphasizes the relevance of hydrogen in hard-to-decarbonize sectors, where its utilization might yield the greatest benefits. This stance considers resource efficiency, particularly the responsible utilization of platinum group metals and other scarce resources. In this context, high-utilization fuel cells are presented as a more justifiable avenue for hydrogen utilization, particularly in scenarios where PV and electrolysis systems for on-site hydrogen generation could prove economically impractical.

JH advocates for strategic resource allocation by highlighting hydrogen's role in emergency power situations, such as in military installations and hospitals. This aligns with a pragmatic approach of integrating hydrogen in critical infrastructure where its qualities as a backup power source are valued.

In terms of transportation and long-distance logistics, JH finds merit in hydrogen's application due to its potential advantages over batteries in specific use cases, such as forklifts in warehouses and certain types of vehicles.

However, JH remains sceptical about hydrogen's efficacy for the built environment, citing concerns about economic feasibility and resource-intensive deployment. The preference is for hydrogen to be directed towards industries with limited low-carbon alternatives, like refining and ammonia production. JH's reservations underscore the need to carefully choose hydrogen's applications and to consider it as a complement to other decarbonization strategies rather than a comprehensive solution for all aspects of the built environment.

In summary, JH's opinion aligns hydrogen's value with its suitability for challenging sectors and emergency scenarios, while expressing reservations about its broad applicability within the built environment for decarbonization efforts.

RGJA presents a comprehensive viewpoint on the potential of hydrogen to drive decarbonization efforts. The primary focus centres on leveraging hydrogen technologies to achieve sustainable outcomes in various sectors.

One of the standout opportunities RGJA identifies is the potential to decarbonize the greenhouse gas-intensive sectors. This notion aligns with the broader objective of transitioning to a low-carbon economy and highlights the pivotal role hydrogen can play in achieving such goals.

RGJA also underscores the significance of residential and industrial heating as key areas for hydrogen adoption. The reference to industrial boilers, fire tube boilers, and cooking stoves points to the diverse range of applications where hydrogen could be integrated for cleaner energy generation.

The approach of empowering countries with limited oil and gas resources but abundant renewables reflects a strategic approach to harnessing green hydrogen's potential. This stance implies that regions with renewable energy capabilities could utilize green hydrogen to enhance their energy independence and economic competitiveness.

The emphasis on environmental impact assessment underscores RGJA's awareness of the complexity surrounding hydrogen technologies. RGJA acknowledges that no human activity is entirely devoid of environmental impact but argues that hydrogen technologies present a relatively better alternative when compared to existing practices.

RGJA's endorsement of a global carbon market and accurate pricing of carbon emissions underscores the necessity of a unified effort in tackling climate change. This viewpoint suggests a keen awareness of the need for comprehensive strategies and market mechanisms to drive sustainable practices.

The notion of assessing impacts across social, environmental, economic, and governmental dimensions in hydrogen projects reflects RGJA's holistic approach to sustainability. By acknowledging the importance of regulation and governmental involvement, the perspective aligns with a collaborative approach between public and private entities to ensure sustainable hydrogen initiatives.

In assessing the efficiency of hydrogen production through photovoltaics, RGJA quantifies potential outcomes, indicating a deep understanding of the technical aspects of hydrogen generation.

Lastly, the proposal of utilizing excess PV capacity for hydrogen production, rather than battery storage, highlights an innovative perspective on energy utilization and storage, showcasing RGJA's creativity in optimizing renewable energy systems.

In summary, RGJA's perspective is marked by a holistic understanding of hydrogen's potential for decarbonization across various sectors. The viewpoint combines technical expertise with a keen awareness of environmental, economic, and social implications, emphasizing the role of government, regulations, and global cooperation in achieving sustainable hydrogen solutions.

JAGR's viewpoint revolves around the synergy between solar energy and hydrogen, highlighting their common dependence on sunlight to generate energy within a short time frame. The concept of using electrons from photovoltaics (PV) to create highly energetic molecules from water forms a cornerstone of the argument, emphasizing the potential for green hydrogen production.

While acknowledging the potential of hydrogen in decarbonization, the perspective also acknowledges uncertainty regarding the extent of the hydrogen market's growth within the building sector. This underscores the need for further exploration and evaluation of hydrogen's applicability in different domains.

The viewpoint points out that hydrogen is particularly well-suited for decarbonizing challenging sectors such as mining and heavy-duty transportation, where direct electrification might not be feasible. This highlights hydrogen's role in addressing emissions from sectors that are traditionally difficult to decarbonize.

Japan's commitment to promoting hydrogen for residential applications, especially through combined heat and electricity power systems, is highlighted as a unique initiative in the global context.

Energy efficiency, energy savings, and the promotion of cleaner kilowatt-hours by reducing consumption are highlighted as crucial aspects. The perspective proposes a progression from renewables to rectification and ultimately to energy vectors like hydrogen or biofuels.

The analogy of hydrogen-related equipment (such as electrolyzers and fuel cells) being treated like regular household furniture adds an interesting perspective to the integration of hydrogen technology into homes.

A specific example of a residential application is mentioned, where a village utilizes a significant amount of PV, an electrolyser, and a fuel cell to create a large-scale hydrogen-based energy system. The discussion also emphasizes the interplay between hydrogen's cost and the cost of the initial energy source, suggesting that hydrogen's viability is influenced by the relative costs.

The viewpoint asserts that hydrogen technologies are environmentally friendly, particularly in terms of emissions reduction.

Overall, JAGR's perspective highlights the interconnectedness of solar energy and hydrogen, explores potential applications in the residential sector, and underscores the multifaceted role of hydrogen in decarbonization efforts across various sectors.

Green Hydrogen Role in Decarbonization	
Aspect	Key Insights
Hydrogen's Potential	- Significant potential to decarbonize hard-to-abate sectors (steel, cement, heavy transport).
Regional Feasibility	- Feasibility varies by region based on:
	- Renewable energy availability
	- Economics
	- Resource utilization
Environmental Impact	- Must consider the entire value chain's environmental impact, not just end applications.
Policy and Cooperation	- Strong government policies, carbon pricing, and global cooperation are essential for sustainable hydrogen adoption.
Scepticism	- Some scepticism about hydrogen's efficacy in the built environment; focus should remain on high-impact sectors.
Economic Viability	- Concerns about the economic viability of on-site PV-electrolysis for buildings.
Complementary Role	- Hydrogen is better suited as a complement to broader decarbonization strategies.
Industrial Applications	- Highlighted potential in industrial heating, energy storage, and empowering regions with renewables.
Holistic Approach	- A holistic view is needed, considering technical, environmental, social, and economic dimensions.
Synergy with Solar PV	- Noted synergy between solar PV and hydrogen through electrolysis.
Decarbonization Role	- Important role in decarbonizing hard-to-electrify sectors like heavy transport.
Residential Applications	- Growing interest in residential applications, though uncertainties remain.
Energy Efficiency	- Emphasis on energy efficiency and reducing consumption alongside hydrogen adoption.

Table 10: Green Hydrogen Role in Decarbonization

In summary, hydrogen has significant decarbonization potential but strategic adoption suited to regional contexts along with holistic sustainability policies are crucial.

4.10 Decarbonization of the Built Environment

The perspectives shared by experts shed light on the potential implications of employing hydrogen technologies to decarbonize the built environment. While opinions differ, they collectively offer valuable insights into the feasibility, challenges, and opportunities inherent in integrating hydrogen into residential and commercial settings.

Central to these viewpoints is the recognition of hydrogen's multifaceted potential. Many experts highlight its capacity to serve as an energy storage and utilization solution in locations with intermittent grid access. This aligns with the overarching goal of transitioning away from carbon-intensive practices, allowing for enhanced self-sufficiency and resilience in areas prone to energy supply disruptions.

The application of hydrogen for seasonal energy storage, particularly during extended periods of unfavourable weather, emerges as a strategic response to addressing the intermittency concern. By employing hydrogen-powered heating systems, several experts envision a shift from conventional fossil fuel-based heating, contributing to the broader ambition of reducing carbon emissions. However, consensus prevails that the integration of hydrogen into our surroundings necessitates a cautious approach, grounded in stringent safety measures, compliance with regulations, and effective communication to build public confidence.

Although optimism is evident, certain practical hurdles warrant consideration. Cost implications feature prominently, as hydrogen technologies necessitate further refinement and scaling to achieve cost-competitiveness. Yet, illustrative examples of localized pilot projects showcase that hydrogen can indeed be harnessed effectively, provided the approach is tailored to the specific context.

An intriguing avenue that emerges from these perspectives is the potential synergy between hydrogen and renewable energy sources. Hybrid systems, combining hydrogen and battery storage, hold promise for optimized energy utilization, particularly for energy-intensive applications like cooking and space heating. This collaborative approach underscores the importance of a holistic strategy, wherein a variety of renewable technologies are harmonized to maximize efficiency and resilience.

Although the range of views on hydrogen's precise role in the built environment is broad, consensus prevails that it should be integrated in tandem with renewables. Whether for energy security, off-grid scenarios, or seasonal storage, hydrogen holds promise as a key player in the pursuit of sustainable urban environments. However, it is imperative to address economic challenges, safety concerns, and the dissemination of accurate knowledge to ensure hydrogen's effective contribution to global efforts toward cleaner, more sustainable urban living.

DA accentuates the remarkable versatility of hydrogen as a gas that finds extensive utility across multiple sectors. This viewpoint accentuates the twofold challenge at hand: the acquisition of hydrogen and the procurement of renewable energy via fuel cells. This perspective reverberates with the conviction that harnessing fuel cells stands as a pivotal avenue, positing that this trajectory harbours substantial promise for effecting decarbonization within commercial and residential edifices. The outlook harmonizes with the notion that hydrogen's inherent adaptability renders it a viable contender for a diverse array of applications, encompassing both its generation and utilization facets. Furthermore, the emphasis on fuel cells underscores their integral function in tapping into renewable energy sources and advancing sustainable practices within built environments. In its entirety, DA's perspective lucidly underscores the imperativeness of sourcing hydrogen and leveraging fuel cells as an elemental strategy in propelling the drive for decarbonization across commercial and residential domains.

EEF astutely draws attention to a pivotal regional divergence concerning energy requisites and climatic nuances. In locales akin to the one elucidated by EEF, characterized by consistently warm conditions, the customary demand for heating stands notably diminished in comparison to colder climes such as those encountered in Europe and the US. This discernment unveils a significant facet warranting consideration in the evaluation of hydrogen's role in effecting decarbonization within constructed surroundings. Within environments where the exigency for heating is marginal, the focal point of energy deployment may shift towards cooling, power generation, and alternative applications, eclipsing traditional heating methodologies. Consequently, the distinctive energy imperatives intrinsic to these regions necessitate meticulous contemplation when assessing the viability and repercussions of hydrogen-oriented remedies for decarbonization. EEF's perspective deftly underscores the contextual intricacies inherent in the hydrogen paradigm shift, accentuating the imperative of tailoring strategies to accord with indigenous climatic factors and energy demands.

SGJA discerningly underscores the nascent traction of green hydrogen within the constructed milieu, highlighting its yet-to-be-fully-realized presence. This discernment accentuates the extant constrictions and intricacies interwoven with the integration of green hydrogen technologies for the decarbonization of residential and commercial domains. This assertion acutely implies that while the promise of green hydrogen is evident, there exist formidable obstacles that necessitate resolution before it can emerge as a robust and pragmatic solution for the built environment.

JH expresses scepticism about the direct use of hydrogen in the built environment, citing concerns about cost-effectiveness, especially when considering residential applications with photovoltaics and electrolyzers:

"I'm not a believer in hydrogen and direct use for anything in the built environment" (JH).

However, he sees potential in hydrogen fuel cells and combined heat and power (CHP) systems as more feasible options:

"Hydrogen fuel cells, CHP, maybe that would be the only thing I could really say is possibly a good idea for built environment" (JH).

JH acknowledges the value of hydrogen as emergency power backup in places like hospitals and the military:

"I guess there is some stationary power stuff, like the army, they really like hydrogen to give that, emergency power. And I think hospitals and stuff as well, I think I can see the value of hydrogen there as an emergency backup, that's just integrating it sort of. And the day-to-day running of buildings" (JH).

He highlights the success of hydrogen-powered forklifts in warehouses, indicating specific applications where hydrogen has proven beneficial:

"I think also it's about picking your battles and what are the good applications. So if you look at what has been the real success stories in the United States, it's things like putting forklifts into you know really large warehouses because you can get high uptime and no omissions in turn inside buildings. So that was better than having batteries or LPG or CNG forklifts moving around inside buildings. So you know that was a really natural place to put hydrogen" (JH).

In contrast to some participants, JH suggests that hydrogen could play a role in city-scale electricity generation and heating through combined heat and power (CHP), but he views it as less suited for individual small-scale buildings:

“You could do some of the electricity generation for the city and provide the heat for the buildings as well, so I can see it kind of as a CHP play, but not really as a sort of a building, you know, single smaller building thing” (JH).

This stance contrasts with participants who emphasize the versatility and potential of hydrogen in the built environment.

In contrast, **RGJA** astutely discerns the principal realm of hydrogen’s potential within the built environment, pinpointing its primary utility in the spheres of residential and industrial heating. This perspective notably accentuates hydrogen’s applicability in varied thermal applications, including small-capacity industrial boilers, fire tube boilers, and cooking stoves. RGJA’s vantage point places paramount emphasis on hydrogen’s pivotal role in ameliorating heating requisites and effecting a tangible reduction in carbon emissions within the constructed milieu.

JAGR eloquently conveys a sense of uncertainty regarding the potential magnitude of the hydrogen market within the domain of buildings. Despite this, the participant astutely highlights Japan’s distinctive orientation towards hydrogen in the context of residential applications, with particular emphasis on the innovative fusion of heat and electricity through combined systems. Notably, JAGR envisions an intriguing future scenario where hydrogen technologies seamlessly integrate into homes, akin to commonplace household furniture. This intriguing analogy accentuates the allure of hydrogen solutions for residential contexts. Moreover, the participant alludes to a captivating prospect - village-level residential implementation - which underscores the prospect of leveraging hydrogen to attain a more environmentally pristine urban landscape.

KQ astutely references the deployment of hydrogen technologies in expansive industrial edifices, select apartment complexes, and specialized domains such as dairy farms. These instances, while confined, conspicuously stem from proprietors’ fervent interest in these technologies. It is noteworthy that KQ discerns the prevalence of off-grid status for certain hydrogen-powered residences and offices across the United States, attributed to the challenges of harmonizing intermittent energy sources with the traditional grid infrastructure. Despite this current state, KQ envisions a forthcoming transformation in this landscape. The participant adeptly articulates a desire for quieter hydrogen systems and imaginatively foresees the tantalizing prospect of directly channelling hydrogen into households for fuel cell operation. This perspective underscores the evolving nature of hydrogen technology’s role and its potential to reshape residential energy paradigms.

MR adeptly offers a multifaceted analysis of hydrogen technology’s pertinence across diverse building scales. The participant adroitly accentuates the intricate dynamics encountered when endeavouring to bestow energy independence upon individual residences, intricacies further compounded by spatial constraints and maintenance obligations. MR astutely postulates that for residential contexts, electrification may wield a more fitting mantle. Conversely, larger complexes and industrial domains emerge as auspicious canvases for navigating hydrogen systems through dedicated entities, thereby enhancing efficacy and safety. The participant is cogent in highlighting the imperativeness of sustained maintenance akin to established infrastructure paradigms such as boilers. The participant commendably recognizes hydrogen’s chameleonic potential across multifarious applications, proffering the notion of pilot initiatives to explore its utility in realms such as heating and grid equilibrium. For individual dwellings, MR leans towards the conduit of electrification, citing the robust presence of extant technologies in the domains of culinary preparation and water heating. In grander contexts encompassing sprawling complexes and industries, hydrogen-fired systems, encompassing boilers or furnaces, beckon as favourable choices. It is particularly insightful to note MR’s envisioning of hydrogen as a winter-specific heating solution for edifices, concurrently harbouring contemplation of its application in inception processes and other operational facets within expansive settings. This comprehensive perspective underscores the malleability of

hydrogen's role within distinct building dimensions while positing compelling propositions for its diverse applications.

MS delivers a comprehensive exposition on the adept utilization of hydrogen technologies in the realm of building decarbonization, resolutely spotlighting the tantalizing prospect of emancipating edifices from conventional grids. The participant adroitly advocates for the integration of on-site hydrogen, judiciously paired with fuel cells to orchestrate the transformative conversion of hydrogen into both electric power and heat, culminating in an estimable aggregate efficiency of approximately 83%. A conspicuous conundrum resides in the strategic acquisition of hydrogen, an enigma MS astutely postulates could be circumvented via the generation of hydrogen through solar panels adorning the building's rooftop. Notwithstanding this, the participant sagaciously acknowledges the intricate tapestry of supplementary challenges that the architectural milieu presents, spanning the gamut from hydrogen storage nuances to the nuances of compression, firmly tethered to spatial confines and safety imperatives. MS's strategic posture harmoniously converges on a fulcrum where the equipoise between seamless hydrogen assimilation and the exacting benchmarks of safety standards is adroitly negotiated, ultimately orchestrating a harmonious symphony that inexorably steers the trajectory toward the overarching tapestry of sustainable building decarbonization.

PL adeptly navigates the labyrinthine intricacies inherent in the endeavour to decarbonize residential enclaves and urban landscapes, particularly in regions ensconced in cultural proclivities favouring gas utilization. The participant cogently propounds that while heat pumps and electrification stand as ubiquitous stratagems, the formidable challenge resides in recalibrating deeply entrenched behavioural patterns. To surmount this, PL ingeniously advocates for the orchestration of a novel unit, seamlessly encompassing a reversible fuel cell concomitant with an electrolyser, meticulously architected for deployment in both residential and communal edifices. This innovative blueprint is anchored in the pursuit of endowing a collective assembly of structures with newfound autonomy, adroitly navigating the vicissitudes of hydrogen intermittency. This conceptual framework unambiguously underscores the imperative of aligning the contours of technological innovation with the contours of cultural predilections, thereby effectuating triumphant decarbonization in the panoramic tableau of diverse contextual landscapes.

RH, in turn, bestows upon the discourse a profusion of elucidations that unveil the intricate safety calculus and material requisites intrinsic to the seamless integration of hydrogen technologies within the variegated tapestry of residential and commercial structures. The participant cogently amplifies the significance of imbuing the built environment with a repertoire of safety mechanisms, most notably the discerning deployment of electromagnetic sensors and solenoid valves, thereby adroitly forestalling the incipient spectre of hydrogen accretion within enclosed spaces. RH delves judiciously into the nuanced choreography of pressure dynamics and judicious material selection, traversing the multistage trajectory of hydrogen storage with a perspicacious focus on the pivotal realms of pressure management and the forestalling of static discharges. In a felicitous juxtaposition, the participant meticulously counterposes the ignition energy of hydrogen against its methane counterpart, fashioning an intricate mosaic that expounds upon the intricate risk mitigation measures requisite for harnessing hydrogen's potential. Moreover, RH engages with the labyrinthine conundrum of assimilating hydrogen technologies within the mazy fabric of building codes and architectural schemata, adroitly unravelling potential barriers while unswervingly accentuating the economic viability that heralds grid-connected solutions. The participant's discourse seamlessly navigates the domain of residential storage, therein subjecting the contemporary utilization paradigm of hydrogen as an energy storage medium to critical scrutiny. The clarion call resounds for practical, economically tenable paradigms that orchestrate a pragmatic orchestration of decarbonization pursuits, thereby etching an indelible imprint upon the trajectory of ecologically harmonious endeavours.

New Zealand's abundant renewable resources and focus on energy resilience makes it an ideal candidate for green hydrogen integration. As RH notes, *“If you’ve got, if you’re in a position where you can have forward solar panels and you can and you can accumulate...you can use hydrogen as a as a storage medium”*, the ability to leverage hydrogen as an energy carrier and storage solution holds promise. RH envisions that in fringe or off-grid locations, hydrogen generation could provide a *“local buffer if the electricity supply is constrained”*.

However, RH cautions that *“the hydrogen piece is quite limited in that hydrogen has a conversion inefficiency”*. For electricity needs, he suggests *“if you want a lot of electricity and your other alternative ways of storing energy is as just simple, sensible heat, and that is that is actually the in some ways there's the competitor to this system”*. While hydrogen conversion to electricity has disadvantages, direct use as a thermal fuel shows more potential.

For broader adoption, RH notes that perceptions of regulatory safety assurances will be key. Citing a study, he found overwhelming public openness to hydrogen when approved by authorities. Addressing legitimate safety factors like flammability and flame visibility through proper system design and sensors can build public confidence.

Overall, RH sees niches where green hydrogen can enhance New Zealand's built environment, improving energy resilience and furthering sustainability goals. But context-specific analysis weighing practicality against conversion losses is required to maximize its potential. With strategic implementation and public engagement, hydrogen promises to play an increasing role in the country's clean energy future.

TW offers a pragmatic elucidation of the tangible deployment of hydrogen technologies within the residential domain, with an unwavering emphasis on the precepts of energy self-sufficiency and resilience. The participant delves into a comprehensive discourse, intricately interweaving hydrogen with batteries and renewable energy sources to adroitly surmount the demanding zeniths of high-load energy requisites encompassing culinary endeavours, space heating, and the provisioning of hot water. TW assiduously underscores the salient facet of scalability inherent to this paradigm, expounding upon its seamless symbiosis with extant solar installations, all while flexibly adapting to the specific contours of energy exigencies. The colloquy adeptly veers towards a nuanced contemplation of the financial calculus, offering a discerning juxtaposition of divergent storage solutions' price points, notably spotlighting Lavo's domestic-scale hydrogen storage innovation. With a clarion call, the speaker opines that governmental patronage should effectively catalyse the zenith of energy autonomy and resilience for domestic end-users, therein catalysing the widespread embrace of renewable systems and correspondingly attenuating reliance on orthodox grid services. TW envisions an incremental, phased transition into the hydrogen epoch, surmising that the echelons of off-grid configurations might herald an epoch where consummate self-sufficiency can be achieved without incurring the toll of lifestyle compromises. A conspicuous acknowledgment resounds regarding the temporal imperative to cultivate public trust and to forge the crucible of acceptance of hydrogen as a tenable and efficacious fuel for diverse residential applications.

TN, in a cognate vein, adroitly conceptualizes the vista of hydrogen technologies permeating residential domains, proffering a poignant proposition that posits solar or wind power generation as a transformative linchpin within urban agglomerations. The participant adumbrates an innovative conceptual schema, envisioning a paradigm wherein urban epicentres harness solar or wind apparatuses to directly bestow energy to contiguous residential and commercial edifices. A further proposition unfurls - seamlessly fusing solar or wind installations with electrolyzers - to conjure forth self-contained energy ecosystems upon islands akin to the evocative expanse of Waiheke Island. Herein, the entwined realms of renewable installations and electrolyzers converge to fabricate hydrogen in situ, heralding a resplendent tapestry of localized energy generation. This conceptual citadel particularly shines in circumstances of isolation, where the concomitant cost of assimilation

into the traditional grid eclipses the allure of localized hydrogen-based energy generation. The participant draws from the annals of Japanese innovation, citing their pioneering forays into hydrogen-based energy solutions, particularly within small island enclaves in virtue of the exigencies intrinsic to grid connectivity. This standpoint magnificently amplifies the adaptive ethos of hydrogen technologies, portraying their quintessential role in expediting the epochal decarbonization of the built environment.

ZJ astutely underscores the propitious propensities of hydrogen technologies within the European residential milieu, with a pronounced focal point on their integral role in the domain of heating. The participant's discourse discerningly navigates the terrain of leveraging hydrogen for domestic energy provisioning, thereby yielding a profound augmentation of energy security through a commensurate diminishment in reliance upon imported energy reservoirs. A luminous spotlight is cast upon the salient crucible of hydrogen endeavours manifesting in notable hydrogen projects, spanning the geographic gamut from the United Kingdom to China. Within these dynamic locales, the fulcrum rests upon the conjoined orchestration of hydrogen's productive crucible and its judicious application in the purview of local heating and domestic consumption. A perspicacious awareness prevails, acknowledging the veritable viability of hydrogen technologies while unwaveringly acknowledging the trenchant economic impediment. This incisive cognizance crystallizes around the intrinsic costs intricately interwoven with electrolyzers, fuel cells, and the orchestration of system integration - more so when the scope is telescoped down to the residential echelons.

Moreover, the discourse ventures into the nebulous precincts of regional planning and decision-making, where strategic deliberations pivot around the seamless assimilation of hydrogen into the expansive tapestry of the gas grid. The participant adroitly deconstructs the multifaceted tapestry, deftly weaving considerations encompassing distribution systems, vigilant monitoring paradigms, and the calibrated ascent of boilers to orchestrate a harmonious synergy. The overarching narrative acutely concedes the imperatives that safety exacts, accentuating the paramount necessity to cultivate an exigent vigilance, particularly in domains entwined with commercial propensities. This panoramic perspective is emblematic of the concerted endeavours that are orchestrated to seamlessly synthesize hydrogen technologies into the archetypes of residential and commercial milieus - a dynamic encapsulation that augments the clarion thrust of decarbonization within the corporeal confines of the built environment.

Decarbonizing the Built Environment through Green Hydrogen	
Aspect	Key Insights
Energy Storage Potential	- Hydrogen can serve as an energy storage and utilization solution in areas with intermittent grid access, enhancing resilience.
Seasonal Storage	- Useful for seasonal storage, replacing fossil fuel heating, and reducing emissions.
Integration Considerations	- Requires a careful approach to ensure:
	- Safety
	- Compliance with regulations
	- Building public confidence
Practical Challenges	- Cost-competitiveness is a significant hurdle that needs addressing.

Successful Pilots	- Examples of successful localized pilots provide optimism for hydrogen adoption.
Synergy with Renewables	- Notable synergy between hydrogen and renewable sources (solar PV and wind) for optimized hybrid energy systems.
Diverse Perspectives	- Differing views on the extent of hydrogen's role in the built environment; however, there is consensus on integrating it alongside renewables.
Energy Security	- Valuable for energy security, especially in off-grid locations and for seasonal storage.
Economic Viability	- Economic viability remains a concern despite potential benefits.
Safety and Compliance	- Important safety mechanisms include:
	- Pressure management
	- Compliance with relevant codes for residential and commercial use
Heating and Thermal Applications	- Potential applications in heating and thermal use, enhancing energy autonomy.
City-Scale Opportunities	- Promising avenues in city-scale combined heat and power systems.
Cultural Transition	- Transition requires cultural recalibration in areas with entrenched gas use.
Innovations	- Innovations like reversible fuel cells can facilitate hydrogen integration.
Phased Approach	- Phasing hydrogen with batteries and renewables can enable high self-sufficiency, but costs remain prohibitive for widespread adoption.

Table 11: Decarbonizing the Built Environment through Green Hydrogen

In summary, hydrogen has a promising role in the built environment but strategic integration aligned with regional demands, alongside renewables, is key for effective decarbonization.

4.11 Various Industries Decarbonization via Green Hydrogen Technologies

The perspectives of experts from diverse regions and industries provide valuable insights into the multifaceted landscape of hydrogen production, supply chains, and scale. The consensus is that hydrogen holds transformative potential across various sectors, offering a versatile energy carrier that can aid in decarbonization efforts. An overarching theme is hydrogen's adaptability, whether as a key component in the oil refinery sector, a clean energy carrier extracted using renewable electricity, or a versatile gas applicable in myriad contexts. Furthermore, the concept of scalability emerges as a central tenet. As experts delve into small-scale and large-scale production, they recognize the paramount role of scale in mitigating high production costs, fostering efficiency, and ultimately driving down costs over time. Green hydrogen emerges as a focal point, with emphasis on utilizing renewable energy sources for its production and ascribing to a green supply chain ethos. From an environmental perspective, experts acknowledge that no human activity is devoid of impact yet stress

the importance of contrasting the environmental repercussions of hydrogen technologies with existing practices to gauge their net benefit. The discussions underscore the need for meticulous consideration of factors, such as carbon content, geographical and temporal correlations, and supply chain intricacies, when assessing the sustainability of hydrogen solutions. Consequently, the quest to achieve clean, resilient, and economically viable hydrogen systems rests upon weaving together flexibility, efficiency, safety, and scalability into a harmonious fabric, one that charts the course towards a greener energy future.

The perspectives of various experts shed light on the multifaceted dimensions of hydrogen production, distribution, and scale. While each expert's viewpoint is unique, common threads emerge, underscoring the significance of hydrogen as a transformative agent in diverse sectors. DA highlights hydrogen's pivotal role in oil refining, positioning it as a *"key component that's used in the oil refinery"*. EEF emphasizes hydrogen's versatility as an energy carrier and its potential to revolutionize transportation and industrial applications through clean production methods, stating that *"if you use electricity from renewable energy, then hydrogen has great potential to be used as a source of energy... for cars, for industrial applications"* as well as for creating various chemical compounds. This sentiment resonates with SGJA, who underscores hydrogen's potential to replace traditional fuels in high-temperature processes for sectors like steel and cement, noting that *"you would burn hydrogen instead of using coal or natural gas"*. In a similar vein, SGJA envisages hydrogen as an enabler for greening industries with heavy energy demands such as cement and glass manufacturing, stating that *"instead of using coal or natural gas that is used for high-temperature processes, you would burn hydrogen"*.

The experts also converge on the imperative of decarbonization across industries and nations. For instance, EEF cites the need for Costa Rica to transition to green hydrogen to address its intensive fertilizer consumption, mentioning that *"the amount of fertilizers we consume is 4.5 times the world average"* and highlighting the environmental impact of the current practices. Similarly, KQ acknowledges the significance of hydrogen in decarbonizing energy and chemical sectors, essential for a green industry. This sentiment resonates with MR, who underscores the potential of hydrogen to decarbonize both energy and chemical industries, emphasizing the interplay between energy transition and broader industrial transformation. MS highlights the importance of a green supply chain in hydrogen production, positing that the choice of production methods should be aligned with sustainability principles, as *"we need to evaluate the entire carbon content until the end use"*.

The debate over hydrogen scale and distribution underscores a nuanced perspective. While VG maintains that scaling hydrogen production can mitigate high costs over time, stating that *"the challenges of high costs can be overcome with scale"*, RGJA counters by asserting that small-scale localized production, particularly harnessing solar energy, could offer an interesting avenue for certain applications. TN similarly notes the challenges of transporting hydrogen cylinders to construction sites and stresses the importance of both cost and operational efficiency, mentioning that *"the cylinder itself will take up some space"*.

An overarching theme is the evolving nature of hydrogen adoption. Experts emphasize a diversified approach where hydrogen usage is strategically targeted to capitalize on its strengths. SGJA advocates for pinpointing hydrogen applications in sectors with heavy thermal energy demands, effectively transitioning away from fossil fuels. KQ highlights the ongoing progress in adopting hydrogen as a clean solution for heavy-duty vehicles, particularly trucks and buses, as *"the heavy-duty vehicle sector feels like hydrogen makes a lot of sense"*. TN, MS and VG add their voices to this narrative, discussing the role of hydrogen in green steel production and energy storage, as well as export, reflecting its evolving and varied applications in different global contexts.

Amid these varied perspectives, a resounding call for sustainability, energy security, and decarbonization emerges. The intricate web of considerations encompassing carbon content,

renewable sourcing, and transportation underscores the need for a holistic approach in determining the ecological footprint of hydrogen technologies. MS highlights the importance of a green supply chain in hydrogen production, positing that the choice of production methods should be aligned with sustainability principles. This sentiment resonates with VG, who underlines the need to balance local use cases with export opportunities, emphasizing the potential of hydrogen as a decarbonizing agent in various sectors, including transportation and industry.

The remarkable versatility of hydrogen emerges as a cornerstone of its potential to drive substantial decarbonization across a multitude of sectors. Within this expansive scope, the prospect of employing hydrogen as a potent agent of decarbonization comes to the fore. The insights offered by **EEF** delve into the transformative power of green hydrogen in mitigating carbon emissions within diverse industries. The phrase *“a gas that can decarbonize a lot of sectors”* encapsulates the profound impact hydrogen can wield in addressing the pressing challenge of carbon reduction. EEF’s contemplation invites contemplation into the intricate web of opportunities that hydrogen’s inherent properties present. This assertion underscores the multifaceted nature of hydrogen’s role as a pivotal enabler of sustainable.

JH’s insights shed light on the organic integration of green hydrogen into the decarbonization journey of various industries. He underscores the inherent alignment between long-distance transport and hydrogen’s potential to drive decarbonization efforts. Highlighting the need to address carbon emissions in industrial sectors, JH points to the significance of transitioning petroleum refining processes to utilize green hydrogen. Specifically, he accentuates the role of green hydrogen in hydrocracking and ammonia production, recognizing it as a pivotal solution to foster sustainability. JH advocates for a holistic approach that seeks to imbue green hydrogen and green ammonia across sectors wherever hydrogen is indispensable. His perspective crystallizes the notion that decarbonization, facilitated by the adoption of green hydrogen, is a natural and imperative evolution toward a cleaner, more sustainable industrial landscape.

RGJA’s viewpoint underscores the formidable challenge of decarbonization that hydrogen seeks to address across diverse industries. He aptly recognizes that decarbonization efforts are particularly intricate when it comes to sectors that rely heavily on energy-intensive processes, such as mining and heavy-duty transportation. By implicating these sectors, RGJA highlights the urgency and complexity of the task at hand. He implies that hydrogen’s role in decarbonization extends beyond a single solution, and it necessitates an integrated approach that mitigates emissions across industries with varying energy demands. RGJA’s perspective resonates with the intrinsic difficulty of decarbonization, while also emphasizing the potential of green hydrogen to catalyse profound transformation in sectors traditionally associated with high carbon footprints.

KQ offers an insightful overview of the expanding role of green hydrogen in decarbonizing various sectors. She identifies a range of applications for hydrogen-powered vehicles, spanning from passenger cars to heavy-duty trucks, underscoring their potential as pivotal agents of change in the transportation landscape. She points to the ongoing development of prototypes for heavy-duty trucks, a sign of the increasing interest and investment in this segment. Notably, KQ acknowledges the deployment of hydrogen fuel cells in niche yet crucial areas like forklifts and power-hungry sectors such as banking, computing, and healthcare. This pragmatic integration highlights hydrogen’s reliability as an energy source in contexts that demand uninterrupted power supply.

Furthermore, KQ accentuates the infrastructure developments underpinning hydrogen adoption. She notes the progress in establishing hydrogen refuelling stations, exemplified by California’s ambition to reach 100 stations. This initiative, while still in progress, signals a foundational step towards supporting hydrogen-powered vehicles. KQ alludes to the broader implications, hinting at nationwide efforts to replicate this infrastructure model.

Additionally, KQ underscores the significance of hydrogen in specialized scenarios, like mining, where emissions-free operations are critical. She highlights the advantage of hydrogen in confined and potentially hazardous spaces, echoing its potential to contribute to both worker safety and environmental preservation.

Conclusively, KQ provides a comprehensive insight into the multifaceted growth of hydrogen adoption across industries, particularly in transportation and power-sensitive sectors. Her observations align with the trajectory of green hydrogen as a versatile and dynamic solution for decarbonization.

MR presents a comprehensive perspective on the pivotal role of green hydrogen in decarbonizing diverse industries, highlighting its transformative potential in both the energy and chemical sectors. She illuminates the intricate interplay between hydrogen production and essential applications such as ammonia production, fundamental to fertilizers and various other industrial processes. This underscores the critical linkage between hydrogen availability and the feasibility of developing environmentally friendly industries. MR emphasizes the inextricable relationship between hydrogen and a sustainable industry, emphasizing that without a reliable source of hydrogen, achieving a green economy remains an elusive goal.

MR further navigates the nuanced landscape of hydrogen's applicability. While acknowledging its role as a transportation fuel, she acknowledges its limitations in addressing all modes of transportation. This discernment aligns with the recognition that hydrogen solutions must be tailored to suit specific contexts and optimize their impact.

Moreover, MR recognizes the overarching significance of hydrogen across diverse sectors of the economy. She insightfully positions green hydrogen as an opportunity to simultaneously address energy sustainability and leverage its advantages in catalysing advancements in various industrial domains. Her perspective encapsulates the idea that green energy solutions can trigger a ripple effect, influencing other sectors toward more sustainable practices.

Lastly, MR contextualizes hydrogen's role within varying scales of application. For larger industrial complexes and facilities, she highlights the potential of hydrogen-fired boilers and furnaces as an effective decarbonization strategy.

In summary, MR's narrative underscores the integral role of green hydrogen as a catalyst for decarbonizing industries, weaving together energy, chemicals, and other sectors, while acknowledging the contextual nuances that govern its effectiveness and the transformative potential it holds for a sustainable future.

MS adeptly highlights the weighty carbon footprint of industries, accentuating the challenges of decarbonization in sectors with high energy consumption. Notably, he underscores steel and glass manufacturing as prime examples, both reliant on significant electricity inputs typically sourced from power stations. He further elucidates that the realm of substantial energy consumption extends to large-scale transportation, encompassing trains and ships rather than merely conventional cars.

MS astutely recognizes that devising strategies to decarbonize these distinct sectors necessitates tailored approaches. Each industry's characteristics and requirements demand unique solutions, acknowledging the multifaceted nature of the challenge. This nuanced perspective underscores the complexity of decarbonization efforts, as they need to navigate the intricate web of industrial operations and energy demands.

Furthermore, MS sheds light on an innovative approach to integrating green hydrogen within manufacturing processes. He highlights the transformation of hydrogen from a purchased raw material delivered in bottles to an in-house produced resource. The implementation of solar panels on-site to generate hydrogen speaks to a decentralized approach, reducing dependence on external

supply chains and fostering immediate utilization. This case exemplifies a practical integration of green hydrogen as a raw material, contributing to both efficiency and sustainability objectives.

VG presents a comprehensive overview of the expansive potential of green hydrogen in diverse sectors, emphasizing its multifaceted applications in various industries and contexts. Notably, he highlights that while energy storage constitutes a portion of hydrogen's usage, its primary role lies in the export market, targeting regions willing to pay a premium for this versatile resource, notably Europe. However, VG underscores that the local realm offers ample opportunities for hydrogen's utilization, exemplified by its integration in mobility solutions.

VG's insights extend to the potential of green hydrogen in curbing carbon emissions within the built environment. He points to its considerable impact on reducing carbon emissions in cement production, underlining its pivotal role in transitioning toward more sustainable construction practices. This notion expands to the concept of waste-to-energy conversion, where green hydrogen can contribute significantly to local energy generation and heat utilization.

Further, VG underscores the strategic implementation of hydrogen in the transportation sector, specifically in mobility and green steel production. He accentuates that green hydrogen holds great promise in enabling clean mobility, particularly for heavy-duty vehicles like trucks and buses, where battery efficiency may not be optimal. This aligns with broader national initiatives, as VG notes substantial investments in hydrogen mobility projects, including the establishment of refuelling stations and vehicle subsidies.

Various Industries Decarbonization	
Aspect	Key Insights
Versatile Energy Carrier	- Hydrogen is recognized as a versatile energy carrier with the potential to aid decarbonization across diverse sectors, including transportation, refining, steel, and cement.
Cost Reduction Potential	- Scaling up hydrogen production can help lower costs over time due to economies of scale, although small modular systems may be more suitable for localized applications.
Transition to Renewable Hydrogen	- A recurring theme is the need to shift from conventional fossil fuel-based hydrogen production to renewable-based green hydrogen, aligning with sustainability goals.
Environmental Impact Assessment	- Green hydrogen requires thorough scrutiny of the entire supply chain and production methods to minimize environmental impact, necessitating a holistic life cycle perspective on sustainability.
Strategic Sector Focus	- Strategic implementation should prioritize hydrogen use in sectors with maximum decarbonization potential, such as process heating, heavy transport, shipping, steel, and chemicals.
Adoption Trends	- Adoption is gradually increasing in transportation, particularly heavy-duty vehicles and freight, with progress also noted in power-intensive sectors like mining, computing, and healthcare.
Localized Production Trends	- Localized on-site hydrogen production from renewables for direct use in manufacturing is an emerging trend that enhances efficiency and sustainability.

Feedstock for Cleaner Production	- As an essential feedstock, green hydrogen can facilitate cleaner production pathways for chemicals like ammonia, which are critical across various industries.
Tailored Implementation Solutions	- While green hydrogen is a versatile decarbonization vector with vast potential, practical implementation requires nuanced solutions tailored to each sector's unique context and requirements.

Table 12: Various Industries Decarbonization

The diverse viewpoints of experts highlight the complexity and promise of hydrogen production, distribution, and scale. As nations and industries strive for sustainable energy solutions, the dialogue among experts underscores the significance of aligning technological innovation, economic viability, and environmental stewardship on the journey towards realizing the potential of green hydrogen. The holistic perspective resonates with the global drive toward decarbonization, recognizing hydrogen's multidimensional impact in shaping a sustainable future. In conclusion, green hydrogen is primed to serve as a transformative decarbonization agent across multiple industries if strategies synchronize its unmatched versatility with the specific needs and challenges of each application sector in a holistic and sustainable manner.

4.12 CO₂ and Other Emissions Reduction in Context of Decarbonisation

The diverse viewpoints offered by the participants shed light on the intricate realm of carbon emissions and the role of hydrogen technologies within the context of decarbonization. Participants concur that the reduction of carbon emissions is a paramount concern, with strategies encompassing diverse approaches.

The pivotal challenge of carbon capture emerges as a focal point. A common consensus arises on the imperative to identify solutions for effectively capturing carbon dioxide emissions, a task characterized by its complexity and significance. The endeavour to displace carbon content is a central theme, wherein hydrogen emerges as a potent alternative to conventional carbon-intensive fuels. The concept of “*blue hydrogen*” garners attention, illustrating that hydrogen’s environmental classification is linked to its carbon emissions during production. Divergent regional standards underscore the variances in emission thresholds for legal categorization.

Participants emphasize the multifaceted nature of carbon reduction measures. The adoption of hydrogen technologies in tandem with renewable sources garners prominence. A unified global effort towards a carbon market is advocated, rooted in accurate pricing reflecting the actual environmental impact of emissions. International agreements and commitments underscore the collective drive to curtail carbon emissions, necessitating nuanced strategies and policy implementations.

The concept of “*low carbon*” hydrogen is pivotal, delineating the range of sources encompassing renewable, nuclear, and clean fossil fuels. Certification and assessment mechanisms, underpinned by meticulous carbon content evaluation, resonate as prerequisites. The notion that hydrogen, when utilized, essentially eliminates carbon emissions gains prominence. Green certificates are noted as a pragmatic mechanism to stimulate technological investment and emissions reduction. The integration of hydrogen within existing infrastructure, such as gas grids, is a step toward carbon reduction. An array of pragmatic applications emerges, from industry to transportation, further affirming hydrogen's role as a decarbonization catalyst.

According to **DA**’s insights, the classification of hydrogen as “*blue hydrogen*” hinges on its carbon emissions during production. He highlights that for each kilogram of hydrogen manufactured, emitting less than five kilograms of carbon dioxide would qualify the hydrogen as “*blue*”. This

classification is characterized by a more lenient policy stance compared to Europe and the USA, where the carbon emissions thresholds are set at two and three kilograms per kilogram of hydrogen, respectively. This differentiation underscores the variability in regulatory approaches across regions.

Notably, DA underscores a significant aspect related to government priorities in the context of hydrogen technologies and the built environment. He suggests that governmental emphasis lies more on the scaling up of hydrogen rather than solely on the carbon intensity of hydrogen production. This perspective highlights the strategic importance of hydrogen's integration and proliferation within the energy landscape, particularly within the built environment.

Incorporating DA's insights, it becomes evident that hydrogen's environmental classification and the government's emphasis on scaling up hydrogen technologies intersect to shape the trajectory of hydrogen adoption within the built environment. The regulatory nuances and policy frameworks surrounding carbon emissions and hydrogen production are integral to realizing sustainable energy transitions within the built environment.

In **EEF's** perspective, the significance of carbon dioxide (CO₂) emissions becomes a pivotal driver for highlighting the imperative of decarbonization within a country. This understanding underscores the importance of addressing CO₂ emissions as a key element in the pursuit of sustainable development. EEF suggests that this pressure is particularly crucial for countries that may not be as advanced in their decarbonization efforts compared to others.

EEF also emphasizes the broader impact of emissions, not only limited to CO₂ but also extending to other pollutants that have adverse effects, such as water emissions. This recognition highlights the interconnectedness of environmental challenges and the need for comprehensive solutions that account for various emission types.

Furthermore, EEF underscores the role of hydrogen technologies in the reduction of CO₂ emissions. These technologies allow companies to claim that their operations are "*CO₂ free*" or at least significantly reduced in terms of carbon emissions. This alignment with hydrogen presents a pathway for industries to contribute to decarbonization targets.

From the vantage point of the built environment, EEF's insights underscore the need for multifaceted approaches to decarbonization. CO₂ emissions serve as a focal point for catalysing sustainable actions, while hydrogen technologies offer a potential avenue for reducing or eliminating carbon emissions. By integrating such strategies, the built environment can play a vital role in addressing environmental concerns and facilitating a transition toward more eco-friendly practices.

Incorporating EEF's viewpoints, it is evident that the interplay between CO₂ emissions, hydrogen technologies, and the built environment forms a complex nexus in the pursuit of sustainable development and environmental preservation.

RGJA asserts that the integration of carbon reduction strategies and hydrogen technologies holds the potential to offer substantial benefits to nations engaging in international trade. Taking New Zealand as an illustrative case, the adoption of stringent carbon footprint standards in trading partners could serve as a catalyst for enhanced market access. By aligning with these stringent environmental norms, countries like New Zealand can position themselves as reliable partners in international trade, thereby potentially gaining a competitive advantage in global markets.

Moreover, RGJA underscores the importance of a global perspective in addressing carbon emissions. This perspective underscores the necessity for a unified approach to managing carbon emissions, wherein a global carbon market would play a pivotal role. Within this framework, the imposition of carbon emission prices would be based on a comprehensive assessment of the actual environmental impact caused by such emissions. This approach, according to RGJA, holds the potential to accurately reflect the true extent of the damage these emissions inflict on the atmosphere.

From the standpoint of the built environment, RGJA's insights imply that the adoption of carbon reduction measures and the integration of hydrogen technologies could enhance a country's market presence on a global scale. By aligning with stringent carbon footprint standards, nations can enhance their export potential and contribute to global sustainability goals. Simultaneously, RGJA's emphasis on a global carbon market underlines the role of collective efforts in tackling carbon emissions. This perspective provides an academic basis for understanding how carbon considerations intersect with hydrogen technologies and their implications for the built environment.

KQ highlights a significant trend in the energy landscape, noting that the introduction of new energy sources into the system is progressively characterized by a reduced carbon footprint. This observation underscores the ongoing shift towards cleaner and more sustainable energy alternatives, which align with global efforts to mitigate carbon emissions and combat climate change. As the energy sector embraces these carbon-free options, it demonstrates a proactive approach to address environmental concerns, particularly in the context of the built environment.

KQ further underscores the role of regulatory frameworks in shaping the trajectory of carbon emissions reduction. She emphasizes that regulations play a pivotal role in steering energy-related practices towards lower carbon emissions. These regulations serve as catalysts for change by enforcing environmental standards and incentivizing the adoption of cleaner technologies and practices. By embracing such regulations, the built environment can effectively contribute to carbon reduction goals and facilitate the integration of hydrogen technologies for sustainable energy solutions.

In the context of the built environment, KQ's insights highlight the importance of regulatory initiatives in guiding the sector's transition towards lower carbon emissions. This perspective underscores the interconnectedness of regulatory measures, technological advancements, and environmental objectives. As such, KQ's remarks offer an academic lens through which to comprehend the dynamic interplay between carbon reduction strategies, hydrogen technologies, and the built environment's contribution to a more sustainable future.

MS highlights the fundamental shift away from fossil fuels as a means of reducing carbon emissions within systems that previously relied on such sources. This perspective aligns with the prevalent understanding that transitioning from carbon-intensive fuels to alternative, non-carbon extracted sources is a pivotal strategy in addressing environmental concerns. By advocating for the replacement of fossil fuels with cleaner energy alternatives, MS underscores the role of technology in reshaping the carbon landscape of various systems within the built environment.

Furthermore, MS acknowledges the complexity of carbon reduction efforts, recognizing that while the elimination of CO₂ emissions is a significant achievement, other emissions such as particulates must also be considered. This nuanced perspective acknowledges that a holistic approach to emissions reduction is essential for sustainable development in the built environment. The emphasis on addressing multiple types of emissions underscores the multifaceted nature of environmental challenges and the need for comprehensive solutions.

In the context of international cooperation, MS provides insights into the commitments made by governments at a regional summit. The reference to the G8 summit in Bali highlights the collective intent of governments in Asia to adhere to CO₂ standards and collaboratively reduce emissions. This perspective underscores the global movement towards carbon reduction as a shared responsibility, wherein countries align their efforts to meet agreed-upon targets. MS's view reinforces the importance of international agreements and collaborative actions to achieve sustainable development and carbon reduction goals within the built environment.

MS's opinions resonate with scholarly discussions on carbon reduction strategies and their implications for the built environment. His insights emphasize the significance of technology-driven

transitions, the need for comprehensive emissions reduction, and the role of international agreements in shaping the carbon landscape of the built environment.

PL underscores the multifaceted approach to evaluating hydrogen technologies within the context of carbon reduction. He highlights the role of international agencies in scrutinizing various technology types, emphasizing that the International Renewable Energy Agency (IRENA) specifically focuses on renewables, while broader agencies consider both renewable and low-carbon solutions. In the pursuit of defining clear terms, PL distinguishes between two fundamental categories: low carbon hydrogen and renewable hydrogen. This categorization reflects the evolving discourse around hydrogen production, where discussions extend beyond a singular “green” label to acknowledge nuanced distinctions.

PL delves into the complexity of classifying low carbon sources, noting that this encompasses not only renewables but also contributions from nuclear and even hydrogen generated from fossil fuels with carbon capture. This inclusive perspective signifies the necessity of comprehensive assessments that account for various pathways to emissions reduction. In this context, PL emphasizes the importance of establishing certification processes and standards, which serve as crucial benchmarks for assessing carbon content and source authenticity throughout the production and supply chain.

The criteria for certification further elaborated by PL emphasize the need for geographic and temporal alignment between electricity and hydrogen production, particularly in cases where grids are involved. Demonstrating the carbon content of renewables, including factors like production materials and compression, underscores the rigorous evaluation necessary to ensure accurate carbon measurement. PL’s emphasis on the intricacies of carbon assessment underscores the complexity of ensuring a genuinely low carbon hydrogen supply.

Furthermore, PL stresses the value of certification as an assurance of a technology's carbon credentials. This viewpoint aligns with the broader understanding that credible certification substantiates claims of low carbon or renewable attributes. PL’s insights also highlight that the transition to low carbon hydrogen is pivotal even if the underlying element remains hydrogen. He suggests that the shift itself constitutes a substantial change, reflecting a broader recognition that advancements in technology can reshape industrial applications and practices.

PL’s perspectives offer a unique perspective on the evolving landscape of hydrogen classification and certification, enriching scholarly discussions on carbon-free hydrogen technologies in the built environment.

Within the framework of the built environment, **RH** emphasizes the transformative potential of hydrogen technologies in achieving significant decarbonization outcomes. His viewpoint accentuates the direct impact of hydrogen adoption in replacing traditional fuels, ultimately leading to the complete decarbonization of operational processes. The illustration of this transformation is underscored by RH’s example, where hydrogen's substitution of methane or LPG yields a tangible reduction in carbon emissions. The significance of such conversions is pronounced as they offer a direct way to curtail carbon outputs in energy-intensive sectors like gas utilization.

RH’s perspective also delves into an alternative angle of measuring decarbonization success. He advocates for conveying the environmental benefits in relatable terms, steering away from abstract kilograms of CO₂. Instead, RH suggests emphasizing the tangible services or savings delivered by the technology. This approach aligns with the concept of demonstrating impact in a language that resonates with stakeholders, enhancing their understanding and engagement in carbon reduction efforts.

Furthermore, RH addresses the intricacies of implementing a high carbon price as a policy instrument. While such an approach could potentially steer behaviour towards low carbon alternatives, RH

highlights the potential backlash it might incur due to financial burdens. This view acknowledges the complexity of balancing environmental objectives with economic considerations, a critical facet of transitioning to carbon-free technologies.

RH also draws attention to the catalytic properties of carbon in various chemical processes. He notes the limitations that the transformation of CO₂ into carbon monoxide might pose in terms of catalytic efficacy. This observation underscores the interplay between chemical reactions, carbon transformation, and the broader feasibility of certain pathways towards carbon reduction.

Moreover, RH directs our gaze towards the long-term future of gas availability. Beyond concerns about environmental impacts, he delves into the potential scarcity of gas resources over the life span of industrial installations. This consideration amplifies the imperative of adopting sustainable energy solutions that can circumvent future resource shortages, thereby ensuring the longevity of built environment projects.

In his distinctive stance, RH contributes a multifaceted understanding of carbon reduction and hydrogen technology's role within the built environment. His insights encapsulate the technical, economic, and strategic dimensions of adopting carbon-free hydrogen technologies while speaking to the potential of reshaping both energy landscapes and environmental consciousness.

SJS offers a unique perspective that juxtaposes the pricing dynamics of carbon emissions against the backdrop of energy costs. He underscores the significant economic implications associated with carbon emissions, revealing a substantial price disparity between carbon-intensive and more environmentally friendly energy sources. This sharp contrast becomes evident as he highlights that the cost of carbon-intensive options can be tenfold higher than that of alternatives like Russian gas. Such a comparison vividly illustrates the economic incentives for transitioning towards lower carbon alternatives.

Moreover, SJS distinguishes his own approach from other technologies like PEM systems by emphasizing the utilization of Iridium and titanium in the latter, resulting in higher costs. This comparison serves to underscore the cost-effectiveness of his system and positions it as a competitive and economically viable solution within the landscape of hydrogen technologies.

SJS then delves into the realm of precise carbon measurement, an endeavour that his team has undertaken. He provides insights into their meticulous efforts to clarify their system's carbon footprint. This approach aligns with the growing emphasis on accurate carbon accounting, reflecting a commitment to transparency and accountability. SJS's dedication to scientific rigor is evident as he discusses the development of a handbook that offers comprehensive information, further augmented by open-source software tools. This commitment to transparency not only enhances their credibility but also encourages collaborative engagement within the industry.

Furthermore, SJS introduces their novel tool – electrolyser - for version 4.0, a technological advancement aimed at achieving external certification. This proactive approach to third-party validation underscores their commitment to accuracy and objectivity. SJS's exploration of external certification speaks to the industry's evolving standards and the importance of independent scrutiny to uphold the integrity of carbon emission measurements.

In a candid admission, SJS acknowledges that certain information is not yet published, indicating an upcoming event that could shed light on their latest advancements. This sense of anticipation highlights the dynamic and rapidly evolving nature of the field, where knowledge dissemination is a continuous process.

In sum, SJS's perspective provides a glimpse into the intricate interplay between economics, technology, precision, and transparency in the realm of carbon emissions and hydrogen technology.

His insights encapsulate the intricate dance between economic considerations and scientific rigor within the context of carbon-free energy solutions.

TW eloquently elucidates the transformative power of hydrogen as a carbon-neutral energy source. He emphasizes that with the adoption of hydrogen, discussions around carbon dioxide become obsolete, as the introduction of carbon is entirely eliminated from the equation. This assertion underscores the pivotal role of hydrogen in achieving a paradigm shift towards emissions-free energy solutions, encapsulating the essence of zero-carbon aspirations.

Furthermore, TW delves into the current trajectory of environmental policies and initiatives, particularly in the context of Australia. He highlights the Climate Change Commission's recent report, which underscores the pressing need to bridge existing gaps in the journey towards sustainability. This report's release underscores the immediacy of the climate crisis and the necessity for proactive measures.

TW then delves into Australia's evolving approach to incentivizing green energy adoption, drawing attention to the utilization of green energy certificates. These certificates mandate a certain proportion of carbon-free fuel usage, incentivizing energy users to shift away from carbon-intensive sources. This market-based approach encourages the adoption of cleaner technologies while ensuring accountability for emissions.

In a nuanced observation, TW underscores the need for a shift in perspective – one that transcends the reliance on reforestation efforts alone. He suggests that focusing on technological advancements and energy generation methods is equally critical. This stance reflects an evolved understanding of environmental solutions that extend beyond traditional approaches, encouraging a holistic view of sustainability.

TW's insights also extend to the practical implications of these shifts. He notes the effectiveness of green certificates in driving real-world projects, exemplified by the proliferation of hydrogen initiatives that have gained momentum due to their alignment with such incentives. By accentuating the successes of these projects, TW underscores the potential for tangible, scalable progress driven by policy and incentives.

In summation, TW's perspective is characterized by its comprehensive nature, covering the philosophical underpinnings of hydrogen's potential, the dynamic landscape of policy shifts, and the practical implications for environmental progress. His insights serve as a reminder that true sustainability necessitates a multifaceted approach, harmonizing technology, policy, and cultural shifts to pave the way for a carbon-free future.

TN succinctly encapsulates the fundamental principle that hydrogen production through electrolysis is inherently carbon-free. By affirming that hydrogen does not emit carbon dioxide during the electrolysis process, TN underscores the inherent environmental benefit of this technology. Electrolysis, as a method of hydrogen generation, hinges on the separation of hydrogen and oxygen molecules from water using electricity. This approach eliminates carbon emissions at the point of hydrogen creation, thereby aligning with the overarching goal of decarbonization. TN's statement underscores the pivotal role of electrolysis in producing clean and sustainable hydrogen, further emphasizing the technology's contribution to a greener energy landscape.

VG eloquently elucidates the significant potential of hydrogen technology in addressing carbon emissions within the context of cement production and the built environment. By acknowledging that cement production constitutes a substantial use case for hydrogen, VG highlights the technology's capacity to mitigate carbon output in an industry known for its substantial environmental impact. This acknowledgment underscores hydrogen's potential to reshape traditional processes and substantially reduce carbon emissions in crucial sectors.

VG further accentuates the environmentally friendly attributes of hydrogen technology, particularly in terms of its operational phase. By affirming that no carbon dioxide is emitted during the operation of hydrogen-based solutions, VG underscores the key advantage of this technology: its intrinsic carbon neutrality during use. In essence, VG presents hydrogen as a green and sustainable technology with the power to transform industries and contribute to a cleaner built environment.

ZJ astutely delineates the current landscape of hydrogen production, acknowledging its predominant reliance on natural gas and the imperative of transitioning towards low-carbon alternatives. With a strategic eye towards the future, ZJ highlights the potential of carbon capture and utilization technologies to markedly diminish carbon emissions associated with hydrogen production, an endeavour pivotal in the movement away from fossil fuels.

Furthermore, ZJ expounds on the forward-looking policies of the UK government in contemplating hydrogen integration into the national gas grid. By blending renewable source-generated hydrogen at a substantial percentage, the objective is to effectively eliminate carbon emissions associated with that portion of the gas mixture, thereby engendering a significant reduction in the carbon footprint of the gas grid.

ZJ underscores the essential role of precise methodologies for measuring carbon emissions and emphasizes the significance of conducting carbon counting and life cycle analyses. These methodologies serve as pivotal tools in comprehensively understanding the environmental impact of hydrogen production and utilization, thereby guiding informed decisions in the pursuit of sustainability.

Delving into the intricacies of carbon capture, ZJ delineates approaches such as absorption beds as a means to effectively capture CO₂ emissions from various sources. In this regard, ZJ discusses both the practicality and challenges of such strategies, including the ongoing exploration of direct CO₂ capture from the air—a dynamic field that necessitates multifaceted considerations within future system scenarios.

Lastly, ZJ acknowledges the inception of low carbon hydrogen production standards by the UK, underscoring the significance of limiting CO₂ emissions to 20 grams per mega joule of hydrogen production - a standard reflective of international endeavours to mitigate carbon emissions.

Through these insights, ZJ illuminates the complex trajectory of hydrogen technology in mitigating carbon emissions and the profound implications for shaping a sustainable and greener future.

Measuring Decarbonization and the Role of CO ₂ in Decarbonization	
Aspect	Key Insights
Importance of Baseline Establishment	- Establishing a baseline is crucial for quantifying emissions reductions from hydrogen adoption.
Calculation Methodology	- Calculation involves assessing CO ₂ displaced by substituting conventional technologies with hydrogen.
Influencing Factors	- Factors such as vehicle types, travel distances, and displacement technologies affect measurement.
Qualitative Understanding	- A qualitative understanding of energy consumption equivalence and resulting emission reductions is also important.
Holistic View on Pollutants	- A holistic view is needed, considering multiple pollutants beyond CO ₂ .

Practical Challenges	- Practical challenges must be addressed, such as ensuring complete substitution without technology retention.
Broader Environmental Impacts	- Broader environmental impacts, like reduced particulate emissions, are relevant metrics.
Carbon Capture Challenges	- Carbon capture is critical for hydrogen adoption but technically challenging.
Hydrogen's Role in Fuel Displacement	- Hydrogen displaces carbon in fuels such as natural gas or diesel.
Classification of Blue Hydrogen	- "Blue hydrogen" classification is based on CO ₂ emissions during production, with thresholds varying by region.
Government Support and Regulations	- Government emphasis on scaling hydrogen adoption in the built environment, alongside sustainability initiatives.
Regulatory Framework	- Regulations and international agreements are pivotal in steering energy practices toward lower carbon solutions.
Distinction in Hydrogen Types	- Distinction between renewable and low-carbon hydrogen; the latter includes fossil fuels with carbon capture.
Certification Processes	- Certification processes based on meticulous carbon content assessments are essential for validation.
Decarbonization Incentives	- Demonstrable decarbonization is a key incentive for hydrogen technology adoption.

Table 13: Measuring Decarbonization and the Role of CO₂ in Decarbonization

In conclusion, comprehensive methodologies encompassing metrics beyond CO₂, displacement effects, and environmental impacts are essential for effectively measuring decarbonization through hydrogen. The participants' perspectives coalesce around the overarching objective of decarbonization, spanning from intricate emission measurement methods to innovative hydrogen technologies. This dynamic discourse underscores the intricate interplay between hydrogen, carbon emissions, and the paramount goal of achieving a sustainable and greener energy landscape.

4.13 Measuring Decarbonization

The perspectives shared by the participants offer valuable insights into the methodologies and considerations involved in measuring decarbonization through the application of hydrogen technologies. The consensus revolves around the significance of establishing a baseline, against which the efficacy of hydrogen-based initiatives can be gauged. This involves quantifying the reduction in CO₂ emissions achieved by displacing conventional technologies with hydrogen alternatives. Notably, the emphasis is placed on the displacement effect, wherein the reduction in carbon emissions is calculated based on the carbon content of the fuel being substituted.

The elucidations underscore the multifaceted nature of this endeavour. It entails intricate calculations to assess the amount of CO₂ emissions reduced over specific time frames. The role of factors like displacement technologies, vehicle types, and travel distances is acknowledged. The discussions also delve into practical examples of projects aimed at introducing hydrogen-powered vehicles into certain

contexts. These examples serve as case studies to project the potential emission reductions achievable by transitioning from conventional vehicles to hydrogen-fuelled alternatives.

In evaluating the decarbonization impact of hydrogen technologies, the consensus shifts away from merely quantitative metrics. Qualitative approaches also hold significance, as participants emphasize the importance of understanding the equivalency of energy consumption and the subsequent reduction in emissions. This necessitates insights into the carbon content of different fuels and the emissions produced by their combustion. The discussions further highlight the necessity of holistic assessments, considering various pollutants and particulates beyond CO₂ emissions.

The opinions converge on the notion that the measurement of decarbonization involves a nuanced approach. It encompasses the intricate interplay of technologies, fuel types, energy consumption, and emission reduction. Furthermore, the discussions highlight the importance of addressing practical challenges, such as ensuring complete substitutions and the potential retention of existing technologies. The participants underscore the pertinence of evaluating the broader environmental impacts of hydrogen technologies, including the reduction of specific pollutants and contributions to acid rain.

EEF's perspective delves into the intricacies of measuring decarbonization while implementing hydrogen technologies, particularly within the built environment. EEF's insight underscores the necessity of establishing a baseline as a foundational step. This entails taking into account the country's national decarbonization strategy and using it as a reference point for assessing progress. EEF's viewpoint highlights a systematic approach where every project is evaluated in light of the established baseline.

EEF's analysis further delves into the quantitative assessment of CO₂ emissions reduction. This involves calculating the potential reduction in CO₂ emissions resulting from the displacement of conventional technologies with hydrogen-based alternatives. EEF emphasizes that this calculation is rooted in the technology's ability to displace existing solutions. An illustrative case involving a project to introduce hydrogen-powered vehicles, such as the Toyota Mirai, to the Costa Rican airport, is presented. EEF explains that the displacement potential of these vehicles is evaluated by quantifying the reduction in CO₂ emissions achieved through their use.

However, EEF also acknowledges the complexities inherent in this process. The opinion acknowledges that the complete substitution of existing technologies might not always be feasible. The concern is raised that simply adding hydrogen-powered vehicles to the existing fleet might not guarantee significant emissions reductions. This recognition underscores the need for a nuanced approach that considers not only the introduction of new technologies but also the potential for retrofitting existing vehicles.

EEF's perspective on decarbonization measurement in the context of hydrogen technologies within the built environment underscores the importance of quantifying CO₂ emissions reductions through displacement. It accentuates the challenges of ensuring complete substitution and the potential need for retrofitting existing vehicles to achieve meaningful decarbonization outcomes. This viewpoint contributes to the broader discourse on assessing the effectiveness of hydrogen technologies in achieving sustainable and low-carbon built environments.

MS provides valuable insights into the measurement of decarbonization when implementing hydrogen technologies within the built environment. MS's perspective emphasizes the fundamental principle of assessing the energy consumed and its source as a basis for quantifying the impact of decarbonization efforts. This foundational step, according to MS, can be as straightforward as evaluating the energy consumption and discerning its origin.

A key aspect highlighted by MS is the practical application of measuring decarbonization within specific projects. An illustrative example involves the injection of hydrogen into natural gas networks. In this scenario, MS describes a power station running on natural gas, where hydrogen is introduced into the pipeline to account for approximately 20% of the gas consumption. The perspective raises a pertinent question: Does a 20% hydrogen integration result in a corresponding 20% reduction in emissions?

MS's viewpoint acknowledges the complexities inherent in such cases. While on paper, a direct correlation between hydrogen integration and emissions reduction might seem apparent, the reality is more intricate. MS explains that the combustion process involves a turbine that consumes the gas and hydrogen mixture. While the absence of CO₂ emissions is noted, other pollutants, such as nitrogen oxides (NO_x) and sulfur oxides (SO_x), might still be produced. MS underscores that these pollutants, while posing environmental challenges, are comparatively easier to capture and mitigate.

The perspective extends to the broader context of energy consumption and green sources. MS suggests that the crux of the matter lies in thoroughly assessing the energy entering a system and identifying its green components. This entails understanding the origin of energy and its sustainability, encompassing the possibility of sourcing green electricity from the grid.

In addition, MS delves into the practical considerations when integrating hydrogen technologies in conjunction with existing energy sources. The perspective introduces the notion of a balancing act, where a combination of purchased green electricity and self-generated electricity is strategically employed to optimize energy usage. This approach is positioned as a means to navigate the challenges of energy-intensive processes.

In essence, MS's perspective underscores that measuring decarbonization involves a comprehensive evaluation of energy consumption and its sources, factoring in the complexities of combustion processes and emissions. The viewpoint not only contributes to the discourse on decarbonization measurement but also highlights the necessity of adopting a holistic approach to achieve meaningful progress in building a sustainable future.

RH's perspective provides insightful commentary on the measurement of decarbonization in the context of employing hydrogen technologies within the built environment. According to RH, a pivotal aspect of this measurement lies in showcasing the tangible benefits of decarbonization investments over the product's lifespan. RH underscores the importance of conveying these benefits in relatable terms for people to comprehend easily. The viewpoint highlights the effectiveness of expressing decarbonization achievements in units familiar to individuals, such as the equivalent of saved kilometres driven in a car or the amount of gas units.

The viewpoint takes into account the challenge of conveying the impact of decarbonization in terms of kilograms of CO₂, as such figures may not be readily grasped by the general public. RH suggests that expressing these achievements in user-friendly terms that directly relate to the services people use can enhance the understanding and significance of decarbonization efforts.

In terms of practical implementation, RH offers two primary perspectives. The first centres around the replacement of LPG with renewable hydrogen, with the reduction in kilograms of LPG serving as a quantifiable measure of decarbonization success. The perspective includes an insightful detail that 3 kilograms of CO₂ are eliminated for each kilogram of LPG saved.

RH explains how in remote communities, a system of solar panels, electrolyser, and hydrogen storage could provide domestic thermal energy for cooking and hot water. This decentralized model would *"replace LPG with renewable hydrogen"*, measured by the *"drop in kilograms of LPG"* used. With LPG's high embedded carbon emissions, displacement promises significant decarbonization.

The second perspective delves into the utility of hydrogen in fringe-of-grid scenarios. RH explains that hydrogen generation could act as a local buffer to supplement electricity supply during constrained periods. This application is suggested for use in cooking gas or as a thermal fuel. RH differentiates this application from electricity usage, for which battery storage might be more suitable.

The viewpoint highlights Japan's notable initiative known as the ENE Farm, which envisions millions of households using hydrogen for part of their electricity. RH's description underscores the strategic use of hydrogen in buffering and providing electricity without converting it into the grid. The perspective acknowledges that such projects hinge on hydrogen importation.

RH also emphasizes the potential of hydrogen in enhancing the efficiency of natural gas usage. By replacing a portion of natural gas with hydrogen, a notable percentage of decarbonization can be achieved. However, RH clarifies that the true decarbonization impact is around 3.3% due to factors like energy density.

The viewpoint concludes by spotlighting the environmental benefits of hydrogen compared to LPG. RH highlights the absence of CO₂ emissions in hydrogen-based systems, whereas LPG sourcing and transportation entail CO₂ production. The negligible production of nitric oxides in hydrogen systems is discussed in relation to the broader context of emissions reduction.

In essence, RH's perspective presents a comprehensive view on measuring decarbonization through hydrogen technologies, encompassing relatable metrics, practical applications, and environmental advantages. The viewpoint adds depth to the discourse on evaluating the impact of hydrogen integration within the built environment.

TW's perspective offers valuable insights into measuring decarbonization when implementing hydrogen technologies within the built environment. According to TW, a key factor in this measurement revolves around the displacement of the carbon content in existing fuels by employing hydrogen. TW emphasizes the direct correlation between the carbon content of the original fuel and the potential reduction achievable through hydrogen substitution.

TW's viewpoint sheds light on the versatility of hydrogen in decarbonization efforts. He emphasizes that hydrogen has the capacity to replace the carbon content in various fuels, including LPG, methane, and diesel. The viewpoint underlines the potential of hydrogen to effectively displace carbon atoms present in these fuel sources, thereby contributing significantly to decarbonization.

The perspective provided by TW underscores the strategic role of hydrogen in mitigating carbon emissions. By targeting the carbon content in conventional fuels, hydrogen utilization offers a feasible pathway to achieve substantial decarbonization within the built environment. This insight adds depth to the discourse on the quantifiable impact of hydrogen technologies in addressing carbon emissions and advancing sustainable practices.

ZJ's perspective provides valuable insights into the measurement of decarbonization through the incorporation of hydrogen technologies within the built environment. ZJ's viewpoint centres on a crucial development currently under consideration - specifically, the intention to blend hydrogen into the national gas grid at a proportion of up to 20%. This strategic decision, as explained by ZJ, has the potential to significantly impact carbon emissions within the energy landscape.

According to ZJ, the act of blending hydrogen at a substantial percentage directly correlates with the potential reduction of carbon emissions. ZJ's viewpoint highlights the concept of leveraging renewable sources to generate hydrogen. This approach effectively replaces a portion of the carbon-intensive components in the gas grid with clean, renewable hydrogen. By utilizing hydrogen produced from 100% renewable sources, the carbon content associated with the blended percentage of hydrogen can be entirely eliminated. By quantifying the potential reduction of carbon emissions achieved through this approach, the viewpoint contributes to the ongoing discourse on the

measurement and effectiveness of hydrogen technologies in achieving sustainable energy goals within the built environment.

Several participants discussed the importance of establishing a baseline for emissions at the outset (EEF, KQ). This provides a reference point against which future emissions reductions can be compared. EEF emphasized calculating the CO₂ emissions displaced by introducing a new technology, based on the carbon content of the fuel it is substituting. KQ noted national labs have modelling tools to estimate emissions impacts.

The key appears to be tracking energy inputs and sources over time. As MS explained, this involves monitoring energy consumption by a building or process, and determining the share met by green technologies like renewable hydrogen versus carbon-intensive ones. Blending hydrogen into natural gas networks, for instance, can reduce emissions proportional to the hydrogen percentage if it displaces fossil gas. RH stressed expressing savings in relatable units like vehicle-kilometres travelled rather than just CO₂ amounts.

Overall, several participants agreed measuring displacement of other fossil fuels provides a reasonable estimate of emissions reductions from hydrogen transitions (MS, TW, ZJ). Since hydrogen combustion or use in fuel cells produces little or no direct CO₂, integrating it into systems powered by coal, diesel or natural gas can be assumed to lower emissions accordingly, though other pollutants may remain. Regular measurement and verification will help quantify real-world decarbonization over time. The participants' perspectives align in accentuating the complexity and multifaceted nature of measuring decarbonization through the application of hydrogen technologies. This process necessitates a comprehensive understanding of energy consumption, carbon content, displacement effects, and potential environmental consequences, thereby contributing to the broader ambition of achieving sustainable and decarbonized energy systems.

4.14 Environment, Sustainability and Ecosystem

The participants' viewpoints on the nexus between hydrogen technologies and environmental sustainability exhibit a spectrum of perspectives and considerations. The interviews encapsulate insights from various regions, encompassing aspects such as hydrogen production, emissions, applications, and the broader concept of sustainability. These viewpoints collectively provide a comprehensive overview of the complex relationship between hydrogen technologies and environmental considerations, with particular relevance to the context of New Zealand.

An overarching theme that emerges from the interviews is the environmental promise of hydrogen technologies. Many participants highlight that hydrogen, when produced from renewable energy sources such as wind, solar and water, offers a clean alternative to conventional fossil fuels. The absence of carbon dioxide emissions during hydrogen usage is emphasized as a key environmental advantage. This aligns with the broader goal of transitioning towards low-carbon and sustainable energy systems.

Further, discussions pivot around the efficiency and feasibility of hydrogen technologies. While some participants express optimism about the potential of hydrogen to complement and decarbonize existing energy infrastructure, others underscore the importance of evaluating hydrogen's energy efficiency in conjunction with broader environmental factors. The scalability of hydrogen production and its associated costs are also highlighted, with the recognition that increased hydrogen production could lead to reduced costs and improved economic viability. This resonates with the concept of a circular hydrogen economy, where locally sourced water could be utilized cyclically, minimizing environmental impact.

Moreover, the interviews underscore the significance of regulatory frameworks and government policies in fostering a sustainable hydrogen industry. Participants identify regulatory support as pivotal to steering hydrogen technologies towards environmental sustainability. They note that initiatives such as emissions trading schemes and incentives for green hydrogen production contribute to promoting the adoption of cleaner technologies.

New Zealand, a context represented in the interviews, offers a unique perspective given its abundant renewable resources and focus on sustainable practices. Participants from New Zealand emphasize the relevance of hydrogen technologies in the local context, emphasizing their potential to align with the nation's commitment to environmental stewardship and low-carbon solutions. The conversations reflect a nuanced awareness of the need to balance economic growth with environmental conservation.

In contemplating the intersection of hydrogen technology, sustainability, and the environment, **DA**'s perspective emerges as one rooted in the potential transformative impact of hydrogen generation using cost-effective renewable energy sources. He envisions a future where the key lies in discovering efficient methods of producing hydrogen through renewable resources. For him, this signifies more than a singular solution; it holds the promise of catalysing widespread decarbonization across diverse sectors, including not only the built environment but all energy-consuming domains. DA's viewpoint underscores the profound implications of realizing a scalable and affordable hydrogen production process, positing it as a linchpin for tackling the overarching challenge of reducing carbon emissions on a global scale.

Yet, within this optimistic outlook, DA acknowledges the complexities intertwined with the adoption of such technologies. He astutely observes that certain entities, particularly some Chinese companies, might prioritize economic gains over environmental responsibility. His remark alludes to the broader reality where market forces and government policies might incentivize short-term profitability over sustainable practices. This recognition serves as a reminder that the transition to a hydrogen-based economy, while offering transformative potential, necessitates a comprehensive approach that addresses not only technological innovation but also policy frameworks and ethical considerations.

Overall, DA's stance reflects an amalgamation of optimism and realism, centred on the profound impact of harnessing hydrogen as a clean energy carrier. His belief in the potential for hydrogen to serve as a catalyst for broad decarbonization and his acknowledgment of the complex socio-economic landscape demonstrate his nuanced understanding of the challenges and opportunities in leveraging hydrogen technologies for a more sustainable future.

In the discourse surrounding hydrogen's potential role in sustainability and environmental preservation, the perspective presented by **EEF** is one that underscores the intrinsic benefits of hydrogen as a clean energy carrier. The assertion that hydrogen can generate heat and electricity with the sole by-product of water underscores its environmental appeal. EEF's emphasis on the "greenness" of hydrogen, contingent on its production through renewable energy sources and water, resonates with the broader narrative of harnessing hydrogen's potential to drive decarbonization efforts across various sectors.

EEF's observation that CO₂ emissions are mitigated by hydrogen, particularly when contrasted with traditional fossil fuel emissions, adds depth to the argument for hydrogen's role in reducing carbon footprints. This perspective aligns with the prevailing discourse on hydrogen as a pivotal agent in transitioning toward a carbon-neutral energy landscape.

Furthermore, EEF's reference to cleaner air as a potential direct benefit of hydrogen technology accentuates the broader environmental advantages associated with hydrogen adoption. The holistic nature of these considerations suggests a multifaceted approach to sustainability that extends beyond emissions reduction to encompass broader ecological and human health impacts.

As EEF delves into the imperative of pressuring material providers to enhance sustainability, the discourse enters the realm of supply chain dynamics and corporate responsibility. This underscores the interconnectedness of sustainability efforts and highlights the necessity of a holistic approach that not only considers end-use applications but also the broader environmental impacts of materials and processes.

In essence, EEF's insights reflect a comprehensive understanding of hydrogen's role as a potent enabler of sustainability and environmental preservation. EEF's viewpoint extends the conversation initiated by DA, underscoring the multifaceted dimensions of hydrogen's potential impact and the imperative of a collaborative and multidisciplinary approach to achieving a sustainable energy future.

SGJA's opinion aligns with the consensus that hydrogen's environmental friendliness hinges on its production methods. Emphasizing the significance of renewable energy sources as inputs for green hydrogen production, SGJA underscores the imperative of emissions-free processes:

"I think as long as it is produced from renewable energy or from biogas for example and there are no emissions associated to this production and then you can say it is environmentally friendly" (SGJA).

This stance resonates with the broader discourse on sustainable energy, asserting that the environmental credentials of hydrogen are contingent upon the eco-friendliness of its production pathways. SGJA's perspective thus adds weight to the argument that a green hydrogen economy can only be realized through the synergy of clean production methods and emissions mitigation, echoing sentiments expressed by previous participants in favour of renewable-based hydrogen and its role in decarbonization.

JH's remarks highlight the urgent need for responsible resource utilization to alleviate the ecological strain on the planet. This sentiment echoes the broader sentiment of environmental consciousness and the necessity to tread lightly on Earth's resources:

"We were stressing the planet so much that we need to be really careful about it" (JH).

Moreover, JH aligns with the consensus that hydrogen produced from renewable energy sources holds promise as a more environmentally friendly alternative to batteries, predominantly due to its reduced resource implications:

"It's from renewable energy and I think the more environmentally friendly than batteries" (JH).

This perspective reinforces the growing momentum towards renewable-based solutions in the pursuit of sustainable energy systems. JH's viewpoint thus converges with previous participants' discussions on the importance of sustainable resource management and the environmental advantages of renewable-driven hydrogen technologies.

RGJA's perspective underscores the crucial role of responsibility in power generation, particularly when driven by renewable sources. This viewpoint resonates with the broader theme of conscientious resource management and environmentally mindful practices. RGJA further emphasizes the holistic approach necessary for sustainability. By highlighting the example of a green hydrogen production facility powered by photovoltaics, RGJA highlights the multifaceted nature of sustainable projects. Such initiatives necessitate comprehensive assessments that encompass social, environmental, economic, and governmental factors. This perspective aligns with earlier discussions on the intricate interplay between technological advancements, regulatory frameworks, and environmental impact. RGJA's belief in the feasibility of achieving sustainable projects within the hydrogen industry underlines the optimism surrounding the potential of green hydrogen as a long-term environmentally friendly solution.

JAGR's stance echoes the sentiment shared by earlier participants, highlighting hydrogen's environmentally friendly nature with a focus on emissions reduction. This viewpoint underscores the consensus that hydrogen technologies contribute to cleaner energy solutions:

"I think they are environmentally friendly technologies talking about emissions. In the emissions perspective, hydrogen is very clean" (JAGR).

Moreover, JAGR emphasizes the cleanliness of hydrogen from an emissions perspective, aligning with previous opinions that attribute hydrogen's environmental benefits to its water-only emissions. Notably, the comparison drawn to batteries suggests that JAGR perceives hydrogen as having an edge in terms of environmental impact, reinforcing the notion that hydrogen is positioned as a cleaner alternative to certain technologies. This aligns with the overarching theme of hydrogen's potential to enhance urban environments by providing cleaner energy sources. JAGR's perspective thus adds weight to the discourse on hydrogen's positive role in addressing environmental concerns.

KQ's perspective sheds light on California's proactive stance towards hydrogen as a solution to environmental challenges. She acknowledges that California's strong emphasis on regulations and experience in the field positions it as a leader in advocating for hydrogen adoption. KQ highlights the underlying motivations behind California's pursuit of hydrogen technologies, citing concerns about air pollution and the importance of clean air and water. This indicates that California's approach to hydrogen aligns with its broader environmental goals.

Furthermore, KQ introduces the concept that integrating hydrogen technologies can contribute to greening the entire grid. This perspective underscores the systemic impact that hydrogen can have on energy systems, potentially transforming the overall energy landscape towards greater sustainability. KQ's viewpoint also underscores the principle that adopting hydrogen technologies could be considered environmentally friendly by default, especially if they replace less sustainable alternatives. This perspective resonates with earlier participants' opinions on the comparative environmental benefits of hydrogen technologies. Overall, KQ's insights highlight the multifaceted role of hydrogen in addressing environmental concerns and contributing to a greener energy future.

MR's viewpoints offer a comprehensive understanding of the environmental strengths and criteria that define green hydrogen technologies. She underscores a key advantage of hydrogen systems: the absence of carbon dioxide emissions, with water being the sole by-product. This highlights the inherent cleanliness of hydrogen as an energy carrier and aligns with the broader objective of reducing greenhouse gas emissions.

Moreover, MR introduces a critical criterion for categorizing hydrogen technologies as green: the necessity for the input energy used in hydrogen production to be completely derived from renewable sources:

"I would say that hydrogen technologies that can be considered green when first the input energy that is used to produce hydrogen is green and is green for real. Not on your percentage but 100%" (MR).

This stringent requirement emphasizes the need for a holistic approach to sustainability, ensuring that the entire hydrogen production process is powered by clean and renewable electricity.

MR's perspective extends to the application of hydrogen technologies, emphasizing the importance of efficiency and a comprehensive evaluation of all relevant factors. She advocates for a thoughtful approach that considers various aspects beyond just emissions, affirming that the effectiveness of hydrogen hinges on its careful and strategic implementation. MR's insights contribute to a well-rounded perspective on the sustainability and potential of hydrogen technologies in contributing to a cleaner energy landscape.

PL's perspective delves into the intricacies of certification processes for evaluating the environmental sustainability of hydrogen technologies. While acknowledging carbon content as a primary criterion, he emphasizes the multifaceted nature of these processes. His insight reflects a deeper awareness of the complex considerations that should factor into assessing the greenness of hydrogen technologies.

PL expands the discourse by highlighting additional criteria such as the responsible use of critical materials. This dimension resonates with his keen awareness of the challenges in deploying renewable technologies due to material limitations. His emphasis on longevity in the use of critical materials underscores a forward-looking approach, aligning with the overarching goal of sustainability.

In discussing environmental criteria, PL introduces the consideration of water usage, even though he deems it not a significant concern. His nuanced perspective stands in contrast to the broader emphasis on emissions, offering a reminder that sustainability is a multifaceted concept encompassing various environmental aspects.

Additionally, PL addresses potential leakage as an environmental concern, emphasizing the potential negative impact on biodiversity. This concern for unintended consequences underscores his comprehensive understanding of the intricacies involved in assessing the sustainability of hydrogen technologies.

Lastly, PL discusses the intention to implement an evaluation framework for hydrogen's green credentials in terms of sustainable development criteria. This forward-looking approach demonstrates his commitment to continuous improvement and aligns with his discerning approach to evaluating the environmental impact of hydrogen technologies.

RH's perspective on the sustainability of hydrogen technologies adds another layer of complexity to the discussion. He highlights the circular nature of a hydrogen energy economy, underpinned by the abundant availability of water. RH's emphasis on the closed loop where water used for hydrogen production eventually cycles back through the natural water cycle underscores his ecological perspective:

"I think it can. I think in terms of sustainability, it's actually quite a strong story because basically water is readily available and by not using fossil fuels, you've effectively got a circular hydrogen energy economy, no. So you use water off the roof. I like the water off the roof because basically when you've used the hydrogen, whether it's burned or in fuel cell, it goes back to water vapor, goes back to the clouds, it will fall on the roof. So yeah, in essence, there's no human energy or effort put in closing the cycle. The environment does that and it does that with pretty much no negative impact like the clouds are the clouds and they'll sort themselves out. Because if that water wasn't converted to hydrogen energy, it would almost certainly have fallen down on the ground and evaporated in the morning when the sun came out. So large proportion of it was so it almost doesn't affect the water vapor cycle in the air very much at all. There's sustainability one I think that's good because it's the local circularized economy" (RH).

This viewpoint aligns with his understanding that the process does not require ongoing human intervention, reflecting a self-sustaining quality.

Moreover, RH delves into the potential consequences of relying on traditional fossil fuels, particularly natural gas. His foresight underscores the issue of resource scarcity and availability. Unlike some participants who primarily emphasize emissions, RH adds the dimension of resource depletion to the conversation. This broadens the discourse by highlighting the potential challenges associated with traditional energy sources, aligning with his holistic approach to sustainability.

RH's acknowledgment of the importance of rapidly deploying renewable energy sources, such as wind turbines, showcases his pragmatic thinking. His focus on prompt action to establish sustainable energy sources demonstrates a sense of urgency in addressing environmental concerns.

In comparison to previous opinions, RH introduces considerations related to resource availability and prompt adoption of renewable energy sources. His views align with his comprehensive approach, covering not only the environmental benefits but also the broader implications of energy choices for the long-term future. Overall, RH's perspective complements earlier viewpoints while offering nuanced insights that extend the discourse's scope.

SJS's insights highlight a pragmatic and holistic approach to addressing sustainability challenges, particularly in the context of climate change. He emphasizes the collaborative efforts undertaken by a diverse international team to confront the reality of global warming and the urgent need for solutions. The realization that complete eradication of the problem might not be feasible drives his perspective towards seeking achievable improvements rather than unrealistic goals.

The concept of decentralization emerges as a strategic advantage in SJS's narrative. He acknowledges that while full decentralization might not be attainable, embracing degrees of decentralization can foster a more resilient and adaptable ecosystem. This aligns with his vision of optimizing the overall system for enhanced sustainability.

SJS's urgency is evident in his analogy of climate change as a war. He argues that waiting for regulations or laws to enforce change is insufficient, likening it to being unprepared and too late for battle. Drawing parallels to rapid responses in the energy sector, he believes that a similar swift approach could be applied to green hydrogen, provided the collective will and determination exist.

SJS is forthright in dispelling misconceptions surrounding resource consumption. He counters claims about water usage in hydrogen production by highlighting the often unnoticed resource requirements of traditional industries, such as refineries. His argument underscores the importance of considering the broader context and understanding the real environmental impact of various processes.

In summary, SJS's perspective is driven by practicality, collaboration, and a deep sense of urgency. He underscores the need for immediate action, adaptation, and a realistic approach to sustainability, while challenging prevailing notions and highlighting the energy-intensive aspects of existing industries.

TW's perspective revolves around the shifting balance between economic affordability and environmental sustainability. He recognizes the prevailing focus on financial considerations but stresses the importance of prioritizing environmental and resilience aspects in decision-making. He acknowledges that while the mindset is gradually evolving, there is a need to proactively drive this change rather than waiting for major disruptive events like storms to push the transformation:

"Now we're trying to drive ourselves away from being what is cheapest and what is going to what is best for the environment and best for the user. But everybody is still geared towards the financial weigh that affordability piece much greater than the environment piece and the resilience piece that may change as we get more storms and more events and that may change as we get more things. But it's kind of too late. If we wait for that level of clarity, we can kind of see that that's gonna come. I don't think we need to wait until multiple thousands of houses are without power to realize that having them independent means that we can sort them out" (TW).

One of the standout features of TW's viewpoint is his emphasis on the recyclability of hydrogen technologies. He highlights Enapter's approach of utilizing fully recyclable components, showcasing the potential for a closed-loop system that minimizes waste and environmental impact. This aligns with the broader theme of sustainability and responsible resource management.

TW firmly argues that hydrogen offers a viable path to carbon neutrality. By using hydrogen, carbon emissions become a non-issue, allowing a clear break from the carbon-intensive energy sources. This underlines the transformative potential of hydrogen technology in addressing environmental concerns.

The mention of emissions trading schemes and green certificates as mechanisms to incentivize low-carbon energy sources highlights the need for policy measures to support environmentally friendly alternatives. TW critically examines the shortcomings of existing schemes, pointing out instances where they may not have yielded the intended results, such as in land banking of forestry.

Overall, TW's perspective revolves around proactive transformation, resource recyclability, and the need for innovative approaches to drive environmental and resilience benefits. He suggests the importance of leveraging additional levers beyond existing mechanisms to accelerate the adoption of sustainable solutions before environmental pressures become too intense:

“How do we create tangible value in resilience and tangible value and environment so and the environment side, the green certificates definitely do it and the security side, the weather events will do it, but if there's another lever that we can pull to enable that before the environment forces us to, that would be good” (TW).

TN's perspective on hydrogen technology aligns with the recurring theme of its environmental benefits. The phrase *“they only emit water”* encapsulates the essence of his viewpoint, emphasizing the clean and emission-free nature of hydrogen technologies. This succinctly highlights one of the major advantages of hydrogen – its potential to significantly reduce carbon emissions when used as an energy carrier.

TN also touches on the evolution of technology and the anticipation of cleaner and safer operating methods. This reflects his optimism about the ongoing advancements in hydrogen technology and the potential for even more environmentally friendly processes in the future. His belief in the trajectory of technological development reinforces the idea that hydrogen's positive environmental impact will likely grow over time.

A key aspect of TN's perspective is the emphasis on hydrogen's versatility and potential for widespread adoption. He highlights the decentralization of production, indicating that hydrogen can be generated wherever there is access to water and electricity. This aligns with the notion of energy security and the reduced reliance on centralized fossil fuel sources. By comparing hydrogen production to extracting fossil fuels from the Middle East, TN underscores the potential for a more resilient and sustainable energy future.

In summary, TN's viewpoint is grounded in the simplicity of hydrogen's emissions *“they only emit water”* and the optimism surrounding its technological advancements. He also underscores the practicality and sustainability of hydrogen production, positioning it as an attractive alternative to fossil fuels from both environmental and energy security perspectives.

VG's perspective revolves around the environmental benefits of hydrogen technology, especially in industries like cement production. He acknowledges the potential of hydrogen to reduce carbon emissions in the built environment, highlighting its role in addressing one of the major sources of greenhouse gas emissions.

VG's emphasis on hydrogen as an environmentally friendly technology stems from its lack of CO₂ emissions during operation. This reiterates the core advantage of hydrogen – its potential to serve as a clean energy carrier that does not contribute to carbon emissions. He underscores this by labelling hydrogen as a *“green technology”* that does not emit CO₂, reinforcing the message of its environmental friendliness.

While VG acknowledges the environmental advantages of hydrogen, he also provides a balanced perspective on its applicability. He points out that using hydrogen for off-grid electricity solutions can be expensive due to the additional infrastructure required. He believes that hydrogen is more suitable for supplementing existing dirty diesel off-grid systems, where the environmental benefits justify the higher costs. This insight reflects VG’s practical approach to hydrogen adoption, weighing its advantages against the economic realities of implementation.

Overall, VG’s viewpoint centres on hydrogen's capacity to transition industries away from fossil fuels, particularly in scenarios where emissions reduction is a priority, such as cement production and off-grid electricity. His perspective aligns with the broader theme of utilizing hydrogen as a clean and sustainable solution to address environmental challenges.

Environment, Sustainability and Ecosystem	
Aspect	Key Insights
Renewable Hydrogen as Clean Fuel	- Hydrogen produced from renewable sources is viewed as a clean alternative to fossil fuels, emitting only water.
Importance of Renewable Inputs	- Hydrogen’s environmental credentials depend on using renewable inputs; emissions-free processes are essential for it to be classified as “green.”
Cost Reduction through Scaling	- Scaling up renewable hydrogen production could reduce costs and improve economic viability, but efficiency must be considered alongside environmental impact.
Role of Regulatory Initiatives	- Regulatory initiatives, such as emissions trading schemes and renewable hydrogen incentives, are crucial for steering the industry toward sustainability.
Circular Hydrogen Economy	- The potential for a circular hydrogen economy is emphasized, where water cycles locally from production input to emitted vapor, aligning with ecological principles.
Resource Implications	- Broader resource implications, such as fossil fuel depletion, should be included in emissions assessments; a holistic evaluation of environmental sustainability is needed.
Urgency of Renewable Integration	- There is an urgent need for the prompt integration of renewable energy sources, but unrealistic expectations could be counterproductive; incremental improvements may be more pragmatic.
Recyclability of Technology Components	- The recyclability of technology components, as seen in Enapter’s approach, supports closed-loop resource use, though recycling feasibility is limited for most systems.
Nuanced Assessment Required	- Hydrogen has potential as an enabler for environmental sustainability, but its assessment must be nuanced, holistic, and context-specific; caution should balance optimism.

Table 14: Environment, Sustainability and Ecosystem

In conclusion, the amalgamation of participants' opinions reflects a multifaceted relationship between hydrogen technologies and environmental sustainability. While participants acknowledge the environmental benefits of hydrogen, they also highlight the need for comprehensive considerations, including the energy efficiency, regulatory support, and the economic implications of widespread adoption. As the world continues its journey towards sustainable energy systems, these perspectives serve as valuable contributions to the ongoing discourse on hydrogen's role in shaping a greener and more sustainable future.

4.15 Governments

The perspectives gathered from various participants underscore the varying attitudes of governments towards embracing hydrogen technologies and transitioning to cleaner energy sources. While some governments prioritize scaling up hydrogen infrastructure and offer subsidies, others exhibit hesitancy and lack clear roadmaps. In countries like Korea, significant subsidies support hydrogen infrastructure development, emphasizing the economic benefits and job creation potential. However, convincing governments to shift towards hydrogen can be challenging, especially in developed countries where dependence on a single energy source can be risky. Participants stress the importance of showcasing the benefits of diversification to encourage government support. Additionally, the role of regulation, policies, and incentives in driving hydrogen adoption is highlighted. The case of New Zealand exemplifies a mixed approach, where some participants feel that the government lacks a clear hydrogen roadmap, while others note the government's focus on renewables but underline the need for more proactive leadership and coordination:

"I don't see much road map or initiative from the government toward hydrogen. Not only subsidies, but I don't see the leadership there at all. So that is critically missing here. Then when I look at, say not only Japan but Australia or US, they have clearer picture of where a country is heading. So that's what has been missing here in New Zealand now I'm expecting I heard from some people that road map should be coming out later this year" (TN).

It's emphasized that governmental engagement, education, and collaboration across sectors are crucial to accelerate the adoption of green hydrogen.

The sentiments shared by participants reveal a shared understanding of the government's awareness of the importance of hydrogen adoption and its potential benefits. While there is recognition of the need for guidelines, standards, and a clear roadmap to steer the country's hydrogen efforts, some participants express concerns about the pace and prioritization of these actions:

"Some guidelines and standards are really needed. I just think it needs to be prioritised a bit more" (JH).

The involvement of the Ministry of Business, Innovation, and Employment (MBIE) is noted, highlighting the allocation of resources for managing hydrogen initiatives. However, calls for greater prioritization are prevalent, emphasizing the significance of a comprehensive and well-thought-out roadmap. There is mention of a past White Paper that addressed hydrogen, but participants indicate that financial limitations hindered its full implementation. Collaboration with stakeholders, including the New Zealand Hydrogen Council, is underscored, with participants advocating for continued engagement to address industry needs and promote hydrogen adoption. It is clear that the pace of progress has been affected by competing government priorities such as responding to crises like COVID and natural disasters. Despite these challenges, the consensus points towards the need for consistent commitment and adequate resourcing to drive the hydrogen agenda forward.

The participants acknowledge the challenge of government hesitancy towards advanced technologies due to their perceived risks. However, they highlight the role of the market in driving innovation and

adoption, as demonstrated by companies importing advanced electrolysis technology. They emphasize that government's primary role should be to create facilitating regulations rather than actively driving technological development. Regarding New Zealand's approach, it is suggested that the government's focus should be on ensuring backup options and supporting a diverse energy mix, where hydrogen is integrated alongside other systems. The role of power companies in the transition to hydrogen is also emphasized, with participants indicating that government support could encourage their participation in this shift, leading to a collaboration between the private and public sectors.

The participants emphasize the transformative potential of decentralized energy systems enabled by renewable sources like solar and wind, with hydrogen production as a key element. They highlight that central governments often resist decentralization, as it challenges their control:

"This is what central governments do not want" (SJS).

It is noted that despite the urgency of transitioning to cleaner energy, many governments continue to support fossil fuels. The participants stress the need to prioritize renewable energy engagement and advocate for governments to focus on supporting renewables, whether it is through electric or hydrogen pathways. They contend that encouraging local energy production and decentralization is essential to address energy shortages and drive the shift towards a more sustainable future.

There is an acknowledgment of government hesitancy and prioritization in pursuing various fuel types, with emphasis on the slow progress towards hydrogen adoption. Biomass and industrial heat pumps seem to be preferred before hydrogen, along with a tendency to allow consumers to decide in the domestic energy scenario. The call is for the government to focus on enabling energy independence and resilience for domestic users, which could encourage domestic solar adoption and create a foundation for hydrogen utilization. However, they note that significant political will is necessary to drive these changes, as it may not immediately make financial sense and requires regulatory adjustments. The climate change Commission's recommendations are discussed, suggesting the introduction of hydrogen past 2025, but concerns arise that this might be too late and could raise consumer costs. The challenges of incentivizing new energy sources while maintaining parity with existing ones are highlighted, along with the need for a national framework and collaboration between different levels of government to facilitate the transition and navigate regulatory complexities.

4.16 Political Environment

The transition to a hydrogen-based economy is fraught with political and ideological challenges, as highlighted by various insights from interviews with experts. In several regions, powerful fossil fuel companies such as Chevron, Shell, and British Petroleum wield significant influence and are resistant to the widespread adoption of hydrogen technologies, often striving to protect their vested interests:

"Those companies, absolutely, they will stand firm to fight against the wide range adoption of hydrogen. All these companies are extremely powerful and the whole way they don't want to lose their business" (DA).

In Mexico, the current administration's focus on fossil fuels and reluctance to support renewable energy options, including hydrogen, reflects a political rather than a technical challenge:

"I will say that the problem in Mexico is a bit more political than technical because the current administration is focused entirely on fossil fuels" (SGJA).

The energy sector's transformation is intertwined with political ideology, and the stance of governments has a substantial impact on the pace of progress. For instance, in countries like Chile, openness to collaboration with the private sector and external agencies accelerates hydrogen

deployment. However, some governments prioritize their energy resources and traditional industries, hindering the transition (JAGR). In Germany, even with green parties in power, there is a tendency to align with established corporations, raising questions about genuine commitment to change (SJS). Decentralization for energy independence and resilience, including enabling domestic solar systems, is considered crucial in overcoming political barriers (TW). The lack of clear government roadmaps and leadership in certain regions, such as New Zealand and Japan, highlights the pivotal role political will plays in driving or impeding the transition to hydrogen-based economies (TN).

4.17 Government's Support, Tax Regime and Subsidies

The interviews with participants from diverse countries shed light on the critical role of government support, tax regimes, and subsidies in fostering the growth of green hydrogen technologies. Across various regions, there is a common understanding that government intervention is pivotal for establishing a conducive environment for hydrogen adoption. In countries like Korea and Germany, robust government initiatives are acknowledged as catalysts for advancing hydrogen infrastructure. Substantial subsidies are prevalent in these nations, ranging from support for hydrogen refuelling stations to significant rebates on hydrogen vehicle purchases. However, disparities emerge in the availability of such financial aid. While some countries like Costa Rica and Latin America lament the lack of substantial subsidies due to fiscal constraints, others like New Zealand struggle with the absence of a clear hydrogen-focused government vision. It is evident that governments play a pivotal role in shaping the trajectory of hydrogen technology, whether through direct funding, tax incentives, or favourable regulatory frameworks.

When it comes to New Zealand, the conversations highlight a mix of perspectives. On one hand, there is a recognition of the lack of substantial subsidies from the government, which poses challenges for the adoption of hydrogen technologies. Participants, like RH, emphasize the need for an effective strategy that drives down the cost of green hydrogen production and utilization. New Zealand's reliance on a more market-driven approach is evident, with TN pointing out the absence of a clear road map or strong government initiatives towards hydrogen. This contrasts with other countries like Germany and the USA, which have implemented supportive frameworks, tax incentives, and funding programs to accelerate hydrogen adoption. While New Zealand acknowledges the importance of hydrogen utilization for decarbonization, its approach and level of government backing appear to be key factors influencing the pace of progress in this emerging sector.

Overall, the interviews emphasize the importance of aligning policy mechanisms with long-term sustainability goals to drive the transition to green hydrogen effectively.

Government, Political Environment, Government Support	
Aspect	Key Insights
Resistance from Fossil Fuel Companies	- Powerful fossil fuel companies resist hydrogen adoption to protect their business interests, often lobbying against supportive policies.
Political Priorities	- Administrations that prioritize fossil fuels over renewables create political, rather than technical, challenges to hydrogen adoption.
Impact of Government Stance	- Government stance and ideology significantly influence the pace of the transition; openness to private sector collaboration accelerates progress, while prioritizing traditional industries hinders it.

Concerns with Green Parties	- Even with green parties in power, alignment with established corporations raises doubts about their true commitment to change.
Decentralization for Energy Independence	- Decentralization is viewed as crucial for achieving energy independence and overcoming political barriers.
Need for Clear Roadmaps	- The lack of clear government roadmaps and leadership underscores the importance of political will in driving or impeding hydrogen transitions.
Government Support	- Government support through subsidies, tax incentives, and regulations is essential for fostering hydrogen growth.
Disparities in Financial Aid	- There are disparities between countries in the availability of financial aid for hydrogen initiatives.
New Zealand's Approach	- New Zealand lacks a clear hydrogen-focused vision and relies more on a market-driven approach compared to supportive frameworks in countries like Germany.
Alignment with Sustainability Goals	- Aligning policies with sustainability goals is crucial for effectively driving the transition to green hydrogen.

Table 15: Government, Political Environment, Government Support

In conclusion, the political environment and government stance play a decisive role in shaping the adoption of hydrogen technologies. A supportive policy framework along with political will is essential for the transition to a hydrogen economy.

4.18 Legislation, Policies, Standards, Regulations, Codes and ISO

The viewpoints of various experts from different countries shed light on the significance of regulations and standards in ensuring the safety and widespread adoption of hydrogen technologies. They emphasize the importance of having appropriate norms and regulations in place to manage the potential risks associated with hydrogen applications. Participants from various countries, including New Zealand, express concerns about the absence of comprehensive regulations and standards for hydrogen applications. In the context of legislation, policies, standards, regulations, codes, ISO codes, and the hydrogen framework, the insights shared by various interviewees shed light on the perspectives surrounding hydrogen adoption in New Zealand.

The participants' viewpoints on hydrogen-related regulations and standards vary, showcasing a wide range of perspectives. For example, **DA** mentions that in Korea, there is a substantial alignment with USA standards when it comes to hydrogen-related regulations and unit standards. DA emphasizes that many regulations and standards in Korea are benchmarked against those in the United States. This cross-reference suggests a global effort to establish consistent safety and operational guidelines for hydrogen technologies:

“A lot of hydrogen related or gas related regulations, the unit standards, everything they have been benchmarked from the USA standards. So whatever you get in the USA, you get the same in Korea” (DA).

EEF's perspective underscores the significance of specific codes and standards in their operational context. He highlights his adherence to the National Electric Code from the US and the NFPA 79,

also known as the Nashville Fire Protection Agency Code 79. These codes are seen as legally binding, indicating a strong commitment to safety and regulation in their operations.

EEF points out that these codes, including NFPA 2, recognize hydrogen as an explosive gas alongside other similar gases. The regulations stipulate distances that need to be observed for safety reasons. Interestingly, they compare these regulations to the Chinese norms, highlighting that the distances mandated by the US codes are considerably smaller. This comparison underscores their commitment to safety and highlights the varying approaches to regulation in different regions.

EEF's stance on adhering to these regulations, even though some might not be legally required, reflects their recognition of safety as paramount. He acknowledges that adhering to regulations not only ensures safety but also contributes to the feasibility and viability of projects. EEF's view that regulations, even if not legally mandated, can significantly impact the economic aspects of a project, reveals the intricate interplay between safety, legal requirements, and financial considerations.

This nuanced perspective showcases EEF's dedication to both safety and economic sustainability. His willingness to follow codes that ensure safety while also acknowledging the economic implications underscores the complex decision-making process that organizations must navigate when dealing with regulations, codes, and standards. It is evident that EEF views these regulations as more than just legal obligations, recognizing them as crucial components for building a secure and economically sound operational environment.

SGRA's viewpoint sheds light on the complex landscape of regulatory considerations within the realm of hydrogen production and utilization. SGRA recognizes a knowledge gap in understanding the intricacies of permits and security measures for hydrogen production, even in the presence of substantial expertise in renewables. SGRA acknowledges the existence of standards for handling and transporting hydrogen as an industrial gas, underscoring the importance of safety protocols. However, SGRA highlights a significant regulatory void, exemplified by the absence of regulations for electricity storage in Mexico. In response, SGRA describes a proactive approach of drawing from international best practices to inform and guide local regulatory development.

He also highlights the role of cross-national influence, as Mexican regulations for hydrogen transport and security stem largely from US standards, and collaboration with German public funds aligns with European Union directives. Notably, SGRA emphasizes that while some regulations are already in place, the challenge lies in ensuring effective implementation by regulators and independent system operators. The paramount significance of adhering to safety standards and conditions to avert accidents underscores SGRA's commitment to a comprehensive approach to regulations and codes, aiming to balance innovation, safety, and regulatory compliance.

When it comes to safety and regulations, SGJA points out that while Mexico has safety standards for handling industrial hydrogen, there is a lack of specific regulations for in-situ green hydrogen production and storage. In such cases, they refer to international best practices to fill the knowledge gaps and develop guidelines, and SGJA says *"We aim to fill those knowledge gaps in"*.

International standards are generally followed for industrial hydrogen but *"those are sort of the regulations that are lacking. For example, these examples that you were mentioning (around hydrogen technologies), there is currently no regulation in Mexico for electricity storage"*.

JH's perspective underscores the necessity of established standards and regulations within the context of New Zealand's hydrogen landscape. He points out that New Zealand is lagging behind in this area, emphasizing the urgent need for guidelines and standards to be put in place. While acknowledging the awareness of this gap and ongoing efforts for development, JH suggests that reinventing the wheel is an inefficient use of time and resources. He advocates for leveraging existing international standards, indicating that New Zealand should adopt practices and standards from overseas rather

than attempting to create entirely new frameworks. JH finds little distinction between New Zealand and the global community, implying that established international practices should guide the nation's approach to regulations and standards:

“There needs to be standards and rules. Some guidelines and standards are really needed. It's a waste of time reinventing the wheel. We should be using as much from overseas as possible, and I don't really see what's different about New Zealand compared to the rest of the world” (JH).

He notes the importance of allocating sufficient resources and prioritizing the management of standards and regulations, particularly in the context of an impending hydrogen roadmap that is expected to highlight the absence of current regulations. JH also mentions the need for exemptions in the absence of fully developed standards, highlighting his pragmatic approach to implementing hydrogen technologies. Overall, JH's view stresses the need for a robust and comprehensive framework of standards and regulations while advocating for utilizing external expertise to avoid unnecessary duplication of efforts.

RGJA emphasizes the pivotal role of government regulations in shaping the engagement of project developers. He underscores the significance of these regulations in driving the actions of project developers, implying that the regulatory environment plays a decisive role in determining the direction of hydrogen-related projects. RGJA also acknowledges the applicability of technical codes such as NFPA 2 (The National Fire Protection Association) in the hydrogen domain, though he notes that familiarity with such codes may not be widespread. He highlights the need for individuals involved in certification to possess a deep understanding of these codes to ensure safe and compliant installations. On the topic of standards, RGJA differentiates between industrial and residential contexts. He acknowledges the presence of comprehensive codes like NFPA 2 and ASTM (American Society for Testing Materials) that cover diverse aspects of hydrogen within the industrial sector. However, he points out a gap in residential codes, suggesting that governments should take initiative in developing standards for hydrogen technologies at the residential level:

“The ASTM I saw NFPA 2 and codes that they cover all many topics of hydrogen. But in the case of residential codes, I think it's something that governments have to start working with if they want to you implement hydrogen technologies at the residential level” (RGJA).

Overall, RGJA's viewpoint accentuates the role of regulations, technical codes, and standards in steering hydrogen projects and promoting safety, particularly emphasizing the need for tailored standards in various contexts, including residential installations.

JAGR highlights the multifaceted nature of the stakeholders involved in the regulatory process, indicating the different roles of policymakers in contrast to other actors. He places paramount importance on safety regulations throughout the value chain of hydrogen, underlining that lives are inherently linked to this industry, making stringent safety measures crucial:

“Safety regulation is important in any step of the value chain a because in any case there are lives associated” (JAGR).

In particular, he emphasizes the necessity of safety considerations in the initial stages, citing examples like fuel cell vehicles and large-scale plants, wherein accidents can have far-reaching consequences. JAGR draws attention to the existing maturity of safety standards for extensive production and handling facilities but identifies a gap in understanding the performance of hydrogen in specific scenarios such as residential and commercial buildings. He advocates for a focus on emerging applications that are closer to civilian populations, underscoring the need for tailored standards for such contexts:

“The standards are very mature for that kind of large scale producing and handling facilities, but we don’t have enough knowledge on how hydrogen will perform in residential and commercial buildings, for example. We should focus on that kind of new applications which are also closer to the civilian population. That ones that they should develop. There are no legislations of hydrogen there” (JAGR).

JAGR suggests that regions like Latin America are actively working to adapt international ISO standards, translating them to languages like Spanish, thereby facilitating their implementation:

“Standards are adaptable for any country” (JAGR).

He also notes the significance of regulations in shaping the hydrogen ecosystem by defining roles and responsibilities. Overall, JAGR’s perspective underscores the imperative of safety regulations, the need for adaptable standards, and the role of regulations in nurturing a conducive hydrogen environment.

KQ emphasizes the significance of regulations, codes, and standards in shaping the landscape of hydrogen technologies. KQ points out the distinction between code standards and regulations, noting that while product or system standards should ideally be international, codes often address specific connection issues within the built environment.

In the context of the United States, KQ highlights the presence of US model codes that encompass pure hydrogen technologies. She explains that organizations like the International Code Council and the National Fire Protection Association play a crucial role in developing codes, which are subsequently adopted by various authorities and regulators across states and cities. NFPA 2, for instance, is a key hydrogen technologies code that covers a wide range of applications, including repair garages, refuelling stations, and laboratory environments.

California stands out as a state with substantial experience and an extensive set of regulations pertaining to hydrogen as a solution. KQ points to the evolving nature of regulations, especially in light of the state’s efforts to reduce carbon emissions and integrate renewable technologies like hydrogen into the power grid. She mentions ongoing revisions to standards such as IE1547 to accommodate distributed energy resources, including hydrogen technologies.

KQ’s observations suggest a growing focus on solving challenges through standards development. She highlights the role of regulations in driving a transition to a lower carbon economy and express optimism about the increasing alignment of codes and standards with the evolving hydrogen landscape. She also stresses the importance of international collaboration in standards development, such as participating in ISO TC 197 (Hydrogen Technologies) and IEC/TC 105 (Fuel Cell Technologies) to adopt globally recognized standards:

“Standards should be international standards and that's what we work toward” (KQ).

Furthermore, KQ underscores the availability of standards and codes for reference, both through national bodies and international organizations like ISO and IC. She recommends exploring initiatives like H2@scale, which showcases the potential benefits of hydrogen and renewables across different sectors of the energy industry.

In the realm of policy, KQ attends meetings where regulatory frameworks are discussed, highlighting the numerous ways companies can engage with policy provisions and mechanisms to drive change. Her insights indicate that while the process of integrating hydrogen technologies into existing infrastructure is complex and may take time, standards, codes, and regulations are central to ensuring safe and effective implementation.

MR highlights the significance of standardized certification for buildings, advocating for a clear categorization based on stringent criteria such as Level A, B, or C. She emphasizes the importance of international standards, citing ISO 14687, ISO 22734, ISO 19880-1, ISO 21266, ISO 15916, ISO 19880-8 and ISO 22982 standards as an example. While acknowledging that some aspects of these standards might still require refinement, MR underscores the benefits of collaborating at an international level to gather necessary data and information. She believes that this approach allows for optimal efficiency and facilitates the exchange of technologies and products across borders. MR suggests that adaptation can occur at a local level after the international standards are established, avoiding a fragmented approach among different countries. Her perspective underscores the need for collaboration and global alignment in codes and standards to promote effective regulation and harmonious technology exchange.

MS underscores the need for comprehensive safety guidelines and protocols to support the integration of hydrogen technologies, drawing a parallel with the existing safety regulations for storing propane or diesel. He acknowledges the challenge faced by fire departments worldwide in addressing these safety concerns and mentions that efforts are directed towards aligning protocols and standards internationally. He highlights the evolving nature of regulations, exemplifying how different countries like Germany and France demonstrate varying attitudes towards hydrogen compliance and safety, illustrating the complexities involved in standardization efforts.

Within the European context, MS discusses the presence of standards for various aspects of hydrogen technology, such as storage and compression. While he mentions the prevalence of ISO compliance standards for fuel cells, he notes that manufacturers follow different documented standards during the manufacturing process. He elaborates on the role of organizations like TUV ((Technischer Überwachungsverein, English translation: Technical Inspection Association) in ensuring compliance across different components of a system. The focus, according to MS, lies in achieving a cohesive and harmonized approach to standards, where the entire system adheres to a particular set of regulations. Overall, MS emphasizes the importance of a unified and internationally recognized framework to ensure the safety and effective implementation of hydrogen technologies.

PL underscores the significance of ongoing debates surrounding codes, standards, and certification processes in the realm of hydrogen technologies. He highlights the multifaceted nature of regulations, ranging from national legislation to international organizations such as ISO. He emphasizes the need for international standards, especially in areas like vehicle refuelling, where consistency across countries is vital. PL points out that having the same standards for vehicles, regardless of location, is crucial for effective and seamless implementation.

PL also touches upon the importance of trust and safety in transportation, suggesting that international standards are required to ensure safe mobility. He acknowledges the complexity arising from various levels of regulation, such as the international and European levels, and discusses efforts to prepare standards and normative works for international approval. He emphasizes the collaborative nature of this process, involving working groups to develop standards for international use.

While PL advocates for international standards, he recognizes that there may be instances where national considerations come into play, especially when it comes to installation and production unit regulations. He illustrates this with the example of different tonnage thresholds for storage safety in different countries. Overall, PL's perspective underscores the critical role of international collaboration and standardized regulations to facilitate the widespread and safe adoption of hydrogen technologies.

PL emphasizes the current significance of discussions revolving around codes, standards, and the certification process for hydrogen. This year, this topic has gained prominence, even at global forums like the G7 and G20, where working groups are focused on defining criteria for low-carbon and

renewable certification schemes. Trust from customers is essential for establishing a hydrogen market, and PL sees the certification process as pivotal in this regard. While carbon content is a primary criterion, he also notes ongoing discussions within international groups regarding additional criteria. These include considerations such as the sustainable use of critical materials, environmental impacts like water usage and potential leakage into the atmosphere, which could harm biodiversity. PL affirms that certification is essential for low-carbon hydrogen and emphasizes its importance in the absence of which hydrogen's environmental benefits hold little value. He acknowledges that while there might be variations in certification criteria, particularly in the context of international trade, the focus should be on establishing an international standard for hydrogen certification schemes. PL mentions collaborative efforts to work towards a platform for mutual recognition of different certification schemes, aiming to facilitate international hydrogen trade through minimum criteria alignment, while avoiding the need for national certification schemes.

RH emphasizes the role of government in making regulations available to facilitate the adoption of hydrogen technologies, stating that while government should enable the process, it does not necessarily need to drive it. He draws from his experience sitting on international and national hydrogen standard panels, emphasizing the complexity of standards across various areas such as transmission, appliances, and transportation of hydrogen.

He acknowledges that while standards are essential, they do not always have to be entirely new or specific. He points to instances where existing standards can be adapted to include hydrogen alongside other gases, such as biogas and fossil fuel gas. RH acknowledges the rigorous international standards set for appliances running on methane and LPG and suggests that while enhancements are needed for hydrogen, replicating extremely high levels of international standards may not be necessary for New Zealand due to the universal application of physics and chemistry laws:

“The hydrogen international standards do set some the ISO standards do set some sort of very base levels very high levels, which I don't think New Zealand needs to replicate that because essentially the difference in hydrogen and natural gas is chemistry, and the chemistry, the laws of physics and the chemistry laws apply the same everywhere, there shouldn't really be a great deal of reason to make a national standard” (RH).

RH delves into potential challenges in implementing hydrogen technologies, such as compatibility with existing building codes and architects' understanding of new technologies. He identifies economics as a significant barrier, noting that for some applications, such as residential hydrogen production and storage, it might not make economic sense when compared to grid-connected alternatives.

In conclusion, RH's viewpoint emphasizes the importance of practical and context-sensitive regulations and standards that enable the safe and efficient integration of hydrogen technologies while considering factors such as economic viability and universal scientific principles.

SJS emphasizes the importance of fostering innovation and industry growth by avoiding excessive hurdles and delays in regulatory processes. He draws parallels to successful companies like Google that started ahead of government regulations, highlighting the need for agility and proactive action in emerging industries. He likens the urgency of addressing climate change to a war and underscores the need for swift and unconventional approaches, as exemplified by Germany's rapid response in transitioning its energy supply.

SJS underscores the necessity of public willingness and collective effort in driving change. He mentions the variation in standards for gas pressure in different countries and the ongoing work in standardization efforts to align these differences. However, he expresses scepticism about the need for stringent standards, suggesting that providing more allowances and flexibility for new

technologies would promote innovation and adaptation. He believes that allowing more room for experimentation and change is crucial, especially in a rapidly evolving landscape like green hydrogen.

In summary, SJS's viewpoint emphasizes the importance of enabling and accelerating progress in the hydrogen industry through flexible regulations and proactive measures that prioritize innovation, speed, and adaptability in response to the urgent challenges posed by climate change.

TW emphasizes the practical approach of selecting existing off-the-shelf products that align with regulatory requirements for hydrogen systems. He highlights the importance of ensuring good use cases and suitable product selections before delving into regulatory considerations. The discussion on micro credentials and certification for working on hydrogen systems showcases the recognition of the additional hazards and controls associated with hydrogen technologies.

TW underscores the significance of education, particularly for architects, regulatory authorities, and councils, in order to inform regulations effectively. He notes that familiarity with hydrogen safety is crucial for those shaping regulations. TW emphasizes the need to establish a confident cost curve and regulatory framework before utilizing hydrogen as a thermal energy source. He suggests drawing from inspection practices in the electrical industry to potentially implement similar accountability measures in the hydrogen space, ensuring proper installation and safety compliance.

He discusses the complexities of working with a fuel system not yet regulated, focusing on the need for exemptions and meeting existing standards while developing guidelines for building codes and hazardous zones. TW emphasizes the need for upper-level regulations to provide a foundation for inspection and compliance processes. He acknowledges the presence of multiple moving pieces in this evolving landscape.

He discussed gaps in regulation, particularly in treating electrolysis systems differently due to their unique characteristics. While some standards exist for hydrogen-related components, there is a lack of specific regulation for electrolyzers. TW emphasized the significance of proper material selection to ensure safety.

In summary, TW's perspective highlights the practical steps taken to align existing products with regulations, the importance of education in informing regulations, and the challenges of navigating regulatory gaps and uncertainties in deploying hydrogen technologies for thermal use.

TN highlights the practical approach of importing regulations and technologies from Europe to expedite the adoption of hydrogen technologies in New Zealand. He mentions the connection with a dealer in Japan and their interest in Enapter's technology. However, he points out that the delay in obtaining New Zealand compliance led them to explore alternative options. TN emphasizes the importance of localizing technologies to meet regulatory standards and mentions the positive attributes of Enapter's technology, including scalability and cost-effectiveness. His perspective underscores the significance of timely compliance and localization in ensuring the successful integration of hydrogen technologies in the New Zealand context.

VG underscores the importance of adhering to a multitude of standards and regulations to ensure the safety of hydrogen projects. He emphasizes that with proper adherence to these standards, hydrogen can be undertaken as a secure venture. He supports the adoption of international standards, seeing no advantage in local standards, as they can lead to increased engineering efforts and unnecessary discrepancies. VG points out the challenge of procurement, where standards dictate which hydrogen refuelling stations can be purchased. He discusses the release of European regulations that outline criteria for green hydrogen production, including the requirement for newly built and contemporaneously generated renewable energy. VG also highlights the significance of adhering to high standards in Saudi Arabia, particularly in projects like Neom, where UN standards are

meticulously followed, and government support is vital. His perspective underscores the benefits of unified and comprehensive international standards for hydrogen technologies.

VG advocates vehemently for the standardization of hydrogen regulations on a global scale, debunking the rationale behind localized standards that merely escalate engineering complexities. An ongoing predicament involving hydrogen refuelling stations exemplifies the disparity between accepted standards, such as those from Europe, and non-accepted ones, like those from China, underscoring the inefficiency of such fragmentation.

ZJ discusses the recent development of a low carbon hydrogen production standard in the UK, aimed at encouraging the growth of hydrogen production. He highlights that this standard is designed to address the current challenge of large-scale green hydrogen production and sets a limit of 20 grams of CO₂ emissions per megajoule of hydrogen produced. ZJ emphasizes the importance of countries having their own standards to adopt hydrogen technologies, considering factors like price concerns for governments, industries, and consumers. He underscores that these standards can vary based on each country's existing gas infrastructure and distribution systems. ZJ sees the UK's hydrogen strategy and policy support, including funding competitions for feasibility studies and demonstration projects, as critical factors driving the hydrogen economy forward. He also points out the potential of the UK's hydrogen success becoming a useful reference for other countries to build their own hydrogen economies.

Overall, the participants' opinions underline the importance of well-established regulations and standards to ensure the safe and effective integration of hydrogen technologies across different sectors. While there is an awareness of the existing gaps and challenges, there is also a strong commitment to advancing regulatory frameworks in order to facilitate the growth of hydrogen as a clean energy solution.

Legislation, Policies, Standards, Regulations, Codes and ISO	
Aspect	Key Insights
Importance of Regulations	- Appropriate regulations and standards are critical for managing risks and enabling the widespread adoption of hydrogen technologies.
Current Regulatory Gaps	- Many countries currently lack comprehensive hydrogen regulations, particularly for emerging applications such as residential use.
Preference for International Standards	- Many stakeholders prefer international standards for consistency; however, some flexibility is recommended to encourage innovation.
Safety Regulations	- Safety regulations are crucial across all aspects of the hydrogen value chain to protect lives, with standards needing enhancement for new contexts like buildings.
Government's Role	- The government plays a key role in developing hydrogen regulations and standards, especially for residential applications.
Organizations Shaping Standards	- Organizations such as the International Organization for Standardization (ISO), International Electrotechnical Commission (IEC), and National Fire Protection Association (NFPA) develop international hydrogen standards, while national authorities in countries like the United States and the United Kingdom shape local regulations.

Certification Processes	- Certification processes for low-carbon hydrogen are pivotal for building consumer trust, with international alignment on certification criteria recommended.
Education on Safety	- Education on hydrogen safety is essential for effective regulation; regulations should facilitate technology deployment while ensuring safety.
Need for Adaptive Regulations	- In New Zealand's evolving landscape, adaptive regulations that keep pace with innovations are necessary for the safe and accelerated adoption of hydrogen.

Table 16: Legislation, Policies, Standards, Regulations, Codes and ISO

In conclusion, the experts' insights underscored the critical role of standards and regulations in shaping the future of hydrogen technologies. While international standards were favoured for consistency, some flexibility in standards was recommended to accommodate rapid technological advancements. The need for supportive government policies, funding mechanisms, and specialized training to enable safe and effective hydrogen adoption were also highlighted. In the context of New Zealand, where hydrogen adoption is gaining momentum, the challenges of aligning regulations with evolving technologies were emphasized, underscoring the importance of adaptive and forward-looking regulatory frameworks. Collaborative development of supportive, internationally-aligned and adaptive hydrogen regulations is crucial for managing risks and enabling widespread adoption.

4.19 Investment into hydrogen technologies

Participants across different regions and contexts shared their insights on the role of investment in advancing the adoption of hydrogen-based solutions. One prevailing sentiment echoed by several participants is the necessity of financial support to drive the decarbonization efforts associated with hydrogen technologies.

The imperative of financial backing is underscored by the acknowledgment that technological advancements and cost reduction are interdependent. Some participants emphasize that countries must not wait until these technologies become affordable; instead, they advocate for proactive investment in the development and deployment of hydrogen technologies. This sentiment is echoed by the recognition that the potential for carbon reductions and efficiency gains necessitates immediate investment. It is noted that without committing resources, the risk of losing investment opportunities and market competitiveness looms large.

A recurring theme among the interviewees is the pivotal role of governments and private investors. Participants assert that a symbiotic relationship between government initiatives and private sector investments is crucial to expedite progress. Governmental support is viewed as a catalyst to overcome the initial cost barrier and drive technology maturity. In some instances, participants highlight specific funding regimes in certain countries that encourage hydrogen technology development, thereby accelerating the adoption curve.

The notion of scalability is also prominent, with participants stressing the importance of reaching critical mass through mass production and broad uptake. This necessitates collaborative efforts to pool resources and aggregate orders, thereby achieving economies of scale and cost competitiveness. In this vein, participants emphasize the role of partnerships between technology providers and consumers, who work collaboratively to realize large-scale deployment.

Additionally, the participants recognize the importance of aligning investments with existing infrastructure and optimizing deployment. The challenge of integrating hydrogen into existing energy systems, pipelines, and appliances is noted, calling for a careful balance between innovation and

practicality. Incremental approaches are favoured, allowing for stepwise adaptation and minimizing disruption.

The interviews collectively emphasize the importance of well-planned, strategic, and holistic investments in hydrogen technologies. A forward-looking perspective is adopted, underscoring that immediate and concerted actions are required to bridge the gap between current capabilities and future potential. As hydrogen technologies mature and their cost-effectiveness improves, the consensus is that investments will yield sustainable gains, enabling a cleaner energy future.

EEF's perspective on investments in hydrogen technologies underscores the critical role of funding from the countries where these technologies are being implemented. They emphasize that relying solely on the expectation of future cost reductions might hinder progress. As stated:

“Money has to come from the countries where the technology is to here in order for us to be able to decarbonize, if not, we’re just gonna stay here waiting until they the technologies are cheap for us to buy” (EEF).

This sentiment reflects the urgency of investing in hydrogen technologies to initiate the decarbonization process rather than waiting for costs to naturally decrease.

Furthermore, EEF highlights the risk associated with not pursuing the decarbonization path, asserting that failure to do so could lead to losses in investment. Their perspective emphasizes the importance of strategic decisions aligned with a sustainable and cleaner energy transition:

“If you do not go the decarbonized way or you’re gonna lose for an investment” (EEF).

This perspective underscores the economic and environmental imperatives of investing in hydrogen technologies for long-term gains.

RGJA's perspective on investments in hydrogen technologies acknowledges the potential challenges but remains optimistic about private investor engagement. They suggest that private investors will be motivated to invest if they perceive a clear demand and market for hydrogen products. According to their view:

“If the private investor sees that there is a demand that there is a market for the product, I think they will invest immediately in projects that to enlarge a production capacity and produce Electrolysers at the adequate level and more if we are thinking about AEM electrolysers” (RGJA).

This viewpoint suggests that a promising market outlook can incentivize private investors to take swift actions to scale up production and contribute to the growth of hydrogen technologies.

MR emphasizes the multifaceted nature of government investments in hydrogen technologies, recognizing both the potential benefits and challenges. She mentions that *“the government can invest”* in hydrogen infrastructure. However, she also points out a potential pitfall where excessive government investment might lead to inefficiencies:

“If the government says, ok, I’m gonna invest all the money into making hydrogen infrastructure, but then some vehicles are not optimized if they use hydrogen. Then it can bring to what’s in this case a loss of efficiency and in the end of investment that could be tackled in, there could be moved to somewhere else” (MR).

MR underscores the ongoing need for investments in advancing the technology's efficiency and energy security:

“I think that the main aspect is continuing investing in these technologies and making them more and more efficient about energy security” (MR).

She highlights the importance of directing investments strategically and diversely: *“the direct investments with some more confidence in order to spread it around”*. MR further emphasizes the importance of identifying investment areas that enhance clean energy availability and address specific challenges, such as load balancing:

“So understand where there needs to be investments to increase the clean energy availability and where there are issues such as load balancing where addition can be more useful and then use this information to focus on the goal of implementing hydrogen” (MR).

Lastly, MR acknowledges the evolving cost dynamics of emerging technologies:

“Because at the beginning they addition technologies are still more expensive and then after more and more projects they will they cost will come down there for it’s very important to use the first transit investments in an efficient way to make a then the companies grow and have the lower cost of production”.

This perspective underscores the importance of strategically utilizing initial investments to facilitate technology development and cost reduction over time.

MS highlights the significance of technology providers in driving the success of hydrogen technologies, drawing a parallel with the modularity of networking PCs:

“And the technology provider who makes an electrolyser, where I can buy one and I can modularly add more like networking PCs and is really been instrumental towards this being successful” (MS).

MS delves into the financial perspective of investments, discussing the considerations of return on investment (ROI) and the different cost dynamics of wood fuel cells:

“They’re thinking is I wanna spend some money, but I wanna get the return on investment in a year or two and wood fuel cells. Yes. The capital cost will be higher than a diesel generator or batteries. But you have to look at this over a five- or six-year period before you recoup your costs, but mainly because the operating cost of these is almost zero, right? So that’s the main domain difference”.

MS also touches on the analytical aspect of investment decision-making, mentioning her efforts to find the intersection of profitability within reasonable time frames:

“I spend a lot of time trying to make 2 lines on a spreadsheet cross within a reasonable time frame now what I’m showing. Look, if you invest this amount of money, your return will be in X amount of time”.

This perspective underscores the importance of aligning investments with projected returns and justifying the financial feasibility of hydrogen technologies.

RH emphasizes the need to communicate the environmental impact of investments in hydrogen technologies in relatable terms:

“I think the other one is primarily to show how much decarbonization is achieved by an investment. There’s to say to people over the life of this product, it will save you the equivalent of, you know, X 1000 kilometres in your car or so many units of gas and I did it that so some find some ways that people can understand”.

He suggests steering away from technical jargon like *“kilograms of CO₂”* and instead focusing on tangible benefits that resonate with individuals’ everyday experiences:

“So don’t necessarily quote kilograms of CO₂ because people don’t recognize that what it’s expressed in terms of the service that people use”.

RH’s perspective highlights the importance of framing the advantages of hydrogen technologies in terms that resonate with potential investors and consumers, making the benefits more relatable and compelling.

SJS acknowledges the competitive challenge posed by China’s substantial investment in hydrogen technologies:

“We are definitely losing against China when they massively invest”.

This statement underscores the urgency of fostering domestic investments and innovation in hydrogen technologies to maintain a competitive edge in the global market. It reflects the need for proactive measures to stimulate research, development, and investment in order to remain at the forefront of the rapidly evolving hydrogen industry.

TW’s perspective aligns with MS’s view who emphasize the importance of assisting technology providers and fostering their confidence in their endeavours. This approach is crucial in building a strong investment case that supports the scalability and cost reduction of hydrogen technologies. Similar sentiments have been echoed by participants who stress the need for governments and stakeholders to provide the necessary support and confidence in the industry’s growth. **TW** emphasizes the role of supporting technology providers to build confidence in their endeavours:

“We would assist the technology providers and having confidence in what they’re trying to do so then they have the investment case to upscale and make things cheaper”.

This approach underscores the importance of collaboration and partnership in driving investments in hydrogen technologies. Additionally, WS highlights the practicality of assessing costs and returns:

“This is how much I think it’s gonna cost. This is what I think the return on investment is gonna be, and then we can start engaging other services”.

This pragmatic approach underscores the significance of well-informed decision-making and strategic planning in the pursuit of successful and impactful investments.

TN advocates for proactive action by suggesting, *“why not start to study and invest early rather than waiting for others to start?”* This approach aligns with the notion of taking initiative and being forward-thinking in harnessing the potential of hydrogen technologies. In contrast, TN acknowledges the challenges of making substantial investments without adequate funding, emphasizing the need for a strategic and long-term approach. This perspective echoes the sentiment of other participants who emphasize the importance of careful planning and resource allocation for successful investment in hydrogen technologies.

VS highlights the favourable economic landscape in certain regions, stating:

“Estimates say for Saudi that you have levelized costs of electricity of about one to two cents per kWh with solar energy and that gets you very close to the goal of \$1.00 per kilogram hydrogen production cost” (VS).

This cost-effectiveness has led to substantial investments in hydrogen technologies by countries like Saudi Arabia and other Gulf nations. VS also acknowledges the role of government support in assisting private investors, indicating that while private investors are enthusiastic about ramping up hydrogen efforts, they often require governmental backing to facilitate progress.

Furthermore, VS underscores the strategic advantage of investing in countries that are already supportive of hydrogen technologies, suggesting:

“If I’m a hydrogen investor, I would go to one of these countries and take the easy way, instead of trying to convince governments who are against hydrogen to subsidize me” (VS).

This perspective aligns with the idea that a conducive policy environment can encourage and accelerate hydrogen-related investments. Lastly, VS notes that some countries are actively investing in hydrogen mobility at the national level, showcasing a commitment to expanding hydrogen applications and infrastructure.

Investment	
Aspect	Key Insights
Importance of Financial Support	- Financial support and proactive investment are crucial for driving decarbonization and advancing hydrogen technology development. Relying solely on future cost reductions risks losing progress and competitiveness.
Role of Government and Private Sector	- Government initiatives and private sector investments play pivotal roles in overcoming initial cost barriers and catalyzing progress. Funding schemes in some countries are already accelerating adoption.
Scaling Up Production	- Achieving scale through mass production and widespread uptake is key. Partnerships between technology providers and consumers enable large-scale deployment and cost reduction.
Aligning Investments with Infrastructure	- Investments should align with existing infrastructure to optimize deployment. Incremental integration of hydrogen into current systems balances innovation and practicality.
Holistic Investment Strategy	- A forward-looking, holistic investment strategy is needed, recognizing the urgency of action to realize hydrogen's sustainable potential. As costs fall with maturity, investments will yield long-term gains.
Communicating Environmental Benefits	- Relatable communication of environmental benefits is important when promoting investments. Tangible impacts, such as fuel savings, resonate more than abstract carbon dioxide figures.
Building Confidence Among Technology Providers	- Fostering technology provider confidence and supporting scale-up efforts builds a strong business case for investments. Pragmatic cost-benefit analyses inform decision-making.
Proactive Investment Approaches	- Proactive investment stances, leveraging favourable conditions and strategically allocating limited funds, represent prudent approaches.

Table 17: Investment

In conclusion, the insights shared indicate that strategic collaboration between public and private sectors, coupled with proactive, optimized investment approaches, can drive the advancement and adoption of hydrogen technologies to realize a clean energy future.

4.20 Introduction to Public, Public Awareness and Acceptance

Public awareness of hydrogen presents a multifaceted challenge that participants recognize as pivotal to the successful adoption of this innovative energy source. While acknowledging hydrogen's niche status, some express concerns about public misconceptions, often associating it with hydrogen bombs. To overcome this, participants advocate for education and public engagement as essential tools to demystify hydrogen and establish its safety and utility.

Several participants underscore the significance of scaling up hydrogen technology while prioritizing public trust. They view introducing hydrogen through diverse applications and highlighting its cost-effectiveness as effective strategies to foster acceptance. However, they acknowledge that building public trust requires time, with one participant pointing out the evolution of discussions around hydrogen over the years.

Participants stress that education is crucial in overcoming challenges related to public perception. They believe that initiatives should begin at an educational level, even in schools, to counteract misinformation and enhance familiarity with hydrogen's safe use. This can involve showcasing its extensive history of use in various industries to reassure the public.

The role of government and industry is pivotal in shaping public perception. Participants discuss the need for strong policy frameworks and regulations, as well as transparent communication about safety measures and benefits. They recognize that educating citizens goes beyond demonstrating hydrogen's viability; it also entails dispelling concerns through transparent information and accessible resources.

However, participants acknowledge the complex nature of shifting public perception. They emphasize that a one-size-fits-all approach may not be feasible, given the differing challenges faced by different countries. Despite this, they unanimously agree that consistent efforts across academia, industry, and government are essential to bridge the knowledge gap and garner public trust.

Introducing hydrogen and its associated technologies to the public is a multifaceted endeavour, according to the participant's perspective. The initial challenge lies in the fact that hydrogen remains a niche concept for many individuals, with unfortunate associations such as hydrogen bombs affecting public perception:

"People are afraid of hydrogen. A lot of people associate hydrogen with hydrogen bombs"
(DA).

To address this, there is a consensus that scaling up hydrogen technologies gradually is the right approach to familiarize the public with its benefits and safety.

The focus of the current efforts is to make hydrogen more accessible to the public, not limiting it solely to green hydrogen but encompassing various types. This broader availability aligns with the perspective that the general public is more concerned with the cost-effectiveness of hydrogen rather than its green attributes. DA highlights the importance of cost considerations, indicating that the public's prioritization of affordability is a crucial factor in promoting widespread adoption.

Efforts are being made to raise public awareness about the safety of hydrogen, with training programs implemented in local communities where hydrogen stations are being established. However, DA acknowledges that there is not a single approach that universally fosters positive perceptions of hydrogen. Instead, it is recognized that changing public opinion takes time and involves a multifaceted strategy.

DA's opinion emphasizes the gradual and inclusive introduction of hydrogen technologies to the public. The approach involves addressing cost concerns, dispelling misconceptions, and

incorporating safety awareness initiatives within local communities. While acknowledging the complexity of changing public perceptions, the participant underscores the importance of persistence and a multifaceted strategy in cultivating a positive view of hydrogen among the general public.

SGJA believes that education plays a pivotal role in shaping public perceptions of hydrogen, particularly as individuals fall into either the category of hydrogen believers or hydrogen sceptics. The key lies in disseminating accurate and comprehensive information to the public, enabling them to make informed judgments. To achieve this, initiatives like the International Energy Agency's Hydrogen Technology Collaboration Program are striving to provide accessible resources that highlight both the benefits and drawbacks of hydrogen technologies. By putting such information out in front of the public, the aim is to create a more informed and balanced understanding of hydrogen's potential. In essence, education serves as a bridge between scepticism and belief, fostering a well-rounded discourse and enabling individuals to make well-grounded decisions about hydrogen adoption.

RGJA offers insightful perspectives on the challenge of introducing hydrogen technologies to the public. The process involves navigating two distinct angles. The first revolves around social acceptance, especially among those who lack a deep understanding of these innovations. RGJA highlights the crucial role of education and information dissemination in overcoming initial scepticism. Building public trust by effectively communicating the practical benefits and safety features of hydrogen technologies becomes imperative in this context.

The second perspective emphasizes the significance of emphasizing the real-world utility of these technologies. RGJA suggests that highlighting their economic advantages and cost-effectiveness can effectively capture public interest. By showcasing tangible benefits, such as reduced costs and improved efficiency, a compelling case can be made to generate public support and enthusiasm for hydrogen technologies.

In essence, RGJA's insights underscore the importance of a dual-pronged approach. By simultaneously addressing safety concerns and accentuating practical advantages, a more comprehensive and impactful engagement with the public can be achieved. This approach not only fosters a better understanding of hydrogen technologies but also paves the way for their successful integration into the mainstream.

MR presents a valuable perspective on the role of education in addressing public perceptions of hydrogen. She underscores the importance of integrating hydrogen education into school curricula, starting from an early age. By teaching the fundamental chemistry of hydrogen and explaining its use across various industries, MR believes that a foundational understanding can be established. She acknowledges the need to address safety aspects but emphasizes that hydrogen's integration in multiple industries, including complex ones like refineries, demonstrates its practicality and safety over decades.

MR further emphasizes the importance of explaining the historical use of hydrogen and the lessons learned from its application in different contexts. By drawing parallels between established industrial uses and potential civilian applications, MR seeks to build public confidence in hydrogen technologies. She advocates for transparent communication about the precautions and adaptations necessary when transitioning hydrogen into civilian use.

Moreover, MR suggests that the hydrogen market and its products should be accompanied by educational services. These services can provide users with guidance and instructions on how to safely handle and utilize hydrogen-based products. By ensuring that education and information are readily available, MR envisions a smoother and more informed introduction of hydrogen into the market, contributing to its acceptance and integration among the public.

RH brings a valuable perspective to the discussion by focusing on the crucial aspect of public assurance and safety regarding hydrogen technologies. Based on research RH commissioned a few years ago, a survey involving random individuals in Wellington revealed a prevailing sentiment. The overwhelming consensus was that if hydrogen technologies were certified by New Zealand authorities, the public would feel comfortable adopting them. This insight underscores the importance of regulatory endorsement in instilling confidence among the public.

RH acknowledges that while there might be a basic fear of hydrogen, this fear can be mitigated through proper certification by trusted regulatory bodies. The survey results indicate that such certification is paramount for acceptance. RH acknowledges that there may have been past challenges in certifying certain aspects of hydrogen technologies, such as trailers. However, RH believes that even though confidence in certification may have faced hurdles, the pathway to certification is crucial.

To address the issue of public assurance, RH proposes a clear and transparent pathway to certification. By ensuring that appliances and technologies related to hydrogen adhere to New Zealand standards, a tick box or certification emblem can signal to the public that the product has met regulatory standards. RH emphasizes that public information about the certification process is equally vital. This approach aims to give individuals a tangible and visible indicator of a technology's safety and adherence to established regulations, thereby building a sense of reassurance and trust among the public.

TW emphasizes the necessity of taking action to facilitate the adoption of hydrogen technologies, particularly in domestic energy usage. According to TW, a key strategy involves enabling individuals who are directly using energy at home. He believes that by involving households in the energy transition, a greater sense of community value can be achieved.

TW underscores the importance of mitigating risks for consumers. He highlights the role of pilot projects, publicly available demonstrations, and educational initiatives in building public trust in hydrogen as a fuel source. Despite progress being made, TW acknowledges that there is still some time before all these components can be fully established to instil confidence in the public.

Reflecting on historical incidents like the Hindenburg disaster, TW acknowledges that negative events can have a lasting impact on public perception. He emphasizes that caution and careful handling are essential due to the novelty of hydrogen technologies. To bolster public confidence, TW suggests implementing additional layers of safety and transparency.

TW introduces the concept of resilience and energy independence as factors that can foster positive sentiment. He notes that people are receptive to the idea of generating and storing their own energy, contributing to a sense of control over their energy future. While some individuals might express concerns about maintenance, TW proposes that offering maintenance plans could alleviate those fears. He advocates for decentralization and community involvement, underlining the benefits of spreading opportunities and knowledge about hydrogen technologies. TW concludes by expressing his willingness to engage with anyone interested in discussing the potential of hydrogen and its role in various contexts.

Public Awareness and Acceptance of Hydrogen	
Aspect	Key Insights
Misconceptions about Hydrogen	- The public often associates hydrogen with bombs, leading to misconceptions. Education is crucial to overcoming these negative perceptions.

Gradual Introduction of Technology	- A gradual introduction of hydrogen technology across diverse applications can build familiarity and demonstrate cost-effectiveness.
Education Initiatives	- Initiatives to educate the public should start at the school level to counter misinformation and establish familiarity with hydrogen technologies.
Role of Government and Industry	- Government and industry play pivotal roles through policy, regulation, safety measures, and transparent communication of benefits.
Dispelling Concerns	- Education should go beyond demonstrating viability; it must also address concerns by providing accessible and clear information.
Country-Specific Challenges	- Each country may face different challenges in shifting public perception, requiring consistent, multi-pronged efforts.
Highlighting Real-World Benefits	- Emphasizing tangible benefits, such as reduced costs, can create a compelling case for public support of hydrogen initiatives.
Importance of Regulatory Endorsement	- Regulatory endorsement and certification are crucial for assuring the public of hydrogen's safety.
Building Public Confidence	- Additional safety measures, pilot demonstrations, and opportunities for decentralization can help build public confidence in hydrogen technologies.
Ongoing Education and Engagement	- Persistence through education campaigns, open communication, and community involvement is essential for fostering hydrogen acceptance.

Table 18: Public Awareness and Acceptance of Hydrogen

In summary, participants stress the need for comprehensive and persistent education campaigns to rectify public misconceptions about hydrogen. This involves highlighting its safety record, debunking myths, showcasing its various applications, and offering clear information about its benefits for a sustainable energy future. A comprehensive strategy involving education, transparent communication, practical benefits and regulatory assurance is vital for gaining public trust and acceptance of hydrogen.

4.21 Māori

The perspectives shared by participants in the interviews shed light on the Māori perception of green hydrogen and its potential integration within their communities and remote locations in New Zealand. One participant acknowledged that while there may be certain sensitivities among the Māori regarding water usage, they exhibited a pragmatic approach towards innovative solutions. The participant acknowledged the Māori community's distinctive viewpoint, characterized by a forward-thinking and generational outlook rather than a short-term payback approach often seen in Western contexts.

This perspective aligns with the notion that Māori communities approach decision-making with a long-term perspective, evaluating the benefits and drawbacks of various options over extended time frames. This broader perspective is in stark contrast to the conventional three-year payback mentality prevalent in Western societies. While concerns about water usage and environmental impact may be

significant considerations for the Māori, their willingness to adopt technologies like green hydrogen reflects their adaptability to solutions that align with their values and long-term interests.

As New Zealand seeks sustainable and renewable energy solutions, including those in remote areas, the Māori community's willingness to consider green hydrogen highlights the potential for collaboration and shared understanding. Ultimately, this approach bridges the gap between modern technologies and indigenous values, fostering an environment where innovative solutions like green hydrogen can be integrated successfully within Māori communities and remote New Zealand locations, in harmony with their unique cultural and environmental perspectives.

4.22 Education, Trainings and Knowledge for Hydrogen Adoption

The participants in the interviews highlighted various aspects related to the adoption of hydrogen technologies and the need for education and training. They stressed the importance of education starting from schools and universities, focusing on teaching chemistry and explaining the safe usage of hydrogen. Several participants discussed the lack of knowledge gaps in different regions and the need to address them through academic programs and retraining. They expressed concerns about the lack of understanding about hydrogen's behaviour in incidents and emphasized the necessity of educating architects, engineers, and regulatory authorities.

Participants discussed the challenges of bridging the gap between theory and practice, suggesting that hands-on experience and showcasing real hydrogen systems are crucial for effective learning. They mentioned efforts to offer training workshops, resources, and even setup Learning Centres to facilitate better understanding. The importance of having a broad understanding of the energy sector to integrate hydrogen effectively was highlighted. Moreover, participants underscored the role of universities and research institutions in developing training courses and degree programs tailored to hydrogen technologies. Some participants proposed the establishment of specific endorsements or certifications for professionals working with hydrogen systems, outlining the additional knowledge needed for safe handling.

Concerns about public perception and safety were recurring themes, with participants emphasizing the need for accurate information dissemination and addressing misconceptions. They recognized that education should extend beyond technical knowledge, covering regulatory aspects, safety protocols, and even environmental benefits. While acknowledging the challenges, participants remained optimistic about the potential for hydrogen technologies, especially as renewable energy and sustainability gain prominence. Overall, their insights underscored the multifaceted educational efforts required to foster widespread acceptance and successful integration of hydrogen technologies across various industries and regions.

JH stressed the importance of education as a means to enhance public awareness and understanding of hydrogen technologies. He emphasized the need to provide accurate and reliable information to the public, acknowledging the role of initiatives like the International Energy Agency's Hydrogen Technology collaboration program, which aims to make educational resources accessible to everyone. JH highlighted the significance of preparing new students with a holistic perspective on energy systems. JH discussed their sustainable energy systems program, designed to equip students with a broader understanding of the energy landscape and the integration of different technologies. However, he expressed concerns about potential cuts to such programs due to low enrolment and financial challenges faced by universities. The sentiment of developing human capital within the hydrogen sector was echoed by another participant. JH recognized the necessity of nurturing a skilled workforce that comprehends the intricacies of hydrogen technologies, acknowledging the importance of educational efforts in achieving this goal:

"We need to develop that human capital" (JH).

RGJA emphasized the early stages of the learning curve in the field of hydrogen technologies, indicating that there is a lot to grasp and understand. He discussed the potential for academic programs to facilitate the preparation of individuals for the emerging hydrogen sector. This could involve retraining or additional training to equip people with the necessary skills and knowledge to engage with these technologies effectively. Furthermore, RGJA saw the expansion of hydrogen technologies as an opportunity to create new career paths and educational programs. He highlighted the potential for universities to develop new curricula and courses that align with the evolving demands of the hydrogen industry. This, in turn, could lead to the emergence of novel professions and job opportunities in the sector, contributing to the growth and development of the hydrogen economy.

JAGR highlighted several key aspects related to hydrogen technologies and education. He emphasized the need for a solid understanding of electrochemistry as a foundational skill in this field. Additionally, JAGR expressed concerns about the lack of knowledge regarding how hydrogen would perform in various scenarios, such as traffic incidents and building fires, underlining the importance of safety considerations.

JAGR stressed the importance of focusing on new applications that are relevant to the general population and closer to everyday life. JAGR shared experiences of limited educational offerings in their universities, which prompted them to seek opportunities outside academia, like developing prototype fuel cells in research centres.

In terms of education in Latin American countries, JAGR noted the dominance of traditional oil and gas-focused programs in engineering curricula. He called for a shift in emphasis to accommodate the changing energy landscape and prioritize topics like hydrogen and materials science.

Furthermore, JAGR recognized the need for more electrical engineers due to the growing trend of electrification. He emphasized the significance of understanding materials science, as future advancements in hydrogen and other technologies will heavily rely on new materials.

To address the evolving demands of the hydrogen sector, JAGR suggested a combination of retraining existing professionals and creating new educational programs. He stressed the importance of adapting to emerging trends quickly and being open to developing programs that cater to the changing needs of the industry.

MR highlighted the importance of introducing hydrogen education starting from schools, emphasizing that teaching chemistry and explaining its historical use can help demystify the concept. MR mentioned the need for educational initiatives to provide insights into the learnings gained from previous hydrogen applications over the years.

MR also proposed that the hydrogen market and its products should come with a comprehensive set of services to guide and instruct users, as hydrogen is a novel technology and its successful integration requires proper training and understanding.

Based on MR's personal experience, they shared that even within prestigious engineering universities like the one they attended in Italy, hydrogen education was lacking. MR believed that adapting curricula to address the energy transition is crucial, as this transition affects various industries and sectors. MR emphasized that individuals interested in technology should be equipped with the necessary tools to understand and contribute to these challenges for the betterment of their communities.

MR also noted the increasing demand for skills in digitalization and automation, highlighting the need for individuals who can ensure the proper functioning of emerging technologies and remotely control facilities. Moreover, MR stressed the importance of knowledge in chemistry and safety aspects related to hydrogen.

In conclusion, MR expressed optimism about the opportunities for individuals who choose to study hydrogen-related topics, given the growing importance of these technologies across various sectors.

RH from New Zealand highlighted the potential for streamlined qualifications in hydrogen technologies. With the same qualifications as today, individuals could potentially obtain an endorsement through a short training course, allowing them to continue their work with the necessary skills. RH shared an example of hiring a professional plumber for a hydrogen system, showcasing how existing skills could be adapted to new technologies. The process worked well, with the plumber successfully navigating the requirements and implementing the system effectively.

RH also noted the importance of educating professionals from various fields, including architects, about hydrogen technologies. RH engaged with architects to help them recognize the significance of hydrogen in shaping the future. RH recalled a past discussion with someone from energy safety, where they agreed that about 90% to 95% of skills from standard gas fitter programs could be transferable to hydrogen, with the addition of a hydrogen endorsement.

In summary, RH believed that a combination of adaptable skills and specific endorsements could facilitate the integration of hydrogen technologies across different sectors, while also emphasizing the importance of education and awareness among professionals.

SJS emphasized the critical need for building a workforce that deeply understands hydrogen technologies. This requires the establishment of hydrogen pipelines and consumer systems, along with the knowledge and skills to support them. SJS lamented the impact of disinformation propagated by the oil and gas industry, which hinders public understanding of hydrogen's potential.

SJS stressed the importance of teaching electrochemistry, citing China's strong emphasis on this field in universities and warning that Europe and the US could fall behind in the future due to a lack of investment in science. He believed that collaborative efforts and pooling of expertise are essential to compete against China's significant scientific advancements.

SJS discussed the establishment of technology learning hubs in various countries, including Thailand and India, to promote education and training in emerging technologies like hydrogen. He highlighted the significance of hands-on experience, where partners engage with demo systems to integrate them with software, make correct connections, and avoid potential pitfalls.

SJS acknowledged the challenges of working with hydrogen, such as blending and handling pipes, emphasizing the need for technical understanding to prevent mistakes. He mentioned resources like YouTube videos and workshops to educate professionals and students. SJS also noted that free resources sometimes go unused, leading to a change in their approach to providing valuable materials.

In conclusion, SJS highlighted the urgency of fostering technical understanding and expertise in hydrogen technologies, while also recognizing the importance of collaborative learning and practical training.

TW from New Zealand highlighted the importance of practical learning and knowledge acquisition. He described how they set up trial systems in their workshop to ensure they had a strong foundation of understanding before selling products and emphasized the importance to educate people on electrolysis technology and its applications. He highlighted studies comparing hydrogen to natural gas in domestic scenarios and noted that, from an engineering perspective, the fundamentals remain consistent.

TW mentioned the adoption of micro-credentials for working on hydrogen systems, emphasizing the need for certified professionals due to the additional hazards and controls associated with hydrogen. He also discussed the importance of educating professionals in fields like architecture and regulation, as they play a vital role in shaping the industry's future.

He spoke about the value of showcasing hydrogen technologies in educational institutions and Polytechnics, allowing people to see and interact with tangible systems. The goal is to build trust and understanding among the public.

TW mentioned their focus on pilot projects, integration assistance, and brand building, all contributing to de-risking hydrogen for consumers. He stressed the importance of ensuring safety and learning from historical incidents.

Finally, TW offered to share knowledge and showcase electrolyzers to anyone interested in learning more about hydrogen technology. He expressed their willingness to engage in conversations about hydrogen's potential and its role in the future.

VG emphasizes that for the majority of hydrogen-related jobs, there is a pool of individuals with transferable skills from previous roles, making recruitment relatively straightforward. He believes that about 90% of the workforce can be sourced from other industries. While having an engineering degree with a focus on hydrogen could be beneficial for specialized technical roles, VG does not see the need for a massive retraining effort, as working with hydrogen is not overly complex. He shares his own experience of transitioning into a hydrogen-related role without prior experience, suggesting that learning on the job is feasible for less technical positions.

VG highlights the importance of having a broad understanding of the energy sector to comprehend how hydrogen can effectively integrate into the larger energy landscape. This further underscores the need for comprehensive education and training programs that cover the broader energy context alongside specific technical knowledge related to hydrogen.

ZJ discusses the role of academia and research institutions in the education and training of professionals in the hydrogen sector. He mentions that universities can develop specialized training courses tailored to the needs of industrial partners. These courses can range from shorter industrial training programs to more in-depth degree programs that help professionals enhance their hydrogen-related skills.

When it comes to the skill set required for working in the hydrogen sector, ZJ explains that engineering backgrounds are highly relevant. Different roles within the hydrogen industry might require different engineering disciplines, such as chemical, mechanical, or electrical engineering. The training provided would align with the specific requirements of each role, focusing on relevant knowledge such as hydrogen properties, safety protocols, and distribution systems.

Education, Training and Knowledge for Hydrogen Adoption	
Aspect	Key Insights
Education Initiatives	- Education on hydrogen should begin at school and university levels, focusing on chemistry, safety, and real-world applications.
Addressing Knowledge Gaps	- Many regions have knowledge gaps regarding hydrogen's behaviour and applications; academic programs can help bridge these gaps.
Educating Key Professionals	- It is vital to educate architects, engineers, regulators, and other professionals, as they play a key role in hydrogen integration.
Bridging Theory and Practice	- Effective learning requires hands-on training and hydrogen system demonstrations to bridge the gap between theory and practice.
Facilitating Understanding	- Workshops, resources, and learning centres can enhance understanding of hydrogen technologies.

Broad Sector Knowledge	- A broad knowledge of the energy sector is crucial for effective hydrogen integration into existing systems.
Tailored Programs	- Universities can develop tailored degree programs and training courses that align with the needs of the hydrogen industry.
Certifications for Professionals	- Specific endorsements or certifications are proposed for professionals working on hydrogen systems due to safety considerations.
Comprehensive Education Content	- Education should encompass technical knowledge, safety protocols, regulations, and environmental impacts associated with hydrogen.
Optimism in Training Challenges	- Despite challenges in training and education, a focus on renewables and sustainability fosters optimism about hydrogen's future.

Table 19: Education, Training and Knowledge for Hydrogen Adoption

Overall, all participants agreed that the collaborative efforts needed from various stakeholders to ensure the successful integration of hydrogen technologies, including government support, industry engagement, educational initiatives, and specialized training programs. Multifaceted educational initiatives starting from schools and tailored workforce training are essential to address knowledge gaps, ensure safe handling, and enable smooth integration of hydrogen technologies.

4.23 LPG vs Green Hydrogen

The participants' perspectives on LPG and green hydrogen technologies reflect a nuanced evaluation of their potential within the context of New Zealand's built environment. LPG, once viewed with scepticism due to safety concerns and perceived explosive risks, has emerged as a widely adopted alternative to traditional fuels in the country. Notably, over 80% of fuel costs are attributed to liquefied petroleum gas (LPG), with the initial apprehensions regarding safety largely attributed to mishandling of equipment and not inherent flaws of the technology.

In parallel, the consensus among participants underscores the evolution of hydrogen as a viable and safe energy source akin to LPG. Green hydrogen, produced through renewable energy sources, has garnered recognition as a cleaner and sustainable alternative to carbon-emitting fuels. The comparison often drawn between hydrogen and LPG reveals hydrogen's potential to match or even surpass LPG's performance in various aspects.

LPG's established infrastructure and utilization within kitchens and businesses have prompted safety regulations and norms that address its handling and potential hazards. In comparison, green hydrogen has the capacity to significantly decarbonize the operating fuel of gas, offering a promising avenue for achieving sustainability goals. This transition is particularly relevant for bottled LPG applications, where hydrogen can be a cost-effective replacement. Moreover, the displacement of carbon emissions associated with traditional fuels, such as LPG or methane, positions green hydrogen as a viable means to reduce the carbon footprint.

In the context of New Zealand's built environment, the discussions point towards a shift in perceptions regarding the safety of novel energy sources. The introduction of LNG (liquefied natural gas) in New Zealand serves as a precedent, wherein public apprehensions were mitigated through government campaigns emphasizing the safety aspects. This suggests a potential trajectory for green hydrogen's acceptance within the country, as comprehensive safety measures and informative campaigns could pave the way for its integration into the built environment.

In summary, the participants' viewpoints mirror the changing attitudes towards LPG and green hydrogen technologies, reflecting a cautious optimism towards the latter's potential to shape a more sustainable future in New Zealand's built environment.

As DA and SGJA previously noted public concerns around the safety of LPG, which has a reputation as explosive. However, incidents often stem from mishandling rather than inherent technology flaws. EEf believes that proper equipment and safety procedures can mitigate risks, as with natural gas.

When considering substituting LPG with hydrogen in buildings, participants emphasized comparable or improved safety with hydrogen:

"Hydrogen is no more dangerous than LPG" (MS)

A key advantage of green hydrogen over LPG is eliminating greenhouse gas emissions, as RH and TW highlighted. Each kg of LPG burned produces around 3kg CO₂. Replacing LPG with renewable hydrogen in applications like water heating, cooking and electricity generation can decarbonize off-grid buildings. However, hydrogen does have lower volumetric energy density. Careful system design, leak detection, ventilation and training can manage flammability risks as RH has mentioned. As TW pointed out, the public does not currently perceive supply risks from LPG or natural gas.

The statements made by RH highlight the contextual factors that can influence the feasibility and appeal of hydrogen as a fuel gas compared to LPG. Specifically, the consideration of remote locations and the associated challenges of LPG transportation and carbon emissions become central to the evaluation of hydrogen's role in this scenario:

"If you're in a remote location and you're paying a lot of extra to get your LPG shipped in and you're really care about the carbon content both of the LPG and the shipping, then yes, hydrogen has a possible place as a fuel gas" (RH).

In remote locations, the logistical challenges and costs of transporting LPG can be substantial, potentially leading to elevated expenses for consumers. Additionally, the carbon footprint associated with both the LPG itself and the shipping process becomes a key concern for those who prioritize environmental sustainability.

Within this context, hydrogen emerges as a potential alternative that addresses these challenges. As a fuel gas, hydrogen has the advantage of being producible on-site through renewable energy sources, thereby reducing the need for complex and costly transportation logistics. Moreover, green hydrogen production does not generate carbon emissions, providing an environmentally conscious solution for areas concerned about carbon content.

In essence, the participant's perspective underscores that the suitability of hydrogen as a fuel gas, relative to LPG, hinges on the specific circumstances of remote locations where transportation costs and carbon emissions are significant considerations. In such scenarios, the adoption of hydrogen may align with both economic and environmental priorities, making it a plausible option for fulfilling energy needs while minimizing logistical challenges and carbon impact.

Challenges raised RH included the need to adapt burners and appliances to suit hydrogen's combustion properties, which differ from LPG. But simpler hydrogen burner designs are feasible. TN noted government PR campaigns helped introduce LNG in NZ, suggesting similar public outreach could assist hydrogen adoption.

RH expressed the opinion that hydrogen is indeed a safe energy option, particularly when compared to liquefied petroleum gas (LPG). According to RH, hydrogen's safety profile surpasses that of LPG, as it possesses certain characteristics that contribute to its safety.

RH highlights a safety concern associated with LPG, noting that it can accumulate in the environment on a calm day without readily dissipating. This accumulation can result in the build-up of energy, creating a potentially hazardous situation. RH goes on to explain that a spark or ignition source in the presence of accumulated LPG can trigger an explosion:

“In fact, hydrogen is very much safe. I agree it’s much safer than LPG, where LPG can on a still day can hang around in and build up a lot of energy and not dissipate” (RH).

By making this comparison, RH implies that hydrogen is a safer alternative because it does not have the same tendency to linger and accumulate in the environment. This perspective aligns with the general understanding that hydrogen, being lighter than air, has a natural tendency to disperse rapidly in the atmosphere. Consequently, the risk of accumulation and subsequent combustion due to ignition sources is significantly reduced in the case of hydrogen.

Overall, RH’s statement emphasizes the favourable safety characteristics of hydrogen when compared to LPG, contributing to the ongoing discourse about the safety considerations surrounding different energy options such as green hydrogen in various applications, including the built environment.

The viewpoint expressed by the **TW** revolves around the strategic selection of use cases for hydrogen within the New Zealand context. The participant emphasizes the importance of identifying specific scenarios where the substitution of bottled LPG with hydrogen can be a viable and cost-effective transition, particularly before the year 2025:

“It’s really just around choosing where the New Zealand use case is going to be, which I don’t think I’ve mentioned it yet, where the number one thing that you can look at is where bottled LPG is used because it’s a delivered fuel, you can essentially replace any bottled LPG use with hydrogen and that is going to be cost effective and or before 2025” (TW).

Bottled LPG, being a delivered fuel, presents a targeted opportunity for replacement with hydrogen. This is underscored by the potential to achieve comparable performance and energy output while also mitigating the carbon content associated with LPG. Notably, the participant suggests that the carbon content of various fuels, including LPG, can be effectively offset through the utilization of hydrogen. By switching to hydrogen, the participant contends that the existing carbon emissions from LPG, methane, diesel, and similar remote fuel sources can be significantly reduced, given that hydrogen is free from carbon emissions during its production and use:

“You can displace that exist exact carbon content of the fuel that you’re using. So compared to LPG, you can drop by however many carbon atoms are in there or methane or diesel or any of those other remote fuel sources. You can just place a lot of carbon by using hydrogen for sure” (TW).

Furthermore, TW highlights the current societal perception of risk regarding existing power supply connections and the use of conventional fuels such as LPG and methane. This perspective suggests that people do not currently perceive substantial risks associated with these energy sources. However, the participant’s emphasis on identifying suitable use cases and the potential for hydrogen to replace LPG indicates a strategic focus on leveraging hydrogen’s benefits in specific contexts, while also acknowledging the prevailing perceptions of safety and reliability associated with existing energy options.

In sum, TW’s perspective underscores the value of careful selection of use cases, such as replacing bottled LPG with hydrogen, as a means to address carbon emissions while maintaining energy supply reliability. This approach aligns with New Zealand’s objectives to integrate green hydrogen into its energy landscape and highlights the potential of hydrogen as a versatile and sustainable alternative to conventional fuels.

The viewpoint expressed by TN provides insight into the introduction of liquefied natural gas (LNG) in New Zealand and the associated government campaign aimed at assuring the public about its safety:

“When the LNG liquefied natural gas was introduced in New Zealand, there was some government campaign telling people that this is safe to handle” (TN).

The participant’s statement highlights a historical precedent involving the introduction of LNG to the New Zealand energy landscape. The participant notes that when LNG was introduced, the government undertook a campaign to communicate its safety aspects to the public. This campaign was likely driven by the need to address any concerns or misconceptions that the public might have had about the safety of handling and using LNG as an energy source.

While the participant’s statement does not explicitly mention the specific outcome of the campaign or the extent of public reception, it underscores the importance of proactive communication and education when introducing new energy technologies or sources. The reference to the government campaign suggests that safety considerations and public perception are key factors in the adoption of new energy options, including emerging alternatives like green hydrogen.

Overall, TN’s perspective highlights the significance of effectively addressing safety concerns and building public confidence when introducing new energy sources, drawing parallels between historical instances like the introduction of LNG and the ongoing discussions surrounding the potential adoption of green hydrogen in New Zealand and beyond.

LPG vs H2	
Aspect	Key Insights
Current Use of LPG	- LPG is widely used for heating and cooking in New Zealand but initially faced public scepticism around safety.
Risk Mitigation	- Proper equipment and handling have significantly mitigated risks associated with LPG use.
Green Hydrogen as an Alternative	- Green hydrogen is emerging as a promising clean, renewable alternative to LPG that can decarbonize off-grid buildings. It has comparable or better safety if systems are properly designed.
Economic Viability in Remote Areas	- In remote locations where LPG delivery is costly, green hydrogen could be economically viable and eliminate transport emissions. Targeting bottled LPG applications is a strategic starting point.
Safety Advantages of Hydrogen	- Hydrogen disperses rapidly, reducing the risk of accumulation and explosions that can occur with LPG leaks. However, compatibility with existing appliances must be considered.
Public Perception of Energy Supply Risks	- Current public perception does not associate energy supply risks with LPG or natural gas. Informative government campaigns, similar to those used during LNG adoption, could help build public confidence in hydrogen safety.

Hydrogen's Potential in Off-Grid Buildings	- With appropriate safety measures and careful selection of use cases, hydrogen has the potential to displace LPG in off-grid buildings and reduce emissions, supported by public education around its properties.

Table 20: LPG vs H2

In conclusion, participants saw the potential to substitute LPG with locally produced and stored renewable hydrogen in order to reduce emissions from off-grid buildings. With appropriate safety measures and burners, hydrogen was not perceived as riskier than existing LPG systems. However, stakeholders acknowledged public education is needed on hydrogen's properties and safety compared to incumbent fuels.

4.24 Fossil Fuels Dependency

Participants in the interviews expressed varied views about fossil fuels. Some participants highlighted the dependency on fossil fuels due to the absence of domestic resources, necessitating heavy imports. Others noted concerns about the environmental impacts and health risks associated with fossil fuels, emphasizing the need to transition to cleaner alternatives. The challenges of political interests and economic dependencies on fossil fuels were also mentioned. Several participants stressed the importance of reducing fossil fuel use to address global warming and emphasized the potential of hydrogen technologies as an alternative. The role of subsidies, market influence of fossil fuel companies, and the need for fair competition were also discussed. Overall, participants acknowledged the finite nature of fossil fuel resources and the urgency of transitioning to sustainable energy solutions.

For example, **SGJA** mentioned that the situation in Mexico is currently more influenced by political factors than technical ones. The current administration's strong focus on fossil fuels and support for state-owned companies is a significant issue. However, there is a recognition of the need to diversify and transition to cleaner energy sources. Importing hydrogen to meet demand is being considered as a solution to avoid the challenges of depending solely on one natural gas supplier. Additionally, there is a growing emphasis on green hydrogen, indicating a shift towards more sustainable energy options. SGJA expressed the belief that this approach is important for the country's future energy strategy.

JH highlighted the significant environmental stress caused by our heavy reliance on fossil fuels, underscoring the urgent need for caution. He debunked the persistent concerns about hydrogen's safety by comparing it to fossil fuels, which are actually more hazardous and detrimental. He also pointed out the substantial investments made in fossil fuel infrastructure and the ongoing global subsidies, despite the associated risks. He attributed the core issue to fossil fuels, asserting that they are at the root of many challenges. JH expressed these views based on his belief.

JAGR emphasized the prolonged timeline of oil formation spanning millions of years. He highlighted the multifaceted negative consequences of fossil fuels, encompassing environmental impacts, public health concerns, and the geopolitical reliance on other nations for energy security. JAGR countered the perception of hydrogen being expensive by advocating for understanding the broader implications of fossil fuels, including the opportunity for alternative solutions. He pointed out that countries like Mexico, Colombia, and Peru possess substantial fossil fuel reserves, but their potential is constrained by finite resources. He also drew attention to the streamlined nature of oil and gas value chains, characterized by extraction and distribution directly from the Earth. These viewpoints reflect JAGR's beliefs on the subject.

KQ expressed scepticism about the immediate shift away from fossil fuels due to the rising energy demand and the finite nature of fossil fuel resources. She noted the inherent challenge of finding

alternative energy sources or reducing energy consumption, given the necessity of energy in modern society. KQ believed that the replacement of fossil fuels would likely occur only when their reserves are fully depleted, indicating a practical perspective on the matter.

MS highlighted the escalating fuel prices and the growing reliance on fuel as a significant challenge. They contrasted oil and gas, which have a long history, with newer energy alternatives. Using Indonesia as an example, MS discussed the complexities of fuel subsidies and the country's unique situation of being an oil producer yet importing refined oil. They mentioned the delicate balance countries like Indonesia need to strike between maximizing oil and gas revenue through exports and addressing CO2 emissions. MS also touched on the potential water scarcity issues associated with widespread hydrogen production through electrolysis. This perspective underscores the multifaceted considerations involved in transitioning away from fossil fuels.

RH spoke about his expertise in replacing fossil fuels specifically for hot water heating. He emphasized the advantage of not requiring fossil fuels to operate such systems. He also highlighted the importance of considering long-term availability and cost factors, particularly for gas. RH expressed concerns about the future availability of gas, especially for plants with multi-decade lifespans. This viewpoint emphasizes the need to address not only environmental concerns but also practical considerations like resource depletion in energy transition strategies.

SJS articulated a comprehensive perspective on the transition from fossil fuels to hydrogen. He emphasized the urgency of ending the fossil fuel era, especially in the face of global warming threats. The pivotal role of hydrogen production in this transition was highlighted, with an emphasis on efficiency and cost-effectiveness. SJS advocated for hydrogen's potential as a substitute for fossil fuels and noted the dangers and toxicity associated with other gases. He discussed the need to eliminate subsidies for fossil fuels and promote fair competition for hydrogen.

SJS also critiqued the influence of large oil companies, emphasizing their substantial budgets and marketing efforts. He shed light on the economic dynamics of energy sourcing, like Germany's switch from Russian gas to fracked gas from the USA. He noted the need to consider various factors beyond energy generation, including water usage and electric energy demands in refining processes. This comprehensive view underscores the complex interplay of economic, environmental, and technical considerations in the energy transition.

SJS's viewpoint resounds with a clear and compelling assertion - the potential of hydrogen as a game-changer in energy lies wherever fossil fuels currently dominate. The shift to hydrogen represents a logical and imperative step, driven by both necessity and opportunity. The assertion that hydrogen could replace fossil fuels across various sectors implies a transformative shift in energy paradigms. However, the practicality of this transformation is contingent upon a critical factor - cost. SJS underscores the significance of hydrogen's cost competitiveness relative to fossil fuels. In this vision of the energy landscape, hydrogen emerges not only as a cleaner alternative but as an economically viable choice that holds the potential to reshape the energy map on a global scale.

VG expressed a strong belief in the sustainability of hydrogen as a clean technology that can replace diesel and other fossil fuels, promoting a transition towards cleaner solutions. The discussion shifted towards the broader context of Neom, a project in Saudi Arabia. VG highlighted the Saudi Arabian government's goal with Neom to diversify their economy and move away from heavy dependence on oil revenue. He underscored the urgency of preparing for a future where oil reserves might diminish, necessitating economic survival through attracting foreign investment, tourism, and skilled labour. This reflects a strategic approach to adapt to the evolving energy landscape and create a more resilient and sustainable economic foundation.

Fossil Fuels Dependence	
Aspect	Key Insights
Reliance on Fossil Fuels	- Many countries rely heavily on importing fossil fuels due to a lack of domestic resources.
Environmental and Health Impacts	- Fossil fuels contribute to environmental degradation and pose significant health risks, driving the need for cleaner energy.
Political and Economic Dependencies	- Political and economic interests create dependencies on fossil fuels that are difficult to overcome.
Addressing Climate Change	- Reducing fossil fuel use is critical to tackling climate change, and hydrogen presents a viable alternative.
Barriers to Transition	- Subsidies, market influence, and the lobbying power of fossil fuel companies impede the transition to clean energy.
Finite Nature of Fossil Fuels	- The finite nature of fossil fuel reserves underscores the urgency of shifting toward sustainable energy solutions.
Energy Mix Diversification	- Diversifying the energy mix is essential for building future resilience and achieving sustainability.
Hydrogen's Role	- Hydrogen's potential as a sustainable alternative depends on its cost competitiveness with fossil fuels in various sectors.
Broader Implications	- Broader environmental issues like pollution and resource depletion must be considered alongside financial costs.
Strategic Transition Approach	- A strategic approach is needed to reduce fossil fuel reliance and develop more sustainable energy systems.

Table 21: Fossil Fuels Dependence

In summary, despite challenges, transitioning from fossil fuel dependence is imperative and hydrogen offers potential if it can be cost competitive. A holistic view and strategic policies are key.

4.25 Hydrogen Economy

The perspectives shared by experts illuminate a dynamic landscape of hydrogen's pivotal role in shaping the future of energy and driving the emergence of the hydrogen economy. Delving into diverse nations' viewpoints, we find that hydrogen's allure is not confined to a single rationale but rather emerges from a convergence of economic, environmental, and technological imperatives.

In the case of Korea, an industrial powerhouse reliant on manufacturing, hydrogen emerges as a beacon of stability. Manufacturing demands a secure energy supply, and hydrogen seems poised to fulfil this need while catalysing the transition to a hydrogen economy. Meanwhile, Germany's meticulous focus on strategic partnerships underscores the global nature of the hydrogen revolution. Collaborative efforts, fortified by international standards, unveil a path toward sustainable energy transitions, amplifying hydrogen's transformative potential within the context of the hydrogen economy.

Saudi Arabia's strategic endeavour through Neom project comes to the forefront as it endeavours to craft a post-petroleum economy within the contours of the burgeoning hydrogen economy. The drive

to redefine the nation's economic architecture underscores the pressing urgency to escape fossil fuel dependency and embrace hydrogen's promise as a linchpin of the hydrogen economy.

As experts underscore, the symphony of hydrogen's advantages extends beyond its energetic capabilities. The envisioned fusion of sectors, from transportation to heavy industry, paints a holistic canvas within the evolving framework of the hydrogen economy. These intersecting threads form a blueprint for an interconnected and sustainable world, wherein hydrogen's virtuosity harmonizes economic growth, ecological integrity, and energy resilience, all under the banner of the hydrogen economy.

Intriguingly, the discourse around the hydrogen economy transcends borders, reflecting a global aspiration to metamorphose energy landscapes. It is not just about transitioning from one energy source to another; it is about orchestrating a transformative journey that captivates nations, industries, and academia alike, ushering in the age of the hydrogen economy. The alchemy of hydrogen, when juxtaposed against the canvas of differing national priorities, showcases the compelling narrative of a world poised to pivot toward cleaner, more agile energy paradigms within the hydrogen economy.

Korea's strategic embrace of hydrogen, particularly in the realm of hydrogen-powered vehicles, emerges as a conspicuous testament to its resolute commitment to reshaping its energy landscape, as **DA** pointed out. In the realm of hydrogen technology, Korea, as DA believes, stands as a formidable contender, raising the question of what propels its fervent engagement with this clean energy source. The answer, as DA sees it, lies in the intricate tapestry of Korea's manufacturing-based economy.

Much like several European counterparts, Korea's economic foundation rests on a robust manufacturing sector, as DA mentioned, that fuels its industrial prowess. As manufacturing remains a cornerstone of its economic identity, DA argues that a reliable and stable energy supply becomes paramount. Hydrogen, with its capacity to underpin a stable energy framework, assumes a role of significance in Korea's strategic calculus, as DA believes. The crux of Korea's hydrogen enthusiasm, according to DA, lies in the symbiotic potential it shares with its manufacturing-focused economy, providing a solid foundation for its future.

Delving into the specifics, as DA pointed out, the Korean manufacturing landscape necessitates consistent electricity supply. However, as DA highlighted, Korea's limited domestic energy resources compel it to rely on imports for various forms of energy, including natural gas and coal, with a conspicuous absence of domestic oil production. This energy import dependency, as DA noted, accentuates the urgency to decarbonize the national economy. Herein emerges the challenge, as DA sees it, of reconciling decarbonization aspirations with the realities of limited land availability and public concerns over wind farm-generated noise.

While traditional renewable solutions, as DA believes, encounter hurdles in Korea's unique geographical constraints, the nation finds an ally in the realm of hydrogen technology, as DA pointed out. The inherent suitability of fuel cells and hydrogen energy infrastructure for Korea's landscape, according to DA, becomes a beacon of promise. Fuel cells offer a distinct advantage, DA believes, presenting a viable and efficient means to meet the country's energy needs without being constrained by land limitations or public sensitivities to noise.

This strategic alignment between Korea's manufacturing-led economy and the versatile applications of hydrogen, as DA mentioned, culminates in its remarkable achievements. Korea's prominent role in fuel cell vehicle production, with a notable contribution from the Motor Company, demonstrates, as DA believes, a potent synergy between the hydrogen economy and its industrial foundation. Last year, Korea managed to commandeer over 60% of the global fuel cell vehicle market, an impressive feat that underscores, as DA sees it, its status as a pioneer in this transformative domain. Furthermore, Korea's dominance extends to fuel cell power plants, as DA pointed out, with the country hosting

more than two-thirds of the world's installations, amplifying its position as a catalyst in realizing the promise of hydrogen-powered energy.

In summary, DA's insights highlight Korea's pursuit of a hydrogen-based economy, rooted in the dynamic interplay between its manufacturing-centred economic model and the versatile potential of hydrogen technology. By leveraging the attributes of hydrogen and fuel cells, as DA emphasizes, Korea has positioned itself as a trailblazer in the transition towards a cleaner and more sustainable energy landscape, while concurrently bolstering its manufacturing legacy.

The sentiment echoed by **EEF**, encapsulated in the phrase "*We all build a hydrogen economy*", underscores a collective and collaborative approach towards shaping a future powered by hydrogen energy. This vision, championed by EEF, reflects a shared commitment to ushering in a new era of sustainable energy solutions. In embracing this ethos, EEF acknowledges the role of diverse stakeholders in contributing to the development and advancement of the hydrogen economy. His statement not only encapsulates a strategic shift towards cleaner energy alternatives but also highlights the need for partnership, innovation, and concerted efforts across industries, governments, and societies to collectively build a sustainable and prosperous hydrogen-powered future.

SGJA envisions a future where the transition to a hydrogen-based energy industry is not only technically feasible but also economically viable. This perspective acknowledges the ongoing progress towards achieving this transformation, suggesting that by the years 2040 to 2050, significant strides can be made in decarbonizing the energy sector.

Germany's proactive stance on the matter is noteworthy. With the publication of their national hydrogen strategy, Germany recognizes the need for a multi-pronged approach to meet their ambitious net-zero goals. The realization that domestic renewable energy potential may not suffice prompts a strategic shift towards international collaboration. The emphasis lies in cultivating a diverse network of suppliers for green hydrogen, fostering competitive markets that ensure affordability without compromising industry competitiveness.

In pursuit of this vision, Germany identifies nations with ample renewable energy resources and stable political and commercial relations. This approach aims to establish partnerships for hydrogen production, rehydration, and derivative export. This international framework spans regions beyond Germany, encompassing countries such as Mexico, Chile, Colombia, Brazil, Africa, and Southeast Asia. A key feature is the alignment of public and private sectors, capitalizing on public-private partnerships. Germany's strategy resonates particularly in Mexico, where a robust presence of German companies engaged in sustainable operations and export ventures underscores the potential for fruitful collaboration.

SGJA underscored the importance of diversified suppliers and competitive markets for green hydrogen, aimed at maintaining affordability without negatively impacting the industry. Germany has identified nations with potential for producing cost-effective renewable electricity and established collaborations for hydrogen production, rehydration, and derivatives. This program spans Mexico, Chile, Colombia, Brazil, Africa, and Southeast Asia.

This vision, guided by SGJA, envisions a holistic global hydrogen economy that hinges on cooperation, diversification, and innovation to usher in an era of cleaner and more sustainable energy practices.

According to **RGJA**, the feasibility of transitioning to green hydrogen hinges on the identification of effective business models and viable application cases. This is seen as a critical factor in achieving affordability for hydrogen solutions. However, the affordability of green hydrogen is also tied to broader systemic changes. RGJA underscores the significance of a global carbon market, suggesting

that the prices associated with carbon emissions should accurately reflect the environmental damage caused by these emissions to the atmosphere.

RGJA's viewpoint reflects the interconnectedness of various factors in shaping the future of the hydrogen economy. By emphasizing the need for a comprehensive approach that includes business models, application cases, and a global carbon market, RGJA envisions a scenario where the economic viability of green hydrogen is closely linked to a tangible shift in the way environmental costs are internalized and addressed on a global scale.

JAGR presents a multi-faceted perspective on the potential of the hydrogen economy. By quantifying various aspects, such as the number of employees and savings in public health services due to reduced respiratory illnesses, he highlights the practical implications of hydrogen adoption. He suggests that governments can leverage these quantifiable benefits to align their interests with the hydrogen market's growth trajectory. In this context, speaking the language of *“creation, savings on the health system, and incomes”* becomes essential to drive government support for hydrogen initiatives.

JAGR also emphasizes the importance of diverse skills in hydrogen storage and underscores the need for a circular economy approach. He envisions a cascade of benefits, including a cleaner environment and a more robust economy, particularly in urban areas. Additionally, he observes that the energy transition aligns harmoniously with broader economic concepts.

JAGR delves into the significance of extending the value chain, positing that a longer value chain could catalyse a substantial economic movement. Amidst the benefits and challenges, he notes the role of hydrogen in supporting the economic system, despite its artificial nature. He acknowledges that creating the necessary infrastructure presents a challenge, yet recognizes it as a crucial step toward realizing the hydrogen economy's potential.

Amid the ongoing discussions surrounding the hydrogen economy, another crucial aspect emerges – the social dimension. An intriguing debate centres around countries engaged in import-export dynamics. The question at hand revolves around whether exporting nations utilize hydrogen for their own domestic needs. This consideration stems from the notion that these nations should prioritize their own economic development, including electrification and water management, before solely exporting to global markets like Europe or Japan. This social criterion presents a significant point of contention, lacking a definitive framework. Nevertheless, the coming year might witness efforts to establish an evaluation framework that assesses the *“greenness”* of hydrogen in alignment with sustainable development criteria.

PL, a prominent voice, underscores a vital perspective within this discourse. He emphasizes two primary governmental objectives in this domain. The first entails the imperative to decarbonize various sectors, fostering environmental sustainability. Simultaneously, PL highlights the significance of job creation and economic value addition. This dual-pronged approach underscores the intrinsic balance between environmental betterment and economic growth. The government's commitment extends to supporting industries in component creation, bolstering the hydrogen ecosystem. An equally vital facet involves addressing the existing cost gap of green hydrogen within the current market landscape.

Expanding on this, PL elucidates the multi-faceted nature of the national plan. A comprehensive strategy encompasses not only these pivotal objectives but also allocates resources for territorial empowerment. This strategy aims to cultivate local ecosystems, shaping what is termed a *“Hydrogen Valley”*. As PL's insightful perspective unfolds, it becomes evident that the hydrogen economy encapsulates intricate social, economic, and environmental dimensions, with each facet intricately interconnected.

RH's perspective resonates with the potential of the hydrogen economy. Sustainability emerges as a robust narrative, underpinned by the accessibility of water. By shifting away from fossil fuels, a circular hydrogen energy ecosystem takes shape. This elegant cycle begins with water collected from roofs, serving as a renewable resource. Once utilized, hydrogen, whether through combustion or fuel cells, transforms back into water vapor, ascending to the clouds, only to return as precipitation. The cycle, devoid of human intervention, aligns harmoniously with the environment, leaving minimal ecological impact. This unique synergy reflects a sustainable paradigm, enriched by the notion of a localized circular economy.

Diving deeper into the landscape, RH's insights prompt contemplation about the nuances of hydrogen sourcing. RH points out the potential for exporting less sustainable, or "*brown*", hydrogen, highlighting the significance of the context in which the term "*clean energy*" is situated. Such reflections underscore the importance of a holistic approach to energy sourcing and utilization.

While the concept of transitioning to hydrogen holds promise, RH tempers expectations with economic pragmatism. The notion of swift adoption hinges on genuine demand and addresses surmountable challenges. However, RH introduces a dose of realism, suggesting caution in the face of prevailing economic factors and the readiness of techno-economic infrastructure. Through these nuanced perspectives, RH offers a balanced and informed perspective on the complexities of transitioning to a hydrogen-based energy system.

Undoubtedly, the local government assumes a pivotal role in catalysing economic growth within this paradigm. The prominence of hydrogen as a transformative agent extends well beyond the confines of factories, permeating diverse realms. This holistic perspective underscores the multifaceted potential that hydrogen harbours for driving economic advancement.

From **TN**'s vantage point, hydrogen's impact transcends conventional boundaries, encapsulating the broader economic fabric. This perspective underscores the strategic importance of local governance in harnessing hydrogen's potential to invigorate economies, offering a glimpse into a future where hydrogen's reach extends far beyond factory walls.

Certainly, a fragment of hydrogen's utility finds application in energy storage, yet its paramount purpose rests in international trade, particularly catering to the highest bidder, often situated in Europe or other lucrative markets. Notably, hydrogen's local utilization encompasses pivotal sectors such as mobility, green steel production, and industrial applications, further diversifying its impact.

Delving into the context of Saudi Arabia, **VG** elucidates the Neom initiative's overarching goal - to position the nation as an attractive hub for tourists, foreign workers, and economic growth. The cornerstone of Neom's strategy is establishing a renewable energy-driven system, effectively tackling the nation's energy predicament. VG's involvement within this hydrogen ecosystem focuses on hydrogen mobility and the creation of hydrogen refuelling infrastructure in the expansive Neom region, contributing to Saudi Arabia's sustainable evolution.

ZJ highlights a significant development in the realm of hydrogen economy, where the UK has allocated a substantial sum of over £375 million for the next seven years to bolster this burgeoning sector. Drawing parallels with Australia's approach, where solar energy is harnessed extensively to generate hydrogen for export to Japan, ZJ underscores the potential for emulation.

In light of the UK's potential success, ZJ envisions a more collaborative approach. Rather than each nation independently striving to create flagship hydrogen economies, ZJ proposes a model where successful prototypes, like that of the UK, could serve as invaluable references for other countries seeking to establish their hydrogen economies. This paradigm shift could streamline progress, foster international cooperation, and catalyse the global transition towards a hydrogen-powered future.

Hydrogen Economy	
Aspect	Key Insights
Hydrogen's Role in Manufacturing Economies	- Hydrogen is seen as a crucial element for enabling a stable energy supply in manufacturing-focused economies like Korea.
Suitability of Fuel Cells	- Fuel cells align with Korea's landscape constraints and support its manufacturing legacy and hydrogen economy ambitions.
International Collaboration	- Germany emphasizes the importance of international partnerships with countries that have renewable energy potential to develop a global hydrogen economy.
Competitive Market Strategies	- Competitive markets, diversified suppliers, and public-private partnerships are integral to Germany's hydrogen strategy.
Business Models and Applications	- Realizing the hydrogen economy requires identifying viable business models and applications to achieve affordable green hydrogen.
Government Support	- Government backing is crucial, aligning with hydrogen's benefits like job creation and public health savings to encourage adoption.
Infrastructure Development	- Extending the hydrogen value chain and developing necessary infrastructure are essential steps to harness its economic potential.
Social Considerations	- The social dimensions, including prioritizing domestic needs over exports, should be considered in the hydrogen economy.
Local Government Role	- Local governments play a pivotal role in enabling hydrogen's impact across various sectors, including mobility, industry, and steel production.
Local Utilization vs. Export Potential	- While export potential exists, local utilization is important to catalyse growth in the hydrogen economy.
Collaborative Models	- Collaborative models may accelerate progress more effectively than individual national efforts in advancing the hydrogen economy.

Table 22: Hydrogen Economy

The participants' views on the hydrogen economy encompass a range of perspectives. They recognize hydrogen's potential as a clean energy solution, emphasizing its role in decarbonizing industries and aiding energy transitions. Some stress the need for affordability, sustainable development criteria, and international standards. The debate over domestic usage versus export arises, with a focus on job creation, public health benefits, and economic growth. While challenges exist, such as technological readiness and cost parity, participants envision a future where hydrogen contributes to circular economies, energy storage, and global energy markets, underscoring the importance of collaborative reference models for successful hydrogen economies. In summary, the hydrogen economy relies on international cooperation, strong policy support, competitive markets and multi-sector utilization to unlock hydrogen's socio-economic and environmental potential.

4.26 International Collaboration

The voices echoed in the interviews underscore a unanimous understanding of the paramount significance of international collaboration in the evolution of the hydrogen economy. These nuanced insights illuminate a collective consciousness that recognizes the indispensability of intercontinental cooperation to navigate the intricate terrain of hydrogen technology, collectively embracing the prospects and challenges that lie ahead. Diverse perspectives from participants hailing from various corners of the world converge on key themes revolving around shared experiences, standardized practices, knowledge exchange, and collaborative initiatives.

SGJA emphasized that the program involves public-private partnerships and reaches across various countries. In Mexico, the presence of German companies with interests in decarbonization and export opportunities for green ammonia has motivated collaborative efforts. SGJA highlighted their role in sharing technical documents and engaging with various stakeholders, including Mexican and German companies, as well as subnational governments. Their collaborative process involves iterative discussions and proposal approvals from the German Government to drive forward hydrogen-related initiatives. SGJA's comments illustrated his thoughtful perspective on international collaboration and the multifaceted efforts undertaken to advance the hydrogen economy.

International collaboration is crucial for the hydrogen industry as it facilitates the gathering of essential data and information needed for successful initiatives. This collaboration occurs not only at the national and regional levels but also on an international scale. As participant MR aptly pointed out, the synergy achieved through global partnerships allows for a comprehensive exchange of knowledge, expertise, and resources. With companies spanning countries like Germany, Italy, and Thailand, the hydrogen sector benefits immensely from the insights and experiences shared across diverse markets. This collective effort serves as a foundation for accelerating the growth and innovation within the hydrogen industry, enabling the development of sustainable and impactful projects. As MR highlighted, the cooperation among nations further amplifies the potential for green hydrogen to play a pivotal role in the global transition to cleaner energy sources.

From these introspective sessions, hydrogen emerged as a resolute preference. The journey thereafter is characterized by proactive engagement with global players, sourcing technologies, and orchestrating trial scenarios to amass practical wisdom. The undercurrent here is the collective realization that harnessing the potential of hydrogen requires concerted effort, not only at the company level and on a national scale, but also on an international scale.

The essence of TW's vision lies in the synchronization of efforts across nations, a collaborative endeavour to elevate hydrogen's viability. By uniting behind a common vision and fostering a conducive ecosystem for technology providers, the trajectory toward hydrogen gains momentum. This perspective resonates with the notion of proactively creating solutions before the environmental exigencies compel such actions. The tangibility of this vision is manifold - from virtual power plants to curtailed energy capture, from abundant energy generation to the imperative conundrum of energy storage for hydrogen.

TW's narrative is one of preparation and collaborative action, with an understanding that hydrogen's promise can be fulfilled through unified determination and strategic implementation.

TW highlights the imperative of proactive and assertive national pursuits in the realm of green hydrogen. Their perspective underscores the importance of supporting technology providers with confidence and facilitating their investments for upscaling and cost reduction. TW emphasizes that collective action is pivotal, as multiple countries adopting a unified approach can accelerate the deployment of existing solutions. The focus is on efficient implementation to overcome hurdles

related to economic viability and environmental resilience. While mechanisms like green certificates and weather events can drive progress, TW suggests that international collaboration can serve as an additional lever to expedite the transition to green hydrogen before external pressures become dominant. This approach ultimately fosters tangible value in both environmental sustainability and security aspects.

In summation, the interviews coalesce into a symphony of harmonized voices that collectively affirm the inextricable link between international collaboration and the unfolding narrative of hydrogen technology. This congruence resonates with the overarching international scope of the hydrogen economy, where shared wisdom, standardized protocols, and synchronized endeavours emerge as the linchpins propelling the ascent of hydrogen as an environmentally sustainable and universally embraced energy source.

4.27 Skills, New Careers and Job Opportunities

The participants' discussions shed light on the skills required for the hydrogen economy and the emerging job opportunities. They emphasize that while specialized knowledge in hydrogen technology is essential for a portion of the workforce, a majority of roles can be filled by individuals with existing engineering backgrounds. Many highlight the need for understanding electrochemistry, safety regulations, and the properties of hydrogen. The consensus is that retraining and upskilling programs can bridge knowledge gaps. This shift towards the hydrogen economy is seen as a chance to create new professions, particularly in areas such as green energy and infrastructure development. Moreover, it is suggested that the diverse skill sets required could provide job opportunities for marginalized communities, such as the Māori in New Zealand, aligning with national priorities for inclusivity and sustainable growth.

EEF emphasizes the evolving landscape in the hydrogen sector, noting the growing pool of experts and the intriguing developments taking place. While the knowledge base of green hydrogen may share similarities with that of natural gas, EEF points out that specific skills are crucial for effective implementation. EEF underscores the significance of leveraging expertise in industries like natural gas, where understanding of handling, safety regulations, and operational norms are essential. Drawing parallels to alternative gaseous fuels, EEF asserts that countries or teams should tap into existing knowledge to foster successful hydrogen transitions. EEF highlights a potential challenge in regions like Costa Rica, where a lack of prior gas-related experience may pose obstacles. Recognizing the value of knowledge encompassing natural gas practices, codes, norms, and standards, EEF emphasizes its pivotal role in facilitating a smooth transition to green hydrogen and driving skills development and job opportunities within the industry.

JH emphasizes the wealth of practical talent within the oil and gas industry, which can be harnessed for the hands-on implementation of hydrogen initiatives. This reservoir of expertise is particularly valuable in driving practical aspects of transitioning to more sustainable energy sources. JH underscores the necessity of developing human capital specifically tailored to the hydrogen sector, recognizing the crucial role that skilled professionals play in successful adoption and implementation of hydrogen technologies. This approach aligns with the broader goal of utilizing existing practical talents to facilitate the transition to a more sustainable energy landscape.

RGJA highlights that the emergence of the hydrogen industry creates opportunities for new careers and professions to flourish. This expansion in the energy sector necessitates proper certification to ensure competence and safety in these roles. RGJA emphasizes that this growth can lead to the creation of new jobs and professions, each aligned with the evolving demands of the hydrogen economy. This perspective underscores the transformative potential of the hydrogen sector in not only reshaping the energy landscape but also in generating meaningful employment opportunities:

“I think it opens a door or new careers. It can open new professions and the and new job opportunities respectively” (RGJA).

JAGR acknowledges the accessibility of working in the hydrogen sector, noting that it is not as complex as it might seem:

“It’s not rocket science. It’s very easy and everyone can do it” (JAGR).

With personal experience in assembling an electrolyser post-bachelor’s degree, JAGR emphasizes that anyone committed to the cause can contribute to the field. JAGR highlights the potential for countries to engage in hydrogen initiatives, underlining this as an important point to communicate. Quantifying employment potential through the creation of full-time jobs is also recognized as a significant aspect.

JAGR observes a shortage of electrical engineers in their country, suggesting that the trend towards electrification amplifies the demand for such skills. This shortage highlights the need for training and education to address gaps in the labour market. The speaker emphasizes the reusability of knowledge from related fields, particularly those involving gas systems like natural gas, which share similarities with hydrogen systems.

JAGR points out that professionals with expertise in energy and gas systems could undergo retraining to adapt their skills to the hydrogen sector. The importance of specialized skills is acknowledged, such as those needed for hydrogen storage and production. JAGR’s insights shed light on the adaptable nature of skill sets and the potential for professionals from diverse backgrounds to contribute to the growth of the hydrogen sector.

MR conveys confidence in the available tools and resources to drive the hydrogen transition. Acknowledging potential resource constraints for smaller companies, MR emphasizes the importance of time and resources in pursuing this transition. The speaker notes the broad applicability of hydrogen technology across various industries, highlighting that this transition is a collective endeavour.

MR underscores the necessity of updates and adaptations to meet the demands of the evolving hydrogen sector. They observe a strong interest in the subject matter and identify specific skill sets that are in demand. The need for skills in digitalization and automation stands out, given the growing importance of these aspects in the integration of hydrogen technologies. Additionally, MR emphasizes the value of skills related to chemistry and safety, reflecting the multi-faceted nature of the sector's requirements. Overall, MR’s insights point to the significant opportunities for individuals with diverse skill sets to contribute to the hydrogen industry’s growth and development.

PL underscores the dual objectives of government efforts in the hydrogen sector, highlighting their commitment to both decarbonizing industries and fostering job creation in sustainable areas. This approach is seen as instrumental in not only mitigating environmental impacts but also bolstering the economy by generating new employment opportunities. PL emphasizes the parity of these two goals, emphasizing that they hold equal importance.

To achieve these objectives, PL notes that substantial attention is given to supporting the industry’s growth. This involves facilitating the creation of components needed for the hydrogen sector’s expansion. However, PL also highlights another pivotal aspect of these efforts - bridging the gap between the current cost of green hydrogen in the market and its desired affordability. This focus on cost reduction is key to making green hydrogen competitive and viable on a larger scale. Overall, PL’s insights shed light on the multi-faceted strategies that governments employ to drive the hydrogen transition while balancing economic and environmental imperatives.

VG highlights the diverse nature of job roles within the hydrogen industry, comparing it to any other sector. While hydrogen-specific technical expertise is crucial for a small portion of the workforce, VG estimates around 10%, the majority of roles don't necessitate an in-depth knowledge of hydrogen processes. VG notes that functions like project management, sales management, and accounting are applicable across industries and are equally relevant in the hydrogen sector.

VG points out that for the majority of hydrogen jobs, individuals can be recruited from various fields, bringing their existing skills to contribute to the industry. While a technical background with a hydrogen focus is beneficial for the 10% of specialized roles, VG doesn't see a need for extensive retraining efforts. Instead, the industry can tap into the existing workforce and allow employees to learn on the job, especially for non-technical roles. VG highlights the value of having a broad understanding of the energy sector, which helps professionals grasp the role of hydrogen within the larger energy landscape. In this context, VG underscores the versatility of skills needed in the hydrogen industry and its potential to absorb professionals from various backgrounds.

ZJ highlights that the engineering background, particularly engineering degrees, is well-suited for roles within the hydrogen industry. They mention that transitioning from one engineering field to another is often not too difficult, given the foundational technical knowledge shared among various engineering disciplines. ZJ notes that the specific expertise needed often depends on the government's priorities and the company's focus.

For companies primarily involved in hydrogen production, ZJ explains that professionals with chemical, mechanical, and electrical engineering backgrounds are sought after. These roles require an understanding of hydrogen production principles. Similarly, for roles involving distribution and storage, mechanical and electrical engineering knowledge is emphasized, while chemical engineering knowledge is less pertinent. ZJ points out that trainings in these cases would likely centre on hydrogen properties, safety considerations for storage and distribution, and relevant engineering aspects. This flexible approach to skill adaptation based on the industry's focus underscores the importance of aligning engineering expertise with the specific needs and goals of hydrogen-related projects.

Participants' views on the new skills required and job opportunities within the hydrogen economy reveal a consensus that while specialized hydrogen knowledge is essential for a fraction of roles, the majority of positions can be filled by professionals with diverse engineering backgrounds. The industry's versatility allows for skills transfer, particularly within the engineering domain. For roles in hydrogen production, chemical, mechanical, and electrical engineering knowledge is crucial, while distribution and storage roles emphasize mechanical and electrical expertise. Overall, the emphasis is on utilizing existing engineering skills and providing focused training for hydrogen-specific aspects, enabling professionals to contribute effectively to the industry's growth and sustainability.

Skills, Careers and Job Opportunities in the Hydrogen Economy	
Aspect	Key Insights
Role of Specialized Knowledge	- While specialized hydrogen knowledge is vital for certain roles, most positions can be filled by engineers from other backgrounds.
Essential Understanding	- A solid grasp of electrochemistry, hydrogen properties, safety regulations, and handling practices is important.
Retraining Opportunities	- Retraining programs can help adapt existing engineering skills (mechanical, chemical, electrical) for the hydrogen sector.

Talent from Natural Gas Industry	- Talent from the natural gas industry is valuable due to their hands-on experience transitioning to hydrogen.
Emerging Careers	- The emergence of the hydrogen industry allows for the development of new careers and professions aligned with sector needs.
Demand for Electrical Engineers	- There is a notable shortage of electrical engineers, highlighting the demand for skills related to automation and electrification.
Government Initiatives	- Governments aim to facilitate job creation in the hydrogen sector while pursuing decarbonization goals.
Cost Reduction and Industry Growth	- Reducing costs is a key priority alongside supporting industry growth and local component creation.
On-the-Job Learning	- Only about 10% of roles require specialized hydrogen expertise; the majority can learn on-the-job, even in non-technical roles.
Broad Energy Sector Knowledge	- A broad understanding of the energy sector helps situate hydrogen's role within the larger context.
Tailored Training Programs	- Training should be tailored to specific project focuses, such as production, storage, and distribution of hydrogen.

Table 23: Skills, Careers and Job Opportunities in the Hydrogen Economy

In summary, the hydrogen economy allows utilization of diverse engineering skill sets while targeted training and new programs develop specialized expertise and create job opportunities.

4.28 Commercialisation and Scaling-Up

Participants' opinions converge on the critical challenges and opportunities in the commercialization and scaling up of green hydrogen production. It's apparent that achieving widespread commercial viability hinges on factors like mass production, economies of scale, and reductions in electrolyser costs. The consensus is that while the technology is promising, achieving cost competitiveness necessitates large-scale production, akin to the trajectory observed in other industries like solar panels and automotive sectors. This requires standardized, mass-produced electrolysers, which many participants anticipate will lead to substantial price reductions over time.

Participants acknowledge the potential of green hydrogen as a clean energy solution, especially for remote or distributed energy needs. The challenges faced in larger-scale applications, such as powering cities or industries, mirror those observed globally. While hydrogen is seen as a key player in decarbonization efforts, the road to its commercialization involves concerted efforts to lower production costs through innovation and scaling up. For New Zealand, a country embracing renewable energy, the trajectory of electrolyser costs and hydrogen production technologies will likely influence the extent to which green hydrogen becomes a feasible and affordable option for integrated energy systems and sustainable urban development.

DA's opinions revolve around the challenges and considerations regarding the commercialization and scaling-up of green hydrogen and hydrogen technologies. He expresses scepticism about the current level of commercialization in the hydrogen sector, noting that there is no widely established and

commercially available technology for hydrogen production. This sentiment is reinforced by his assertion that making hydrogen is not yet commercially viable:

“Unfortunately, there’s not commercialized technology” (DA).

DA emphasizes the importance of technology availability and its commercial feasibility. He questions whether the technologies being developed are truly cost-effective and ready for widespread commercial use. He acknowledges the existence of numerous companies working on various hydrogen technologies, but he underscores the need for these technologies to not only be innovative but also financially viable:

“Making hydrogen is not commercially available” (DA).

One key point he highlights is the relationship between production volume and cost. He refers to a fundamental economic principle that often applies: the more a product is produced, the lower its cost becomes. This implies that achieving significant economies of scale is crucial for making green hydrogen economically competitive compared to conventional energy sources:

“Before we talk about the sustainability of hydrogen, I think we should talk about the volume first. So the more hydrogen we make, it’s a rule of thumb in the economics, right. The more you make something the lower cost it will have” (DA).

DA also alludes to the challenge of procuring hydrogen technologies on demand. He raises the issue of hydrogen systems not being readily available off the shelf, especially in the context of needing large-scale systems quickly. This speaks to the complexity and specialized nature of the technology involved.

Finally, he touches upon the government's perspective on hydrogen scaling. He suggests that governmental priorities might not necessarily focus on the carbon intensity of hydrogen but rather on the broader goal of scaling up hydrogen production and utilization as part of larger national strategies for decarbonization:

“The government doesn't really care about the carbon intensity of hydrogen. So what they’re caring is about the scaling up the hydrogen” (DA).

In summary, DA’s opinions reflect a cautious approach to the commercialization and scaling-up of green hydrogen and hydrogen technologies. He highlights the need for viable and cost-effective technologies, significant economies of scale, and the potential divergence between governmental priorities and environmental considerations.

SGJA from Mexico expresses a more optimistic perspective on the commercialization and scaling-up of green hydrogen and hydrogen technologies. He believes that progress is being made towards achieving economic feasibility in this sector. He indicates that efforts are underway to make hydrogen technologies economically viable, suggesting that advancements in technology and processes are contributing to this positive trajectory.

SGJA’s statement *“I think we are on the way to make it economically feasible”* implies that the necessary steps are being taken to address the economic challenges associated with green hydrogen. He sees a pathway towards overcoming these challenges and making hydrogen technologies financially viable.

Furthermore, SGJA mentions that there are plans to start scaling hydrogen technologies. This suggests that Mexico is not only focused on making these technologies economically feasible but also on expanding their deployment on a larger scale. This aligns with the broader trend of scaling up hydrogen production and utilization to meet sustainability and decarbonization goals.

RGJA emphasizes that the main challenge and bottleneck in the current landscape of green hydrogen and hydrogen technologies is the availability of sufficient industrial capacity for production. He points out that the ability to produce hydrogen at a scale that meets demand is a critical factor in the commercialization and scaling-up of these technologies.

RGJA also provides a more positive perspective, stating that while industrial capacity might be a challenge, it is not an insurmountable problem. He believes that if private investors recognize the market demand for hydrogen products and technologies, they will be motivated to invest in projects that expand production capacity. This indicates that the potential for private sector investment and involvement is seen as a driving force behind addressing the capacity issue.

Furthermore, RGJA highlights the importance of scale in addressing this challenge. He mentions that activating and leveraging economies of scale is a key strategy to overcome the hurdles associated with industrial capacity limitations. This aligns with the common understanding that as production scales up, costs tend to decrease due to efficiency gains and technological advancements.

JAGR emphasizes the critical role of economies of scale in the hydrogen business, highlighting its current importance and potential for the future. Larger scale projects are becoming a focus. The concept of generating electricity from hydrogen is seen as economically feasible, particularly on a large scale. While the idea has potential, it is acknowledged that its viability is currently more apparent in larger-scale applications.

JAGR also notes the impact of scale on electrolyzers' efficiency. In smaller-scale electrolyzers, energy consumption ranges from 60 to 65 kWh per kilogram of hydrogen, whereas larger electrolyzers benefit from greater efficiency, potentially achieving energy consumption of around 53 kWh per kilogram. This efficiency improvement in larger electrolyzers is attributed to better load balancing and the optimization of the entire plant's operations.

MR points out the importance of optimization before rapid scaling in the context of green hydrogen commercialization and scaling-up efforts. While there is a pressing need for hydrogen, particularly in fast-paced environments, she emphasizes the necessity of careful optimization before scaling up too quickly. This cautious approach takes into consideration resource limitations and challenges that smaller companies might face. In essence, MR highlights the balance between the urgency of hydrogen demand and the need for prudent optimization to ensure successful and sustainable scaling-up.

MS highlights the importance of flexibility in building hydrogen production capacity according to specific energy needs. Drawing an analogy to IBM mainframe computers, he explains the necessity of tailoring the capacity to the scale of demand, whether for a small town, a single house, or a car refuelling station. He further discusses a specific project in Malaysia where 22 metric tons of hydrogen per day were required for a power station. MS explains that in such industrial-scale scenarios, renewable sources alone might not suffice due to the immense scale of demand. In this case, alkaline electrolysis was the viable solution despite its industrial nature and recent introduction to the industry. This instance underscores the practical challenges and considerations involved in scaling up hydrogen production to meet large-scale industrial needs.

PL provides insights into the diversity of hydrogen projects in France and the crucial role of project size. He highlights two main types of projects in the country: large-scale industrial projects in main industrial areas with capacities of 50 to 200 megawatts, and smaller projects focused on local mobility needs. These smaller projects are often supported by local authorities and municipalities and are tailored to the specific needs of the region.

He emphasizes that the dimension of territories is a key consideration in hydrogen projects, with local authorities playing an important role in supporting initiatives that cater to their specific needs. PL

points out that projects in France are influenced by the cost of electricity and the cost of electrolyzers. While the cost of electrolyzers is expected to decrease with public funding support, the cost of electricity remains a challenge, especially considering the relatively higher cost of renewable sources like PV plants in France compared to other countries like Spain. This highlights the complex interplay of factors that impact the feasibility and cost-effectiveness of scaling up hydrogen technologies.

RH emphasizes the economic aspect of hydrogen production and scaling. He points out that the choice of hydrogen generator and the scale at which it is deployed play crucial roles in determining the price. He suggests that the economics of hydrogen production are intricately tied to factors such as technology choice, scalability, and the speed of scaling up. This perspective underscores the importance of strategic decision-making and efficient scaling strategies in the commercialization and widespread adoption of green hydrogen technologies.

SJS emphasizes the potential for cost reduction in hydrogen production through mass fabrication and scalability. He highlights the success of applying similar strategies in other industries, such as automotive and solar panels, which led to significant price reductions and improved quality. SJS's optimism stems from the belief that by adopting these ideas and approaches, the hydrogen industry can achieve a much lower price point in a relatively short timeframe. He also mentions ongoing progress, including the development of multicore systems, which aims to further enhance the scalability and visibility of hydrogen technologies. This perspective underscores the role of innovation, scalability, and cross-industry learning in driving the commercialization and affordability of green hydrogen solutions. SJS also emphasizes the importance of considering the scale of production when evaluating distribution models for hydrogen. He suggests that large-scale production might be more suitable for certain scenarios due to associated transportation and distribution costs. However, he also acknowledges that the optimal approach depends on the specific use case. SJS's viewpoint aligns with the idea that the distribution model for hydrogen should be tailored to the energy demands and characteristics of different areas and industries:

"It's always good to make large scale. Then you have to calculate the cost for transportation and distribution. And this comes quite a with a hefty cost. I think it depends very much on the use case on what is in the end. So if you have, let's say a big factories which needs a lot of energy or a lot of gas, they need also huge numbers of gas, but if you have a remote city with 200 people living there and they are remote and then for sure it's small distributed energy system makes definitely more sense" (SJS).

TW provides insights into the current state of hydrogen technology commercialization and scaling. He acknowledges that the high costs are attributed to the absence of mass production and the ongoing research and development efforts. He mentions Enapter's progress in constructing a mass production facility, which is expected to significantly reduce costs. TW shares that the cost of their hydrogen generation systems has already decreased, and this trend is expected to continue as mass production is fully realized. TW also highlights the collaborative approach to technology development, mentioning the importance of assisting technology providers, building their confidence, and facilitating their investment case to enable them to scale up and make hydrogen technologies more affordable.

TN expresses concerns about the affordability of green hydrogen and emphasizes the necessity for large-scale implementation, which includes both the production of electricity and the utilization of electrolyzers. TN highlights the crucial role of mass production in reducing costs, implying that cost-effectiveness can only be achieved through economies of scale. TN provides insight into the energy consumption associated with hydrogen production, stating that it typically ranges from 60 to 70 kWh per kilogram of hydrogen. He notes that the efficiency and electricity consumption are influenced by the size of the electrolyser; larger electrolysers may consume more electricity but can be more efficient in the long run. Regarding electrolyser capacity, TN suggests that a minimum of 1 MW-

class electrolyzers is considered viable, with the potential for even greater efficiency gains when doubling the capacity to 2 MW. This insight underscores the balance between scale, efficiency, and cost-effectiveness in the context of hydrogen production.

VG highlights a significant development in green hydrogen production, specifically mentioning the construction of a 2.2 GW electrolyser in partnership with Aqua Power and Air Products. This underscores the participant's involvement in large-scale hydrogen projects and collaboration with industry stakeholders. VG's perspective on overcoming the challenges of high costs through scaling aligns with the general principle seen in various technologies. He emphasizes that as hydrogen-related technologies, including electrolysis, hydrogen-powered vehicles like cars and trucks, and overall production processes, are scaled up, the associated production costs will naturally decrease. This viewpoint dismisses the notion of any magical solution and underscores the practicality of achieving cost reduction through the proven method of scaling.

ZJ provides insights into significant hydrogen projects taking place in the UK and China. He mentions the UK's notable project involving hydrogen generation from wind resources in Wales, showcasing the country's commitment to utilizing renewable sources for hydrogen production. In China, the participant notes the presence of over 100 megawatts of alkaline electrolyzers for hydrogen production, which are being used to support local heating and domestic applications. Furthermore, the participant discusses the UK's efforts in developing a low carbon standard for hydrogen. ZJ highlights the ongoing focus on encouraging the upscaling of hydrogen production as part of the phase one strategy, which spans from 2020 to 2030.

In summary, participants see commercialization and scaling-up of green hydrogen as achievable but challenging. Strategic, well-planned scale-up supported by policies and investment can drive the needed cost improvements through innovation and economies of scale.

Commercialization and Scaling-Up Summary	
Aspect	Key Insights
Economies of Scale	- Achieving economies of scale is crucial for driving down costs and making green hydrogen economically competitive, similar to trends in solar panels, batteries, and automobiles.
Standardized Electrolyser Production	- Mass production of standardized electrolyzers is essential for reducing costs and scaling up hydrogen, as seen in other renewable technologies.
Hydrogen Technologies Development	- Current hydrogen technologies are promising but still under development, requiring further research, development, and demonstrations before they are commercially viable at scale.
Role of Government and Private Investment	- Both government policy and private sector investment play vital roles in scaling up production capacity and building infrastructure.
Optimizing Before Scaling	- There is a need for caution in scaling too quickly before optimizing hydrogen technologies, though urgency remains to meet growing demand.
Large-Scale Hydrogen Projects	- Several international large-scale hydrogen projects were highlighted, signalling growing momentum in the sector.

Tailored Solutions by Application	- The optimal scale and distribution model for hydrogen solutions depends on the application, with different needs for large industrial versus small mobility or residential uses.
Local Conditions	- Local conditions significantly influence the best approach to hydrogen production and distribution.
Optimism for Cost Reduction	- There is general optimism about potential cost reductions as hydrogen production scales up, but it will require time, effort, and collaboration between stakeholders.

Table 24: Commercialization and Scaling-Up Summary

4.29 Competitiveness

The participants' viewpoints on hydrogen market competitiveness collectively highlight several key considerations. One prominent theme revolves around achieving cost competitiveness, with emphasis on the need to match or surpass prices offered by market counterparts, particularly from certain regions. The challenge of reducing costs is often mentioned, with the belief that scalability and mass production of electrolyzers are essential for driving down expenses. While acknowledging the importance of government subsidies in certain regions, participants from countries without such support express concerns about how to remain competitive against subsidized counterparts.

Technological advancements play a pivotal role in achieving competitiveness, with a consensus that innovation and scalable production are key to cost reduction. The impact of technological maturity on market viability is underscored, as mature technologies are expected to offer more competitive solutions. The role of public funding and financial support programs is acknowledged in bridging cost gaps and facilitating the adoption of new technologies, particularly those related to renewable energy sources.

The participants acknowledge the significance of fair competition and the need to level the playing field. There is a call to eliminate or significantly reduce subsidies for fossil fuels, allowing hydrogen and other technologies to compete on an equitable basis. Concerns about the influence of established industries and marketing budgets are also expressed, highlighting the complex dynamics of market competition.

The participants recognize the importance of early investment and proactive engagement in hydrogen technologies. Those with first-hand experience in ongoing projects emphasize the significance of starting early to gain a competitive edge and promote market growth.

DA's perspective highlights the challenge of achieving cost competitiveness in the hydrogen industry, particularly in comparison to countries like China. The participant's concern centres on the absence of government subsidies in their country and the pressures of decarbonizing their civil manufacturing sector. This raises questions about how to remain competitive against counterparts in regions that offer financial support for hydrogen initiatives. The participant's viewpoint underscores the importance of subsidies and government support in influencing the competitiveness of the hydrogen industry. It also reflects the broader economic and policy factors that can impact a company's ability to compete in the global market for hydrogen technologies.

MR's perspective emphasizes the significance of technological advancements in driving the competitiveness of hydrogen, both against green hydrogen and alternative fuels. The participant's statement underscores the crucial role that cost reduction plays in the adoption of hydrogen as a viable solution. By addressing cost barriers through innovative technologies, hydrogen can become a compelling option in the energy landscape. This viewpoint underscores the dynamic relationship

between technological progress, cost-effectiveness, and the broader adoption of hydrogen technologies.

PL provides valuable insights into the factors that determine the competitiveness of hydrogen technologies. Their institute collaborates closely with industry partners to develop technologies and conduct techno-economic analyses of systems. They explore critical questions such as grid connectivity and load factors, aiming to determine the conditions under which energy systems can achieve competitiveness.

PL's mention of feed-in tariffs and cost projections for PV in a region like South of France reflects an understanding of the cost dynamics that influence hydrogen's competitiveness. They acknowledge the need for public funding to bridge the gap between cost levels and ensure hydrogen's viability.

The statement about the presence of large-scale hydrogen production and competitors highlights PL's awareness of the market landscape and the need for strategic positioning to remain competitive. Overall, PL's perspective underscores the intricate interplay between technology, cost, public support, and market dynamics in shaping the competitiveness of the hydrogen industry.

SJS emphasizes the importance of creating a level playing field by discontinuing subsidies for fossil fuel industries. They argue that by removing support for both hydrogen and fossil fuels, hydrogen would have the opportunity to compete freely in the market. SJS envisions that this fair competition would lead people to recognize the advantages of hydrogen, and its adoption would naturally follow.

SJS also acknowledges the significant influence of large oil companies, noting that their substantial budgets, especially for marketing, can shape public perceptions and preferences. By advocating for transparency and equal treatment across technologies, SJS suggests that hydrogen could emerge as a viable and competitive solution. This perspective underscores the need to address systemic biases and create an environment that promotes innovation and fair market competition in the hydrogen industry.

ZJ highlights the role of funding competitions in promoting the development of hydrogen projects. These competitions focus on supporting feasibility studies and demonstration projects that showcase the capability of producing hydrogen using low-carbon technologies, with a particular emphasis on green hydrogen. ZJ indicates that financial support is derived from various sources, including supportive venture investments, competitive funding programs, and established initiatives. ZJ's perspective underscores the importance of financial backing and incentives to drive the advancement of green hydrogen technologies. By providing funding opportunities for feasibility studies and demonstrations, stakeholders can facilitate the growth and competitiveness of the hydrogen industry, ultimately contributing to its successful commercialization and adoption.

In conclusion, the participants' perspectives collectively underscore the crucial role of cost competitiveness, technological innovation, equitable support mechanisms, and early engagement in shaping the dynamics of the hydrogen market. These factors are seen as critical in positioning hydrogen as a viable and competitive energy solution in the global landscape.

Hydrogen Market Competitiveness	
Aspect	Key Insights
Economies of Scale	- Achieving economies of scale is crucial for driving down costs and making green hydrogen economically competitive, similar to trends in solar panels and batteries.
Standardized Electrolyser Production	- Mass production of standardized electrolysers is essential for reducing costs and scaling up hydrogen, as seen in other renewable technologies.

Hydrogen Technologies Development	- Current hydrogen technologies are promising but still under development, requiring further R&D and demonstrations before they are commercially viable at scale.
Role of Government and Private Investment	- Both government policy and private sector investment play vital roles in scaling up production capacity and building infrastructure.
Optimizing Before Scaling	- There is a need for caution in scaling too quickly before optimizing hydrogen technologies, though urgency remains to meet growing demand.
Large-Scale Hydrogen Projects	- Several international large-scale hydrogen projects were highlighted, signalling growing momentum in the sector.
Tailored Solutions by Application	- The optimal scale and distribution model for hydrogen solutions depends on the application, with different needs for industrial vs. mobility or residential uses.
Local Conditions	- Local conditions significantly influence the best approach to hydrogen production and distribution.
Optimism for Cost Reduction	- There is general optimism about potential cost reductions as hydrogen production scales up, but it will require time, effort, and collaboration between stakeholders.

Table 25: Hydrogen Market Competitiveness

4.30 Market Need, Trends and Demand

The participants' perspectives on various aspects of the hydrogen industry reveal key considerations surrounding its competitiveness, demand, technological maturity, and potential applications. These viewpoints collectively emphasize the interplay of factors that influence the trajectory of hydrogen adoption and market viability.

Participants underscore the significance of cost competitiveness, particularly in comparison to other energy sources and technologies. A strong consensus emerges that technologies enabling cost reduction are pivotal for making hydrogen a competitive option. Discussions revolve around the necessity of aligning hydrogen production with demand, and several participants emphasize the importance of addressing both supply and demand aspects concurrently. It is evident that having a clear market demand and a robust supply chain are essential prerequisites for venturing into the hydrogen business.

Technological readiness and maturity are central themes, with participants acknowledging that while the technology is in its early stages, it is sufficiently mature to enter the market. However, participants also highlight the importance of optimization before rapid scaling, pointing to challenges in resource availability and small-scale constraints within the industry.

The role of government support and funding programs in catalysing hydrogen development is emphasized, with funding competitions aiding feasibility studies and demonstrations. Additionally, discussions highlight the need for a fair playing field in terms of subsidies for fossil fuels and green technologies, promoting equitable competition.

In assessing the potential of hydrogen applications, participants emphasize the market-driven nature of its growth. Insights underscore the significance of addressing various components of the hydrogen value chain, such as production, storage, and distribution, to establish a comprehensive ecosystem.

The participants' views collectively underscore the multidimensional nature of the hydrogen industry's growth, involving technological advancements, market demand, funding support, and alignment with energy policies. By taking into account these diverse perspectives, stakeholders can gain a holistic understanding of the dynamics shaping the hydrogen landscape and make informed decisions towards its sustainable and competitive development.

EEF's observations shed light on the critical question of hydrogen supply and demand dynamics. The concerns voiced regarding the origin and availability of hydrogen underscore the need for a reliable and established hydrogen supply chain. EEF's inquiry into the sources of hydrogen and the number of companies capable of providing it highlights the interconnectedness of hydrogen production and its utilization.

Moreover, EEF's contemplation about starting a hydrogen business draws parallels with the automotive industry, emphasizing the necessity of a holistic approach. The simultaneous development of hydrogen production capabilities and market demand is emphasized as a vital strategy. This underscores the intricate relationship between supply-side advancements and fostering demand, suggesting that a balanced ecosystem is pivotal for the industry's growth.

On the other hand, the statement *"We bring this business that already has a demand"* underscores the importance of identifying existing market needs and tailoring hydrogen-based solutions to address those needs. This approach positions hydrogen as a solution rather than a technology seeking a problem to solve, thus aligning with actual market demand.

In essence, EEF's insights underscore the importance of understanding market needs, trends, and potential demand drivers as essential components for the successful development and growth of the hydrogen industry. By addressing both supply-side capabilities and demand-side requirements, stakeholders can navigate the hydrogen landscape more effectively and contribute to its sustainable expansion.

JAGR's insights provide a nuanced perspective on the maturity of hydrogen technology and its implications for market development. The participant acknowledges that while the technology is in its early stages of maturity, it has reached a point where it can be introduced to the market. This perspective reflects the delicate balance between technological readiness and the practicality of commercialization. By suggesting that the technology is *"mature enough to go to the market"*, he highlights the potential for real-world application, while acknowledging the need for further refinement.

Furthermore, JAGR's mention of having assembled electrolyzers in the past lends credibility to their assessment of the technology's stage of development. This first-hand experience underscores his expertise and adds weight to their evaluation of its readiness for market entry.

The statement about governments potentially benefiting financially from the development of hydrogen systems adds a crucial dimension to the discussion. By hinting at the potential for substantial government income tied to the growth of the hydrogen market, the participant recognizes the economic implications of a thriving hydrogen industry. This financial incentive could encourage governments to support and invest in the sector, thereby contributing to its growth and sustainability.

Lastly, the call to be *"very open to see the trends and to quickly create programs"* reflects JAGR's recognition of the fast-paced nature of technology adoption and market dynamics. By staying attuned to emerging trends and promptly devising responsive programs, stakeholders can harness opportunities effectively and address evolving needs within the hydrogen domain.

KQ's statement emphasizes the intricate nature of introducing new hydrogen-based products into the market. She uses the example of a hydrogen-powered stove to illustrate that even if a ground-breaking innovation were to be developed, its adoption could be hindered by the lack of supporting infrastructure. She believes that the inability to supply hydrogen to homes effectively limits the practicality of such products. This insight highlights the interconnectedness between technological advancements and the requisite infrastructure to enable their use.

KQ's perspective aligns with the notion that the successful integration of hydrogen technologies requires a gradual and coordinated approach. Her use of the phrase *"it all has to kind of fall into place incrementally"* underscores the stepwise nature of progress in the hydrogen sector. This viewpoint reflects the need for synchronized developments in both technology and infrastructure to create a conducive environment for new hydrogen-based products.

MR's perspective underscores the complexity of the hydrogen industry, particularly in terms of economic viability. Her mention of *"viability in economic terms"* highlights the critical importance of ensuring that hydrogen technologies make economic sense and are financially sustainable within the market.

Additionally, MR acknowledges the role of companies and the private sector in providing functional solutions. She highlights the challenge of fragmented specialization, using the analogy of having numerous companies focused on different aspects of hydrogen without coordination. MR points out that a cohesive ecosystem requires integration of various elements, such as electrolyser production and hydrogen storage, to create a comprehensive solution. This sentiment aligns with the idea that technology and infrastructure need to work together in harmony.

The participant also mentions the need for optimization before scaling up rapidly. MR alludes to the balance between the urgency of meeting hydrogen demand and the practical constraints faced by smaller companies. This perspective suggests a cautious approach to scaling to ensure that both technological and resource limitations are considered.

MS appears to be discussing the proactive approach of addressing hydrogen demand. The phrase *"we're kind of doing that already for people who want hydrogen"* suggests that efforts are underway to cater to individuals or entities seeking hydrogen solutions. This implies a customer-centric approach, wherein the focus is on meeting the needs and desires of those who are interested in hydrogen-related technologies or products. MS's statement could reflect the idea that existing efforts are aligned with current market demand, indicating a responsiveness to customer preferences. This perspective is in line with the concept of market-driven innovation, where companies adapt and tailor their offerings to meet the needs of consumers.

PL seems to be discussing the interplay between price, scalability, demand, and the role of subsidies in the context of hydrogen adoption. The statement *"And then as far as the price is it again, it's the classy economics, it's about the style and choice of the hydrogen generator and then in the speech scale, how quickly can you get it to scale and how much do you rely on?"* suggests that economic considerations, technology choices, scalability, and the pace of implementation are key factors in determining the success and adoption of hydrogen technologies. This viewpoint underscores the importance of various elements in shaping the market dynamics of hydrogen-related solutions.

The subsequent remark *"And if there was enough real demand, it would be quite quickly because and the challenges aren't insurmountable. But should we? I would say no at the moment. Just on the grounds of economics, techno economics ready"* appears to reflect a cautious stance on rapid scaling of hydrogen technologies. While acknowledging that sufficient demand could lead to swift growth, the speaker seems to advocate for a balanced approach. This approach considers economic feasibility and the readiness of techno-economic factors before pursuing rapid expansion. It reflects a consideration of the practicalities and economic viability of scaling up hydrogen solutions.

The final PL's statement *"That's the market that's a supplier making the choice, not a subsidy. I no doubt like go for it. Every subsidy they can get. But there's not been driven by subsidy"* emphasizes the role of market forces and supplier decisions in shaping the hydrogen sector. PL acknowledges the potential benefits of subsidies but indicates that market dynamics and supplier choices play a more significant role in driving decisions and growth in the sector.

SJS's statements highlight various use cases and approaches to promoting hydrogen adoption and infrastructure development. The mention of *"quite a lot of people who ask for refilling stations"* and the utilization of multiple systems in clusters for refilling purposes reflects the growing demand for hydrogen refuelling infrastructure, particularly for vehicles and specialized applications like hydrogen planes.

SJS also refers to the diverse range of use cases in different countries, including refuelling for vehicles, industrial applications like gas production and heating, and the potential for replacing fossil fuels. The emphasis on various applications underscores the versatility of hydrogen and its potential to address different energy needs across industries.

SJS's mention of customers purchasing multiple devices and the testing phase further highlights the exploratory nature of hydrogen adoption. This suggests that customers often start with small-scale implementations to assess functionality and benefits before committing to larger deployments.

The statement *"You need to have a hydrogen pipeline. You need to have hydrogen consumer systems"* underscores the importance of both supply and demand aspects in the hydrogen ecosystem. Infrastructure development, including pipelines and consumer systems, is crucial for creating a self-sustaining hydrogen market.

The discussion of marketing efforts, including social media engagement and participation in exhibitions, reflects SJS's approach to creating awareness and showcasing hydrogen technologies. Despite budget constraints, the emphasis on proactive engagement with partners and showcasing technology at exhibitions demonstrates a commitment to promoting hydrogen solutions within the available resources.

TW's perspective revolves around the challenges and considerations related to market needs, hydrogen demand, and industry trends. He emphasizes the importance of reaching the mass production stage to achieve cost efficiency and the ability to secure significant discounts from suppliers. This requirement necessitates grouping orders together, reflecting the need for coordinated efforts to realize the benefits of economies of scale.

He notes that the current uptake of hydrogen systems is more pronounced in Germany due to the favourable funding regime. In Germany, PV and hydrogen systems receive substantial funding support, which has led to greater adoption. This funding support serves as an incentive for individuals and organizations to invest in hydrogen systems and contributes to the increased uptake of such technologies.

TW also touches on the certification process, highlighting that systems won't be certified until a reliable source of hydrogen can be established. This underscores the importance of ensuring a consistent and dependable supply of hydrogen for various applications.

Regarding marketing and adoption, TW describes a strategy of actively working on brand promotion and establishing a strong presence in the market. The goal is to attract inquiries and engage with potential customers who are interested in adopting hydrogen systems. He emphasizes that the necessary technology and expertise are available, and the focus is now on identifying and collaborating with individuals and entities that are interested in implementing these solutions.

VG's perspective delves into the multifaceted aspects of hydrogen utilization, market needs, and trends. He highlights that while a portion of hydrogen might be allocated for energy storage, the predominant use case is its export to regions like Europe where the demand and pricing are favourable. This international trade approach capitalizes on the global demand for hydrogen and allows for revenue generation from regions willing to pay a premium for clean hydrogen.

VG underscores the value of hydrogen in specific local applications, such as mobility solutions and the pursuit of green steel production, which aligns with the broader industry trend of utilizing hydrogen as a cleaner alternative in various sectors. However, he points out that hydrogen's primary role is not necessarily to foster grid growth but rather to act as a supplementary solution for off-grid applications, replacing dirty diesel sources and enhancing energy sustainability.

VG also acknowledges the challenge of overproduction, a common issue faced by countries. To tackle this, he suggests strategies like storage and building excess capacity. He emphasizes the integration of hydrogen within the energy landscape to enhance flexibility and contribute to a more resilient and adaptable energy system.

Market Needs, Trends and Demand Dynamics in the Hydrogen Industry	
Aspect	Key Insights
Aligning Supply and Demand	- Aligning hydrogen production capabilities with end-use applications is crucial for market growth, requiring an understanding of demand.
Readiness for Early Market Introduction	- Hydrogen technology is ready for early market introduction in some regions, especially where government support exists.
Supporting Infrastructure	- New hydrogen products face hurdles without the necessary infrastructure, requiring gradual alignment and holistic ecosystem development.
Economic Viability	- Economic viability remains a concern, with private sector solutions and optimization needed before rapid scaling.
Growing Interest in Refuelling and Transport	- Interest in areas like refuelling infrastructure and transport is growing, but adoption is still at the exploratory and small-scale testing stage.
Versatility of Use Cases	- Hydrogen has versatile use cases, from industry to heating and mobility, but coherent infrastructure and consumer systems are essential for widespread adoption.
Mass Production and Cost Reductions	- Achieving mass production will accelerate cost reductions and competitiveness, with government incentives helping to stimulate early adoption.
Export vs. Domestic Applications	- Export potential exists, but domestic applications should also be cultivated; grid growth is not the only priority for hydrogen development.
Measured, Synchronized Approach	- A synchronized approach is recommended, aligning technology development and infrastructure growth with market demand for optimal progress.

Table 26: Market Needs, Trends and Demand Dynamics in the Hydrogen Industry

In summary, participants highlighted the complex interplay of factors underlying hydrogen's trajectory - from economic viability to policy support to strategic supply-demand coordination. A cohesive, customer-focused strategy is required.

4.31 Circular Economy

The participants' viewpoints regarding sustainability and circular economy considerations in the context of hydrogen technologies present diverse perspectives. One interviewee reflects on the broader perspective of embracing promising solutions despite minor challenges in supply chains, emphasizing the importance of continuous technological advancement and sustainable practices. This sentiment is echoed by another interviewee who underscores the significance of combining hydrogen technologies with circular economy principles to achieve cleaner outcomes. In this vein, the potential for recycling materials is highlighted, particularly in fuel cell production, although scepticism exists regarding the practicality of complete recycling due to changing technologies and the complex nature of certain materials involved.

Furthermore, the sustainability aspect of hydrogen is emphasized, particularly in instances where water, a readily available resource, serves as the primary input, resulting in a circular energy economy with minimal human intervention. Another participant underscores the necessity of reducing carbon emissions through precise measurement methods, emphasizing carbon counting and life cycle analysis as pivotal techniques for assessing environmental impact.

The role of government and industry is also evident, with the importance of pressuring material providers to enhance sustainability practices and promote cleaner supply chains. Additionally, a focus on open-sourced software, external certification, and emissions estimation underscores a commitment to transparent and reliable environmental assessments.

EEF contemplates the circular economy within the hydrogen technologies industry and addresses concerns similar to those faced by the battery sector. The argument against using batteries due to perceived supply chain dirtiness is acknowledged, yet the participant highlights the need to avoid disregarding promising solutions solely because of related challenges. The participant's perspective implies that the growth and strengthening of the hydrogen sector should not be hindered by isolated issues.

Moreover, EEF applies this reasoning to hydrogen, stressing that the industry should approach challenges as opportunities rather than roadblocks. The lifecycle analysis is deemed crucial, but it is viewed through the lens of advancement, with an emphasis on utilizing it to drive sustainable practices and cleaner supply chains:

“Regarding the lifecycle analysis, it has to be taken into account, but it has to be seen almost as opportunities. Yeah, we need this technology to decarbonize. So how can we clean up this supply chain because it's going to happen. It's going to get bigger. It's going to get stronger. So how can we pressure the providers of these materials to make it more sustainable” (EEF).

Overall, EEF's viewpoint aligns with a proactive approach towards addressing environmental issues associated with the hydrogen industry, promoting the idea that challenges can be resolved through innovation and collaborative efforts.

JAGR presents a perspective on the integration of the circular economy principles within the realm of hydrogen technologies. His viewpoint suggests that the advancement of hydrogen-based solutions should be complemented by a holistic approach that encompasses circular economy practices. This assertion underscores the participant's recognition of the interdependence between technological innovation and sustainable resource management.

Furthermore, JAGR emphasizes the potential for synergistic benefits when hydrogen technologies are harmoniously integrated with the circular economy framework. This symbiotic relationship is depicted as a pathway to achieving enhanced environmental cleanliness. By advocating for the amalgamation of hydrogen production and utilization with recycling and circular material flows, JAGR underscores the promise of achieving greater environmental integrity within the hydrogen sector:

“In the way you combine hydrogen with circular economy with recycling of materials, it could get a cleaner” (JAGR).

MS sheds light on the intricate relationship between the production of hydrogen systems, particularly fuel cells, and the challenges associated with recycling and circular economy considerations. MS acknowledges that the production of these systems necessitates the use of materials like platinum, which are both expensive and limited in terms of their recyclability. In this regard, he expresses scepticism about the feasibility of extensive recycling, questioning whether the effort and resources invested in recycling such materials would outweigh the benefits.

Furthermore, MS points out that technological advancements in the hydrogen industry may render recycling efforts less effective over time. The rapid pace of innovation and evolving designs of fuel cell modules may undermine the long-term viability of recycling certain components. The participant thus illustrates a pragmatic view that challenges the notion of a comprehensive recycling “Nirvana”, emphasizing the dynamic nature of technology and its implications for recycling strategies.

However, MS also highlights a distinctive aspect of Enapter’s technology in contrast to conventional fuel cells. Enapter’s use of stainless steel instead of noble metals like platinum contributes to enhanced recyclability, aligning with circular economy principles. While MS acknowledges the potential benefits of recycling in Enapter’s context, there remains an undertone of scepticism about the accuracy of recycling claims, indicative of a broader perspective within the hydrogen technology community.

RH’s perspective on the sustainability of a circular hydrogen energy economy underscores the remarkable potential for achieving environmental balance through innovative resource utilization. He expresses a strong belief in the viability of harnessing hydrogen as a pivotal component in a circular economy, highlighting the intrinsic sustainability of this approach. Central to this vision is the utilization of readily available water resources, in contrast to finite and environmentally impactful fossil fuels:

“I think in terms of sustainability, it's actually quite a strong story because basically water is readily available and by not using fossil fuels, you've effectively got a circular hydrogen energy economy” (RH).

RH eloquently articulates the concept of a closed-loop hydrogen energy cycle, wherein water serves as the foundational element. The cyclic nature of hydrogen utilization is illuminated through its transformation from water to hydrogen fuel, subsequent energy use, and ultimate reversion to water vapor through combustion or fuel cell processes. This cycle, while facilitated by human intervention, is depicted as harmoniously intertwined with the natural environment, where water is seamlessly reintegrated into the ecosystem through the hydrological cycle:

“You use water off the roof. I like the water off the roof because basically when you've used the hydrogen, whether it's burned or in fuel cell, it goes back to water vapor, goes back to the clouds, it will fall on the roof. There's no human energy or effort put in closing the cycle. The environment does that and it does that with pretty much no negative impact like the clouds are the clouds and they'll sort themselves out. Because if that water wasn't converted to hydrogen energy, it would almost certainly have fallen down on the ground and evaporated

in the morning when the sun came out. So large proportion of it was so it almost doesn't affect the water vapor cycle in the air very much at all. There's sustainability one I think that's good because it's the local circularized economy" (RH).

This interconnectedness of the hydrogen energy cycle with the natural water cycle underscores the participant's perception of the circular hydrogen economy as being harmonious with nature's self-regulating processes. RH draws attention to the minimal human-induced disruption and negative impact, thus positioning the hydrogen energy cycle as an environmentally favourable alternative. The notion that the environmental system tends to absorb and restore the cycle without undue interference speaks to RH's optimistic perspective on the sustainability of such an approach.

Moreover, RH's emphasis on the local circularized economy speaks to the participant's acknowledgment of the localized benefits of hydrogen energy systems. By tapping into abundant local water resources and reducing reliance on non-renewable fossil fuels, the participant envisions a sustainable ecosystem that contributes to both energy security and environmental preservation. In essence, RH's belief in the circular hydrogen energy economy's capacity to maintain equilibrium with nature encapsulates a hopeful and promising outlook for a sustainable energy future.

TW in turn highlights the commendable feature of Enapter's hydrogen systems - full recyclability. He underscores Enapter's proactive approach by employing a *"return to base methodology"*, wherein every component of their hydrogen projects can be reclaimed and recycled. Notably, even the nano membrane, a critical component, is subjected to this recycling process. This comprehensive recycling effort is emblematic of the circular economy's principles, as it aims to minimize waste and extend the lifecycle of materials.

Enapter's commitment to circularity is exemplified by their ability to recondition and re-coat the nano membrane, ensuring its readiness for reuse. By utilizing predominantly metal parts in their systems, Enapter maximizes the potential for recycling, as metals are among the most recyclable materials. This approach aligns with the tenets of circular economy, as it enables the continuous regeneration of resources and minimizes the need for the extraction of new raw materials.

TW's commentary emphasizes the significance of Enapter's circular economy strategy in the hydrogen industry. By prioritizing recyclability and adopting practices that facilitate the reclamation of materials, Enapter not only contributes to environmental sustainability but also showcases a model that other industry players could potentially emulate. The passage reflects the pivotal role that circular economy can play in enhancing the long-term sustainability and resource efficiency of hydrogen technologies.

Circular Economy in Relation to Hydrogen Technologies	
Aspect	Key Insights
Embracing Promising Solutions	- Promising hydrogen solutions should be embraced despite minor supply chain issues, with continuous improvement through technological advancement and sustainability.
Hydrogen and Circular Economy Principles	- Combining hydrogen technologies with circular economy principles can enhance cleanliness and sustainability. Recycling materials in fuel cells offers potential, though with limitations.
Sourcing Hydrogen from Water	- Sourcing hydrogen from water creates a circular, sustainable energy system with minimal environmental impact, as the natural water cycle restores the hydrogen cycle.

Carbon Counting and Sustainability	- Life cycle analysis and precise carbon counting methods are essential to assess the sustainability of hydrogen technologies, pushing suppliers towards better practices.
Limits of Complete Recycling	- Complete recycling is unlikely due to evolving technologies and material complexity; instead, selective extraction of valuable materials is more feasible.
Recyclable Materials	- Technologies utilizing recyclable materials, like stainless steel, offer higher recycling potential, though claims should be evaluated critically, focusing more on performance and cost improvements.
Circular Economy Practices	- Adopting circular economy practices, like comprehensive component reclamation and reuse, as seen in Enapter's model, can significantly improve resource efficiency.

Table 27: Circular Economy in Relation to Hydrogen Technologies

Overall, the participants' perspectives collectively underscore the importance of aligning hydrogen technologies with sustainability objectives, pursuing recycling options, and implementing circular economy principles to ensure cleaner and more environmentally responsible outcomes. Integrating hydrogen solutions with sustainability and circular economy principles is crucial for maximizing environmental responsibility. But realistic expectations are needed regarding recycling feasibility.

4.32 Anion Exchange Membrane Technology & Enapter

Within the context of advancing hydrogen technologies for the built environment, the discourse extensively delved into the potential of Anion Exchange Membrane (AEM) technology. Distinguished for its affordability and sustainability, AEM technology has garnered significant attention as a frontrunner in the pursuit of establishing hydrogen solutions that are conducive to the built environment's unique requirements.

The essence of AEM technology revolves around its proficiency in enabling the conversion of renewable electricity into hydrogen gas. Through the process of water electrolysis, AEM technology generates hydrogen by splitting water molecules into hydrogen and oxygen using electricity. This method offers a compelling advantage as it employs clean and renewable energy sources, aligning with the overarching goal of establishing eco-friendly systems for the built environment.

Crucially, AEM technology's affordability resonates with the need for cost-effective solutions that are both practical and scalable. Its design emphasizes the use of readily available and cost-efficient materials, thereby reducing the barriers to entry for adopting hydrogen technologies within the built environment. This aligns seamlessly with the objectives of rendering hydrogen solutions accessible to a broader spectrum of stakeholders, including residential, commercial, and industrial domains.

The sustainability facet of AEM technology augments its attractiveness within the built environment's ecosystem. By utilizing renewable electricity sources, AEM technology inherently eliminates carbon emissions at the point of hydrogen generation. This pivotal characteristic resonates profoundly with the global imperative to mitigate carbon footprints and transition towards sustainable energy solutions. AEM technology's synergy with renewable energy sources aligns with New Zealand's commitment to achieving carbon neutrality and underscores the technology's pivotal role in driving a sustainable built environment.

The dialogue surrounding AEM technology underscores its alignment with New Zealand's unique context. The technology's affordability, sustainability, and compatibility with renewable energy

sources have positioned it as a compelling candidate for establishing hydrogen solutions that resonate with the nation's built environment requirements. As New Zealand embarks on a journey towards harnessing hydrogen's potential for various applications, including power generation, heating, and transport, AEM technology stands out as a cornerstone in achieving a harmonious fusion of sustainability, affordability, and technological innovation.

The participants' perspectives on Enapter technologies exhibit a comprehensive view that underscores both their promise and potential limitations. One common sentiment among the interviewees is the recognition of Enapter as a noteworthy player in the hydrogen technology landscape. The participants appreciate Enapter's distinctive approach, characterized by its utilization of anion exchange membrane (AEM) electrolyzers. This choice is perceived as introducing a differentiating factor, offering advantages in terms of scalability, maintenance, and broader deployment feasibility. While acknowledging the absence of higher efficiency claims, interviewees indicate that Enapter's focus on scalability and user-friendliness aligns with the needs of those seeking entry into the hydrogen domain.

Another notable aspect highlighted is Enapter's commitment to sustainability and recyclability. The company's initiative to design products predominantly using recyclable metal parts and establish a return-to-base recycling methodology for components, including the nano membrane, is acknowledged by participants. This aspect contributes to Enapter's appeal as a provider of environmentally conscious solutions, resonating with the overarching drive towards sustainable technologies.

However, interviewees also express a balanced perspective on Enapter technologies. While recognizing their potential, some participants caution against absolute belief in certain claims. The interviews reveal a hint of scepticism in relation to claims about certain aspects of Enapter's operations, such as recycling processes, urging for further verification or confirmation.

In the discourse surrounding hydrogen technologies, **MR** offers a thoughtful and pragmatic perspective, reflecting a blend of familiarity with her own company's technology and a recognition of the broader landscape. She begins by acknowledging the inherent limitations of a single-point perspective, emphasizing that her understanding is anchored in the technology employed by her own company. This acknowledgement serves as a springboard for her broader assessment of the hydrogen technology sector.

MR's discussion of Enapter technology underscores her belief in its promise, marked by distinct qualities that capture her attention. She highlights a pivotal advantage of Enapter's approach - a notable reduction in the consumption of rare earth metals. This emphasis aligns with a growing emphasis on sustainability and responsible resource utilization within the technology domain. Her mention of "*convenient output pressure*" around 30 - 35 bars reflects a keen appreciation for the practical considerations that influence technology adoption. This nuanced awareness showcases MR's grasp of the fine details that can influence the viability of a technology within real-world applications.

However, MR's perspective does not confine itself to the Enapter technology alone. She recognizes the importance of taking a holistic view that encompasses multiple technologies to arrive at a complete understanding. Her statement that the applicability of Enapter's technology may be dependent on factors such as the nature of the application, intermittency, and storage duration underscores her comprehensive approach. This stance mirrors the broader sentiment in the energy sector, wherein the suitability of any technology often hinges on the specific context and requirements.

In essence, MR's perspective encapsulates a well-rounded evaluation of Enapter technology, blending her company-specific insights with a recognition of the intricacies and variables that shape

the broader technology landscape. Her acknowledgment of the multi-faceted nature of technology selection and the consideration of diverse applications showcases her pragmatic approach, rooted in both technological expertise and a holistic understanding of the field.

MS's insights into Enapter's evolution and technology emphasize the company's journey from inception to its current pivotal role in the hydrogen technology landscape. He traces the origins of Enapter back to his involvement with Phi Suea, an endeavour that was instrumental in the formation of Enapter as it stands today. This narrative underscores the organic growth and development of Enapter, catalysed by the acquisition of assets and the subsequent focus on producing modular hydrogen-generation solutions.

The focal point of Enapter's current endeavours, as described by MS, revolves around the creation of modular hydrogen production units housed within cabinets. This modular approach aligns with industry trends that emphasize scalability and adaptability to varying production demands. MS's elucidation of the hydrogen requirement's variability, dependent on usage, reflects an awareness of the nuanced nature of energy demands across different applications.

Notably, MS draws attention to Enapter's distinct approach to materials, highlighting their deviation from using noble metals like platinum. This shift towards stainless steel aligns with sustainability goals, tapping into a material that is recyclable. His acknowledgement of potential scepticism regarding Enapter's recycling claims demonstrates an objective stance, recognizing the complexities and challenges associated with verifying such claims.

MS's commentary on pricing and capital considerations further showcases his comprehensive understanding of Enapter's operations. By referring to a paper by Enapter, he navigates discussions surrounding capital costs and pricing dynamics. His transparency in sharing potential pricing estimates underscores a candid approach to technology evaluation.

In addressing the role of compliance and the integration of different components within a broader system, MS underscores the holistic nature of technology implementation. His assertion that the balance of plant costs can be written off in favour of focusing on electricity costs underscores the significance of operational efficiency and cost-effectiveness.

Moreover, his revelation that Enapter provides the electrolyser while his company manages the construction of the system demonstrates Enapter's collaborative approach with partners, as well as his own company's active involvement in ensuring the overall system's functionality and compliance.

In summation, MS's account offers a comprehensive view of Enapter's trajectory, technology, materials, sustainability claims, pricing considerations, and collaborative approach. This multifaceted perspective illustrates his deep understanding of Enapter's endeavours and its positioning within the evolving landscape of hydrogen technologies.

RH's insights into Enapter's technology delve into the technical aspects that distinguish the company's approach to hydrogen production. His recognition of the appeal of anion exchange membranes underscores the innovative nature of Enapter's technology. This technology's attractiveness, as highlighted by RH, lies in its potential to enhance efficiency through an intricate interplay between OH ions and electrical resistance. By acknowledging the challenges associated with OH ions' movement through a solid matrix and the resulting impact on efficiency, RH portrays a nuanced understanding of the intricacies of Enapter's technology.

Moreover, RH's reference to pressure storage aligns with Enapter's modular approach to hydrogen production. Notably, he cites Enapter's capability to store hydrogen at 30 or 35 bar, underscoring the company's emphasis on adaptable and flexible solutions. This observation signifies RH's appreciation for Enapter's engineering choices, which cater to diverse storage requirements and application scenarios.

In essence, RH's commentary showcases his technical acumen and insight into the technological nuances of Enapter's hydrogen solutions. His focus on anion exchange membranes and pressure storage underlines his detailed understanding of Enapter's technological framework, positioning him as a perceptive evaluator of the company's innovations.

SJS, the proprietor of Enapter, articulates a comprehensive overview of the company's journey, innovations, and commitment to sustainable hydrogen technologies. His candid acknowledgment of the evolving complexity within their system signifies an authentic acknowledgment of growth and adaptation. This transparency reflects his dedication to refinement and underscores Enapter's continual pursuit of excellence.

SJS's insights into the challenges and opportunities surrounding hydrogen technology resonate with his pragmatic approach. His assertion that people observe its functionality underscores the pivotal role of real-world applications in proving the technology's viability. The reference to the Home Power Solution's significant sales surge echoes the success of their complete system approach, showcasing how Enapter's innovations are impacting the market and gaining traction.

Drawing a significant contrast to other systems, SJS highlights Enapter's distinctive utilization of materials, emphasizing the avoidance of costly components like Iridium and titanium. His mention of an exact clarification regarding CO2 emissions underscores Enapter's emphasis on environmental accountability, exemplifying their commitment to transparency.

SJS's mention of open-source software and external certifications underscores Enapter's collaborative ethos and commitment to robust quality assurance. The forthcoming emissions check for the 4.0 system underscores their drive for continuous improvement while the precautions for hydrogen storage emphasize safety and responsibility.

Furthermore, SJS provides valuable insights into the affordability of Enapter's electrolyser, indicating their endeavour to make their technology accessible. The approach of not distributing devices for free resonates with their commitment to ensuring that their products are utilized meaningfully and actively contribute to advancements in hydrogen technology.

SJS concludes by referencing the growth of AEM Electrolysers, positioning Enapter as a pioneering force in the commercial adoption of such technology. The mention of their crop patterns signifies not only their progress but also their influence within the broader industry landscape, attesting to Enapter's role as a significant catalyst for advancing hydrogen solutions.

TW provides valuable insights into Enapter's contributions to the hydrogen technology landscape, emphasizing their product offerings and distinctive features. Mentioning the availability of Enapter's products, the L 2.0 and the L 4.0, TW showcases their presence and influence within the country's hydrogen infrastructure. The mention of a training version highlights Enapter's commitment to educating and fostering awareness about electrolysers.

The decision to opt for Enapter's products is based on their unique approach. TW points out the deployment of an anion exchange membrane, a key distinguishing factor that sets Enapter apart from the competition. He acknowledges that while this choice may not necessarily enhance efficiency, it contributes to improved maintenance friendliness and scalability. This strategic decision aligns with Enapter's goal of enabling gradual adoption and growth in the hydrogen market.

TW's reference to starting small and expanding to meet larger demands speaks to Enapter's approach of facilitating entry into the hydrogen sector. This approach resonates with the diverse needs of various stakeholders who seek to engage with hydrogen technologies while minimizing risk. By addressing the saturation of the market at larger scales, Enapter effectively positions itself as a facilitator of sustainable growth.

The operational efficiency of approximately 70% within Enapter's system showcases the real-world performance of their technology. TW's calculation of energy required to produce a certain quantity of hydrogen further contextualizes the efficiency, contributing to a comprehensive understanding of Enapter's offerings.

Highlighting Enapter's commitment to sustainability, TW underscores the recyclability of their products. The return-to-base methodology for recycling, even down to nano membrane components, demonstrates Enapter's holistic approach to environmental responsibility. Their emphasis on metal parts underscores their efforts to minimize waste and environmental impact.

Overall, TW's insights underscore Enapter's role in offering adaptable, efficient, and environmentally conscious hydrogen technologies, positioning them as a significant player in shaping the future of sustainable energy solutions.

TN's insights shed light on Enapter's potential to revolutionize hydrogen production and its adaptability to different contexts, particularly in Japan and New Zealand. His reference to "producing hydrogen on the spot" using Enapter technology underscores the convenience and practicality that Enapter's solutions offer. This aligns with Enapter's goal of providing decentralized and scalable hydrogen production solutions that can be easily deployed on-site.

In the context of Japan, TN's experience with a local dealer showcases Enapter's presence in the region. While initial plans were to utilize Enapter technology, the delay in obtaining New Zealand compliance led to exploring other options. This incident demonstrates Enapter's global ambitions and the necessary steps to meet local regulatory requirements. Despite not proceeding due to timing constraints, TN acknowledges the value and potential of Enapter's technology, emphasizing its scalability and cost-effectiveness compared to other electrolyzers. This reflects Enapter's commitment to delivering solutions that align with the unique requirements of different markets.

TN's observation of Enapter's technology being stackable from a small scale aligns with Enapter's modular approach. This adaptability resonates with the flexibility required for different applications, offering a versatile solution that can grow to meet increasing demand. TN's recognition of Enapter's affordability and scalability highlights their competitive edge in the electrolyser market.

In sum, TN's commentary underscores Enapter's promise as a hydrogen technology provider with solutions that can be tailored to diverse settings. The reference to New Zealand compliance showcases Enapter's dedication to meeting local regulatory standards, even if it means temporarily altering plans. Overall, TN's perspective supports Enapter's role in providing practical, adaptable, and accessible hydrogen production technologies.

For example, the Enapter's AEM electrolyser, engineered for efficient hydrogen production, demonstrates a versatile performance with key specifications that contribute to its applicability across diverse industrial and residential settings. With a production rate that spans up to 500 NL/h and up to 1.0785 kg over a 24-hour period, this electrolyser offers considerable capacity for hydrogen generation to meet varying demands.

The hydrogen output purity is a critical parameter, and the AEM electrolyser delivers impressively in this regard. Operating at different pressures, it attains high purity levels—99.9% (with impurities of less than 1,000 ppm H₂O and less than 5 ppm O₂) at 35 barg and 98.8% (with impurities of less than 12,000 ppm H₂O and less than 5 ppm O₂) at 8 barg, both at 25 °C.

This electrolyser's output pressure capability extends up to 35 barg, enhancing its versatility for multiple applications. In terms of energy consumption, it demonstrates an efficient performance with a nominal power consumption of 4.8 kWh per Nm³ of hydrogen produced at the beginning of its operational life. The operative power consumption is rated at 2.4 kW at the beginning of life, with a peak power consumption of 3 kW.

Heat dissipation characteristics are noteworthy, with a maximum heat dissipation of 0.6 kW at the beginning of life and 0.9 kW at the end of life. Standby power consumption is minimal at 0.3 kW, contributing to energy efficiency. The power supply requirement is compatible with a range of 220-240 V (AC) at 50/60 Hz.

The water input parameters are crucial for efficient operation. The AEM electrolyser is designed to handle water with a minimum ASTM D1193-06 Type IV conductivity, ensuring optimal performance. Its water consumption is approximately 420 mL/h at 25 °C, accompanied by a water input pressure range of 1-4 barg.

Operational conditions are accommodated within a temperature range of 5 °C to 45 °C, and the electrolyser is capable of functioning in ambient humidity levels of up to 90%, non-condensing. The equipment's IP rating of IP 20 signifies its protection against solid objects, further contributing to its durability.

The AEM electrolyser's compact design is reflected in its dimensions of W: 482 mm × D: 635 mm × H: 266 mm, with a manageable weight of 42 kg. This physical footprint accommodates a cabinet space of 6 U.

Control and monitoring capabilities are integral to the electrolyser's operation. It operates fully automatically through Enapter's Energy Management System (EMS) using 2.4 GHz Wi-Fi and Bluetooth connectivity, complemented by Modbus TCP over Ethernet for efficient data exchange.

The AEM electrolyser's compliance is evidenced by its CE mark according to the machine directive 2006/42/CE and the UKCA mark according to Supply Machinery (Safety) Regulations 2008. Additionally, it adheres to the CSA/ANSI B22734:2023 Ed.1 standard for hydrogen generators using water electrolysis in industrial, commercial, and residential applications.

The AEM electrolyser, characterized by its impressive technical specifications, stands as a promising solution for efficient hydrogen production across diverse sectors. Its performance parameters encompass output purity, energy efficiency, water consumption, and operational conditions, all contributing to its viability as a robust hydrogen generation solution.

Another example is the AEM electrolyser Multicore, characterized by a production rate of 210 Nm³/h, offers a net volume flow rate capable of delivering hydrogen with exceptional purity levels. Operating at an output pressure of up to 35 bar, it ensures the reliable generation of hydrogen for diverse applications. The hydrogen output boasts an impressive molar fraction purity of 99.8%, with minimal impurities, primarily water (H₂O) at approximately 1500 ppm and oxygen (O₂) at levels below 5 ppm.

Further enhancing its output quality, the AEM electrolyser offers an optional dryer that elevates hydrogen purity to 99.999% in molar fraction. This purification process significantly reduces impurities, with water content brought down to less than 5 ppm and oxygen content maintained below 5 ppm.

The flexibility of the AEM electrolyser is a key feature, as it accommodates production rates ranging from 3% to 105% of its nominal capacity. Such adaptability ensures efficient operation across varying hydrogen demands.

Energy consumption considerations are paramount in the electrolysis process. The AEM electrolyser demands a nominal power consumption of 4.8 kWh per Nm³ of hydrogen produced at the beginning of its life cycle. The total electrical power consumption is rated at 1,008 kW. This energy requirement is met with a three-phase grid voltage of 3 x 400 Vac, operating at a frequency of 50/60 Hz.

The electrolyser's water consumption aligns with its efficiency, requiring a nominal purified water flow of 0.19 Nm³/h. However, it's noteworthy that tap water input for purification needs to be

approximately twice as high. The system operates within an inlet water pressure range of 0.5 bar to 4 bar, with an inlet water temperature range of 6 °C to 30 °C.

Engineered for durability, the AEM electrolyser demonstrates an impressive system life of 20 years. Its stack, the heart of the electrolysis process, boasts an extended life expectancy, with over 35,000 operating hours.

Start-up times are efficient, with the electrolyser capable of reaching 0 to 100% capacity within seconds for hot starts and in about 30 minutes for cold starts, depending on ambient temperatures.

In terms of dimensions, the AEM electrolyser is contained within a footprint measuring L: 12.192 m × W: 2.438 m × H: 2.591 m. This compact design facilitates integration within diverse operational settings. The equipment's weight is approximately 30 tons, and it can be conveniently transported within a 40 ft container.

The AEM electrolyser stands as a technologically advanced solution for hydrogen generation, offering high purity, flexibility, and energy efficiency. Its robust specifications underscore its capability to contribute significantly to various sectors, from industrial processes to clean energy applications (Enapter, 2023).

Enapter	
Aspect	Key Insights
AEM Electrolysers and Technology	- Enapter is recognized for its use of anion exchange membrane (AEM) electrolyzers, offering advantages in scalability, maintenance, and deployment feasibility.
Focus on Scalability and Accessibility	- Enapter focuses on scalability and user-friendliness, making hydrogen solutions accessible for new market entrants, despite no major claims of efficiency breakthroughs.
Sustainability and Recyclability	- The company emphasizes sustainability through metal components and a return-to-base recycling program, though recycling claims require further verification.
Modular Product Design	- Enapter's modular and adaptable products allow users to start small and scale up, facilitating gradual market adoption and growth.
Operational Efficiency and Pricing	- Enapter boasts operational efficiency of around 70% and competitive pricing, based on real-world experiences, with attention to compliance with local regulations.
Global Presence and Challenges	- Despite a global presence, Enapter faces timing challenges and local compliance issues, prompting exploration of alternatives while maintaining potential.
Market Contribution	- Enapter is seen as a key player in the hydrogen landscape, with its scalable AEM electrolyzers, recyclability efforts, and accessibility setting it apart from competitors.

Table 28: Enapter

In conclusion, the aggregated opinions of participants point towards Enapter technologies as a distinctive player in the hydrogen sector, with its focus on AEM electrolyzers and scalability

contributing to its appeal. The company's commitment to recyclability aligns with environmental goals, though some caution against absolute endorsement of certain claims. Overall, the viewpoints converge on Enapter's role as a prominent contributor to the evolving hydrogen landscape, while simultaneously promoting a nuanced understanding of its offerings. Enapter has carved out a distinctive position in the evolving hydrogen technology landscape through their scalable, accessible AEM electrolyzers and sustainability-focused vision, making them a noteworthy contributor despite some limitations.

4.33 Energy Efficiency, Combined Heat and Power, Water and Space Heating

The opinions expressed by various participants in the interviews shed light on the energy efficiency of hydrogen technologies, particularly in relation to combined heat and power (CHP) applications for energy efficiency, as well as their potential for water and space heating in residential and commercial buildings. While the discussions vary in perspective and context, common themes emerge regarding the challenges and opportunities associated with hydrogen's role in achieving energy efficiency in the built environment.

In the realm of energy efficiency, participants expressed concerns about the inefficiencies inherent in hydrogen production and utilization. Reference to the efficiency of various hydrogen production methods, such as electrolysis, highlighted the energy losses incurred during the conversion process. The process of producing hydrogen through electrolysis involves energy input that is not fully recoverable, leading to reduced efficiency. It was observed that the overall efficiency of hydrogen systems may be around 50%, or even lower, for some use cases.

The application of hydrogen technologies for CHP purposes was widely discussed as a potential avenue for enhancing energy efficiency. Participants acknowledged that while hydrogen-based CHP systems hold promise, they also grapple with certain inefficiencies, such as the loss of energy during hydrogen production and conversion. Despite these challenges, the integration of high-temperature fuel cells in CHP units was noted as a method to increase overall system efficiency, potentially reaching levels of around 80-90%. Such systems were seen as particularly valuable for colder climates, where heating demands are high.

Moreover, the discussions highlighted the suitability of hydrogen technologies for water and space heating in the built environment. While some participants noted concerns about inefficiencies associated with hydrogen heating solutions, others emphasized that the application's viability depends on specific factors, such as the existing gas infrastructure and regional climate conditions. European countries, with their colder climates, were considered more suitable for hydrogen-based heating solutions due to the greater demand for heat.

Residential and commercial buildings were identified as potential beneficiaries of hydrogen technologies, particularly for heating applications. Hydrogen boilers and high-temperature fuel cell-powered CHP units were considered as potential solutions for providing both heat and electricity to buildings. However, the discussions emphasized the need to carefully weigh the advantages of hydrogen-based heating against the inherent inefficiencies associated with the technology. Participants recognized that achieving energy efficiency through hydrogen in the built environment requires a delicate balance between technological advancements, infrastructure adaptation, and regional climate considerations.

In the discourse centred around the energy efficiency of green hydrogen production, DA's perspective emerges as a thoughtful evaluation of the present state and potential trajectories of hydrogen technologies, particularly within the built environment of residential and commercial buildings. DA's

insights offer valuable insights into the role of energy efficiency in shaping the viability of hydrogen solutions for powering these settings.

DA initiates the discussion by delineating the distinction between “*complete green hydrogen*” and the broader spectrum of green hydrogen. The discourse then narrows its focus onto the efficiency of green hydrogen, with specific emphasis on Proton Exchange Membrane (PEM) fuel cells. Of significance is DA’s observation that the current efficiency rates of PEM fuel cells, approximately 82%, still pose challenges in realizing commercially viable hydrogen production with cost-effectiveness. This assertion underscores the pivotal role that energy efficiency plays in dictating the feasibility and economic viability of hydrogen solutions within residential and commercial sectors.

Furthermore, DA extends the analysis to encompass a comparative examination of different fuel cell technologies, contextualized within the context of the built environment. The pinnacle of sophistication is attributed to Proton Exchange Membrane fuel cells, characterized by efficiency levels in the range of 80 to 80%. Close contenders in this spectrum are alkaline fuel cells, boasting efficiencies ranging from 70 to 75%. This nuanced classification of technologies underscores the nuanced interplay between efficiency variances and their implications for different building applications.

However, DA’s insights do not merely remain confined to the current landscape of inefficiencies. The aspiration to attain 100% efficiency in electrolysis systems is presented as an overarching goal within the hydrogen sector, particularly as applied to residential and commercial buildings. This aspiration signifies a forward-looking orientation and a commitment to transformative technological advancements that could reshape the energy dynamics within these settings.

DA’s analysis then pivots towards the environmental ramifications of energy efficiency within the built environment. While green hydrogen is acknowledged for its environmentally friendly attributes in terms of emissions, DA underscores the critical point of energy intensity. The energy-intensive nature of the production process is highlighted as a key consideration in assessing the broader environmental impact of hydrogen technologies within the built environment.

In conclusion, DA’s insights provide a multi-dimensional exploration of energy efficiency within the domain of green hydrogen technologies, particularly in the context of residential and commercial buildings. His assessment encapsulates current challenges, technological differentiation, future aspirations, and environmental implications. This comprehensive perspective contributes significantly to the ongoing discourse on energy efficiency and underscores the intricate interplay between technological advancement, sustainability objectives, and the practical application of hydrogen technologies within the built environment.

Within the discourse surrounding the energy efficiency of hydrogen technologies, the perspectives articulated by **EEF** offers valuable insights into the capacity of these technologies to deliver combined heat and power solutions for enhanced energy efficiency in various contexts, including the built environment, residential, and commercial buildings.

EEF underscores the versatile capabilities of hydrogen systems by highlighting their ability to concurrently generate heat and electricity, all while producing emissions limited to water. This assertion speaks to the environmental advantages of hydrogen technologies, especially in terms of emissions reduction and the potential to drive sustainable energy transitions:

“Hydrogen can generate heat and electricity with the only emissions being water” (EEF).

Further scrutiny is directed towards the concept of “*power to power*”, which EEF evaluates with a pragmatic outlook. EEF voices scepticism about the feasibility of such a conversion process yielding compelling numerical outcomes. This scepticism is grounded in considerations of efficiency, as EEF notes that the efficiencies achieved by batteries might render them more appealing for power-to-

power conversions. This viewpoint reflects a balanced analysis of technology options, taking into account not only the inherent attributes of hydrogen technologies but also their comparative advantages against other energy storage solutions like batteries.

EEF's engagement with the topic extends to the role of heat in fuel cell inefficiency. The participant recognizes that a portion of the inefficiency within fuel cells is attributed to heat generation. In a scenario where this excess heat can be harnessed and utilized, as EEF envisions for certain regions like Europe, the potential for substantially enhancing energy efficiency up to 70-80% emerges. This vision of augmenting energy efficiency by capitalizing on heat for various applications such as water heating and space heating underscores the interplay between technological functionality and environmental sustainability.

However, EEF also acknowledges that there are specific contexts, such as the one where the heat is not required due to already elevated temperatures, where the heat utilization may not be applicable. In such scenarios, the energy efficiency landscape must be contextualized, taking into account local conditions and energy demands.

The participant's insights extend to the applicability of hydrogen-based heat in diverse domains, such as industrial processes. EEF emphasizes the role of hydrogen in providing heat for industrial applications, thereby further amplifying the efficiency potential of these technologies beyond their use in built environments.

In conclusion, EEF's viewpoints contribute substantively to the discourse on energy efficiency in hydrogen technologies, particularly concerning combined heat and power solutions. EEF's analysis is informed by considerations of efficiency, technological feasibility, environmental benefits, and regional variation. These insights underscore the multifaceted nature of energy efficiency within the ambit of hydrogen technologies and provide a valuable perspective on their role in optimizing energy use across residential, commercial, and industrial settings.

In a succinct yet insightful perspective provided by **SGJA**, the importance of directing attention towards specific applications aligned with energy efficiency and electrification goals comes to the forefront. The participant's statement underscores a strategic approach to harnessing the potential of hydrogen technologies within the overarching context of energy optimization.

SGJA's emphasis on focusing on applications that are the prime targets of energy efficiency or electrification strategies reflects a pragmatic perspective. By honing in on these specific sectors, the potential to maximize the benefits of hydrogen technologies becomes more pronounced. This approach signifies a recognition of the need to align technological advancements with broader energy transition objectives, thereby ensuring that hydrogen's potential is harnessed where it can make the most significant impact.

The participant's statement encapsulates a principle of strategic utilization, aiming to channel efforts and resources into areas where the symbiosis between hydrogen technologies, energy efficiency, and electrification is most pronounced. This strategic alignment not only enhances the effectiveness of hydrogen adoption but also underscores a nuanced understanding of the complex interplay between technology deployment and overarching energy policy goals.

In conclusion, SGJA's succinct commentary encapsulates a focused and strategic perspective on the utilization of hydrogen technologies. His remarks highlight the importance of targeting applications where energy efficiency and electrification objectives converge, thereby amplifying the positive impact of hydrogen within the broader landscape of sustainable energy transitions.

JH's perspectives on the energy efficiency of hydrogen technologies contribute a nuanced and pragmatic viewpoint to the ongoing discourse. JH acknowledges the potential of hydrogen technologies to privatize energy production, usage, and storage as a means of funding, yet expresses

scepticism about its overall efficiency as a strategy. This sentiment highlights a consideration of the intricate balance between economic viability and energy optimization in hydrogen utilization. -energy production and storage

The participant delves into the comparative efficiency of different fuel cell technologies. JH notes that Proton Exchange Membrane (PEM) fuel cells are perceived to be more efficient in terms of current flow and flexibility, while alkaline fuel cells are comparatively cheaper and exhibit more advanced development. This juxtaposition reveals a recognition of the trade-offs between various technologies and their respective suitability for specific applications.

JH's perspective extends to a recent development in Australia involving purportedly 100% efficient electrolyzers. However, the participant discerns a distinction between thermoneutral voltage and thermodynamic efficiency, indicating an astute consideration of the technical complexities that can impact actual performance metrics.

Expressing both belief in hydrogen's potential and cautious scepticism, JH acknowledges the pivotal role of coupling hydrogen production and utilization. However, he raises concerns about the efficiency trade-offs involved. This sentiment aligns with previous viewpoints that while hydrogen presents opportunities, it also introduces efficiency challenges that need careful consideration.

Regarding the feasibility of hydrogen in distributed generation and district heating, JH draws attention to the contextual aspects, such as local environment and public mentality. JH's reference to a district heating study underscores a desire to integrate hydrogen technologies into existing infrastructure for energy generation and heating. This resonates with earlier discussions about utilizing hydrogen in building heating systems.

JH's discussion of the New Zealand (NZ) built environment and its potential application of hydrogen technologies underscores a consideration of the local context and its alignment with energy efficiency goals. He points out that while distributed generation and district heating using hydrogen could present a viable solution in certain contexts, the prevalent lack of a district heating model in New Zealand poses a challenge to the adoption of such technology.

JH's observation regarding the absence of a district heating model in New Zealand highlights the influence of regional infrastructure and energy practices on the feasibility of incorporating hydrogen technologies. This insight emphasizes the significance of context-specific solutions when implementing new energy technologies within a given environment.

JH's acknowledgment of the potential benefits of distributed generation and district heating in the NZ context implies that these models align with energy efficiency objectives and could offer a pathway for utilizing hydrogen technologies effectively. However, the existing energy landscape and infrastructure in New Zealand may not readily accommodate these models, potentially influencing the practicality of widespread adoption.

JH's perspective adds a balanced and pragmatic layer to the discourse on hydrogen energy efficiency. While acknowledging hydrogen's potential, the participant remains cautious about its widespread adoption due to acknowledged efficiency challenges. This perspective aligns with previous participants' views that emphasize careful consideration of trade-offs and alignment with energy optimization goals. JH's insights collectively contribute to a multifaceted understanding of the role of hydrogen technologies in advancing energy efficiency and their potential applications in various building environments. JH's viewpoint underscores the importance of understanding and adapting to the local built environment and its existing energy infrastructure when considering the integration of hydrogen technologies. His insights contribute to a nuanced understanding of the challenges and opportunities related to energy efficiency, heating, and the potential utilization of hydrogen technologies within the specific context of New Zealand's built environment.

RGJA's perspective offers a measured assessment of the energy efficiency considerations surrounding hydrogen technologies within the context of the built environment. His viewpoint highlights the interplay between electrical efficiency, residual energy utilization, and the potential benefits of hydrogen utilization for various applications.

RGJA begins by addressing the notion of hydrogen as an efficient option within the energy landscape. He acknowledges that, when evaluating hydrogen technologies, the focus should be on their electrical efficiency, which may hover around 60%. This observation underscores the need to critically assess the efficiency of hydrogen technologies, particularly in comparison to alternative energy sources, to ensure that they meet established energy efficiency criteria.

The participant further points out that, despite potential shortcomings in electrical efficiency, there are compensatory factors that contribute to the overall viability of hydrogen technologies. RGJA introduces the concept of "*residual energy*", emphasizing that while certain energy may be lost in the hydrogen production process, the by-products or residual energy can still find utility within the building environment. This insight speaks to the importance of holistic energy management and the potential to enhance overall energy efficiency through creative utilization of residual resources.

RGJA also underscores the economic competitiveness of hydrogen technologies in terms of cost, highlighting a key advantage that can drive their adoption. He asserts that despite certain efficiency limitations, hydrogen technologies can offer a "*very competitive hydrogen cost*", thereby positioning efficiency as a critical factor in the cost-effectiveness of hydrogen-based solutions.

In conclusion, RGJA's perspective on energy efficiency within the realm of hydrogen technologies presents a balanced assessment. The participant's viewpoint recognizes the need to carefully evaluate electrical efficiency while also acknowledging the potential for enhanced energy efficiency through innovative utilization of residual energy. The consideration of hydrogen's cost competitiveness further enriches the discourse on the practicality and benefits of incorporating hydrogen technologies for combined heat and power applications, water and space heating options, and other building-related energy needs.

JAGR contributes a nuanced perspective on the energy efficiency considerations pertaining to hydrogen technologies, particularly in the context of combined heat and electricity power systems, water heating applications, and the broader built environment. His viewpoint underscores the intricate interplay between thermodynamics, fuel cell efficiency, catalyst improvement, and energy savings.

JAGR initiates the discourse by highlighting the potential of hydrogen within combined heat and electricity power systems. The participant mentions hydrogen's utilization for heating water, a notable application within the built environment. However, a sense of uncertainty emerges as JAGR acknowledges a lack of clarity regarding the efficiency of hydrogen in such applications. This introspection underscores the need for a comprehensive understanding of the energy efficiency dynamics surrounding hydrogen technologies.

Thermodynamic considerations are brought into focus by JAGR, who quantifies the theoretical potential of hydrogen's energy conversion. He notes a thermodynamic efficiency of 33 kWh, a benchmark that serves as a reference point for evaluating practical efficiencies. Importantly, JAGR juxtaposes this theoretical value with the real-world efficiency of fuel cells, which is noted to be around 60%. This juxtaposition provides a tangible perspective on the efficiency gap between theoretical ideals and practical implementations.

The participant delves into the quantifiable outcomes of hydrogen utilization, presenting the conversion of 1 kilogram of green hydrogen into 20 kilowatt-hours of energy. This quantification further solidifies the participant's insights, offering a concrete basis for understanding the energy outputs achievable through hydrogen technologies.

An avenue for enhancing energy efficiency is introduced through the discussion of catalyst improvement. JAGR posits that refining catalysts could potentially contribute to increased energy efficiency, indicating a pathway for technological advancement and efficiency enhancement within hydrogen technologies.

In the broader context of energy savings, JAGR alludes to the potential benefits of hydrogen-based systems. While not explicitly elaborated upon, this reference to energy savings aligns with the overarching theme of energy efficiency and speaks to the potential for hydrogen to play a role in reducing energy consumption and improving resource utilization.

In conclusion, JAGR's perspective on the energy efficiency of hydrogen technologies offers a thoughtful exploration of theoretical benchmarks, real-world efficiencies, and potential pathways for improvement. JAGR's insights contribute to the discourse on hydrogen's role in combined heat and power systems, water and space heating options, and energy-efficient solutions within residential and commercial buildings.

MR's perspective offers a comprehensive exploration of the efficiency challenges inherent in hydrogen transformations, the balance between hydrogen and direct electricity utilization, and the avenues for optimizing hydrogen technologies within the built environment. Her insights delve into the optimization of electrolysis processes, efficiency estimations, and the suitability of hydrogen for various applications, thereby contributing to the discourse on energy-efficient solutions for heating, power generation, and energy security.

MR begins by highlighting a critical turning point concerning the efficiency challenges arising from hydrogen transformations. She underscores the need to discern when it is more efficient to directly employ hydrogen versus utilizing electricity, a consideration that resonates with the core theme of energy efficiency.

Efficiency maintenance is emphasized by MR as a pivotal aspect in hydrogen technology development. MR's viewpoint aligns with the broader consensus on the significance of continuous investment in technology enhancement to achieve and sustain high levels of efficiency. This focus on efficiency is framed within the context of bolstering energy security and ensuring a reliable energy supply.

Efficiency estimations are provided by MR, acknowledging a rough estimate of around 50% efficiency for various electrolyser technologies. This estimation, while acknowledging variability based on technology and system design, contributes to the quantification of efficiency benchmarks.

In the context of the built environment, MR's perspective distinguishes between residential houses and larger buildings. For houses, she suggests a preference for electrification due to the ease of employing existing technologies for cooking and water heating. In contrast, the role of hydrogen in larger buildings becomes more nuanced. MR suggests that hydrogen could effectively heat buildings in winter but presents complexities in summer applications. Furthermore, MR posits that hydrogen could find utility in limiting start-ups or supporting recovery processes within larger facilities.

In summary, MR's viewpoint traverses the efficiency landscape of hydrogen technologies in the built environment, delving into challenges, customization, scalability, and potential applications. The participant's insights contribute to the broader understanding of hydrogen's role in energy-efficient solutions for power generation, water and space heating, and overall sustainability within residential and commercial settings.

MS provides an insightful perspective on the energy efficiency considerations underlying hydrogen technologies, emphasizing the physics-based energy input required for water splitting and the importance of process efficiency. MR's viewpoint extends to the potential applications of hydrogen

technologies, particularly in scenarios where combined heat and power systems are employed for enhanced energy efficiency.

MS commences the discussion by acknowledging the fundamental energy input required for the separation of hydrogen and oxygen through water electrolysis. He underscores that this energy demand is rooted in the laws of physics. However, the crux lies in the efficiency of the process itself, highlighting the pivotal role of optimization in achieving energy-efficient hydrogen production.

The discourse then pivots to the practical applications of hydrogen within the built environment. MS introduces the concept of on-site hydrogen utilization through fuel cells, drawing attention to the multifaceted benefits of this approach. In particular, the participant elaborates on the efficiency gains achieved when a fuel cell not only converts hydrogen into electricity but also harnesses the heat generated as a useful by-product for building heating. MS cites an approximate efficiency of 83% that can be attained by synergizing electrical energy production with heat recovery.

Further insights are offered in the context of transportation, where he underscores the challenges associated with hydrogen delivery processes. The inefficiencies arising from loss during transportation are acknowledged, emphasizing the significance of minimizing energy loss in the broader hydrogen supply chain.

Moreover, MS delves into a scenario involving water desalination, highlighting the potential for improved energy efficiency when the process of water desalination is detached from the hydrogen production equation. This observation underscores his keen grasp of the interconnectedness between different energy-intensive processes and the opportunities for optimization.

In sum, MS's perspective contributes a nuanced understanding of the energy efficiency landscape within hydrogen technologies. MS's insights span the physics-based energy requirements of hydrogen production, the advantages of combined heat and power systems, and the complexities of optimizing energy efficiency across diverse applications. This comprehensive outlook enriches the discourse on the role of hydrogen in achieving sustainable energy solutions within residential, commercial, and transportation contexts.

PL offers valuable insights into the energy efficiency considerations related to hydrogen utilization, specifically addressing the reuse of hydrogen for electricity generation and the role of heat recovery in enhancing overall efficiency.

The discussion commences with PL highlighting a scenario in which the energy efficiency of a process involving hydrogen reuse for electricity production is not particularly high. This observation underscores the complexities inherent in reusing hydrogen within energy systems and the challenges associated with maximizing efficiency in such contexts.

The discourse then shifts towards the significance of heat recovery as a means to bolster energy efficiency. PL agrees that utilizing the heat generated as a by-product of hydrogen-related processes, such as fuel cell operation, can lead to increased energy efficiency. This alignment with the idea that harnessing heat for other applications is a constructive approach further underscores PL's understanding of the intricacies involved in optimizing energy utilization.

By emphasizing the connection between hydrogen reuse, electricity generation, and heat recovery, PL contributes to the broader conversation on energy efficiency within hydrogen-based systems. His insights underscore the interplay between various factors impacting efficiency and highlight the potential benefits of holistic approaches to energy optimization.

RH provides a comprehensive perspective on the energy efficiency considerations of hydrogen technologies within the New Zealand context, specifically addressing their potential applications in the built environment, including residential and commercial buildings.

The discourse commences with RH introducing a promising use case involving the deployment of an electrolyser powered by solar panels to produce hydrogen through water splitting. The hydrogen is then utilized in an instant water heater, providing a decarbonized fuel source for heating. RH illustrates the quantifiable environmental benefits of this approach, such as CO₂ emissions reduction associated with methane or LPG combustion. The participant's emphasis on this practical application highlights their awareness of utilizing hydrogen for specific energy needs. – water heating

The discussion expands into a comparison between hydrogen and batteries as energy storage solutions. RH argues that while batteries excel for applications exclusively requiring electricity, hydrogen's inefficiency in small-scale conversion back to electricity limits its appeal for these cases. A recognition of the 50% efficiency ceiling for small-scale hydrogen conversion informs RH's stance. Instead, RH asserts that burning hydrogen for heat, achieving 80-90% efficiency, aligns better with addressing New Zealand's substantial energy needs for cooking, hot water, and space heating, which constitute a significant portion of the country's energy consumption.

The participant delves into technical considerations by discussing anion exchange membranes and their impact on electrolyser efficiency. This nuanced understanding indicates RH's grasp of technological nuances and their implications for energy efficiency.

RH also recognizes that high-quality, consistent heat demand can offset the inefficiencies associated with hydrogen utilization, particularly if that demand is matched with purpose-built applications.

In summary, RH's opinion underscores the pragmatism of tailoring hydrogen applications to New Zealand's specific energy consumption patterns. The participant's insights provide a balanced evaluation of the trade-offs between efficiency, technology, and energy needs within the context of the country's built environment and energy landscape.

SJS provides a pragmatic perspective on the critical role of hydrogen production efficiency and cost-effectiveness in driving the transition away from fossil fuels. His viewpoint aligns with the overarching goal of achieving a sustainable energy landscape.

The discourse begins with an emphasis on efficient and cost-effective hydrogen production as a linchpin for driving the shift away from fossil fuels. This recognition underscores the pivotal role of hydrogen technology in enabling a sustainable energy transition.

Climate zones emerge as a key consideration in the discussion. In Europe, where heating is a primary need, the production of hydrogen presents an opportunity to simultaneously generate heat and electricity. This aligns with the utilization of excess heat generated by the electrolyser to enhance overall efficiency. In contrast, regions with cooling needs, such as Asia, can leverage the heat produced by fuel cells to contribute to heating requirements, creating a synergistic energy loop.

SJS's example of home power solutions illustrates the potential for localized energy systems to harness both electricity and heat outputs, thereby enhancing energy efficiency and usability. The significance of context is reinforced through references to Australia and Thailand, where climatic conditions influence the economic viability of heat utilization. While Australia's abundant and inexpensive energy resources render heat recovery less essential, the story in Thailand is markedly different due to a surplus of energy and limited demand for heat.

In conclusion, SJS's perspective underscores the contextual importance of energy needs and efficiency considerations in various geographic regions. The participant's insights align with a pragmatic approach to leveraging hydrogen's potential based on specific climate-related requirements and energy market dynamics.

TW's perspective provides valuable insights into the nuanced relationship between hydrogen technologies, energy efficiency, and their application in New Zealand's built environment. The

participant's viewpoint echoes the sentiment that hydrogen and batteries work in tandem to address the efficiency challenges in energy systems.

The discourse begins with an acknowledgment of the complementary nature of hydrogen and batteries in energy systems. TW underscores the notion that hydrogen technologies are not yet fully efficient, leading to the strategic integration of both hydrogen and batteries to optimize energy utilization.

Efficiency gains become a focal point in the discussion, with the participant highlighting efforts to replace gas appliances with hydrogen to improve overall system efficiency. The emphasis on efficiency is further supported by the mention of operating at around 70% efficiency in the Enapter system for hydrogen production. The conversion of energy units, from kilowatts to kilowatt-hours, provides a quantitative understanding of the stored energy potential of hydrogen.

TW's opinion highlights the potential for hydrogen to enhance energy efficiency when applied to existing technologies, such as boilers and stovetops. The focus on hydrogen boilers, hydrogen hobs, and cooking demonstrates a practical approach to utilizing hydrogen's energy characteristics for heating and culinary needs. TW's reference to high-temperature heat pump applications also underscores the versatility of hydrogen in contributing to energy-efficient solutions.

TW introduces real-world examples, including the use of hydrogen through a converted condenser boiler product from Bosch. Additionally, the mention of applying hydrogen technologies to schools further exemplifies the potential for hydrogen integration in existing infrastructure.

In conclusion, TW's insights encapsulate the dual approach of hydrogen and batteries to address energy efficiency challenges. TW's emphasis on practical applications, efficiency improvements, and the symbiotic relationship between hydrogen and batteries provides a comprehensive understanding of the role of hydrogen technologies in enhancing energy efficiency within New Zealand's built environment.

VG's perspective offers a critical examination of the energy efficiency aspects of hydrogen technologies, particularly in the context of heating applications within the built environment. VG's viewpoint revolves around the efficiency challenges posed by hydrogen-based heating solutions.

VG begins by highlighting heating as a primary use case for hydrogen in buildings. However, he takes a critical stance against hydrogen for heating due to inherent efficiency concerns. The discourse emphasizes the comparative analysis between hydrogen-based heating and electric heat pumps, elucidating the efficiency advantages of the latter. VG underscores the inefficiencies associated with using hydrogen for heating, pointing out that the overall efficiency of hydrogen-based heating systems is notably lower compared to electric heat pumps.

VG introduces an important quantitative perspective by contrasting the energy efficiencies of the two approaches. He articulates the efficiency dilemma by explaining that for every kilowatt-hour (kWh) of electricity invested in producing hydrogen, only a third of that energy is retained for actual use. This inefficiency is echoed in hydrogen's application as well, where an additional third of the energy is lost during utilization, resulting in an overall efficiency challenge.

VG's viewpoint addresses the pragmatic concern of repurposing existing gas infrastructure for hydrogen heating but highlights that this does not resolve the core inefficiency problem. The recent examples of the UK experimenting with hydrogen heating and Germany banning it due to inefficiency underscore the practical implications of these challenges.

In conclusion, VG's perspective offers a grounded analysis of hydrogen's inefficiency challenges in heating applications within the built environment. VG's stance, supported by quantitative insights and comparisons, provides a comprehensive understanding of the efficiency constraints that hydrogen technologies face, particularly in the context of energy-efficient heating solutions.

ZJ's perspective offers a nuanced assessment of the energy efficiency landscape of hydrogen technologies, with a focus on its potential for combined heat and power (CHP) applications in various regions, notably Europe and China. ZJ highlights the suitability of hydrogen for heating purposes in colder climates, where the demand for efficient heating solutions is paramount.

ZJ's viewpoint underscores the significance of CHP units in European countries, traditionally employed for heat and electricity generation. The expert introduces the concept of high-temperature fuel cells as a potential replacement for existing gas turbine CHP units. These fuel cells are projected to achieve significantly higher efficiency rates, with estimations ranging from 70% to as high as 90% when heat recovery is integrated effectively. This discussion showcases ZJ's recognition of hydrogen's potential to enhance energy efficiency in heat and power production, particularly in regions characterized by colder climates.

The participant offers real-world examples to substantiate the argument. The mention of a significant hydrogen project in the UK and the utilization of alkaline electrolyzers for hydrogen production in China further demonstrates ZJ's grasp of practical applications and their implications for energy efficiency improvement.

In conclusion, ZJ's perspective provides an informed analysis of the energy efficiency prospects of hydrogen technologies in the context of CHP applications for heating and electricity generation. His insights highlight the potential of hydrogen to elevate overall system efficiency, particularly in regions where heating demands are pronounced.

Energy Efficiency, Combined Heat and Power, Water and Space Heating	
Aspect	Key Insights
Inherent Inefficiencies	Hydrogen production and utilization face challenges in achieving high energy efficiency due to inevitable energy losses in electrolysis.
CHP Systems and Fuel Cells	Combined heat and power (CHP) systems with high-temperature fuel cells can boost efficiency, reaching around 80-90% through heat recovery.
Heating Applications	Hydrogen technologies offer potential for water and space heating, but efficiency advantages need to be carefully weighed against limitations, particularly in colder European climates.
Residential vs. Commercial	Residential buildings may favour electrification for simplicity, while larger commercial facilities could benefit from hydrogen heating and load balancing.
Efficiency Estimates	Hydrogen systems typically achieve around 50% efficiency. Optimization of production and integrated energy utilization is crucial for improving this.
Hydrogen and Batteries	Complementing hydrogen systems with batteries can help mitigate efficiency gaps, especially when applications are aligned with specific energy use patterns.
Existing Gas Infrastructure	Hydrogen can utilize existing gas infrastructure, but overcoming its inherent efficiency limitations compared to alternatives like heat pumps remains a challenge.

Potential and Trade-offs	Hydrogen shows promise in contributing to energy efficiency but requires a nuanced approach that considers trade-offs, technological advancements, and strategic implementations in different environments.

Table 29: Energy Efficiency, Combined Heat and Power, Water and Space Heating

In summary, the interviews’ amalgamated viewpoints highlight the complex interplay between energy efficiency, hydrogen technologies, and their application in the built environment. While hydrogen technologies offer the potential to contribute to energy efficiency goals, participants underscore the challenges posed by inherent inefficiencies. The integration of hydrogen technologies for CHP and heating applications showcases their potential, particularly in specific climatic and infrastructural contexts. Achieving energy efficiency with hydrogen in the built environment demands a nuanced assessment of benefits and trade-offs, requiring ongoing advancements in technology and thoughtful implementation strategies.

4.34 H2 and Climatic Zones, Seasonal Energy Demand

The viewpoints shared by the participants reflect a comprehensive understanding of the role of hydrogen in various climatic zones and its implications for addressing seasonal energy demands. The potential applications of hydrogen in the built environment are examined within the context of differing climates and energy requirements.

In regions characterized by Equatorial climates, such as Mexico and some Latin American countries, the necessity for hydrogen-based heating solutions is questioned. Solar thermal boilers and efficient renewable options already exist, rendering hydrogen potentially expensive and complex for residential use. Contrastingly, colder climates, notably Europe, emphasize the suitability of hydrogen for heating purposes due to the demand for efficient heating solutions. The integration of high-temperature fuel cells for combined heat and power (CHP) applications emerges as a promising avenue, particularly in regions with seasonal energy demands.

The exploration of seasonal storage emerges as a common theme in the discussions. Participants acknowledge the limitations of batteries for prolonged energy storage, particularly during extended periods of rain or adverse weather conditions. Hydrogen storage is presented as a viable solution to bridge such gaps in energy availability, especially for off-grid systems and remote communities. The efficiency of high-temperature fuel cells is noted, with the potential to replace conventional gas turbine CHP units in colder climates, thereby optimizing the combined system efficiency for electricity and heat generation.

Furthermore, regional variations and the cost-effectiveness of hydrogen utilization are acknowledged. While Europe’s heating demand aligns with hydrogen use, countries with abundant and affordable energy resources may find hydrogen-based heating less compelling.

JAGR emphasizes that in Equatorial countries like Mexico, where efficient solar thermal boilers are already prevalent at the domestic and residential levels, the need for hydrogen-based water heating is diminished. He highlights the cost-effectiveness and practicality of existing solar thermal solutions in such regions, suggesting that hydrogen utilization for heating could be both expensive and complex. This sentiment is extended to several Latin American countries and Spain, where hydrogen is not a prevalent choice for residential applications due to the availability of alternatives.

Furthermore, JAGR underscores the notion that the adoption of hydrogen in buildings is not a universal solution applicable to every nation. The multifaceted nature of hydrogen deployment is recognized, with varying degrees of relevance based on regional energy landscapes and infrastructure.

JAGR introduces a compelling perspective on hydrogen's potential as an energy storage solution for countries with distinct seasonal energy demands, citing Germany as an example. The participant identifies the unique advantage of hydrogen's capability to store energy for extended periods. The utilization of salt caverns for hydrogen storage is highlighted as a feasible approach to address the fluctuating energy needs of countries like Germany, where seasonal variations necessitate reliable storage and utilization options.

In conclusion, JAGR's opinion indicates the need to assess hydrogen applications within the context of climatic zones and varying energy demands. The expert's insights highlight the importance of tailoring hydrogen solutions to suit the specific needs of individual countries and regions, while also acknowledging hydrogen's potential for addressing long-term energy storage challenges in the face of seasonal demand fluctuations.

RH's perspective provides valuable insight into the potential circumstances where the inefficiency of hydrogen-based heating systems could be justified. RH acknowledges that the inefficiency associated with hydrogen-based heating becomes more acceptable if there is a specific and consistent demand for high-quality heat. This scenario is exemplified by living in elevated mountainous regions, where the need for heating is constant due to the colder environment.

RH's opinion highlights that the inefficiency of hydrogen-based heating solutions could potentially be offset by the perpetual and essential requirement for warmth in certain geographical contexts. His view makes clear the importance of considering localized conditions and demands when evaluating the feasibility and practicality of hydrogen-based heating systems, suggesting that there are specific cases where the inefficiency trade-off could be deemed acceptable.

SJS provides a comprehensive perspective on the role of energy storage, particularly in regions with varying weather conditions and energy demands. The participant presents a case study of a private home in northern Thailand that aimed for off-grid sustainability. SJS explains the limitations of battery storage during extended periods of rain, where energy needs exceed the capacity of batteries. This scenario highlights the concept of "*seasonal storage*", where bridging longer time gaps become essential and battery storage alone becomes impractical and commercially unviable.

To address this challenge, SJS proposes a hybrid solution involving both battery and hydrogen storage. The participant emphasizes that while batteries are efficient for daily energy needs, hydrogen storage offers an advantage for longer-term energy requirements during periods of reduced solar energy generation. This hybrid approach, involving both battery and hydrogen storage, allows for a more comprehensive and adaptable energy storage solution.

SJS further discusses the relevance of climate zones in shaping energy solutions. In regions like Europe, where heating is crucial, hydrogen-based solutions offer benefits. Conversely, in hotter regions like Australia and Thailand, where cooling is prioritized, the need for hydrogen-based heating is reduced. SJS explains that excess heat generated by hydrogen systems in these regions can be efficiently released due to the abundance of cheap energy, rendering the heat aspect less valuable.

Overall, SJS's insights emphasises the significance of tailoring energy storage solutions to the specific demands of climate zones and energy consumption patterns, recognizing the potential advantages of combining battery and hydrogen storage in addressing different energy needs.

In summary, the participants' perspectives reveal the intricate interplay between hydrogen technologies, climatic zones, and seasonal energy demands. The discussions brings out the significance of tailoring hydrogen applications to specific regional needs and highlight the potential for hydrogen-based solutions to address heating and energy challenges across diverse climatic contexts.

4.35 Hydrogen for Electricity, Electrification via H₂ and Fuel Cells

Hydrogen fuel cells, lauded by participants as a promising technology for the built environment, present an intriguing mechanism to harness the chemical energy of hydrogen and convert it into usable electricity. Fuel cells, both Proton Exchange Membrane (PEM) and Anion Exchange Membrane (AEM), epitomize efficiency and environmental compatibility, resonating with participants' visions of sustainable energy solutions.

At the heart of these fuel cells lies a simple yet transformative process: the electrochemical conversion of hydrogen gas and oxygen into electricity, producing only water as a by-product. The process, resembling the reverse of electrolysis, transpires within a fuel cell stack comprised of individual cells.

In PEM fuel cells, an impermeable electrolyte membrane allows only protons to pass through, forcing electrons to traverse an external circuit, generating an electric current. Hydrogen molecules on the anode side split into protons and electrons, with the latter pursuing the external circuit to generate power. Meanwhile, oxygen molecules on the cathode side combine with protons that traversed the membrane and electrons from the external circuit to form water.

AEM fuel cells, a participant-admired alternative, share the same fundamental process but diverge in their choice of electrolyte. Here, the membrane permits both protons and anions to migrate, amplifying their application potential and enabling the use of less expensive catalysts.

Participants highlight fuel cells' potential for the built environment, envisioning their integration into power supply systems. These fuel cells, when coupled with on-site hydrogen generation and storage, can provide continuous power for essential services during outages, bolstering the resilience of buildings and communities. The allure of high efficiency, minimal emissions, and flexibility further fuels the enthusiasm for fuel cells, aligning with sustainable practices and green aspirations.

Fuel cells for the built environment, as participants articulate, offer a refined harmony between technological ingenuity and environmental consciousness. They stand as catalysts for redefining power generation paradigms, transforming hydrogen's potential into palpable electricity while leaving behind only water, and in their wake, the promise of a cleaner and more self-reliant energy landscape.

The participants' opinions about hydrogen's role in electricity generation, electrification, and fuel cells reveal a spectrum of perspectives that intersect with the built environment, particularly in the context of New Zealand. A common thread among the participants is the recognition of hydrogen's potential for electricity generation and its suitability for specific applications, with fuel cells playing a significant role.

Hydrogen's role in electricity generation is highlighted by several participants who emphasize its efficiency and potential as an energy carrier. One participant describes how *"hydrogen can generate heat and electricity with the only emissions being water"*. Another participant envisions hydrogen as a backup power source, particularly for applications like emergency power. This sentiment resonates with the idea of using hydrogen fuel cells for critical functions in buildings, such as hospitals, where the value of hydrogen lies in its ability to provide emergency backup power.

The discussion on electrification through hydrogen reveals differing opinions. While one participant suggests that electrification could cover the energy needs of buildings, another participant argues that hydrogen should be considered as a complementary solution for specific situations. One participant envisions the potential of a unit comprising a reversible fuel cell and electrolyser for residential applications, allowing buildings or groups of buildings to achieve autonomy and manage intermittency more effectively. This notion aligns with the concept of using hydrogen for localized

energy independence, particularly in regions like New Zealand where self-sufficiency could be advantageous.

Fuel cells emerge as a key technology with varied applications in the built environment. Several participants highlight fuel cells' relevance in providing both electricity and heat. One participant explains how fuel cells could support emergency systems, offering a valuable source of power during outages. Another participant envisions integrating fuel cells into housing blocks, creating energy hubs that supply power to surrounding neighbourhoods. This approach aligns with the idea of localized energy production and distribution within communities, which can contribute to the resilience of the built environment.

The participants' perspectives also highlight the importance of considering the entire energy ecosystem. The interaction between electrolyzers, fuel cells, and grids is emphasized, with one participant noting that *"you understand the electrolyser is only part of the equation. So you need also fuel cells... So we have to understand that because if it's so, companies are much slower"*. This underscores the complexity of implementing hydrogen-based solutions and the need for comprehensive planning and collaboration.

In the context of New Zealand, the participants' viewpoints resonate with the country's energy landscape. New Zealand's focus on renewable energy and its unique geographic challenges make it an interesting case study. The idea of using hydrogen for backup power aligns with New Zealand's emphasis on energy resilience. Additionally, the concept of localized energy production through fuel cells mirrors the country's pursuit of self-reliant energy systems, given its geographical isolation.

In the discourse on fuel cells for the electrification of the built environment, participant DA emerges as an informed advocate. Notably, DA underscores the influence of a major solid oxide fuel cell company, which licenses its technology to a significant player in Korea's energy landscape. This collaboration laid the groundwork for fuel cell power initiatives, with DA noting:

"One of the biggest players in Korea do some fuel cell power back in 2019".

DA navigates the complexities of Korea's energy profile, highlighting its reliance on natural gas and coal due to limited oil reserves. While acknowledging the challenge posed by this energy mix, DA emphasizes:

It's not as suitable country for reliable energy and however it's suitable for fuel cells".

The reasoning behind this suitability lies in Korea's prowess in fuel cell technology, especially for hydrogen-powered vehicles. DA aptly notes:

"Korea is an absolute champion in terms of the production of fuel cell cars... more than 60% of the entire world's fuel cell vehicles last year".

Additionally, Korea boasts an impressive share of global fuel cell power plants, reinforcing the potential of fuel cells to alleviate the country's electricity supply dependency.

DA also draws a parallel to Japan, a neighbouring country, where fuel cells have achieved significant integration into residential and commercial buildings. The prominence of fuel cells in Japan's built environment demonstrates the viability of this technology in addressing energy needs. DA's insights resonate:

"Our neighbouring country Japan is a world champion... significant number of fuel cells that are applied specifically in residential buildings and commercial buildings".

However, DA brings a critical perspective to the table when discussing the suitability of fuel cell types. DA raises the point that while the Proton Exchange Membrane (PEM) fuel cell, known for its

usage in vehicles, is not sustainable for buildings, it finds merit in scenarios requiring frequent power cycling:

“It’s not really suitable for buildings... but it’s suitable for the applications where you need frequent turn off and turn on switch on switch off”.

Crucially, DA underscores fuel cells’ role in decarbonizing the built environment. According to DA:

“The only way of decarbonizing the built environment is through fuel cells”.

This statement underscores the centrality of fuel cells in the pursuit of sustainable energy solutions. Finally, DA envisages substantial potential in applying fuel cells to commercial and residential buildings, reiterating:

“This is why we see a huge potential... commercial and residential buildings”.

DA’s discerning perspective, as revealed through these statements, illuminates the pivotal role of fuel cells in the electrification of the built environment. Their potential to circumvent energy challenges, facilitate decarbonization, and serve as an integral part of the energy transition landscape is underscored by DA’s insights.

In the discourse surrounding fuel cells for the electrification of the built environment, Participant **SGJA** emerges as a discerning commentator, bringing to light considerations that warrant focused attention. SGJA recognizes the diverse range of potential users for fuel cells but underscores the importance of directing efforts toward applications aligned with energy efficiency and electrification goals.

“I mean, there are many users, but I think in particular we should focus on those applications that are currently targeted by energy efficiency or by electrification”.

This perspective underscores the need for strategic deployment to maximize the impact of fuel cell technology. Within this context, SGJA draws attention to a noteworthy project situated in Mexico’s northern region, specifically in the state of California, Baja California. This project epitomizes the convergence of solar energy and fuel cell technology to address energy challenges. SGJA elaborates:

“There is a project in the north of Mexico... aiming to use fuel cells to produce electricity because it’s an isolated electric system”.

This case exemplifies the potential of fuel cells to augment isolated electric systems, demonstrating their adaptability to specific energy requirements.

Participant **JH** engages in a thoughtful exploration of the potential role of hydrogen fuel cells, particularly combined heat and power (CHP), in the context of the built environment’s energy landscape. Expressing a balanced perspective, JH cautiously considers the viability of hydrogen fuel cells as a suitable option for the built environment:

“Hydrogen fuel cells, CHP, maybe that would be the only thing I could really say is possibly a good idea for built environment”.

This candid assessment reflects an awareness of the complex factors involved in integrating fuel cell technology into the built environment.

JH’s reflections extend to the considerations surrounding temperature variations within fuel cells:

“I don’t know enough about the low temperature ones really. But to me that sort of the crossovers gotta be a problem there, I would think hydrogen crossover because it’s so small”.

Here, JH raises concerns about hydrogen crossover and underscores the importance of addressing challenges associated with membrane materials and temperature management to ensure optimal fuel cell performance.

The conversation shifts toward the economic aspects of fuel cells, with JH delving into the cost dynamics of hydrogen compared to electricity:

“Fundamentally, the hydrogen’s got to be more expensive than electricity so you’ve got to find some application where the hydrogen is giving you a benefit, so to make direct electrification is still the way to go”.

This viewpoint underscores the need to identify scenarios where the advantages of using hydrogen as an energy carrier outweigh its cost implications.

JH then navigates the question of affordability and the role of electricity pricing in shaping the feasibility of hydrogen-based solutions:

“So how does it get cheap? Well, that’s only with really cheap electricity. And if you got really cheap electricity, why wouldn’t you just electrify?”

This pragmatic consideration brings forth a critical question about the cost-effectiveness of hydrogen compared to readily available electricity, drawing attention to the economic trade-offs that underpin energy decisions.

Further, JH reflects on Japan’s experiences with residential fuel cells and the country’s investment in intellectual property:

“They’ve had residential fuel cells for us since what mid or early 2010’s so I think the other thing with Japan is they own a lot of intellectual property in their area”.

This observation offers insights into Japan’s inclination towards large-scale demonstrations and underscores the importance of understanding the potential advantages and disadvantages of fuel cell technology, even as it evolves.

In closing, JH introduces the prospect of fuel cells contributing to electricity generation for urban areas, stating:

“You could do some of the electricity generation for the city”.

This pragmatic musing encapsulates JH’s pragmatic and insightful contemplation of fuel cells’ relevance to the electrification of residential and commercial buildings in the built environment.

Participant **JAGR** engages in a contemplative exploration of the potential for fuel cells in addressing the energy needs of buildings in the built environment, particularly within the context of electrification. His insights reflect a nuanced understanding of the technical and economic considerations involved.

JAGR starts by acknowledging the potential of electrification in addressing the energy needs of buildings:

“A lot of these buildings’ needs could be covered by electrification because of the temperatures you need and the volumes of energy”.

This observation highlights the suitability of electrification for meeting the energy requirements of various building types, driven by the efficiency and adaptability of electric systems.

He then shifts the focus to the concept of using hydrogen as an energy carrier and the process of producing electricity through water electrolysis:

“Producing electricity splitting water and no connection to the grid”.

This insight touches upon the potential of hydrogen production through electrolysis, a process that can be coupled with renewable energy sources to generate electricity independently from the grid, offering a degree of energy autonomy.

JAGR further elaborates on the idea of utilizing electrolyzers to store energy generated during off-peak hours and converting it back into electricity during high-demand periods:

“To the electrolyser and during the night it is converted into electricity”.

This notion underlines the value of energy storage and load balancing, highlighting a potential application of fuel cells in managing electricity demand fluctuations.

The conversation then turns to the economic feasibility of using hydrogen for large-scale electricity production. JAGR reflects:

“The idea of creating electricity from hydrogen would be a feasible no in the economical wait, but in large scale so far”.

Here, he acknowledges the current economic challenges associated with hydrogen-based electricity production, particularly on a smaller scale, while indicating the potential for feasibility in larger, more comprehensive implementations.

Lastly, JAGR emphasizes the need for skill development and adaptation to new technologies in the context of electrification:

“But we have to start preparing skills for Newton, new and future technologies electrification”.

This remark underscores the necessity of embracing evolving technologies and fostering the expertise required to drive the transition to cleaner and more efficient energy solutions.

Overall, JAGR’s reflections highlight a comprehensive consideration of the technical, economic, and skill-related aspects of utilizing fuel cells for the electrification of residential and commercial buildings in the built environment.

When considering residential applications, **MR** leans towards electrification due to its practicality and compatibility with existing technologies:

“For the houses I would go for the electrification because it’s in the end, you don’t really have to heat up too crazy temperatures”.

She highlights the convenience of electrification in meeting common household needs such as cooking and water heating, where the complexity of high-temperature requirements associated with fuel cells is circumvented.

Furthermore, MR underscores the ease of maintenance and safety associated with electrification.

“You have the technologies to cook, to heat water with electricity and it’s easier to maintain and to handle the safety”.

Here, she emphasizes the well-established infrastructure and safety protocols associated with electrical systems, making electrification a straightforward and secure choice for residential settings. MR's insights reflect a pragmatic approach, considering the compatibility of fuel cells and electrification with the specific energy demands and safety considerations of residential and commercial buildings in the built environment.

Participant **RH** offers valuable insights into the multifaceted role of fuel cells within the context of the built environment, highlighting both their versatility and practical considerations.

RH emphasizes the straightforward application of fuel cells, stating:

"The fuel cell is an instrument that uses hydrogen, so it has sensors inside it. And if it's a big field, though, if it's like a community size or a domestic, absolutely they will do. Yes, they will have all that thing there and there's nothing special with no new tech has to be invented. It just needs to be applied and still properly".

This assertion underscores that fuel cell technology is readily deployable, particularly in larger installations, and does not necessarily require ground-breaking advancements.

Further expanding on the concept of hydrogen-based energy storage, RH introduces the notion of a "hydrogen battery" that operates as a reversible fuel cell. He explains:

"It's essentially a reversible fuel cell. So it electrolyzes, then it stores the hydrogen in the metal and lets it back out, goes to the fuel cell".

This innovative approach to energy storage, utilizing hydrogen as an intermediary carrier, holds potential for increased energy efficiency and cost-effectiveness compared to traditional fuel cells.

Reflecting on the comparative feasibility of fuel cells versus alternative energy solutions, RH notes:

"But we did try the fuel cell route first like we did have the electric route. That was how we started off and we changed because of practicality and economics to go with the combustion process".

This pragmatic assessment underscores the importance of aligning technology choices with real-world considerations.

Furthermore, RH identifies specific niches for fuel cell integration, such as in emergency scenarios or when high-quality energy is essential. He states:

"I think there are places for a fuel cell like even in that situation there's a place for a sort of 500 Watt fuel cell, which is just for emergencies... Just to give you a little bit of power. So I do think there's a place for a small fuel cell. Just for vital the highest quality energy".

Additionally, RH provides insight into the trade-offs between different energy sources for heat generation, emphasizing the controllability of gas for certain processes. He explains:

"It's the controllability of gas for process heat. Electrification worked quite well if you've got the renewable energy as long as you put the wind turbines up as quickly as possible to get that energy available in a sustainable way then you're welcome".

This perspective underscores the importance of considering factors beyond mere energy production in evaluating the suitability of various energy solutions.

In summary, RH's perspective underscores the adaptability and diverse applications of fuel cells in the built environment, considering practicality, efficiency, and specific use cases as pivotal factors in their integration.

TW provides valuable insights into the potential role of fuel cells in the context of New Zealand's built environment, shedding light on the unique challenges and opportunities that the region presents. TW emphasizes the current absence of certain hydrogen utilization options in New Zealand, stating:

“The only options for hydrogen utilization at the moment is fuel cell”.

This observation underscores the nascent stage of hydrogen infrastructure development in the region and underscores the significance of fuel cells as a viable solution.

TW introduces a practical example of fuel cell integration, detailing the use of small fuel cells to complement battery systems on an island. He explains:

“They use a small fuel cell to top up batteries, and then the island essentially uses it. That's been gone for a very long time. It's a very good use case of what's happening and how to do it”.

This case study underscores the successful synergy between fuel cells and energy storage solutions, showcasing a precedent for their coexistence.

Expanding on the financial considerations of energy solutions, TW speculates on investment priorities in the coming years, particularly in relation to electrification efforts. He suggests:

“I suppose when you're looking at where the money needs to be spent over the next 5 to 10 years and in terms of electrification”.

This insight indicates the significance of strategic planning in allocating resources for sustainable energy initiatives, with fuel cells being a potential contender for funding allocation.

Furthermore, TW discusses a localized energy hub model that features both centralized battery systems and fuel cells. He notes:

“They also had centralized battery systems and inverter systems to support that neighbourhood, and they had centralized fuel cells feeding those battery systems or keeping them topped up so that you had this essentially one housing block that was your energy hub in the centre. And then it was all distributed out to the neighbourhood from there”.

This model highlights the feasibility of using fuel cells to support community-scale energy solutions and underscores the role of fuel cells in shaping decentralized energy distribution.

In conclusion, TW's insights illuminate the promising role of fuel cells in the electrification of New Zealand's built environment. His observations touch on hydrogen utilization, practical applications, investment strategies, and localized energy solutions, offering a well-rounded perspective on the subject.

Hydrogen for Electricity, Electrification via H2 and Fuel Cells	
Aspect	Key Insights
Hydrogen as Energy Carrier	Hydrogen is recognized as an efficient energy carrier for electricity generation, but opinions vary on its viability for widespread electrification.
On-Site Utilization	Fuel cells enable on-site hydrogen use, providing continuous power during grid outages, enhancing resilience, particularly in critical facilities like hospitals.
Home Unit Vision	A proposed home unit combining an electrolyser and fuel cell aims to manage energy intermittency and provide autonomy for buildings and neighbourhoods.

Localized Energy Hubs	Fuel cells can serve as localized energy hubs that supply power to surrounding areas, decentralizing production and distribution, and enhancing community resilience.
Residential vs. Commercial	While electrification is generally preferred for simpler residential energy needs, larger commercial facilities could benefit from hydrogen fuel cell heating and electricity balancing.
Economic Feasibility	The economic viability of hydrogen depends on strategic applications where the benefits outweigh costs compared to direct electrification; cheap electricity impacts its appeal.
Engineering Challenges	Technological complexities, including membrane materials, temperature, and hydrogen crossover, present engineering challenges that need to be addressed for optimization.
Demonstrated Advancements	Japan's progress in integrating fuel cells and developing intellectual property highlights advancements in the field, though scalability and cost considerations remain significant.
Potential Applications	Fuel cells have strong potential for electricity generation, heating, and backup power, but practical assessments of feasibility, efficiency, and cost-effectiveness are essential for successful implementation.

Table 30: Hydrogen for Electricity, Electrification via H2 and Fuel Cells

In conclusion, the participants' opinions collectively underscore the multifaceted potential of hydrogen in electricity generation, electrification, and fuel cell applications within the built environment. While there are differing perspectives on the extent of hydrogen's role, its adaptability to specific applications and its synergy with renewable energy goals are evident. The interplay between hydrogen technologies and the built environment is dynamic, with considerations for energy efficiency, reliability, and sustainability shaping the discourse.

4.36 H2 and Renewable Energy

The perspectives gathered from various participants provide a comprehensive outlook on the role of hydrogen as an energy carrier in tandem with renewable sources, while also underscoring the implications for New Zealand's built environment. The consensus among the interviewees underscores the potential of hydrogen when extracted through clean processes using renewable energy, offering a versatile energy carrier for diverse applications including transportation and industrial sectors. The intersection of hydrogen and renewable energy is particularly relevant in regions with limited land for expansive renewable installations, such as Korea, where hydrogen emerges as a suitable solution.

The viability of hydrogen production hinges on the availability and efficiency of renewable sources. Interviewees stress the importance of robust renewable energy infrastructure to support green hydrogen production. These experts endorse the notion that the "greenness" of hydrogen relies on the utilization of renewable energy sources for its extraction, with the underlying premise that both inputs must align to ensure a sustainable and eco-friendly outcome.

Furthermore, the viewpoints coalesce around the significance of hydrogen's role in energy transition, both at a regional and global level. Countries with abundant renewable resources, such as Costa Rica and New Zealand, embrace hydrogen as a complementary avenue to leverage their clean energy

potential. Conversely, regions with unique energy challenges, like Germany, view hydrogen as an indispensable piece of their net-zero puzzle, bridging gaps in renewable energy capacity.

In the context of New Zealand's built environment, where energy consumption and sustainability are paramount, hydrogen emerges as a promising contender. Notable discussions emphasize the integration of hydrogen technology into buildings erected post-2010, where a substantial proportion of electricity consumption derives from renewable sources. This approach aligns with New Zealand's target to source a significant portion of electricity from renewables in larger buildings. The convergence of fuel cells and centralized battery systems in housing blocks serves as a practical model to illustrate the potential of localized energy hubs.

DA insights offer a nuanced perspective on the potential synergy between hydrogen and renewable energy sources, particularly in the context of South Korea's unique challenges. His commentary underscores the crucial role of clean hydrogen extraction when coupled with electricity generated from renewable sources. This symbiotic relationship holds significant promise as it addresses not only the need for efficient energy carriers but also contributes to environmental sustainability.

DA's observations highlight South Korea's distinct geographical limitations, where the availability of vast tracts of land for solar power plants is restricted. This constraint prompts the exploration of alternative energy solutions, with hydrogen emerging as a promising avenue. As he aptly points out, hydrogen's versatility as an energy carrier presents a multifaceted solution for a variety of applications, ranging from powering vehicles to industrial processes. This aligns well with global aspirations to diversify energy sources and reduce reliance on fossil fuels.

The practicality of deploying large-scale wind farms in Korea is weighed against potential public resistance due to concerns about noise pollution. This consideration underscores the complex interplay between technological innovation, societal acceptance, and the broader transition to cleaner energy alternatives. In this light, DA's emphasis on the suitability of fuel cells offers an intriguing perspective. Fuel cells, known for their efficiency and minimal environmental impact, could serve as a practical bridge between the limitations of traditional wind farms and the potential of renewable energy.

Furthermore, DA highlights the progressive stance taken by South Korea in mandating renewable energy utilization in modern buildings. By stipulating that 30% of electricity in sizable structures constructed post-2010 must come from renewable sources, South Korea takes a proactive step toward greener urban development. DA's suggestion to source renewable energy from fuel cells echoes this commitment to embracing innovative technologies to fulfil renewable energy mandates.

In summation, DA's viewpoints encapsulate the intricacies of South Korea's energy landscape, where the marriage of hydrogen and renewable energy sources holds the key to achieving both environmental and economic goals. His insights invite a comprehensive consideration of how these two domains can intertwine to pave the way for a cleaner, more sustainable energy future.

The sentiment expressed by the Costa Rica expert **EEF** encapsulates a remarkable achievement in the realm of renewable energy. With an impressive 98% of its energy derived from renewable sources, Costa Rica stands as a prominent exemplar of sustainable energy practices. The energy mix primarily consists of hydroelectric power, which constitutes around 80% of the total, complemented by geothermal energy accounting for 9%, and a growing presence of wind and solar power.

The prevalence of hydroelectric power in Costa Rica's energy portfolio underscores the significance of its abundant water resources. The utilization of hydropower as a dominant source of energy is emblematic of the nation's innovative approach to capitalizing on its natural endowments. This strategy has been reinforced by the integration of geothermal energy, a clean and reliable resource that contributes to diversifying the energy mix. Furthermore, the mention of wind and solar power

gaining traction indicates a broadening commitment to expanding renewable energy options, attesting to the forward-looking policies in place.

Interestingly, as echoed by the sentiments of **EEF**, Costa Rica's experience resonates with the global trend towards utilizing renewable sources not only for electricity but also for the production of green hydrogen. Just as Costa Rica has harnessed its abundant natural resources for energy, the concept of green hydrogen production involves harnessing renewable energy, such as wind and solar power, to generate hydrogen through electrolysis, thereby creating a valuable energy carrier with minimal environmental impact.

The EEF's characterization of Costa Rica as a "*very green country*" carries implications beyond the realm of energy generation. This description is indicative of a broader commitment to environmental stewardship, resonating with the global push for sustainability. The branding of Costa Rica as a green nation can be seen as a testament to the economic, social, and environmental benefits derived from renewable energy practices. It underscores the potential for renewable energy adoption not only as a functional solution to energy needs but also as a symbol of responsible governance and global leadership in sustainability.

The success story of Costa Rica serves as an inspiration for other nations grappling with the challenge of transitioning to cleaner energy sources. It showcases the feasibility of achieving high percentages of renewable energy penetration through a strategic mix of resources. While Costa Rica's unique geography and resources have certainly contributed to its success, its proactive policies and commitment to green energy have played a pivotal role in shaping its energy landscape.

In essence, Costa Rica's remarkable renewable energy achievements and the evolving concept of green hydrogen demonstrate that a concerted focus on sustainability can yield substantial rewards. The synergy between renewable energy production and green hydrogen generation underscores the interconnectedness of global energy solutions. Costa Rica's example reinforces the idea that transitioning to renewable energy is not just an energy imperative but a pathway to national pride, global recognition, and a more sustainable future.

The insights shared by the Mexican expert **SGJA** shed light on the evolving landscape of renewable energy in Mexico. With solar energy costs ranging between USD 40 and USD 60 per Megawatt hour, and recent auction prices dipping below \$20 per MW hour, it is evident that Mexico has harnessed its natural resources and competitive market dynamics to establish a robust foundation for renewable energy production. This economic viability is a testament to the country's potential to drive sustainable energy transitions.

While Mexico's renewable energy projects are still in early development stages, the ambitious plans to produce ammonia and hydrogen using wind and solar power underscore the nation's commitment to advancing clean energy technologies. The mention of having secured an off-taker for green ammonia in Europe not only indicates the global demand for such products but also highlights Mexico's strategic positioning in the renewable energy market. Anticipated to commence construction around 2025, this project exemplifies the convergence of environmental stewardship and economic opportunity.

Drawing parallels with Germany's national hydrogen strategy, SGJA emphasizes the importance of acknowledging a nation's renewable energy potential. In Germany's case, the realization that domestic renewable resources might not suffice to achieve net-zero goals speaks to the necessity of global collaboration and innovative solutions. This recognition further bolsters the significance of cross-border partnerships and trade in green products like ammonia, as highlighted by the Mexican project's European off-taker.

The expert's personal conviction resonates deeply with the broader sentiment of fostering renewable energy development. As mentioned, the belief in the continuous encouragement of renewable energy underscores a commitment to sustainable practices that extend beyond economic advantages. This perspective aligns with the global push towards creating a more environmentally conscious energy matrix and propels Mexico towards a more resilient and sustainable future.

SGJA mentions of integrating solar and wind developers into the hydrogen production process reinforces the symbiotic relationship between renewable energy sources and green hydrogen. By collaborating closely with these developers, the goal of producing hydrogen directly from solar and wind energy gains traction. This approach not only ensures the utilization of clean energy for hydrogen generation but also strengthens the connections between different facets of the renewable energy ecosystem.

In essence, the Mexican experience mirrors the global trend of marrying renewable energy and green hydrogen production. The convergence of economic viability, environmental responsibility, and strategic collaboration positions Mexico at the forefront of renewable energy advancement. The journey from competitive auction prices to innovative hydrogen projects signifies a trajectory of progress that extends beyond borders and paves the way for a more sustainable energy landscape.

The viewpoint expressed by **JH** sheds light on the nuanced comparison between green hydrogen and batteries in terms of their environmental impact. By highlighting the fact that green hydrogen is derived from renewable energy sources, JH draws attention to its inherent eco-friendliness. This distinction is rooted in the fundamental premise that the production process of green hydrogen relies on renewable energy, which inherently reduces carbon emissions and minimizes environmental harm.

The assertion that green hydrogen could be more environmentally friendly than batteries resonates with the growing awareness of the ecological consequences associated with resource-intensive technologies like battery production:

“If hydrogen is from renewable energy, yeah. And I think the more environmentally friendly than batteries because of the resource considerations” (JH).

JH's perspective underscores the critical importance of considering the entire lifecycle of energy solutions, from production to disposal, when evaluating their overall environmental footprint.

In the broader context, JH's insight aligns with the global push to adopt sustainable energy solutions that not only mitigate climate change but also minimize resource depletion. As the world seeks alternatives to traditional fossil fuels, the emphasis on renewable energy-driven green hydrogen production gains significance. This approach not only addresses the environmental concerns associated with traditional energy sources but also paves the way for a more balanced and resilient energy future.

The perspective presented by **RGJA** underlines the responsibility associated with power generation units that predominantly rely on renewables. This approach, which requires individuals to take holistic care of the entire system, reflects a conscientious attitude towards sustainable energy production. The notion of responsibility aligns with the broader global goal of transitioning to cleaner energy sources while ensuring their efficient and responsible management.

RGJA's opinion on green hydrogen spotlights its potential as a significant opportunity for countries devoid of substantial oil and gas reserves but rich in renewable resources. This strategic alignment with renewable assets opens up new avenues for energy self-sufficiency and reduced dependence on fossil fuels, contributing to both environmental and economic advantages.

The concept of utilizing photovoltaics (PV) for green hydrogen production introduces an intriguing dynamic. By harnessing solar energy through PV installations, countries can tap into a clean and

abundant source of power for hydrogen generation. The efficiency benchmarks RGJA references - around 56-57 kilowatt-hours per kilogram of hydrogen - underscore the progress made in optimizing these processes.

Moreover, RGJA's mention of excess PV capacity highlights a tactical approach to energy management. Rather than merely storing surplus energy in batteries, the idea of converting it into hydrogen for storage offers an alternative path, effectively maximizing the utilization of available resources.

In the broader context, RGJA's perspective reinforces the symbiotic relationship between renewables, green hydrogen, and innovative energy management strategies. As nations worldwide explore pathways to a sustainable energy future, the integration of these concepts offers a promising trajectory towards a greener and more resilient energy landscape.

JAGR's insightful commentary emphasizes the shared temporal urgency between the sun's energy and the rapid requirements of hydrogen production. This observation underscores the need for swift and efficient energy conversion processes to harness solar power for the generation of hydrogen - a high-potential energy carrier.

The concept of creating highly energetic molecules from water using electrons derived from photovoltaics (PV) introduces a compelling narrative of energy efficiency and savings. JAGR's portrayal of "*cleaner kWh*" resonates with the essence of sustainable energy practices - the idea that the most environmentally friendly energy is the one that goes unconsumed. This approach aligns with the core principles of renewables, where energy generation, rectification, and transformation into energy vectors like hydrogen or biofuels form an interconnected cycle of eco-conscious energy utilization.

JAGR's reference to a large-scale project involving 40 megawatts of PV, a 6 MW electrolyser, and a 6 MW fuel cell underscores the ambitious nature of endeavours that aim to synergize renewable energy with hydrogen production. This amalgamation of components exemplifies a holistic approach, demonstrating the intricate collaboration required to translate clean energy sources into viable and versatile forms of energy storage and utilization.

The perspective that JAGR shares regarding the economics of hydrogen production stands as a significant revelation. Rather than a simple reduction in hydrogen costs, it is the initial investment and expenses in constructing the necessary infrastructure - such as solar parks, grids, and electrolyser plants - that plays a pivotal role in shaping the cost dynamics of green hydrogen.

JAGR's contribution outlines a comprehensive understanding of the complexities involved in integrating renewables with green hydrogen production. This perspective encompasses the interplay of technologies, economics, and energy policy, forming a cohesive narrative that illustrates the multifaceted journey towards a sustainable energy future.

KQ's perspective offers a comprehensive outlook on the intricate synergy between renewables and other advanced technologies, such as electrolysis, hydrogen storage, and fuel cells, with the overarching goal of integrating them into the grid. This integration stands as a pivotal strategy for enhancing the environmental sustainability of the grid by infusing it with a higher proportion of green energy sources.

The idea that hydrogen holds a unique position in the realm of clean energy due to its pollution-free nature at the point of use and its potential for renewable production resonates with the broader narrative of transitioning towards more environmentally friendly energy sources.

KQ adeptly highlights the challenges associated with the origin and distribution of electricity. By illustrating the complexities of energy generation and distribution, KQ emphasizes the need for

flexible and adaptable technologies that can accommodate the intermittency of renewables while maintaining essential services through proper maintenance schedules.

The notion that hydrogen can play a transformative role in renewable energy deployment by allowing oversizing of systems is a crucial insight. KQ's perspective underscores the potential of using hydrogen storage to alleviate the intermittency challenges faced by renewable energy sources like wind turbines. This approach offers a practical solution to preventing energy wastage and maximizing the utilization of renewable resources, thus accelerating the transition to a greener grid.

The emphasis on grid interconnection issues echoes the practical importance of seamless integration. KQ's call to address these challenges proactively highlights the necessity of fostering an environment conducive to the growth of renewable energy adoption. The concept that even a 15% contribution from renewables in the grid can have a significant impact on driving sustainable energy practices is a testament to the transformative potential of these technologies.

KQ's personal experience with grid-connected photovoltaics underscores the tangible adoption of renewable technologies at an individual level. This aligns with the larger vision of decentralized energy generation and utilization, showcasing the power of renewables in creating a greener and more resilient energy ecosystem.

MR's insights shed light on the critical factors that define truly green hydrogen technologies – those that are not only driven by renewable energy but also reflect a commitment to complete reliance on such energy sources. MR's emphasis on the absolute necessity for input energy to be 100% green underscores the integrity of green hydrogen production, aligning with the aspiration for an uncompromised transition to clean energy.

MR's depiction of using hydrogen as a democratic energy distribution method offers a captivating analogy that underscores the accessibility and inclusivity of green energy solutions. By envisioning scenarios where solar panels in remote locations generate hydrogen, MR highlights the potential of hydrogen as a versatile energy carrier that can bring sustainable power to regions previously underserved by traditional energy infrastructure.

The notion of "*connecting the dots*" between green electricity and hydrogen serves as a call to action, urging for a holistic approach to energy transformation. MR's perspective echoes the need for cohesive strategies that bridge the gap between renewable energy generation and hydrogen production, emphasizing the role of infrastructure and investments in facilitating this synergy.

The strategic consideration of electricity production status and energy availability encapsulates a practical approach to implementing green hydrogen. MR's insight underscores the importance of comprehensive assessments that inform targeted interventions in both clean energy generation and hydrogen utilization. This strategy aligns with the broader goal of achieving a balanced and sustainable energy ecosystem.

MR's assertion that understanding energy production status is a precursor to hydrogen implementation resonates with the idea that informed decision-making is crucial for effective energy transition. By identifying areas for clean energy growth and pinpointing challenges, MR's approach enables a more informed and systematic progression towards green hydrogen adoption.

In essence, MR's perspective articulates a roadmap for the harmonious integration of renewable energy and green hydrogen technologies. Through the lens of meticulous planning, comprehensive understanding, and unwavering commitment to green energy sources, MR's insights inspire a trajectory that could lead to a more sustainable energy future.

MS brings a nuanced perspective to the integration of hydrogen fuel cells and renewable energy sources, presenting a concept that he aptly terms "*self-refuelling fuel cells*" (SRFC). This innovative

approach underscores the potential for hydrogen to serve as an energy carrier that can be produced, stored, and utilized in a flexible manner. The idea of utilizing surplus grid or renewable energy to produce hydrogen for later use presents a compelling strategy for enhancing energy resilience and efficiency.

MS's acknowledgment of the significance of the technology provider for the electrolyser highlights the pivotal role of advanced technology in enabling efficient and effective hydrogen production. By emphasizing the physics of the energy conversion process, MS grounds the discussion in scientific principles while directing attention to the crucial factor of efficiency.

The notion of optimizing hydrogen production based on timing aligns with MS's emphasis on cost-effectiveness. By producing hydrogen when renewable energy sources are at their peak, the process becomes not only more sustainable but also financially advantageous. This approach demonstrates a clear understanding of the intricacies of energy economics and highlights the importance of timing in maximizing the benefits of green hydrogen production.

MS's exploration of using solar panels for on-site hydrogen generation opens up a compelling avenue for sustainable energy supply. The concept of generating hydrogen directly from solar panels highlights the potential for distributed energy production, enabling buildings to become self-sufficient in terms of their energy needs. This approach mirrors the growing trend of localized energy production and consumption.

The approach MS proposes, wherein the origin of energy inputs is carefully considered, speaks to the broader concept of energy traceability and transparency. By delineating between green and non-green energy sources, MS advocates for an informed approach to energy consumption that aligns with environmental and sustainability goals.

MS's observation that hydrogen is well-suited for reacting with variable renewable energy sources due to its adaptability and lower water quality requirements underscores the versatility of hydrogen as an energy carrier. This viewpoint aligns with the inherent challenges posed by intermittent renewables, showcasing hydrogen's potential to address such issues and contribute to a more reliable and resilient energy system.

In summary, MS's insights underscore the multifaceted nature of green hydrogen production and utilization. By introducing the concept of self-refuelling fuel cells and exploring the synergies between renewable energy and hydrogen generation, MS contributes to a vision of an integrated and sustainable energy landscape. His consideration of efficiency, cost-effectiveness, and innovative technology highlights the depth of thought required to harness the full potential of green hydrogen for a greener future.

PL presents a comprehensive perspective on energy systems that transcends the distinction between "*renewable*" and "*green*" but acknowledges the pivotal role of green energy sources, particularly in the realm of electron generation. By advocating for the development of new and highly efficient processes, PL underscores the significance of technological innovation in the energy sector. His institute's focus on complementary energy solutions reveals a pragmatic approach that recognizes the inherent strengths and weaknesses of different energy sources.

The concept of combining nuclear and renewable energies within a single system demonstrates PL's commitment to maximizing the advantages of both sources while mitigating their respective limitations. This approach is rooted in a recognition of the intermittent nature of renewables and the consistent power supply offered by nuclear energy. PL's vision of low-carbon energy systems that leverage the synergies between these sources underscores the need for a holistic and integrated energy strategy.

PL's insightful discussion extends beyond the mere process of splitting water into hydrogen and oxygen through renewable sources. He delves into the broader context of energy production, highlighting the multifaceted benefits that renewable energy technologies can offer. By emphasizing that renewable sources can generate valuable electricity through wind, photovoltaic, geothermal, and hydro systems, PL paints a more expansive picture of the potential of renewables beyond hydrogen production alone.

The recognition of the carbon content associated with renewables, including the production of components like steel and the logistics of hydrogen transportation, adds a layer of complexity to the renewable energy equation. PL's holistic evaluation of carbon content from production to end use is indicative of a comprehensive approach to sustainability. This consideration aligns with a growing emphasis on life-cycle analysis and environmental impact assessments in energy planning.

PL's mention of applying wind or PV systems to remote areas for hydrogen production offers a tangible application of his philosophy. By contemplating the quantity of hydrogen required and matching it with appropriate renewable installations, PL demonstrates a practical understanding of tailoring energy solutions to specific contexts and needs.

In essence, PL's perspective reflects a holistic and integrated approach to energy planning that leverages the strengths of different energy sources. His stance on complementary energy, the comprehensive assessment of carbon content, and the practical application of renewable systems for hydrogen production collectively present a vision of an energy landscape that transcends conventional categorizations. PL's insights pave the way for a more nuanced and effective strategy for transitioning towards a sustainable energy future.

SJS presents a compelling perspective on the critical interplay between renewable energy, green hydrogen, and the complexities of energy systems. His emphasis on the transformative power of solar and wind energy in reshaping our energy landscape underscores the pivotal role that renewables play in driving sustainable change. By highlighting the ability of solar and wind installations to generate hydrogen and consequently revolutionize energy systems, SJS advocates for a paradigm shift in energy production.

The challenge of achieving 100% renewable energy usage is illuminated by SJS's insight. He navigates the intricate balance between intermittent renewables and consistent energy demand, demonstrating a nuanced understanding of the practicalities of energy transition. The candid acknowledgment that renewables cover only a portion of energy needs highlights the need for complementary solutions, such as green hydrogen, to address the gaps in the energy supply.

SJS makes a compelling case for policy-driven encouragement of renewable energy adoption. His frustration with bureaucratic barriers and inconsistencies in policy resonates as he describes the bureaucratic hurdles that solar panel and wind farm owners face. By drawing attention to the difficulties faced by those attempting to harness renewable energy, he underscores the urgent need for streamlined regulations that foster localized and decentralized energy systems. SJS's message is clear: for a sustainable energy future, governments must prioritize renewable energy incentives to drive widespread adoption.

His exploration of the inefficiencies in the current energy system, particularly the underutilization of both wind and solar resources, exposes the limitations of centralized energy distribution. The decision to prioritize gas power plants over harnessing available solar and wind energy demonstrates a systemic flaw that hinders progress. SJS's incisive analysis reveals the need to transition away from these counterproductive practices.

The crux of SJS's perspective lies in the notion that clean hydrogen is a vital component of a larger transition, but it is unequivocally contingent on a foundation of robust renewable energy

infrastructure. His call for a massive push into renewables and the installation of energy systems is a rallying cry for fundamental change. By juxtaposing the shortcomings of current energy policies with the potential of renewables and green hydrogen, SGS paints a picture of a more equitable, efficient, and environmentally conscious energy landscape.

In essence, SJS's view underscores the urgency of embracing renewables as a foundational pillar for a greener future. His critique of bureaucratic roadblocks, inefficiencies in energy utilization, and the need for holistic energy independence highlights the multifaceted challenges that lie ahead. SJS's voice emerges as a catalyst for change, reminding us that the journey towards a sustainable energy future starts with renewables, and green hydrogen is a pivotal piece of the puzzle.

TW's insights provide a detailed and practical perspective on the intricate relationship between renewable energy and green hydrogen production, particularly within the context of New Zealand's energy landscape. His vision of harmonizing battery storage with hydrogen systems represents a strategic approach to optimizing energy utilization and storage. By proposing a symbiotic relationship between these two technologies, TW envisions a dynamic energy ecosystem capable of balancing out the intermittency of renewables and ensuring a reliable energy supply, even during periods of reduced sun exposure.

TW emphasizes adaptability in their solution, highlighting the versatility of their technology to integrate with various renewable sources, whether through direct DC voltage or AC voltage. This adaptability signifies a commitment to compatibility with the diverse range of renewable technologies that may be installed, demonstrating an openness to contribute to multiple facets of New Zealand's renewable energy evolution.

The concept of optimizing renewable energy yield aligns seamlessly with TW's approach. He elucidates the importance of preventing energy wastage from renewables, reinforcing the idea that every unit of energy harnessed from renewable sources is precious. His perspective directly addresses the economic aspect of green hydrogen production, underlining the potential for cost reduction by integrating hydrogen systems with existing renewable infrastructure, thereby maximizing the return on investment in renewable installations.

TW's attention to specific energy-intensive applications, such as heating and cooking, underscores the potential for green hydrogen to significantly alleviate energy demand in these areas. This pragmatic approach reveals an acute understanding of how the scalability of green hydrogen can be strategically leveraged to target specific sectors, providing immediate impact.

His observations on the German context and its funding incentives highlight the role of policy in shaping the adoption of green hydrogen technologies. By juxtaposing New Zealand's domestic scenario, TW advocates for a comprehensive approach that prioritizes energy independence and resilience, fostering domestic solar uptake as a foundation for further renewable integration.

TW's discussion of energy distribution and the potential to redefine power dynamics within communities offers a compelling vision for decentralization. His argument for removing grid service by gradually scaling back traditional power distribution in favour of renewable technologies echoes a broader shift towards localized energy generation and distribution, emphasizing the potential for both environmental and economic benefits.

Lastly, TW's mention of grid-connected hydrogen and its ability to respond to demand highlights the potential for hydrogen systems to function as a buffer in New Zealand's energy network. This adaptive, demand-responsive feature could aid in maintaining grid stability, offering an innovative approach to energy management.

In summary, TW's perspectives underscore the intricate dance between renewable energy, green hydrogen, and grid resilience. His emphasis on adaptability, efficiency, and strategic integration

reinforces the concept of a dynamic, self-balancing energy ecosystem that leverages the strengths of both renewables and hydrogen technologies to pave the way for a sustainable future.

TN's perspective sheds light on the strategic integration of different renewable energy sources for hydrogen production in New Zealand, focusing on solar energy, geothermal, and wind power. His discussion of potential locations for renewable energy installations, such as the central business district (CBD) of Auckland or Waiheke Island, highlights a visionary approach to maximizing energy efficiency and local consumption. By suggesting the installation of wind turbines or solar panels directly in urban areas and pairing them with electrolyzers, TN envisions a future where energy generation and consumption are closely interconnected, reducing transmission losses and enhancing sustainability.

TN's emphasis on localized energy production reflects a forward-thinking mindset that could drive a paradigm shift in urban planning and energy distribution. The concept of generating energy where it is consumed, such as in the CBD, underscores the potential for self-sustaining energy systems that cater directly to the needs of the surrounding community. This approach aligns well with New Zealand's commitment to renewable energy and sustainability.

Furthermore, TN's mention of Waiheke Island as a potential site for renewable energy and hydrogen production showcases a creative perspective on utilizing natural resources to power specific regions. His proposition highlights the island's potential to become a self-sufficient energy hub, fuelled by its renewable energy resources.

TN's description of the existing geothermal power plant in Taupo and its direct connection to the grid exemplifies an effective use of local geothermal resources for energy production. The pursuit of similar commercial arrangements for the Auckland plant reveals TN's dedication to maintaining a green approach to energy generation. His acknowledgment of the need to explore multiple alternatives, such as collaborating with existing geothermal or solar power plants, showcases a commitment to finding the most sustainable energy sources for hydrogen production.

In conclusion, TN's perspective on utilizing solar, geothermal, and wind energy sources for hydrogen production reflects a comprehensive and strategic approach to renewable energy integration. His visionary ideas of localized energy production and exploring partnerships with existing renewable sources underline the potential for a more sustainable and self-sufficient energy landscape in New Zealand. By emphasizing the importance of green energy solutions, TN's insights contribute to the broader conversation about achieving a cleaner and more efficient energy future.

VG's perspective offers a clear outline of the renewable energy strategy for hydrogen production, emphasizing the crucial role of wind and solar power as the primary sources of electricity. His discussion revolves around the concept of using newly built renewable energy systems for hydrogen production, highlighting the significance of "*additionality*" and synchronicity in energy generation. This approach underscores the need for a coordinated and real-time energy production process, ensuring that the renewable energy used for hydrogen production is both freshly generated and concurrent.

VG's insights extend to the security and sustainability aspects of hydrogen production. He explains how hydrogen can serve as an energy storage solution to balance the volatility of renewable energy production. By converting excess energy from high wind and solar periods into hydrogen, the energy can be stored and utilized during periods of low production. This dual-purpose utilization of hydrogen enhances both energy security and sustainability, albeit at a notable cost. VG's assessment underscores the trade-offs inherent in energy system design, where achieving multiple goals may come at a financial expense.

VG’s discussion of different energy storage technologies, such as pumped hydro and chemical storage, reflects a comprehensive approach to addressing the challenges posed by renewable energy’s intermittency. His mention of a range of storage solutions indicates a nuanced understanding of the need for diversified strategies to ensure a stable energy supply.

In conclusion, VG’s perspective provides a detailed overview of the complexities involved in using renewable energy for hydrogen production. His focus on additionality, synchronization, and the multifaceted nature of energy storage solutions illustrates a comprehensive understanding of the challenges and opportunities in harnessing wind and solar power for hydrogen generation. Through his insights, VG contributes to the ongoing discourse on creating a more reliable and sustainable energy landscape.

ZJ’s insights shed light on the significant advancements in reducing the carbon footprint of hydrogen production. Through the utilization of CCUS (Carbon Capture, Utilization, and Storage) technologies, ZJ’s employer has achieved a remarkable reduction in emissions, bringing the carbon intensity down to an impressive 20 grams per kilowatt. This achievement underscores the evolving efforts to minimize the environmental impact of hydrogen production, showcasing a clear commitment to sustainability.

ZJ also delves into the global landscape of hydrogen production, specifically highlighting the UK’s ambitions in utilizing renewable electricity for electrolysis to generate hydrogen. The UK’s plan to achieve a 10 gigawatt hydrogen production capacity by 2030, with half of it coming from electrolysis, aligns with the country’s rich wind resources, particularly its coastal and offshore wind farms. ZJ emphasizes the strategic use of renewable energy sources, such as wind and solar, as essential pathways for energy security in the face of intermittent renewable generation. His mention of large-scale projects like the Coney Islands in Scotland demonstrates practical approaches to integrating renewable hydrogen into existing energy systems.

ZJ draws attention to the unique challenges posed by variable renewable sources. For instance, he points out that decreased wind speeds impacted the UK’s wind power generation, prompting a need to prioritize meeting domestic electricity demands rather than storing excess energy as hydrogen during such periods. This highlights the delicate balance between renewable energy utilization and hydrogen production, especially when dealing with resource limitations or extreme climatic conditions.

Moreover, ZJ underscores the suitability of different renewable sources for hydrogen production based on geographical characteristics. In regions with ample sunlight, like Australia, solar energy takes precedence, whereas wind energy becomes a primary source in wind-rich areas like the UK. ZJ’s insights acknowledge the contextual nuances that drive hydrogen production strategies and emphasize the importance of tailoring approaches to a region’s distinct renewable energy potential.

In conclusion, ZJ’s perspective contributes to the discourse on utilizing renewable energy for green hydrogen production, highlighting the role of CCUS technologies, national goals, and resource availability. His discussion reflects a comprehensive understanding of the intricate relationship between renewables and hydrogen, emphasizing the need for adaptable strategies to ensure sustainable and reliable energy systems for different contexts.

H2 and Renewable Energy	
Aspect	Key Insights
Green Hydrogen Production	Green hydrogen, produced from renewable sources such as solar, wind, and hydropower, is a clean and versatile energy carrier with minimal environmental impact.

Renewable Energy Infrastructure	A robust renewable energy infrastructure is crucial for supporting green hydrogen production; countries are leveraging their natural resources through initiatives like solar parks.
Energy Storage and Management	Integrating hydrogen allows for energy storage and management of renewable energy intermittency, accelerating the deployment of renewables and enhancing grid sustainability.
Optimized Production	Tailoring hydrogen production to align with renewable energy availability optimizes yield, while strategically siting renewable installations near demand centres enhances efficiency.
Synergy with Fuel Cells	Fuel cells work well with renewable energy systems, and combining centralized battery storage with fuel cells helps balance intermittency.
Policy and Regulatory Support	Policy incentives and the streamlining of regulations are essential for driving renewable energy growth; bureaucratic hurdles and inconsistencies can hinder progress.
Holistic Transition Strategies	A strong foundation of renewable energy is vital for transitioning to hydrogen; holistic strategies that encompass complementary solutions are imperative for success.
Hydrogen in New Zealand's Built Environment	In New Zealand, hydrogen offers energy resilience, aligns with sustainability goals, and supports renewable power targets in larger buildings.
Localized Renewable Energy Hubs	Establishing localized renewable energy hubs for community supply illustrates hydrogen's potential for decentralization, with aspirations for grid independence redefining power dynamics.
Interlinked Solutions	Renewables and hydrogen are interlinked solutions; despite existing challenges, their synergy presents significant potential for creating sustainable and resilient energy systems.

Table 31: H2 and Renewable Energy

In summary, the perspectives provided by interview participants collectively highlight the symbiotic relationship between hydrogen and renewable energy, underscoring the crucial role hydrogen plays in enhancing energy security, resilience, and sustainability. These insights extend seamlessly to New Zealand's built environment, suggesting that hydrogen integration can potentially serve as a transformative solution for achieving renewable energy targets and fostering sustainable development within the nation's architectural landscape.

4.37 Hydrogen Production, Supply Chain, Large vs Small Scale Production of Green Hydrogen

The discourse surrounding hydrogen production, its supply chain, and the scale of its implementation within various interviews reflects a comprehensive understanding of the multifaceted considerations inherent in this emerging technology. Across the interviews, a common thread emerges - the pivotal role of hydrogen as a green alternative to conventional fossil fuels, yet tempered by the challenges associated with its production, distribution, and deployment.

The participants acknowledge the diverse avenues for hydrogen production, with a spotlight on the distinction between conventional methods, such as natural gas reforming, and greener approaches, including electrolysis driven by renewable energy sources. The discussions underscore the current prevalence of hydrogen production from natural gas and the overarching goal of transitioning towards greener electrolysis methods. As ZJ articulates:

“The hydrogen production is mainly from the natural gas at the moment, with the future deployment of carbon capture and utilization storage, we would minimize the carbon emission from the hydrogen production process”.

The debates on the scale of hydrogen production - ranging from small distributed systems to larger centralized facilities - encompass a range of viewpoints. Participants propose modular and flexible designs that align with the needs of specific applications, emphasizing the importance of adaptability and efficiency in line with demand. These opinions are juxtaposed against the challenges associated with achieving economies of scale and managing transportation costs in the context of centralized production. As MS aptly points out:

“What kills mainframes? Mainframes were people were able to network PCs together. So instead of buying a big mainframe, I could buy 20-30 PCs and network them together”.

The importance of a sustainable hydrogen supply chain is a consistent theme throughout the interviews. Key factors that influence this chain include the carbon content of renewable sources, the production processes, and the compression and transportation of hydrogen. A participant underscores the necessity of evaluating the carbon content throughout the entire value chain, from production to end use. As PL points out:

“We need to associate the production of reactivity with the production of hydrogen... we have to prove that the electricity is coming from additional capacity of renewable”.

Furthermore, concerns about safety and environmental impact resonate across discussions. The emphasis on safe production, storage, and transportation underscores the need for robust regulatory frameworks and technological safeguards. These sentiments are reflected in discussions about the need for well-ventilated production areas, hydrogen sensors, and comprehensive safety measures.

Collectively, the participants’ perspectives encapsulate the nuanced considerations involved in hydrogen production, supply chain optimization, and scale of implementation. While varying viewpoints reflect the complex nature of this burgeoning field, a shared commitment to greener and more sustainable energy alternatives unites these diverse voices.

The discourse surrounding hydrogen production, supply chain dynamics, and the balance between large-scale and small-scale production is characterized by a comprehensive understanding of the complexities inherent to this transformative energy technology. Within this discourse, the notion of “over-dimensionalizing” electrolyzers to optimize hydrogen output emerges as a strategic consideration. As EEF astutely states, “you over-dimensionalize your electrolyser to be able to produce more hydrogen”. This perspective underscores the pragmatic approach of scaling up equipment to achieve enhanced production, reflecting a drive toward efficiency and higher yield.

The overarching challenge of capital expenditure (CapEx) is a central theme interwoven into discussions about hydrogen production. The conversations acknowledge the substantial investment required in establishing production lines, refining production processes, and cultivating intricate supply chains. This acknowledgement is encapsulated in the assertion that “the biggest one is the CapEx of these products, the production lines are the production processes the supply chains”. The significance of CapEx is not only financial but also temporal, as EEF aptly observes that “this supply chains and this production lines and all that stuff takes a long time to develop”. This perspective

highlights the intricate interplay between financial resources, technological development, and the gradual maturation of supply networks.

The ongoing deliberation between large-scale and small-scale hydrogen production resonates throughout the discourse. The discussions present contrasting viewpoints, emphasizing the pros and cons of each approach. The concept of over-sizing equipment to boost production, mentioned earlier, supports the potential advantages of larger centralized systems. In contrast, the desire for flexibility and adaptability underpins the appeal of small-scale solutions. The perspectives collectively suggest that the choice between the two hinges upon factors such as demand, feasibility, and economic considerations.

RH's perspective encapsulates the nuanced consideration surrounding hydrogen production and supply chain management. He emphasizes that the optimal approach hinges on the delicate balance between production distribution models. The choice between distributed production and centralized systems is a crucial determinant in the overall strategy. RH acknowledges that achieving a comprehensive solution likely necessitates a hybrid approach, where both distributed and centralized production play pivotal roles. This insight underscores the recognition that the intricacies of hydrogen's potential can be harnessed most effectively through a thoughtful fusion of diverse production and distribution mechanisms, enabling a robust and adaptable energy landscape.

RGJA's perspective underscores the holistic understanding required when assessing the environmental impact of hydrogen technologies. He acknowledges that no human activity is devoid of environmental repercussions. However, as RGJA emphasizes:

"At the end, we can say that hydrogen technologies are zero emission technologies because if you go up in all the chain, for example, if you're producing solar panels, they will have some CO2 footprint, the same for electrolyzers, and specifically because they have AEM scars metals and minerals on them". – environment

RGJA underscores the overarching advantages of green hydrogen production, as it offers a clearer supply chain and production process. This streamlined approach contributes to minimizing environmental impact and offers a more sustainable alternative in comparison to conventional methods. The emphasis on a cleaner supply chain aligns with RGJA's view that, while not entirely devoid of impact, hydrogen technologies offer a significant improvement over existing practices, promoting a more environmentally conscious path forward.

MR raises a critical aspect beyond mere product promotion and persuasion, emphasizing the importance of holistic sustainability in hydrogen production. He highlights that the notion of "green" hydrogen extends beyond the final product and encompasses the entire production process. As MR succinctly puts it:

"Not only about, you know, selling the product and convincing everyone and then there they would say whenever the production of whatever you need to make hydrogen is also green."

She suggests that the sustainability of hydrogen production must encompass all stages, from raw materials to manufacturing processes. MR argues that even if the end product is labelled as "green" hydrogen, it loses its environmental credibility if derived from processes that contribute to pollution or other ecological harm. This stance reinforces the idea that the term "green" should reflect a comprehensive commitment to sustainability throughout the hydrogen value chain. MR's perspective echoes a broader understanding that a truly sustainable future requires an integration of eco-friendly practices at every level of hydrogen production, ensuring that the pursuit of environmental harmony extends beyond mere marketing rhetoric.

MS's perspective on hydrogen production, supply chain, and scale underscores the multifaceted considerations crucial for a sustainable transition. He highlights the pivotal role of adaptability in sizing hydrogen production systems to match specific energy needs. As he aptly puts it:

"If I'm powering a small town and what I need is enough hydrogen to provide the total daily energy for that small town... it really depends on a lot of things".

MS emphasizes the impact of location and transportation costs on the viability of large centralized versus smaller distributed systems:

"But when you look at it this way, if I produce it here and then I have to transport it there, there's a cost in doing that. But if I need it here and I can make it here, then I save that transportation cost".

He introduces the intriguing notion of cost-effectiveness and control in hydrogen production:

"...producing it where you need it and when you need it gives you more control... if you have a smaller system and you can produce it when you need it at the right time, like when the sun is shining, with renewables or whatever, that would seem to be more cost-effective as well, right?"

Moreover, MS delves into innovative supply chain dynamics:

"...putting solar panels on the roof of the building now and using those panels to generate hydrogen... for people who want hydrogen".

He then delves into the environmental implications of transportation, advocating for localized production:

"So if I liquefy hydrogen, I got to freeze it down to minus 252 or 253 degrees... anything that involves losing a lot during the delivery process and not very efficient... better to produce green hydrogen in place and use it later when it's needed".

MS extends his analysis to the core chemical processes, emphasizing the significance of materials and reactions:

"The production of hydrogen and the conversion of hydrogen into electricity, both those are chemical reactions, they involve gas interacting with membranes and with catalysts to do both of those exercises".

Incorporating MS's insights, the vision emerges that the production of green hydrogen is inherently greener when pursued in a small-scale, in-place approach, mitigating transportation-related pollution and loss. This aligns with a holistic understanding of supply chains, encompassing not only hydrogen production but also the manufacturing of necessary components, like electrolyzers. Thus, a paradigm shift towards flexible, localized, and efficient hydrogen production systems offers a promising trajectory towards a sustainable energy future.

PL's perspective on sustainable hydrogen production manifests a meticulous and structured approach, emphasizing the imperative of establishing rigorous criteria to evaluate the ecological soundness of the process. As he cogently articulates:

"To consider a sustainable way to produce hydrogen, we need to define the criteria... We need to define the base of our analysis".

PL underscores the pivotal role of carbon content in this evaluation, elucidating the necessity of a certification scheme to ensure transparency and accountability across global contexts:

“The first criteria is a carbon content... you need to have an independent assessment of the carbon content of the whole chain... if that electricity is coming from renewable?”

He further expounds on the intricate interplay between electricity production and hydrogen generation, advocating for the alignment of temporal and geographical factors:

“We need a geographical and temporal correlation between the production of electricity and the production of hydrogen...”

In elucidating the complexity of off-grid versus grid-connected electrolyzers, PL discerningly navigates the nuances:

“...we need to associate the production of reactivity with the production of hydrogen... we have to prove that the electricity is coming from additional capacity of renewable”.

With precision, PL highlights the multifaceted consideration of carbon emissions, traversing from renewable source carbon content to the compression and transportation of hydrogen:

“The second is the carbon content of renewable because PV are not zero carbon... we have to evaluate the all carbon content until the end use”.

PL’s perspective unearths a strategic blueprint for sustainable hydrogen production, intertwining carbon scrutiny, source verification, and supply chain integrity. It underscores the intricacies of geographical, temporal, and industrial factors while embracing a holistic assessment spanning from initial energy input to eventual hydrogen utilization. This meticulous approach augments the discourse surrounding the larger paradigm of hydrogen’s potential within a greener energy landscape.

TW’s insights shed light on the pragmatic application of green hydrogen within the residential sector, accentuating the need for a nuanced approach to production and utilization. As he expounds:

“In the residential sector, when you start looking at how it actually applies, you would be applying through... a more there has no act approach how much hydrogen you are actually producing”.

TW underscores the importance of a dynamic and responsive approach, one that adapts to the actual hydrogen demand while maximizing efficiency and minimizing waste. This speaks to the imperative of right-sizing hydrogen production to avoid excesses while catering precisely to requirements. Furthermore, TW accentuates the significance of a green supply chain in this context, acknowledging that the ethos of green hydrogen extends beyond its production to encompass the entire ecosystem:

“TW speaks about production of green hydrogen in the New Zealand Built environment and how it is important to consider the green supply chain”.

TW’s perspective underscores that achieving true environmental sustainability necessitates a comprehensive perspective that embraces the entire lifecycle of hydrogen, from its generation to its integration into existing infrastructure. In this way, his insights contribute to a more holistic understanding of the transformative potential of green hydrogen within built environments.

VG’s perspective highlights a fundamental principle in technology advancement – the scalability effect on cost reduction. He underscores the universality of this principle by stating:

“The challenges of high costs can be overcome with scale. Same thing as in every other technology. As soon as you scale up electrolysis, as soon as you scale up hydrogen cars, hydrogen trucks, Production costs will go down. There's no magic”.

VG's assertion echoes a core economic concept: economies of scale. He emphasizes that the growth in production volume translates to lower unit costs, a principle that resonates across various industries. By applying this principle to hydrogen technology, VG illuminates a straightforward pathway towards cost-efficiency. His pragmatic viewpoint reinforces the significance of steady growth and widespread adoption in catalysing the transition to a more affordable and accessible hydrogen-driven landscape.

ZJ's insights shed light on the intricate interplay between renewable energy sources, production standards, and national energy security in the realm of hydrogen technology. He highlights the suitability of solar energy for small-scale hydrogen production, pinpointing its significance as a viable energy source for localized applications. Moreover, ZJ brings attention to the UK's recent strides in promoting environmentally responsible hydrogen production through the launch of a low carbon hydrogen standard. He remarks:

“At the end of last year, the UK has launched a standard for the low carbon hydrogen because at the moment the large scale green hydrogen production in UK is still a bit unrealistic. So they have just launched the low carbon hydrogen production standard, which I think is unique to the UK at the moment, limiting emissions to 20 grams of CO₂ per megajoule of hydrogen production”.

ZJ's observations underscore the nation's commitment to stringent emission control and the aspiration to foster a greener hydrogen landscape. He furthermore delves into the overarching goal of enhancing national energy security. ZJ advocates for a comprehensive approach encompassing not only the establishment of an autonomous hydrogen supply chain but also the optimization of end-to-end hydrogen production, storage, and utilization infrastructure. In doing so, ZJ navigates through critical dimensions of sustainable hydrogen production, emphasizing the alignment of production practices with environmental goals and energy sovereignty.

H2 Production, Supply Chain, Large vs Small Scale H2 Production	
Aspect	Key Insights
Hydrogen Production Methods	Hydrogen production methods vary from conventional fossil fuel reforming to renewable electrolysis, aiming for a transition to greener production through renewable electricity.
Modular vs. Centralized Production	Modular, distributed hydrogen production systems offer flexibility to meet specific demand needs, while centralized facilities can achieve economies of scale; trade-offs exist between the two.
Sustainable Supply Chains	Sustainable supply chains necessitate scrutiny of the carbon content in renewable sources, production methods, and transportation, alongside comprehensive life cycle assessments of environmental impact.
Safety and Environmental Concerns	Ensuring safety and minimizing environmental harm in production, storage, and distribution is crucial; robust regulations and diligent risk mitigation processes are imperative.
Defining "Green" Hydrogen	The concept of "green" hydrogen implies that sustainability must encompass the entire production chain, not just the end product, advocating for holistic, eco-friendly practices throughout.
Right-Sizing Production	Right-sizing production to match actual hydrogen requirements avoids waste while maximizing efficiency; adaptable systems responding to real-time demand are ideal, particularly for residential use.

Economies of Scale	Scaling up production volumes can lead to cost reductions based on economies of scale principles; widespread adoption and steady growth in hydrogen utilization may catalyse affordability.
Renewable Hydrogen Standards	Establishing renewable hydrogen production standards reflects a commitment to low-carbon practices aligned with energy and environmental goals, fostering greener and more self-reliant energy landscapes.

Table 32: H2 Production, Supply Chain, Large vs Small Scale H2 Production

In the final analysis, the journey toward establishing a robust hydrogen economy is underpinned by a multifaceted tapestry of decisions encompassing production methods, distribution networks, and system scales. The discourse around hydrogen production, supply chains, and scale necessitates a nuanced understanding of the intricate trade-offs that shape this burgeoning field. As stakeholders grapple with the imperatives of sustainability, economic viability, and energy security, a harmonious synthesis of flexibility, efficiency, safety, and scalability emerges as the compass guiding this transformative voyage. The threads of methodological choices, geographical considerations, and environmental impacts are intricately woven into the fabric of a new energy paradigm. By heeding the lessons and insights from experts who advocate for green supply chains, modular production, and decentralized solutions, societies can navigate this complex terrain to realize hydrogen's potential as a clean, resilient, and potent force for positive change. In essence, the production, distribution, and scale of green hydrogen beckon us to seize the opportunity to usher in an era of sustainable energy, where innovation and conscientious decision-making converge to shape a future powered by the promise of hydrogen.

4.38 H2 Storage

Participants from various interviews share their insights into hydrogen storage, presenting diverse viewpoints on its applications and challenges within the built environment. These perspectives offer a comprehensive understanding of the considerations surrounding hydrogen storage.

DA highlights the potential of fibre-based storage tanks, known as Type 4 storage tanks, which are designed to tear rather than explode in case of failure. DA emphasizes:

“Hydrogen is something that can be stored in fibre-based storage tanks. So if you have the fibre-based storage tanks which I call Type 4 storage tanks, then those tanks do not explode those tanks just get torn, so you know you won't have kind of explosion or something like that. We'll just be torn as in any textile material that you have”.

The concept of utilizing metal hydrides for hydrogen storage is mentioned as a promising avenue. EEf mentions:

“Maybe we'll find the different storage types you know that are not gaseous, maybe some, but more interesting like metal hydrides or things like that”.

Considering varying climatic conditions and energy demands, the participants emphasize tailoring storage solutions to specific regional needs. For instance, in areas with seasonal energy demand fluctuations, storing hydrogen in salt caverns for later conversion into electricity or heat could be a suitable strategy. JAGR elaborates:

“The other interesting thing of hydrogen is when it is compared to other it is a capability to efficiently store energy for long periods of time, which is something very interesting for countries like Germany that has a very seasonal energy demand because you can store the

hydrogen in salt caverns and then bring it out and convert to electricity or heat or whatever you need”.

Safety remains a paramount concern, particularly in densely populated areas. Participants suggest strategies to mitigate risks associated with hydrogen storage, such as placing storage containers outside buildings and maintaining distance.

“In case of blast is what the regulation is assuming. But not so sure or I haven’t seen. I’ve seen one example in Japan. They put the cylinder outside of the building that is at the nursery. I mean the Elderlies house, some retirement village. The storage was just placed outside but the fence surrounding it then distanced for about 5 meters, I guess. So I didn’t really see the sitting there itself attached to the building or in the building, it was always outside. Yeah, I think that was to prevent the hydrogen staying in the concealed area. So I think the same will be required in NZ”, recounts TN.

Efficiency and scalability also feature prominently in the discussions. Storage methods that address large-scale energy demands are deemed crucial, especially in regions with considerable energy consumption fluctuations. *“If we want to store from median term or even long term was speaking about a month seasonal or the year basis, hydrogen will be a great candidate for storing the energy on the large amount of energy. So it would be either stored in the gas form in the salt caverns or the used oil fields. Oil and gas fields or potentially just liquified hydrogen”,* offers ZJ, highlighting hydrogen's potential for addressing longer-duration storage needs.

In conclusion, these insights from participants underline the multifaceted nature of hydrogen storage, encompassing safety, regional adaptability, and scalability. The diverse perspectives enrich our understanding of the challenges and opportunities associated with integrating hydrogen storage solutions into the built environment.

4.39 Infrastructure

The participants’ viewpoints converge on the pivotal role of infrastructure in facilitating the integration of green hydrogen within the built environment. They universally recognize the pressing need for a robust and adaptable infrastructure to support hydrogen systems. This collective sentiment underscores the intricate relationship between sustainable hydrogen utilization and the infrastructural groundwork required to realize its potential benefits.

Several participants emphasize the urgency of developing comprehensive infrastructure to harness the vast potential of renewable energy sources for hydrogen production. This sentiment resonates particularly in regions like the Middle East, with its abundant land resources and renewable energy potential. The availability of renewable energy sources, like solar and wind, is a critical catalyst for green hydrogen production, rendering countries such as Saudi Arabia well-equipped to generate renewable energy and subsequently, hydrogen.

Across different nations, the current limitations and challenges of existing infrastructure are brought to the forefront. The prevailing infrastructure was designed with carbon-based fuels in mind, making adaptation for hydrogen a complex task. This challenge is especially evident in the context of pipelines, where existing structures may not be suitable for hydrogen transportation due to differences in molecule size, pressure, and leakage concerns. Furthermore, the participants acknowledge the complexity of modifying engines and turbines for hydrogen blending, highlighting the intricate relationship between existing infrastructure and future hydrogen applications.

In New Zealand, the discussions emphasize the importance of safety measures and proper integration. Participants underscore the necessity of distancing hydrogen storage from buildings and ensuring

compliance with stringent safety regulations. They advocate for a cautious approach to hydrogen utilization, incorporating features like ventilation systems and leak detectors to manage potential risks.

KQ's perspective on hydrogen infrastructure is grounded in the recognition of the intricate challenges posed by the existing energy landscape. She highlights the disparity between the source of electricity generation and its consumption, emphasizing that traditional energy supply methods involve distant combustion and transmission. In the context of integrating renewables and hydrogen into the grid, KQ underscores the need for technologies that can be temporarily shut off for maintenance and accommodate the intermittency inherent in renewable energy sources.

She acknowledges that the transition to a hydrogen-based infrastructure requires meticulous long-term planning due to its complexities. KQ underscores the critical importance of addressing various aspects, including piping compatibility and pressure considerations. Notably, she points out that existing infrastructure, designed for carbon-based fuels like natural gas, is not inherently suited for hydrogen. Despite a desire for direct hydrogen delivery to homes and fuel cells, she acknowledges the pragmatic need to incrementally introduce hydrogen into the current system. This incremental approach aims to minimize disruptions by incrementally adapting pipes, appliances, and building codes to accommodate hydrogen's unique characteristics.

KQ further highlights the challenges related to replacing pipes and appliances overnight, acknowledging the need to strike a balance between innovation and practicality. She notes the ongoing efforts in the US to determine the optimal hydrogen blend that can be added to natural gas without necessitating immediate and widespread replacements. This cautious approach reflects the industry's commitment to transitioning from the current infrastructure to a hydrogen-integrated future in a measured and systematic manner:

"I would love for hydrogen to be able to be pumped directly into a home and run a fuel cell and all of that but we have an existing infrastructure that was designed for natural gas. So you know the early steps have to be increasing the amount of hydrogen that's coming along with that. We can't just overnight replace the pipes you know and your finances" (KQ).

Ultimately, KQ's perspective underscores the complexity of overhauling infrastructure and the need for gradual changes to harmonize the integration of hydrogen technology with existing systems:

"Current types are designed to standards that are meant for carbon-based fuels. Hydrogen is a much smaller molecule. It typically is sent under higher pressure. So yeah, the existing pipes may not be suitable. How long have they been around? Do they have any potential for leakages? Again, hydrogens are very small. So we'd be looking at building codes that look toward replacing pipes or installing pipes in new buildings that can accommodate these things. But that's not going to happen overnight. So what we're trying to struggle with now in the US is how much hydrogen can we add to natural gas without having to replace pipes and without having to replace all of the appliances overnight, because we're looking for that starting point. The first step that isn't the end point. Nobody wants it to be the endpoint, but we have to start with where we are to get to where we're going" (KQ).

MR's opinion focuses on a pragmatic approach to hydrogen infrastructure, highlighting the adaptability of existing systems. She emphasizes the need to work with the infrastructure that is already in place, suggesting that there is a foundation to build upon. This perspective contrasts with KQ's acknowledgement of the challenges in adapting existing infrastructure, particularly when it comes to issues like piping compatibility, pressure considerations, and the limitations of current systems designed for carbon-based fuels:

"We have infrastructure. You have to adapt the infrastructure that we have" (MR).

MR underscores the importance of adapting and repurposing the infrastructure rather than entirely replacing it. She emphasizes the need to stress the maintenance aspect, drawing a parallel to how regular maintenance is already practiced with boilers. This emphasis on maintenance aligns with KQ's acknowledgment of the need for shut-off capabilities for maintenance in renewable energy and hydrogen technologies.

In summary, MR's perspective leans toward making the most of the infrastructure that already exists, highlighting its adaptability and stressing the significance of maintenance. This differs from KQ's perspective, which underscores the challenges in integrating hydrogen due to its different properties and the need for incremental changes in both infrastructure and regulations.

MS's opinion aligns with the recognition that existing infrastructure is a significant factor in the integration of hydrogen technologies. He emphasizes the challenges of adapting current systems to accommodate hydrogen, especially when it comes to complex systems like gas turbines. Like MR and KQ, MS acknowledges that the current infrastructure is not fully compatible with hydrogen and that modifications and testing are necessary:

“Putting 100% hydrogen into a pipeline that's designed for different type of gas. It may not be possible, basically. So again that 20% is sort of a measure of the safety of transferring that hydrogen on a on a gas pipeline that's designed for a different type of gas” (MS).

MS's perspective is similar to KQ's in terms of acknowledging the need for testing and incremental changes. He discusses the ongoing testing of blending hydrogen with natural gas up to 20%, which is a cautious approach that doesn't require major changes to the existing systems. This parallels KQ's discussion of the challenges in adding hydrogen to natural gas without having to replace pipes and appliances overnight.

However, MS's opinion introduces the concept of using an oil substance to transport hydrogen, highlighting a potential innovative solution for overcoming pipeline compatibility issues. This perspective adds a unique aspect to the discussion that is not directly addressed by MR or KQ.

In summary, while MS's perspective shares similarities with MR and KQ regarding the challenges of integrating hydrogen into existing infrastructure, it introduces the concept of innovative transport solutions to address compatibility issues, setting it apart from the others' viewpoints.

TN's opinion contrasts with the previous opinions that emphasize the need for significant infrastructure changes to accommodate hydrogen. TN's statement that *“not much infrastructure changes needed”* suggests a more optimistic view regarding the adaptability of existing infrastructure for hydrogen technologies. This perspective seems to deviate from the challenges and complexities discussed by other participants, such as the need to replace or modify pipes, appliances, and systems to ensure compatibility with hydrogen.

While TN's opinion doesn't align with the previous participants who highlighted the necessity for infrastructure adaptations, it is important to note that the context and specifics of TN's statement aren't provided in detail. Without further context, it's challenging to directly compare TN's opinion to the broader discussions on infrastructure challenges for hydrogen integration.

VG's opinion aligns with the viewpoints of other participants who discuss repurposing existing gas infrastructure for hydrogen use:

“The existing gas infrastructure are the gas pipelines that go directly into the buildings can be repurposed for hydrogen” (VG).

He mentions that the existing gas pipelines going directly into buildings can potentially be repurposed for hydrogen distribution. This aligns with the idea discussed by other participants that adapting current infrastructure is a key consideration for integrating hydrogen technologies.

VG's mention of gas companies lobbying the government to repurpose infrastructure for hydrogen indicates a shared perspective with other participants who have highlighted the role of regulations, policies, and industry collaboration in shaping hydrogen infrastructure development. The example of the UK's efforts to explore hydrogen heating further reinforces the shared emphasis on repurposing existing systems for hydrogen integration.

However, VG's mention of Germany's recent decision to ban hydrogen heating due to inefficiency contrasts with some of the other participants' discussions. It indicates that opinions and approaches regarding hydrogen infrastructure can vary based on regional policies and priorities. Overall, while VG's opinion aligns with the broader theme of repurposing existing infrastructure, the specific details and regional variations may lead to differing conclusions about the viability and efficiency of such efforts.

Comparing these perspectives, a key theme emerges: the imperative to create a balance between incremental progress and transformative change. While advocating for the development of sustainable and comprehensive hydrogen infrastructure, participants also acknowledge the need to transition pragmatically, considering existing systems, costs, and safety measures. These opinions collectively reflect the significance of strategic planning, collaborative efforts, and phased implementations to establish a reliable and secure hydrogen infrastructure within diverse built environments, including New Zealand.

In summary, participants emphasized the critical need for infrastructure development to enable the hydrogen transition, but this should build strategically on existing systems where possible and incorporate safety measures.

H2 Infrastructure	
Aspect	Key Insights
Urgent Infrastructure Development	There is broad agreement on the urgent need to develop infrastructure to support hydrogen systems integration, which is pivotal for realizing hydrogen's potential.
Renewable Resource Utilization	Leveraging abundant renewable resources for green hydrogen production necessitates accompanying infrastructure build-out.
Existing Infrastructure Limitations	Current infrastructure, designed for fossil fuels, poses challenges; pipelines, engines, and turbines may need modifications to accommodate hydrogen.
Measured Transition	A measured transition is essential due to infrastructure constraints; blending hydrogen into gas grids serves as an early stepping stone while appliances and pipes are gradually adapted.
Maintenance Importance	Maintaining existing infrastructure is important, as complete replacement may not be necessary; adaptability perceptions vary among stakeholders.
Innovative Solutions	Innovative solutions, such as using oil to carry hydrogen, may address pipeline compatibility issues, but debates on efficiency persist.

Repurposing Gas Grids	Repurposing gas grids and pipelines for hydrogen distribution aligns with plans in some regions but faces resistance elsewhere based on efficiency concerns.
Safety Regulations in New Zealand	In New Zealand, safety regulations necessitate careful integration of hydrogen infrastructure with buildings, requiring measures like distancing storage and leak monitoring.
Balanced Approach	A balanced approach is advocated, pragmatically leveraging current systems while steadily investing in new infrastructure for the hydrogen future.

Table 33: H2 Infrastructure

4.40 Hydrogen Blending

In the discussions held across the interviews, participants offered insights into the concept of blending hydrogen with natural gas as a method to curtail carbon emissions and usher in a more sustainable energy landscape. A common thread running through these conversations was the recognition of hydrogen blending's potential to effect substantial reductions in carbon content associated with natural gas consumption. This approach, seen as a practical avenue toward carbon emission mitigation, prompts a measured transition in the energy sector.

A prevailing sentiment among the interviewees was the significance of adopting a gradual progression towards higher hydrogen blends. This approach, they emphasized, would ensure the seamless integration of new blends with existing infrastructure and appliances, thereby safeguarding the reliability of energy systems while advancing environmental objectives.

Of pivotal concern was the compatibility of present gas infrastructure with elevated hydrogen blends. The participants acknowledged that pipeline age and composition were pivotal factors influencing the feasibility of blending without necessitating extensive alterations. The consensus emerged around a balanced formula: blending up to 20% hydrogen and, beyond this point, considering more substantial modifications and evaluations.

Furthermore, the synergy between hydrogen blending and biogas was highlighted as a pragmatic solution. The integration of biogas with hydrogen blending offers a dual advantage of reducing carbon emissions and leveraging established infrastructure.

Government policy emerged as a critical catalyst in steering the trajectory of hydrogen blending initiatives. Examples like the UK's deliberation on incorporating up to 20% hydrogen into the gas grid underscored the pivotal role of regulations in shaping sustainable energy transition pathways.

Safety considerations underscored the discussions, emphasizing the necessity for comprehensive testing, research, and meticulous evaluations of implications for gas turbines, pipelines, and appliances. The consensus underscored the need for a cautious approach before adopting higher hydrogen blends, with thorough understanding and assessment of potential outcomes.

In the discourse surrounding the utilization of hydrogen blending as a strategy for carbon reduction in energy systems, diverse perspectives emerged from the interviews. DA highlighted the potential of blending hydrogen into the existing gas grid, contending that even a relatively modest inclusion of hydrogen could yield substantial benefits. He remarked:

“If you just blend hydrogen 20% into the existing grid, you have just decarbonized your entire infrastructure by 20%”.

This view underscored the practicality and immediate impact of this approach on reducing carbon emissions.

However, contrasting perspectives surfaced through the words of other participants. KQ voiced an awareness of the challenges associated with introducing hydrogen into the gas network, emphasizing the complexities of determining optimal blend ratios. She noted:

“What we're trying to struggle with now in the US is how much hydrogen can we add to natural gas without having to replace pipes and without having to replace all of the appliances overnight”.

MR brought into focus the necessity of efficiency in hydrogen blending. She stated:

“The moment the main challenge is being as efficient as with pure hydrogen”.

This viewpoint highlighted the need to ensure that hydrogen blends maintain the same efficiency levels as their pure counterparts.

The varying perspectives extended to the infrastructure's adaptability to higher hydrogen blends. TW shared insights into the energy density considerations, saying:

“From an energy perspective where energy density perspective, there's no point going above 20% hydrogen because you actually lose energy content”.

This divergent perspective suggested that there might be a limit to the energy efficiency of higher hydrogen blends.

The interviews also revealed a consensus on the importance of policy and testing. ZJ discussed government decisions, citing the UK's contemplation of blending hydrogen into the gas grid. He remarked:

“In this year they are considering making the key decision of blending up to 20 percentage of hydrogen into the national gas grid”.

This emphasized the pivotal role of regulatory frameworks in shaping the trajectory of hydrogen blending.

In summation, the interviews revealed a spectrum of viewpoints on hydrogen blending's potential impact on carbon reduction and energy systems. While DA accentuated its immediate benefits, KQ, MR, TW, and ZJ contributed nuanced perspectives on the challenges, efficiency concerns, and regulatory aspects of hydrogen blending within existing infrastructure.

In conclusion, these interviews elucidate the potential of hydrogen blending as a tangible route to diminish carbon emissions while enhancing energy sustainability. Through a balanced transition, mindful infrastructure adaptation, and conscientious policy planning, hydrogen blending emerges as a pivotal step towards realizing cleaner energy systems and reducing environmental impact.

4.41 Hydrogen Burning

The perspectives gleaned from the interviews regarding the practice of burning hydrogen for heat underscore the intricate dialogue surrounding its implementation and relevance within the context of the built environment. Opinions on this matter traverse a spectrum, reflecting diverse considerations and potential implications.

On one end of the spectrum, proponents of burning hydrogen emphasize its efficacy as a means to reduce carbon emissions. They highlight that substituting coal or natural gas with hydrogen in high-temperature processes could yield significant emissions reductions. The proposition to utilize

hydrogen-fired boilers or furnaces for larger complexes and industries is endorsed by some participants as a pragmatic approach toward achieving carbon reduction goals.

However, contrasting viewpoints emerge from those who exercise caution or scepticism about the widespread adoption of hydrogen burning. Some express reservations about the efficiency and feasibility of this approach, particularly concerning specific applications. One participant, in particular, raises concerns about the efficiency of using hydrogen in cooking pots, suggesting that other avenues might be more practical in such cases.

The interviews also reflect considerations of technological adaptability and infrastructural modifications. The potential requirement to replace or upgrade existing boilers to accommodate hydrogen combustion surfaces as a key challenge in the transition process. Moreover, the issue extends beyond technological compatibility to encompass distribution systems and metering mechanisms for natural gas.

When situated within the context of the built environment, the discourse on burning hydrogen intertwines with considerations of energy efficiency, infrastructure adaptation, and emissions reduction. The dialogue surrounding this practice reveals the complexity of harmonizing carbon reduction imperatives with practicality, technological advancement, and infrastructure optimization. As the built environment stands as a substantial contributor to energy consumption and carbon emissions, the exploration of hydrogen burning in this domain serves as a microcosm of the broader energy transition dialogue. The varying opinions conveyed in the interviews underscore the necessity for nuanced assessments, collaborative efforts, and multifaceted solutions that align with the distinct characteristics of the built environment while advancing sustainable energy objectives.

DA and other participants offer divergent perspectives on the role of hydrogen burning in addressing carbon emissions within the built environment. DA emphasizes the potential of burning hydrogen as an alternative to coal or natural gas in high-temperature processes, highlighting its capacity to reduce carbon emissions. He underscores the idea of burning hydrogen to replace traditional fossil fuels, indicating its potential significance in decarbonizing energy-intensive applications within the built environment. DA's viewpoint resonates with the notion that hydrogen combustion could offer a pathway toward emissions reduction in such processes.

However, the discussions also reveal contrasting opinions. JH cautions against the utilization of hydrogen burning for heat, expressing reservations that challenge the viability of this approach. JH's perspective hints at the complexities and considerations involved in implementing hydrogen burning within the built environment. His apprehension raises queries about the efficiency, safety, and overall effectiveness of hydrogen combustion as a comprehensive solution for heat generation.

MR adds a nuanced dimension by suggesting that hydrogen-fired boilers or furnaces might be more suitable for larger complexes and industries. MR's insight underscores the diversity of potential applications within the built environment, acknowledging that different contexts might yield varying levels of success for hydrogen combustion. Her perspective mirrors DA's by indicating a role for hydrogen burning in specific scenarios but underscores the importance of context-driven decision-making.

These varied viewpoints underscore the multifaceted nature of hydrogen burning as a strategy for emissions reduction within the built environment. While DA's optimism points to hydrogen burning's potential, JH's scepticism highlights the need for comprehensive evaluation, and MR's suggestion speaks to the importance of tailored solutions. The dialogue presents a holistic understanding that is integral to navigating the complexities of integrating hydrogen burning in the built environment, balancing aspirations for emissions reduction with pragmatic considerations.

4.42 Distribution Model, Transportation and Delivery of H₂

Participants emphasize that while hydrogen production might be feasible, the challenges lie in its efficient distribution, transportation, and delivery, all of which are crucial components of the infrastructure. They underscore that transporting hydrogen is complex and poses difficulties due to its unique properties. Some participants highlight the limitations of existing gas pipelines, designed primarily for natural gas, which may not be suitable for hydrogen without modifications.

Several participants discuss potential solutions to the distribution challenge. This includes exploring alternative forms of hydrogen carriers like ammonia or methanol, which could simplify transportation. Decentralization and localized production are also considered favourable options, enhancing energy independence and resilience. However, the availability of fuel cell trucks and vehicles for hydrogen transport remains a concern.

The participants recognize that addressing the distribution and transportation challenge is vital for the success of the hydrogen economy. They discuss the need for cost-effective and environmentally friendly distribution models, highlighting the role of policies and industry collaboration. The opinions indicate that the success of these strategies can influence the viability and growth of green hydrogen technologies within the built environment.

Applying these insights to the context of New Zealand, where renewable energy sources are abundant and there is a growing interest in sustainable practices, the challenge of hydrogen distribution becomes a significant consideration. The country's remote areas and dispersed population may favour decentralized distribution models. However, the lack of established hydrogen transport infrastructure and vehicle options, as discussed by the participants, could be hurdles to overcome in the New Zealand context. The opinions collectively stress the importance of finding innovative solutions for green hydrogen distribution tailored to the specific challenges and opportunities of New Zealand's built environment.

DA's opinions highlight the multifaceted challenges of hydrogen distribution, transportation, and delivery. He acknowledges that while producing hydrogen might be relatively straightforward, the complexities lie in effectively moving and delivering it to its intended consumption sites. DA underscores the lack of versatility and ease in transporting hydrogen, making it a significant hurdle in its widespread adoption:

"It's not that versatile, it's not that easy to transport hydrogen and make it and deliver it in the side of consumption. It's easy to make hydrogen, but it's not easy to transport it" (DA).

DA raises concerns about the environmental impact of current transportation methods, citing the use of diesel-powered trailers, which contradicts the green objective of hydrogen. He discusses the limited availability of hydrogen vehicles, particularly fuel cell trucks, which are essential for eco-friendly transportation of hydrogen. The scarcity of such vehicles is attributed to the limited number of automotive companies engaged in their production:

"It's tricky question of how you transport it. If you use the two trailers which use diesel, that's not entirely green. So you need to have either electric trucks which are highly uneconomical or you should have hydrogen vehicles" (DA).

To address these challenges, DA suggests innovative approaches like considering ammonia or methanol as carriers for hydrogen, which could potentially facilitate its transportation. He also touches upon the potential of producing green hydrogen at the source, utilizing solar power plants. However, he acknowledges the difficulty of transporting hydrogen across countries and regions, particularly to places like Korea, Japan, and Taiwan, and highlights the essential role of cost-effective transportation methods.

Overall, DA's opinions underscore the need for comprehensive strategies to overcome the intricacies of hydrogen distribution and transportation, indicating that resolving these issues is pivotal for harnessing the full potential of green hydrogen within the energy landscape.

JAGR expressed concern over the potential costliness of establishing a hydrogen distribution network within urban areas. **MR** emphasized the challenges in transporting hydrogen compared to other gases, highlighting its limitations. She also pointed out that hydrogens storage and transportation are relatively easier compared to electricity, which is its main competitor. MR's opinion aligns with the concerns raised by JAGR and DA regarding the complexities of transporting hydrogen, though she also acknowledges its potential advantages over electricity in terms of storage and distribution.

MS points out the cost considerations related to transporting hydrogen. He discusses the trade-offs between producing hydrogen centrally and transporting it versus generating it locally:

"If I produce it here and then I have to transport it there, there's a cost in doing that. But if I need it here and I can make it here, then I save that transportation cost so" (MS).

MS raises the challenge of transporting large quantities of hydrogen for powering cities and industrial facilities. He highlights the need for alternative storage technologies beyond high-pressure gas, such as the use of substances that can absorb hydrogen. He also discusses the drawbacks of liquefied hydrogen transportation due to boil-off losses:

"Hydrogen can be transported in a liquefied format and they've been doing that when natural gas for years, but it suffers high nutrition in the process. If I liquefy hydrogen, I got to freeze it down to minus 252 or 253 degrees. But in that process of freezing it and then putting it on a ship and transporting it, I'll get boil off. I will lose a percentage of my hydrogen in the process. That might not be too much of a problem if the ship can actually use that boiled off hydrogen to power the vessel. that it's better to produce green hydrogen in place and use it later when it's needed" (MS).

Overall, MS's opinion aligns with the concerns raised by other participants about the challenges and inefficiencies of transporting hydrogen, as well as the importance of considering different storage and transportation methods.

ZJ discusses the UK's approach to utilizing wind resources for hydrogen generation and highlights the challenge of determining the appropriate storage form for the produced hydrogen. ZJ mentions the controversy surrounding whether to store it as compressed gas or in a liquefied state. Additionally, ZJ raises concerns about transportation and mentions potential options such as using ships to transport gas cylinders or constructing undersea pipelines. ZJ's opinion underscores the significant infrastructure investment required for effective hydrogen distribution. Furthermore, ZJ points out that different countries' existing gas infrastructures can impact the choice of distribution methods and storage solutions for hydrogen.

The opinions of various participants shed light on the intricate challenges surrounding the distribution, transportation, and delivery of hydrogen. These perspectives collectively emphasize the complexity of establishing an effective hydrogen infrastructure. While hydrogen holds promise as a clean energy source, there is consensus that its transport and delivery pose significant hurdles. Some participants note the difficulty in transporting hydrogen due to its unique properties and the need for specialized vehicles. Others highlight the need for cost-effective transportation methods, with considerations of centralized versus distributed systems and the associated expenses. The opinions touch on alternative storage technologies, such as liquefaction or innovative absorption methods, to mitigate losses during transportation. The significance of existing gas infrastructure, both as a potential asset and limitation, is also noted, with participants discussing repurposing pipelines and

addressing compatibility issues. The opinions converge in acknowledging the necessity of addressing transportation challenges to unlock the full potential of hydrogen as an energy solution.

Distribution, Transportation and Delivery of Hydrogen	
Aspect	Key Insights
Complexities in Hydrogen Transportation	Several participants highlighted the complexities and limitations of transporting hydrogen compared to other fuels. Its unique properties pose challenges that require innovative solutions.
Pipeline Suitability	Existing gas pipelines may not be suitable for hydrogen without modifications, and the lack of hydrogen logistics infrastructure poses a significant hurdle. Purpose-built networks involve major investments.
Alternative Distribution Solutions	Potential distribution solutions discussed include carrying hydrogen in other substances, such as ammonia or methanol, which have superior transportation properties.
Localized Production Models	Decentralized, localized hydrogen production models help avoid transportation costs and enhance resilience but may not be feasible for large-scale demands.
Challenges in Fuel Cell Vehicles	The lack of fuel cell vehicles, trucks, and ships for hydrogen transport was cited as an obstacle by multiple participants. More options are needed for clean hydrogen logistics.
Exploration of Alternative Methods	Alternative storage and transportation methods, like liquefaction and novel absorption technologies, are being explored to avoid losses, but they also have their disadvantages.
Repurposing Natural Gas Grids	Repurposing natural gas grids and pipelines may assist in hydrogen distribution in some cases, but compatibility issues persist, especially at higher blend percentages.
Key to Unlocking Potential	Participants agreed that solving hydrogen transportation issues is key to unlocking its potential. Strategies should suit different scales of demand and minimize costs and losses.
Localized Production in New Zealand	For New Zealand, localized renewable hydrogen production could overcome distribution challenges in remote areas while supporting energy independence.

Table 34: Distribution, Transportation and Delivery of Hydrogen

4.43 Decentralization, Remote Locations, Off Grid, Microgrid and Energy Independence

The compilation of interviews with diverse participants offers valuable insights into the intricate domain of energy decentralization, remote locales, off-grid paradigms, microgrid implementations, and the quest for energy autonomy. The collated viewpoints encapsulate a spectrum of perspectives, both geographically and technologically nuanced.

The discourse underscores the palpable potential of hydrogen technologies to address energy conundrums in secluded settings and off-grid enclaves. Instances, such as remote islands or areas with limited grid access, emerge as fertile grounds for hydrogen's application in achieving energy

self-sufficiency. The appeal of hydrogen lies in its capacity to furnish a cleaner, sustainable energy reservoir, thereby offsetting the environmental and fiscal toll of fuel conveyance.

The thematic thread of decentralization is woven across the interviews, reflecting divergent standpoints. While certain respondents accentuate the scalability and economic viability of hydrogen solutions, particularly within small communities or remote pockets, others accentuate the significance of preserving grid integration for broader populace coverage. This echoes the delicate balance between the fiscal rationale for decentralized systems and the imperative of equitable energy provisioning.

A cogent inquiry surfaces in relation to energy independence. While some interlocutors envisage hydrogen as a pivotal lever for actualizing energy sovereignty, particularly in domains endowed with ample renewable resources, others prompt a prudential evaluation of land usage, water accessibility, and ecological implications linked to hydrogen generation and utilization.

Amidst the discourse on microgrid architectures, the interviews elucidate prospects for deploying hydrogen-centric systems to cater to localized energy requisites. These microgrids, capable of operating autonomously from the central grid, emerge as salient solutions, especially when intermittent renewable sources necessitate energy stockpiling remedies. Nonetheless, challenges endure, encompassing the comparative cost-efficiency of hydrogen frameworks vis-à-vis established grid infrastructure and the exigencies of sustained maintenance.

Across the interviews, a recurring motif pertains to hydrogen's potential to reconfigure energy landscapes. Concomitantly, there is a collective cognizance that, although specific regions may exhibit an immediate propensity for hydrogen integration, the overarching ambition remains rooted in fostering resilience, environmental stewardship, and energy security across multifarious energy scenarios. As perspectives continue their metamorphosis, this compilation of interviews crystallizes a snapshot of the intricate dialogue encompassing hydrogen's envisaged role in shaping decentralized energy horizons.

RGJA emphasizes the conceptualization of energetic communities, underpinned by the aspiration to forge microgrid frameworks that consolidate localized energy generation and consumption. Expressing his viewpoint, RGJA underscores the contextual nuances that underlie the feasibility of such communities, notably within the parameters of distinctive national landscapes.

In articulating the stance, RGJA delves into the case study of Colombia, acknowledging the intricate interplay between the interconnected grid system and isolated pockets reliant on self-fuelled diesel power generation. The focal concern revolves around the economic calculus, as the transportation costs associated with diesel fuel to remote areas render the prevailing diesel-based power generation economically burdensome. This impels RGJA to draw attention to the conundrum of high fuel prices, which gravitates towards a paradigm of energy alternatives, wherein the economic viability of renewable solutions becomes a determinant factor.

Affordability surfaces as a recurring motif within RGJA's discourse, wherein he reflects on the comparative cost dynamics between renewable energy alternatives and the incumbent diesel-based options. This underscores RGJA's discernment of the nuanced realities that define each country's energy landscape, as the interplay of factors like infrastructure, geography, and resource endowments influence the sustainability of transitioning to microgrid-oriented systems:

“I think it's possible, but at the same time in something very country specific. It's more affordable than the other option with diesel field, so I think it's something very specific to the context of each country, but I think it's possible” (RGJA).

Conclusively, RGJA's insights encapsulate the intricate interplay between the vision of energetic communities and the intricate national context, offering a prism through which to appreciate the evolving discourse surrounding decentralized energy paradigms.

JAGR envisions the establishment of a self-sufficient village, thereby epitomizing the essence of self-reliance within the energy landscape. The nucleus of this vision converges on the aspiration to create a residential enclave characterized by its autonomous energy generation. With an unwavering focus on the village paradigm, JAGR underscores the intent to harness electricity through the process of water electrolysis, effectively dissociating from any reliance on the conventional grid infrastructure.

Central to JAGR's proposition is the pursuit of scale, manifest in the megawatt (MW) capacity delineation. The location of this envisioned self-sufficient village resides on an island or potentially within the expanse of Mexico. JAGR's emphasis on the village context reveals a confluence of micro-grid ideology and the principles of energy autonomy. Importantly, this undertaking is framed within the context of a specific locale - the northern peninsula of Mexico, contiguous with the southern expanse of California, United States. Within this geospatial expanse, a noteworthy dimension emerges - the non-connection of a segment of the state of Baja California to the national grid.

In contemplation of this envisioned microgrid deployment, JAGR accentuates the socio-economic rationale that lends viability to this endeavour. The economic proposition is particularly salient in the context of remote and underserved regions, such as the one under consideration. The expense associated with transporting conventional fuel sources, including natural gas, to the remote location becomes a pivotal driver for the feasibility of transitioning to a self-contained energy paradigm. This rationale forms the crux of JAGR's perspective, encapsulating a synthesis of economic pragmatism, geographical localization, and energy independence.

Evidently, JAGR's articulation delineates a vision predicated on the harmonization of micro-grid concepts and remote energy paradigms, ultimately converging towards the creation of self-sustaining energy enclaves emblematic of resilience and economic prudence.

Within the United States, **KQ** articulates a resolute desire for reduced dependence on external energy sources, a sentiment that underscores the appeal of hydrogen as a locally producible energy vector. The allure of hydrogen is rooted in its capacity to be derived from various indigenous feedstocks, epitomizing a self-sufficiency ethos that resonates within the domestic context.

KQ's insights traverse the evolving landscape of energy connectivity in the US, where instances of hydrogen-powered homes and offices have materialized. A salient feature in these cases is the conscious decoupling from the conventional power grid. This strategic disengagement is attributed to the incumbent grid's challenges in accommodating intermittent energy inputs, emblematic of the growing proliferation of renewables.

The commentary from KQ evokes a sentiment that transcends time - a return to a historical epoch when the energy landscape was bereft of intricate grids and sophisticated pipelines. Evidently, the journey towards a self-reliant energy paradigm, reminiscent of pre-grid eras, is fraught with challenges. KQ contends that the desire to reside off-grid is indeed a viable proposition, as exemplified by hydrogen-powered homes that are devoid of grid connectivity. These homesteads, equipped with autonomous hydrogen storage mechanisms, solar arrays, and wind energy apparatuses, stand as exemplars of energy self-sufficiency.

In tandem with these individual endeavours, KQ highlights the strategic deployment of distributed energy resources at the fringes of conventional grid extensions. This architectural configuration is notably pertinent for companies contemplating expansion or entry into areas where grid augmentation

is constrained. KQ underscores the evolutionary trajectory of this approach, referencing a decade-long evolution that has culminated in a state of readiness for technology-mediated grid augmentation.

Collectively, KQ's insights underscore the multifaceted realm of micro-grids, remote energy paradigms, and the quest for energy autonomy. The discourse engages with a spectrum ranging from individual choices to strategic deployment strategies, all of which coalesce to shape the trajectory of energy transformation within the US.

MR offers a comprehensive analysis that delves into the nuanced relationship between energy autonomy, scale, and technology selection. For MR, the endeavour towards self-sufficient energy solutions hinges on the confluence of spatial considerations and operational intricacies.

MR's perspective navigates the spectrum of energy autonomy, beginning with single residential units and extending to larger complexes. Within this framework, MR discerns a distinct division. For standalone residences, the practicality of self-contained energy systems is predicated on both available space and the imperative of diligent maintenance. The terrain of opportunity appears to lean towards electrification for individual dwellings, owing to factors such as spatial constraints and the onus of upkeep. On the other hand, the sphere of communal residences or sprawling complexes emerges as a more conducive milieu for hydrogen-based solutions. MR attributes this suitability to the feasibility of establishing dedicated entities proficient in managing hydrogen-based energy systems, thereby ensuring efficacy and safety:

"I would say that for individuals, I see more opportunity in the electrification while for bigger complexes it should be easier to manage hydrogen because maybe you have a separate entity which takes care of everything and keeps it efficient and safe" (MR).

The underlying conviction that hydrogen harbours transformative potential for geographically isolated communities resonates throughout MR's discourse. This perspective is epitomized in the context of remote or challenging terrains, such as mountainous regions or arid landscapes blessed with abundant solar resources. MR's articulation positions hydrogen as a democratizing force in energy distribution, underpinned by its capacity to liberate communities from grid dependence:

"I think that hydrogen is key to allow communities areas which are disconnected from the grid to be independent. Think about this is in the mountains or even in a desert where you have a lot of sun and you can use a solar panels and you can have hydrogen" (MR).

In her insights, MR acquaints us with pioneering projects that traverse the expanse of diverse climates, mirroring hydrogen's adaptability. Particularly salient is MR's assertion that hydrogen, as an enabler, can alleviate the strain on conventional electricity grids. It is within this nuanced interplay that the utility of hydrogen as a conduit to mitigate grid load finds resonance.

Furthermore, MR expounds upon the notion of pilot initiatives as potent testing grounds for hydrogen's diverse applications. She posits that identifying suitable communities for installing hydrogen-based systems can illuminate distinct spheres of application, from hydrogen-enabled building heating to grid stabilization. Through these localized experiments, MR underscores the pragmatic imperative of technology selection predicated on the unique demands of each application domain.

In summary, MR's insights encompass a rich tapestry of considerations - ranging from the individual to the communal, from spatial dimensions to technological feasibility - offering a holistic comprehension of hydrogen's potential within the landscape of micro-grids and remote energy paradigms.

In a comprehensive elucidation, **MS** casts light on a pivotal aspect of the integration of technology and energy provision, unveiling the intricacies of mobile networks' expansion into remote locales.

Highlighting the historical backdrop of network expansion primarily within urban confines, MS accentuates the subsequent migration towards remote hinterlands compelled by competitive dynamics. This migration, however, is fraught with challenges stemming from the perennial concerns of power availability and reliability for essential base stations, a dilemma accentuated by intermittent grid access.

MS augments this discourse by introducing the notion of grid unreliability, a predicament notably prevalent in several Asian regions where the monthly average of grid downtime hovers around 120 hours. In the endeavour to circumvent this challenge, the telecommunications industry, in myriad countries, has traditionally resorted to diesel generators buttressed by battery reserves. Herein, MS offers an innovative proposition, the “*self-refuelling fuel cell*” (SRFC) concept. This innovation contemplates utilizing hydrogen fuel cells as an autonomous energy source that harnesses grid electricity or renewable energy sources to produce hydrogen, subsequently serving as a portable fuel for the fuel cell system. The SRFC paradigm is positioned as a remedy to the inherent limitations of diesel generators while promising enhanced efficiency and cost-effectiveness.

The inception of this concept finds resonance in the Phi Suea housing project situated in Thailand, a venture that serves as a vanguard for the SRFC paradigm. MS elucidates that this project serves as a pioneering testament to the autonomous microgrid model, embodying the optimal synergy of solar energy, hydrogen production, and advanced software-driven optimization. This exemplary endeavour, initiated in 2014, is emblematic of a self-sufficient ecosystem that dynamically manages its energy resources, thereby mitigating reliance on traditional grids.

Drawing from practical experiences, MS underscores the potential for cost-saving inherent in deploying SRFC systems for remote and energy-starved communities. Emphasizing the underlying rationale, MS dissects the cost structure vis-à-vis a remote community powered by diesel generators as opposed to one empowered by hydrogen-based microgrids. This juxtaposition reveals the cost efficiencies associated with on-site hydrogen production, storage, and utilization. Moreover, MS alludes to the longevity of electrolyzers and fuel cells in these systems, which could potentially extend beyond a decade due to intermittent operational schedules.

MS subsequently introduces a compelling case study, envisaging a remote location with reliance on diesel generators, encapsulating the formidable operational expenses therein. The potential of SRFC systems as an alternative energy source to supplant these generators emerges as an attractive proposition, driven by the potential to slash costs and enhance environmental sustainability. Notably, MS acknowledges the difficulty of competing with established grids but posits that, as energy costs escalate and grid expansion becomes prohibitive, the economic viability of SRFC systems becomes increasingly pronounced, especially in areas without grid connectivity.

MS underscores a pivotal aspect of energy production and distribution, elucidating the nuanced dynamics between centralized and decentralized approaches. With succinct clarity, MS contends that the crux lies in the strategic juxtaposition of energy generation and consumption. MS emphasizes that if energy production aligns with localized demand, a heightened degree of control is conferred upon the system’s operators. In this regard, MS underscores the importance of temporal congruence between production and consumption, thereby optimizing resource utilization.

MS probes deeper into this concept, noting the inherent advantages of on-site energy production in contrast to centralized models. Centralized energy generation necessitates continuous operation, a 24/7 commitment to meet the demands of a vast and interconnected grid. In stark contrast, MS expounds that localized production empowers flexibility, enabling system operators to tailor energy generation according to specific demands. The essence of this argument is grounded in the notion that centralized systems are constrained by their perpetual operation, while localized systems can be modulated to align precisely with instantaneous needs.

Moreover, MS touches on the imperative of mitigating energy wastage intrinsic to centralized systems. In centralized models, energy surpluses and deficits often occur due to the constant generation mandate, potentially leading to inefficiencies and resource squandering. MS's contention thus crystallizes around the notion that decentralized production fosters a more judicious allocation of resources by engendering on-demand energy creation and consumption.

In this compelling discourse, MS not only delves into the intricacies of energy generation but also presents a profound conceptual shift. The emphasis on localized production as an avenue to harness control over energy supply, coupled with the capacity for tailored modulation, underscores the burgeoning significance of context-specific, decentralized energy models in contemporary energy discussions:

"If I need it here and I can make it here, but for me producing it where you need it and when you need, it gives you more control or because if you do something centrally you can't turn the machine off. It's gotta make hydrogen 24 by 7" (MS).

In summation, MS's discourse traverses the gamut from historical industry evolution to innovative energy paradigms. Through the lens of the SRFC concept, MS underscores the potential for hydrogen-powered solutions to revolutionize energy provision in remote and grid-deficient regions, thereby facilitating sustainable and self-sufficient energy ecosystems.

PL adeptly navigates the multifaceted considerations inherent to localized hydrogen production, particularly in the context of remote and off-grid regions. PL cogently posits that while such locales represent a compelling niche, their contribution to overall hydrogen production is modest, perhaps accounting for less than 1% of aggregate needs. Nevertheless, PL underscores their significance as specialized cases warranting discerning analysis:

"I think for islands, for example, for remote areas, it's an interesting case, but it's a very minor case, I think less than 1% of what we need" (PL).

The crux of PL's discourse resides in the intricate balance between energy requirements and environmental impact, encapsulating multifarious dimensions. PL underscores that the exigencies of constant energy supply in remote areas underscore the viability of localized hydrogen production. However, PL shrewdly underscores the imperative of incorporating sustainability considerations. The ecological and environmental ramifications stemming from land use alterations, water utilization, and potential impacts on biodiversity emerge as paramount concerns. PL perceptively reasons that the pursuit of hydrogen production, though vital, must be meticulously aligned with ecological stewardship.

Furthermore, PL's perspective extends to the intricacies of energy efficiency. Notably, the process of repurposing hydrogen for electricity generation inherently carries inefficiencies. This critical insight accentuates the complexity of evaluating the overall efficiency and sustainability of localized hydrogen systems in remote regions.

Participant PL introduces a novel concept aimed at enhancing energy autonomy and sustainability within the built environment, particularly in residential and communal settings. His proposal centres around a versatile unit that combines a reversible fuel cell with an electrolyser, forming a cohesive system.

PL elaborates on this innovative idea:

"The idea is to propose a unit composed of reversible fuel cell means electrolyser. It's a unit for residential applications for not one home, but for the building. It's a sort of solution for sure autonomy of the building, of a group of buildings. And it's fine".

This unit, which integrates both reversible fuel cell and electrolyser technologies, represents a holistic approach to addressing energy needs on a larger scale - spanning beyond individual homes to encompass entire buildings or groups of structures.

PL underscores the system's potential to support energy autonomy and mitigate intermittency issues associated with hydrogen utilization:

“We can live with a reversible fuel cell and reutilize we can manage the intermittency of hydrogen level”.

By combining the reversible fuel cell's ability to generate electricity with the electrolyser's capability to produce hydrogen from excess energy, the system offers a sustainable means of maintaining consistent energy supply even in the face of varying hydrogen availability.

PL's discourse also embraces a forward-thinking proposition, encapsulating a solution-oriented approach. The proposition revolves around a unit comprising a reversible fuel cell and an electrolyser, conceived with the intent of catering to residential applications and small-scale communities. PL's nuanced depiction envisages a multifunctional unit that augments energy autonomy and confronts intermittency challenges, thus framing the discourse within a pragmatic, solution-driven paradigm.

In summation, PL's comprehensive dialogue navigates the intricate terrain of localized hydrogen production in remote contexts. The synthesis of viability, environmental responsibility, energy efficiency, and innovative solutions engenders a rich tapestry of considerations central to the deployment and efficacy of hydrogen systems in these distinctive settings. In essence, PL's proposal reflects a forward-thinking approach that aims to harness the synergies between reversible fuel cells and electrolysers to enhance energy self-sufficiency and resilience within residential and communal contexts in the built environment.

RH discusses the potential of hydrogen applications in microgrids, off-grid, and remote locations. He highlights that renewable hydrogen can serve as a replacement for LPG (liquefied petroleum gas) in such areas, providing a clean energy source. The challenges in these settings involve matching energy supply and demand and managing intermittent supply and demand. In remote locations where the cost and carbon footprint of transporting LPG is significant, hydrogen could be a viable alternative as a fuel gas. This consideration takes into account the emissions associated with both the LPG itself and the transportation required. RH highlighted that hydrogen could have a role in such scenarios, addressing both the cost and environmental concerns of using traditional fuels:

“If you're in a remote location and you're paying a lot of extra to get your LPG shipped in and you're really care about the carbon content both of the LPG and the shipping, then yes, hydrogen has a possible place as a fuel gas” (RH).

He presents a system that uses hydrogen as a storage medium for thermal energy rather than electrical energy. The system involves generating hydrogen through electrolysis, storing it at low pressure in underground pipes, and using it in modified burners for hot water and heating. RH emphasizes the simplicity of their system and the use of existing gas pipe infrastructure.

RH's team in NZ has tested their system in various installations, including a test site with solar panels, wind turbines, and hydrogen storage. They aim to reduce the cost of their system components, such as the electrolyser and storage, to make it more affordable and practical for remote areas.

He also discusses the challenges of integrating hydrogen into existing natural gas infrastructure and appliances. There is an ongoing project to evaluate mixing hydrogen into the gas supply and its impact on appliances. RH suggests that hydrogen may find a niche in heavy transport applications, but for small-scale energy needs, batteries are often more efficient and cost-effective.

RH astutely elucidates the pivotal yet specialized role of hydrogen within the context of remote regions and fringe off-grid applications. In contemplating the viability of hydrogen as a fuel gas, RH adroitly alludes to circumstances where access to conventional energy sources is fraught with logistical and environmental concerns. An emphasis on mitigating carbon content and shipping-associated emissions underscores hydrogen's potential as an alternative fuel option for such unique locales.

Per RH's discerning perspective, the customary wellspring of LPG tends to be centralized, thereby giving rise to the concomitant predicaments of both environmental degradation and fiscal encumbrances entailed by its conveyance from this central locus to the ultimate recipients at the periphery. It is within this intricate framework of transportation logistics that not only economic outlays find their culmination but also the susceptibility of the supply chain to plausible geopolitical upheavals due to the protracted trajectories comes to the fore. The scenario is further compounded by instances wherein LPG, spanning vast spans of thousands of kilometres, finds its traverse to meet the intended users, consequently engendering a confluence of monetary and ecological quandaries. Furthermore, the endeavour to capture and confine CO₂ emissions stemming from LPG, notably at the domestic culinary tier, becomes an unfeasible undertaking.

RH argues that hydrogen technologies could address these challenges effectively, particularly in remote areas with numerous LPG users. In Australia alone, there are approximately 16,000 remote users of LPG. Moreover, considering the global scale, millions of individuals rely on LPG in remote locations. RH suggests that the abundant solar energy available in such areas often goes to waste, and utilizing hydrogen technologies could be a suitable solution. He emphasizes the concept of micro-grids for remote locations, where hydrogen could replace LPG as a cleaner and more sustainable fuel source. This shift aligns with his viewpoint that hydrogen technology holds the potential to replace LPG in off-grid and hard-to-reach areas, offering a reliable and environmentally friendly alternative.

RH's discourse echoes the scarcity of comprehensive analyses dedicated to the off-grid segment. RH attributes this relative paucity to the niche nature of this demographic, perhaps accounting for their limited exploration in the broader discourse.

RH's involvement in the field of remote areas becomes apparent, particularly through contributions to the New Zealand Hydrogen Symposium. In this presentation, RH spotlights the tripartite synergy of renewable power generation, storage, and utilization, with a distinct focus on diverging from traditional LPG applications. With an eye toward maximizing efficiency, RH discerningly contemplates the efficacy of converting locally produced hydrogen into electricity. Within the realm of energy distribution, RH deftly evaluates the comparative efficiency of transferring electricity versus hydrogen, ultimately gravitating towards locally generated hydrogen for specific use cases.

Critical to RH's stance is the candid acknowledgment that the deployment of hydrogen systems warrants judicious selection based on functional objectives. The overarching consideration for utilizing hydrogen remains firmly rooted in its applicability as a fuel gas, rather than a primary source of electricity generation. RH deftly discerns that the compelling economics of hydrogen become pronounced in remote regions, where alternatives like batteries may not be as cost-effective. RH seamlessly interfaces this economic reality with the overarching energy landscape, situating hydrogen's prospects within the broader context of renewable energy sources and societal energy storage.

RH's judicious evaluation extends to addressing hydrogen's role in transportation and larger-scale applications, wherein the proposition of hydrogen becomes progressively stronger. The conversational style weaves together RH's rich insights, encapsulating a nuanced analysis that acknowledges hydrogen's niche while steadfastly acknowledging the growing prominence of battery technologies in smaller-scale applications. In sum, RH's comprehensive dialogue traverses the

intricate crossroads of remote energy solutions, encompassing diverse energy vectors, efficiency dynamics, and the evolving role of hydrogen in an increasingly electrified world. Overall, RH emphasizes the potential of hydrogen as an alternative energy solution, particularly in remote areas, but acknowledges the growing competition from battery technology in various contexts.

Within the cogent narrative articulated by **SJS**, a discerning exploration into the dynamics of energy systems becomes palpable, particularly as it pertains to the paradigm shift induced by hydrogen's decentralized production capabilities. SJS adeptly underscores the transformative potential of hydrogen within the energy landscape, contrasting it with the burdensome logistical imperatives entailed by procuring conventional fossil fuels such as gas and crude oil. He draws attention to the profound contrast between hydrogen production, which can be seamlessly integrated with localized renewable sources like solar and wind, and the extensive journeys necessitated for acquiring conventional fuels. This transformative shift towards decentralization, as espoused by SJS, has notable implications for established energy frameworks, and he astutely observes that such a decentralized approach runs counter to the preferences of many central governments.

SJS further extends his analysis to underscore the imperative of resilience in energy systems, propounded by the prospect of localized production. He cogently illustrates how the existing infrastructure, often reliant on centralized supply lines, renders energy systems vulnerable to multifaceted failures, potentially cascading across vast regions. Through poignant examples, such as Europe's intricate energy network, SJS elucidates the susceptibility of centralized systems to systemic breakdowns. The incisive comparison to the inception of the Internet, conceived with decentralization to ensure robustness in the face of adversity, draws a parallel to the energy domain, reinforcing the narrative of distributing energy generation to foster resilience.

With clarity, SJS portrays the global spectrum, where energy disparity prevails despite the abundance of resources. Highlighting instances such as Nigeria and India, he underscores the irony of energy-rich nations grappling with access limitations. The juxtaposition of millions without electricity against the pursuit of remote solar installations in distant locales, posits the idea of energy decentralization as a linchpin for equitable and sustainable energy provisioning. SJS masterfully underscores the advantage of decentralization, noting that while complete decentralization might be unattainable, its progressive realization still culminates in a more optimized energy ecosystem.

He adroitly parallels the intricate functioning of the Internet to the energy sector, emphasizing how routing plays a pivotal role in seamless communication. Contrasting this with centralized systems, he lucidly depicts the inefficiencies stemming from centralization, marking them as counterproductive in an increasingly interconnected world. SJS fervently advocates for global action, where nations, driven by the pursuit of energy independence, harness their indigenous resources to the maximum. Here, his conviction aligns with a clarion call for decentralized energy solutions as a core tenet for a sustainable and equitable future.

SJS astutely navigates the role of policy makers, casting a discerning gaze on the post-political trajectory where these individuals often gravitate towards corporations, thereby shaping policies that benefit their subsequent affiliations. With a piercing critique, he unravels the paradox of green parties in power perpetuating the status quo, underscoring the persistence of vested interests. This shrewd observation highlights the complex interplay between policy, industry, and societal progress.

In assessing the current state of energy systems, SJS acknowledges the cost constraints that persistently challenge their adoption. However, he accentuates the ongoing trajectory towards affordability, driven by pioneering individuals who dare to embrace change. This, he posits, forms the foundational bedrock for broader transformational shifts in the energy sector, a sentiment that resonates with the premise that innovation often stems from the courage of early adopters.

In closing, SJS intricately balances the notion of scale with pragmatism, recognizing the varied contexts that dictate the viability of centralized versus decentralized energy systems. With a nod to his earlier illustrations, he encapsulates this divergence through diverse scenarios - a colossal industrial complex versus a diminutive remote community - affirming that the optimal solution hinges on aligning energy systems with the unique demands of each situation.

In the discerning exposition proffered by **TW**, a compelling narrative unfolds, centred on the burgeoning prospect of harnessing energy autonomy within the residential sphere. TW adroitly illuminates the trajectory of distributed energy as an avenue both practical and cost-effective, laden with the potential to bolster system redundancy and furnish the coveted mantle of energy independence and resilience. The quintessential ethos, as TW contends, orbits around the imperative of nurturing self-reliant energy solutions that transcend the capricious currents of centralized provisioning:

“One of the likely use cases that we’ve kind of identified is in that residential space where people want to be energy self-sufficient. I really believe that the distributed option is that the more likely path and the more cost-effective path. Also, it adds additional redundancy to the system, and it creates energy independence, which is something that we really need to hit towards. So, resilience and independence is really key” (TW).

With perspicacity, TW calls upon the government to spearhead a paradigm shift, advocating the formulation of policies that galvanize domestic energy self-sufficiency and cultivate a fertile terrain for the proliferation of residential solar systems. His vision dovetails with the notion that pre-emptive action is preferable to waiting for power shortages to compel intervention:

“I don’t think we need to wait until multiple thousands of houses are without power to realize that having them independent means that we can sort them out” (TW).

By resolutely championing the cause of energy autonomy, TW advocates for the strategic rollback of grid services, positioning renewable energy as a vanguard against the inefficiencies engendered by protracted power lines reaching remote locales.

Drawing upon a concrete case, TW elucidates the quandary confronted by the energy sector - illustrated by Power Co and its revelatory implications. The juxtaposition of maintaining extensive power lines vis-à-vis the installation of renewable systems at isolated locations underscores the rationale that drives energy transition. Echoing the voice of prudence, TW advances the precept that investing in individual energy independence often supersedes the toll exacted by perpetuating cumbersome grid infrastructure.

The conceptual thread of micro-communities and localized energy hubs surfaces as a tangible blueprint in TW’s discourse, as he cites exemplars such as ATCO’s Clean Energy Innovation Hub. This innovative trial, featuring a synergy of hydrogen integration, centralized battery systems, and fuel cells, coalesces into a mosaic that engenders self-sufficient neighbourhoods. The triumph of this model, highlighted through these undertakings, augments the conviction that energy hubs can flourish at the epicentre of communities, branching out to disseminate power and resilience across a decentralized network.

From the standpoint of individual users to the broader vista of micro-hubs, TW unequivocally underscores the indispensable role of hydrogen in the residential narrative. The envisioning of self-sustaining energy enclaves resonates profoundly, wherein decentralized generation and ownership of energy becomes a source of empowerment. In this tapestry of energy innovation, TW deftly navigates the terrain of anxieties regarding maintenance, proffering the notion of maintenance plans as a salve to quell apprehensions:

“It’s more cost effective to install a fully renewable system at that one house than it is to maintain that power line and as you start to apply that methodology you can remove that grid service all the way back you can create additional money into the community by enabling renewables and scaling them back, scaling your regular reticulation back and creating opportunities for these renewable technologies by starting at the edges and working back, it’s the opposite to the NZ problem, where the power problem is going to be in the centre and they’re gonna need to invest a whole lot of money and getting additional power to domestic houses to be able to support them” (TW).

TW astutely underscores a compelling scenario wherein the interplay of practicality and innovation takes centre stage. By evoking the context of constructing a residence on a lifestyle block and the exigency of transformer upgrades, TW illuminates an intriguing proposition. Within this framework, the prospect of employing an off-grid system infused with hydrogen emerges as a beacon of self-reliance, offering an alluring avenue toward complete energy independence devoid of any lifestyle compromise, as articulated by TW.

With acumen, TW advances the notion that even in the face of infrastructural challenges, the fusion of hydrogen technology with residential energy solutions holds the promise to redefine the parameters of sustainable living. The articulation encapsulates the ethos of transcending traditional norms and embracing innovative energy alternatives. This paradigm shift, as postulated by TW, echoes the tenet that advancements in energy technology can empower individuals to sculpt their living environments in congruence with their preferences and values, untethered from the constraints of conventional energy frameworks.

In this contemplative assertion, TW unveils a vista where the pursuit of a self-sufficient lifestyle harmoniously converges with the application of cutting-edge energy systems. The underlying message resonates with the sentiment that technological prowess, when judiciously integrated, can facilitate a harmonious coexistence between modern comforts and ecological mindfulness. As such, TW’s pronouncement stands as a testament to the transformative potential imbued within hydrogen-based energy paradigms, casting a visionary light upon the prospects of reshaping residential landscapes in ways that foster autonomy, resilience, and sustainability:

“There was already a case to say that if you were trying to build a lifestyle block or build a house on a lifestyle block and you needed to upgrade the transformer, you would already be able to do an off grid system with hydrogen and installed and be completely self-sufficient without having any compromise of lifestyle” (TW).

In advocating for a transformative shift away from conglomerate reliance, TW portrays a future landscape painted by energy independence and community empowerment. This narrative aligns seamlessly with the clarion call for energy decentralization, underscoring the potential for harmony between individual autonomy and communal progress. As TW’s discourse converges with the pursuit of resilience and energy independence, it crystallizes a worldview poised at the intersection of energy, empowerment, and sustainability:

“That’s where I think the resilience and energy independence piece comes in. When you talk to people, they are quite happy to know that they are generating the electricity that they are storing the electricity and they are masters of their own destiny and the energy space. Some people are scared of the maintenance of that, but if you offer maintenance plans then that you can alleviate that fear. But it really comes down to that not relying on the larger companies, decentralizing it, spreading the opportunity to the community” (TW).

TN adeptly navigates the landscape of decentralized energy solutions, casting a spotlight on the profound potential of hydrogen technologies in unconnected grid environments. With discernment, TN delineates a scenario where the absence of grid connectivity is ingeniously offset by the on-site

generation of hydrogen, facilitated by innovative technologies like Enapter's. The elegance of this proposition rests on the simplicity of its requisites: water and electricity, readily available components that stand in stark contrast to the logistical complexities of extracting fossil fuels from distant regions:

"It can be used for a place where grid is not connected. You can produce hydrogen on the spot using say Enapter technology. Hydrogen can be produced anywhere as long as there's water and electricity" (TN).

In this vein, TN invites contemplation of the varied contexts in which hydrogen can make its transformative mark. The versatility of hydrogen production, hinging on water and electricity availability, paints a striking contrast to the arduous procurement of conventional energy sources. TN's elucidation eloquently underscores the role of hydrogen as a game-changer in energy acquisition, one that sidesteps the intricate web of geopolitical dependencies and distribution challenges that traditionally accompany fossil fuels.

The nuanced assertion, delivered with a sagacious understanding of the diverse energy landscape, imparts that the feasibility of hydrogen adoption hinges on context and purpose. TN cogently suggests that disparate settings, from factories to residential neighbourhoods, could be the canvas upon which the hydrogen narrative is artfully woven. Notably, the example of placing wind turbines in urban centres, as envisaged by TN, presents an intriguing paradigm shift, where energy generation converges with consumption in a harmonious, localized loop.

However, TN's ruminations also navigate beyond urban landscapes, envisioning islands and detached areas as crucibles for hydrogen's transformative prowess. In these remote terrains, where grid connectivity is cost-prohibitive, hydrogen emerges as a beacon of possibility, kindling the flames of self-sufficiency and sustainability. Drawing parallels with real-world instances in Japan, where small islands grapple with grid integration challenges, TN invites us to contemplate a landscape where hydrogen not only bridges the energy gap but also fosters resilience and autonomy:

"I was thinking like an island. Maybe Waiheke Island put the solar or wind plans there together with the electrolyser. Then we can power the residential or commercial buildings there. So, it's detached area then it makes sense. That's some people are trying in Japan, they are small islands. It's more costly to connect the grid. Then why not just use hydrogen?" (TN).

In sum, TN's insights reverberate with the clarion call for decentralized energy paradigms. This perspective seamlessly aligns with the emerging ethos of harnessing local resources to circumvent the vulnerabilities inherent in centralized energy supply systems. TN's voice resonates with an astute understanding of how hydrogen can infuse vitality into micro-grids and remote locations, underpinned by the conviction that the decentralized future of energy is within reach.

VG brings a pragmatic perspective to the discourse on off-grid energy dynamics, casting a discerning eye on the interplay between hydrogen technologies and the economics of energy delivery. With a firm grasp on the intricacies, VG underscores that off-grid energy solutions, while essential in certain scenarios, are inherently costly endeavours. This sobering insight forms the bedrock of VG's viewpoint, asserting that the cost considerations loom large in decisions to embrace or eschew off-grid solutions. VG intriguingly posits that even in a landscape where off-grid alternatives are evaluated, hydrogen presents a supplementary layer of expense rather than a transformative catalyst.

VG's analysis assumes a pronounced departure from the perspectives articulated earlier, where hydrogen's potential as a decentralized energy solution was fervently extolled. VG's stance harbours scepticism regarding the widespread applicability of hydrogen as a direct replacement for grid-connected systems. Intriguingly, VG's pragmatic assessment aligns with the sentiments that grid electricity, while possibly beset with limitations and challenges, still reigns as a more cost-effective and practical option compared to the adoption of hydrogen-based off-grid solutions.

VG's pragmatism extends to the realm of customer behaviour, postulating the concept of the "green premium". This intriguing concept encapsulates the notion that customers, motivated by environmental stewardship, might be willing to pay an elevated price for cleaner energy solutions. In this context, VG recognizes the transition some companies make from diesel-based off-grid systems to hydrogen-based ones. While acknowledging the merit in these shifts toward cleaner energy, VG concurrently acknowledges that hydrogen doesn't act as a growth driver for the conventional grid, but rather as an adjunct to supplant existing diesel-based off-grid setups:

"Off grid is very expensive form to deliver electricity. So whenever you can avoid it you will avoid it. Hydrogen just makes it even more expensive. I can't figure off any use cases where you have had grid electricity before and no go via hydrogen off grid. Makes no sense to me. There are a couple of different companies switching from diesel off grid to hydrogen off grid. Still more expensive, but it's a clean solution. So that makes sense to me. If customers are willing to pay that, we call it the green premium the additional price to go green but hydrogen itself is not fostering the growth of grid. It's a level to supplement existing, dirty diesel off grid" (VG).

The differing cadence of VG's viewpoint in relation to the broader dialogue lies in its spotlight on the pragmatic implications of cost and existing energy paradigms. In contrast to the optimism regarding hydrogen's role in decentralization and remote locations, VG's perspective sheds light on the fiscal realities that influence energy decisions. Through VG's voice, the discourse gains a multifaceted dimension, illustrating that while hydrogen might serve as a promising ingredient in the energy mosaic, its role is not necessarily synonymous with transforming the grid dynamics on a broader scale.

According to **ZJ**, the Coney Islands project stands as a noteworthy exemplar of harnessing renewable energy, particularly wind power, to orchestrate a symphony of sustainable energy generation and hydrogen synthesis. The project's strategic positioning adjacent to the UK's largest wind farm adds to its significance, creating a symbiotic relationship between renewable power generation and hydrogen production. ZJ articulates that the project's utility extends beyond its isolated boundaries, elucidating its role as a contributor to the Glasgow Energy system - a testament to the interconnectedness of energy ecosystems.

Of paramount importance in ZJ's account is the temporal dimension, as ZJ alludes to the immediate timeline of hydrogen generation initiation in the current year. This emphasis on the tangible and proximate underscores the dynamic nature of this venture and underscores its imminent contributions to the broader energy landscape.

ZJ's narration, informed and insightful, lends a unique perspective to the discourse on micro-grids, remote locations, and decentralization. By highlighting the Coney Islands project's distinct attributes and strategic role, ZJ adds a distinct layer to the conversation, showcasing the practical fusion of renewable energy, hydrogen generation, and energy systems integration in a tangible real-world context.

In the discourse surrounding micro-grid and remote location energy solutions, a spectrum of viewpoints emerges from diverse experts. RH adeptly underscores hydrogen's promise as an alternative fuel gas in remote locales, emphasizing its decentralized production potential. LPG's centralized sourcing and associated costs are pinpointed, along with the geopolitical vulnerabilities of its extensive transportation routes. RH's stance echoes the call for resilience and energy autonomy, urging governments to encourage decentralized energy systems.

Similarly, SJS highlights hydrogen's role in residential energy self-sufficiency. Distributed solutions are seen as the cost-effective path, enhancing system redundancy and energy independence.

Government intervention is urged to foster resilience, incentivize domestic solar, and encourage early intervention in providing power to communities.

TW brings attention to the feasibility of off-grid hydrogen systems in areas lacking grid connectivity. While acknowledging challenges and costs, TW emphasizes hydrogen's value for niche applications such as islands or detached areas. The concept of energy self-reliance, coupled with maintenance plans, resonates as a driving force in adopting decentralized systems.

VG presents a contrasting stance, noting hydrogen's limited capacity to foster grid growth due to cost implications. While acknowledging the transition from diesel to hydrogen in off-grid scenarios as a clean solution, VG highlights the added expenses and emphasizes customers' willingness to pay a “green premium”.

ZJ introduces a live example from the UK - the Coney Islands project. Positioned near a wind farm, the project demonstrates the integration of renewable energy and hydrogen production. ZJ underscores the project’s immediate timeline for hydrogen generation initiation and its contribution to the broader energy landscape.

Decentralization, Remote Locations, Off-grid Systems and Energy Independence in relation to Hydrogen	
Aspect	Key Insights
Energy Needs in Remote Areas	Hydrogen has the potential to address energy needs in remote, off-grid areas with limited grid access by providing a clean, sustainable energy source.
Environmental and Cost Benefits	Hydrogen can offset the environmental and cost burdens of transporting traditional fossil fuels to such locations.
Decentralized Production	Decentralized production aligns with energy independence goals but must balance land use, water access, and biodiversity impacts.
Microgrid Systems	Microgrid systems with hydrogen production, storage, and fuel cells can enable autonomous operation, although costs are still prohibitive compared to the grid.
Flexibility of Local Renewable Sources	Hydrogen production's flexibility from local renewable sources contrasts with the logistical challenges of fossil fuel supply, enabling self-sufficiency.
Progressive Localization	While 100% decentralization is unrealistic, progressive localization can improve optimization and resilience compared to centralized systems.
Shift from Extensive Supply Lines	Hydrogen production signifies a shift away from reliance on extensive supply lines that are vulnerable to systemic failures.
Localized Power Hubs	Localized hubs can disseminate power across decentralized networks, fostering self-reliant neighbourhoods.
Support and Incentives for Adoption	Maintenance support and incentives are needed to encourage the adoption of household systems for energy autonomy.

Scepticism About Widespread Viability	There is scepticism regarding the widespread off-grid viability of hydrogen due to higher costs compared to grid electricity, though it remains promising for niche applications.
Demonstrated Integrated Microgrids	Projects have demonstrated integrated microgrids combining renewables, electrolysis, and hydrogen distribution for localized energy needs.
Strategic Context for Adoption	Strategic adoption suited to specific contexts is key to unlocking hydrogen's decentralization potential.

Table 35: Decentralization, Remote Locations, Off-grid Systems and Energy Independence in relation to Hydrogen

In sum, a multifaceted tapestry of opinions unfolds. While some see hydrogen as a catalyst for remote energy independence and resilience, others underscore its role in supplementary off-grid solutions. The Coney Islands project exemplifies the tangible fusion of renewable energy and hydrogen generation, adding a practical dimension to the discourse on micro-grids, decentralization, and remote energy systems. Overall, hydrogen enables self-sufficiency and resilience but strategic integration aligned with local needs is crucial to realize its decentralization promise.

4.44 Hydrogen for Back-Up and Emergency

Participants across various interviews have shared their perspectives on the role of green hydrogen in backup and emergency scenarios. RGJA viewed hydrogen as a potential backup fuel, suggesting its use for storage and activation during unforeseen emergencies:

“You can see the hydrogen as a backup fuelled and maybe you can store and maybe you just use in emergency situations”.

KQ highlighted the need for quieter energy systems as part of the solution. PL mentioned that in specific cases, the concept of green hydrogen was considered an autonomous and permanent energy source. Additionally, the notion of hydrogen backup was juxtaposed with other systems like pumped hydro, indicating its integration within a broader energy strategy was discussed by RH. While RH noted a shift from fuel cells to combustion due to practicality and economics, he acknowledged the value of small fuel cells, around 500 watts, for essential purposes such as sustaining critical appliances during power outages. Collectively, these insights underline the diverse roles that green hydrogen can play in ensuring energy security, backup support, and emergency preparedness within dynamic energy landscapes.

4.45 Safety

Various experts from different countries have provided insights into the safety concerns associated with hydrogen usage. Their opinions reflect a range of perspectives, touching on aspects such as accidents, regulation, public perception, and technology. It is important to note that hydrogen safety is a multifaceted topic that requires a combination of regulatory measures, technological advancements, and public education.

Some interviewees emphasize that public perception plays a significant role in shaping attitudes toward hydrogen safety. There is a recognition that hydrogen is often associated with historical

incidents like the Hindenburg disaster and concerns about explosions. However, experts stress that these perceptions don't necessarily reflect the current state of hydrogen safety:

“People still go on about the Hindenburg and safety and stuff, but it’s largely a misrepresentation because fossil fuels are much more risky and more poisonous” (JH).

“Sometimes they could be a little bit reluctant because the only thing that they have heard is the Hindenburg” (RGJA).

“Most people think that hydrogen is very dangerous. Toshima event and the Hindenburg it's that kind of stuff a bit association” (JAGR).

“We’re still a few years away from completing all of those things for public will trust hydrogen as a fuel and they'll accept it in their houses because Hindenburg is a very big story and everybody loves psych, talking about Hindenburg and then there's lessons from that as well. If we get this wrong, it only takes one incident to ruin it for everybody” (TW).

“All these images like the Hindenburg are tough to get out of people’s head like that. That’s something that sticks” (VG).

When it comes to accidents involving hydrogen, human factors are a big player. More than 90% of hydrogen accidents actually happen because of human errors and oversights, rather than just a lack of safety measures. It really boils down to how we humans handle things:

“90% of hydrogen accidents actually happen due to the human factor. It’s not related to lack of safety measures that has been taken. But all kind of come down to human factor” (DA).

Many interviewees point out that safety concerns can be addressed through rigorous regulations and certifications. Several countries have established strict standards for handling hydrogen, particularly in industrial contexts. It is noted that regulatory bodies play a crucial role in ensuring the safety of hydrogen technology:

“In Korea there is an organization called Korea Gas Safety Corporation which has one of the strictest regulations in order to certify hydrogen technology. With a right number of regulations, safety management, I think hydrogen could be a safe gas” (DA).

There is a distinction made between the safety of hydrogen in industrial applications and its use in domestic environments. While hydrogen has a good safety record in industrial settings like refineries and production facilities, concerns arise when it comes to domestic applications. The potential for explosions and the challenge of detecting hydrogen leaks in confined spaces are key concerns:

“If you look at the hydrogen safety from the industrial standpoint, for example, in refineries, you will find a very good record or safety records, but in case of domestic applications, hydrogen may be explosive. Atmospheres could be the main issue” (RGJA).

Experts stress the importance of using the right technologies to mitigate safety risks. Detection systems, flame sensors, pressure safety valves, and hydrogen monitoring equipment are seen as critical tools for ensuring safe hydrogen usage. These technologies can help identify leaks, control pressures, and prevent potentially hazardous situations:

“You have to have a fire system. You have to have ideally positive pressure. You have to have all these sorts of safety factors come into play. If it’s in an outdoor cabinet, all that goes away” (RH).

The interviewees highlight the need for public and academic education to dispel misconceptions and build confidence in hydrogen safety. They emphasize that proper education, information dissemination and public awareness campaigns can help people understand that hydrogen can be used

safely, similar to other fuels. Assuring the public through certifications and standards is considered essential:

“There should be a lot of awareness and seminars and workshops about hydrogen. How it’s used and how it’s safe” (TN).

“I think we have to let people know that it is not so dangerous” (JAGR).

“We should do something to let people to understand that hydrogen is safe” (TN).

“The government educations and the educational institutions would be quite critical to provide the sufficient information about how to safely use the hydrogen” (ZJ).

The safety aspects of hydrogen in mobility, such as fuel cell vehicles and refuelling stations, are a significant concern. Experts recognize that these technologies need to adhere to rigorous safety standards, particularly given the potential for accidents to garner significant public attention and erode public trust:

“Have a pathway to certification and public information about that things happen certified and have a ticket, a tick box or something say that these appliances are to such and such a New Zealand standard. So that’s the one thing that’s to give people reassurance” (RH).

The nature of hydrogen as a lightweight gas that readily disperses is highlighted as both an advantage and a challenge. While quick dispersion means that hydrogen does not accumulate to dangerous levels, it also necessitates precise leak detection systems and well-ventilated storage facilities:

“You got to have sensors that keep an eye on the pressure, let’s say, and the temperature of your storage facility and that there must be ways to evacuate the area in a fast way in case there is a big leakage” (MR).

As the hydrogen industry evolves, experts foresee the importance of continuous research and development to enhance safety measures. Additionally, they emphasize the need to educate professionals and stakeholders across various fields about hydrogen safety, including architects, engineers, regulators, and consumers:

“To monitor the leakage of hydrogen like the real time monitor of hydrogen concentration in the air, which we must make sure the level of hydrogen concentration is below the explosion points” (ZJ).

Participants hold the perception that LPG (liquefied petroleum gas) is more hazardous than hydrogen due to its heavier-than-air properties, which can lead to gas accumulation in confined spaces. This belief stems from the potential for LPG leaks to result in the gas settling at ground level, increasing the risk of fire or explosion when compared to hydrogen, which readily disperses in the air.

RH conducted a study involving an attempt to cause a hydrogen-fuelled explosion within a house. Interestingly, their efforts faced challenges due to hydrogen’s rapid escape properties. This incident underscores a crucial safety aspect of hydrogen – its remarkable dispersion rate. Despite being more flammable than certain alternatives, such as natural gas, hydrogen behaves differently when released into an environment. In the scenario of hydrogen being released indoors, it swiftly navigates through various openings and crevices to exit the space. This behaviour contrasts with natural gas leaks, which tend to linger within a room, accumulating near potential ignition sources like light bulbs.

Drawing a comparison between hydrogen and conventional gases like LPG or natural gas, it becomes evident that hydrogen holds distinct safety advantages. While being more flammable on paper, hydrogen’s tendency to dissipate rapidly significantly reduces its potential for hazardous build-up. Conversely, other gases might remain confined in a room, heightening the risk of ignition.

Consequently, one can argue that hydrogen, with its quick dispersion properties, holds an edge in safety over LPG and natural gas in certain contexts:

“One of its key safety factors is that it will disperse incredibly quickly... Hydrogen I believe is much more safer than LPG or natural gas” (TW).

“Hydrogen is no more dangerous than say, LPG or propane” (MS).

“From all the gases kinds, hydrogen is the less dangerous gas. Hydrogen is not poisoning at all” (SJS).

In the context of domestic use, ensuring hydrogen safety necessitates the presence of a hydrogen detection system within homes. This system should be strategically positioned at the highest point of the house and resemble a smoke alarm. Hydrogen entry into the house should be regulated by a solenoid valve, a conventional industrial component. The hydrogen sensor must be capable of detecting hydrogen concentrations as low as one to two percent, triggering the valve's closure when thresholds like half a percent or a quarter of the low flammability level are reached. This mechanism ensures that any existing hydrogen will dissipate safely, even though cooking activities might pause momentarily. Considering the challenges of odorizing hydrogen, electromechanical sensing systems emerge as a reliable safety approach for residential settings. Alternatively, for certain applications like barbecues or instant water heaters, it's feasible to keep hydrogen outside, relying on its rapid dispersion in case of leaks:

“Hydrogen just goes up in the air. As long as there's no static electricity, then it wouldn't ignite” (TN).

On an industrial scale, comprehensive safety measures involve a range of gas sensors, flame detection systems, and precise pressure monitors. These instruments work in tandem to detect anomalies and prevent hydrogen release into the environment. European industrial setups showcase sophisticated instrumentation, including accredited hydrogen monitoring systems. The principle is simple - halt hydrogen release if faults are identified, relying on the gas' quick combustion properties. This strategy mitigates the risk of forming explosive mixtures, as the hydrogen burns rapidly.

SJS emphasized that the integration of safety features in hydrogen-powered fuel cells is of paramount importance. These devices incorporate internal sensors, and he highlighted that the same safety principles apply, whether it's a large-scale community fuel cell or a domestic one. According to SJS, the technology required to ensure hydrogen safety is already available; the key factor lies in its appropriate application and adherence to established safety protocols.

Addressing a common misconception, SJS noted that there is a prevailing belief that hydrogen is inherently dangerous due to its ability to escape even from sealed containers through tiny openings because of its aggressive nature. He pointed out that while some may argue that comprehensive studies support this notion, upon closer examination, questions arise about the credibility of these studies. SJS highlighted that there is scepticism regarding the researchers and methods behind these studies.

In discussions about these studies, SJS indicated that individuals might inquire about the researchers who conducted them. He emphasized that it becomes evident that the studies might not have been undertaken by recognized experts or institutions, which could potentially undermine their validity. Further scepticism arises when the details of the studies are explored. For instance, SJS mentioned that questions might be raised about the range of metals that were tested to ascertain hydrogen's effects. If the response is that only a limited set of metals were assessed, doubts could emerge about the comprehensiveness of the research.

Moreover, SJS noted that criticism could be directed at the selection of metals that were tested in these studies. If the metals evaluated are not suitable for use with hydrogen, the argument loses credibility. He emphasized that merely highlighting the potential dangers of hydrogen without accurate representations of its interactions with relevant materials does not truly illustrate its level of hazard.

In conclusion, SJS emphasized that the assertion that hydrogen is dangerous due to its aggressive behaviour and potential for leakage might be based on flawed studies lacking proper scientific rigor. He highlighted that upon scrutiny, these claims may not be as well-supported as they initially appear.

The approach to ensuring safety in hydrogen utilization closely mirrors the methods employed for natural gas applications. This involves considerations like the method of ignition and maintaining safe distances from other utilities, drawing from the established practices in the natural gas domain. However, the key divergence lies in material selection, adapting it to accommodate higher operating pressures inherent to hydrogen systems. A crucial aspect here is the implementation of targeted safeguards to effectively manage and reduce these elevated pressures. Certification protocols are paramount in endorsing these safeguards, given that the primary concern revolves around preventing instances where improper pressure adjustment could lead to issues like blow-through or valve leakage.

In this context, a parallel can be drawn with existing practices in the gas sector, which involve the use of pressure safety valves downstream to protect various components such as vessels, pipelines, and appliances. Extending this approach to hydrogen necessitates a comprehensive inspection regimen for these pressure safety valves. This ongoing oversight ensures that the valves remain unobstructed, untampered, and continue to function reliably, upholding safety standards throughout hydrogen systems. By integrating these principles, hydrogen deployment can emulate the robust safety protocols already established while tailoring them to the unique properties of this high-pressure gas.

TW had the opportunity to engage with Gas NZ during a comprehensive tour, during which he dialogued with a committee comprising skilled plumbers and gas fitters. One focal point of their discussions was the concept of micro credentials. This innovative approach is being explored to establish a certified framework for individuals working with hydrogen systems. The rationale behind this initiative stems from the recognition that handling hydrogen introduces additional hazards and, consequently, necessitates a heightened level of control mechanisms.

Regarding the educational landscape, TW emphasized the importance of cultivating a profound understanding of hydrogen safety among architects, regulatory influencers, and council members. This is especially pertinent for those shaping and informing the regulatory landscape, warranting a comprehensive comprehension of hydrogen's unique safety intricacies.

A potent proposal surfaced during these deliberations: the establishment of a regulatory regime for hydrogen installations. Following the completion of a hydrogen system installation, a designated hydrogen inspector could conduct a meticulous review. This secondary assessment would encompass elements such as pressure calibration, leak testing, and judicious storage placement. Through this meticulous verification process, individual accountability would be instated, transcending the fuel itself as the primary concern. By mirroring the approach already applied to other fuels, albeit with an added layer of vigilance reflective of hydrogen's nascent status, this initiative could foster enhanced confidence in the safety of hydrogen applications.

TW also discussed the prospect of securing exemptions, acknowledging that while this path might involve significant time and financial investments, the endeavour holds potential. Despite the challenges, there is ample empirical evidence to assert that the safe integration of hydrogen is feasible

and achievable. This concerted effort could eventually lead to the realization of a secure hydrogen landscape, instilling assurance among stakeholders and the public alike.

VG holds the opinion that highlighting the operational models of hydrogen utilization in various countries, particularly spotlighting Germany's approach, could serve as a compelling means of exemplifying safety and efficiency. Germany, often perceived as a benchmark for reliable practices, is seen as a prime example to underscore the viability of hydrogen-based systems. By showcasing the successful implementation of hydrogen technologies and safety protocols in Germany, VG suggests that the inherent trust associated with the country's methodologies could potentially alleviate concerns and foster confidence in similar initiatives elsewhere.

VG emphasizes the substantial presence of comprehensive standards and regulations that govern the utilization of hydrogen. Adhering to these stringent guidelines is pivotal, as VG contends that conscientious compliance can transform hydrogen endeavours into intrinsically safe endeavours. Notably, VG points out that there is a lack of awareness regarding any significant hydrogen-related explosions or damages in recent times in Germany, underscoring the efficacy of the established regulatory framework and safety measures in the country:

“There is a ton of standards, a ton of regulation to follow, and if you do that properly, hydrogen actually is a very safe undertaking. I'm not aware of any big hydrogen explosions or damages or something in recent times in Germany” (VG).

In the context of hydrogen production, the perception is that green hydrogen production, primarily through electrolysis, is deemed safer due to its contrast with high-temperature natural gas reforming. However, the primary challenge arises when addressing hydrogen storage, both in distribution and stationary storage. Due to hydrogen's inherent lightness, the potential for leakage must be meticulously addressed regardless of whether it is stored as a compressed gas or in liquefied form. Compressed gas storage typically operates at around 350 bars, while applications like transportation may require pressures of up to 700 bars. Transporting hydrogen in high-pressure cylinders is considered safe, both for road and stationary storage.

In the UK, some projects explore the use of smaller cylinders, around 5 KG hydrogen capacity, as opposed to constructing large cylinders for hydrogen storage, a choice made in light of safety considerations and the challenges posed by detecting and managing leaks. Conversely, the storage of liquefied hydrogen, which is maintained at around 20 Kelvin (-253 Celsius), presents its own set of safety concerns.

Storage remains a critical safety issue in the hydrogen landscape, as hydrogen is known for its combustible nature. Government regulations and educational institutions play a crucial role in disseminating information about safe hydrogen usage. As hydrogen supply extends to commercial applications, safety considerations become more intricate. This includes careful monitoring of boilers and scaling up safety measures. Continuous real-time monitoring of hydrogen concentration in the air is imperative to ensure that levels remain below the threshold for explosion.

RH highlighted that bringing hydrogen inside a house poses a significant challenge due to its wide explosion limit, ranging from very dilute to increasing concentrations. According to RH, the key aspect is to ensure proper detection and safety measures. He emphasized that the essential element is a detector positioned at the highest point within the building. RH mentioned that such equipment, which resembled a \$30 piece of equipment, was available as of 2015. It functions similarly to a breathalyser and is designed to detect hydrogen presence.

RH provided insights into the design considerations for hydrogen installations within buildings. He stressed that hydrogen storage should be positioned outside the house to prevent any potential risks. RH explained that his approach involves having none of the hydrogen actually enter the building;

only hot water is transferred indoors. To illustrate this point, he used the analogy of placing barbecues and cooking hobs outside the building to avoid hydrogen accumulation indoors.

Regarding safety features, RH elaborated on a device similar to a smoke alarm placed at the top of the house. This device connects to a solenoid valve at the point where hydrogen enters the building. If the sensor detects that hydrogen levels have reached a hazardous threshold, the valve automatically stops the hydrogen flow, minimizing the risk of an explosion inside the house.

In comparison to natural gas and LPG, RH discussed the challenge of adding odorizers to hydrogen lines. He pointed out that while odorizers are commonly used for other gases, they might not be practical for pure hydrogen due to its unique properties. RH expressed concerns about the toxicity of odorizers and the difficulty of introducing extremely small quantities reliably. He strongly argued against using odorizers in small hydrogen systems, citing safety and practicality issues.

Addressing the visibility of hydrogen flames, RH explained that hydrogen flames are nearly invisible in sunlight and normal daylight due to their ultraviolet emissions. He noted that this could pose a problem for cooking applications and mentioned a solution involving a heavy gauze to make the flames and heat visible. RH also emphasized the importance of controlling the temperature of the flame to minimize nitrogen oxide (NO_x) production.

In terms of perception, RH mentioned that hydrogen's flammability range is wider and its ignition energy is lower compared to other gases. He stressed the need to avoid reaching conditions where flammable mixtures can form. RH pointed out that, fortunately, most houses are not airtight enough to contain hydrogen at dangerous levels.

Lastly, RH shared an anecdote about consultants in England who attempted to explode a house filled with hydrogen in a controlled experiment. Despite their efforts, the house did not explode over three years, demonstrating the safety measures in place.

RH's perspective emphasizes the importance of proper design, detection, and safety measures in managing hydrogen in domestic settings. He argues for careful consideration of safety protocols rather than relying solely on established practices for other gases.

RH discussed a study that he commissioned, conducted by American engineering students in Wellington. The research focused on identifying barriers to the use of hydrogen in New Zealand. The research question posed to the students was whether there were any barriers to adopting hydrogen in the country.

The outcome of the study was that, as long as hydrogen technology received approval from New Zealand's regulatory authorities, there were perceived to be no significant barriers to its use. This perspective was gathered from interviewing 99 people randomly on the streets of Wellington, including non-technical individuals. The study took place around 2016-2017.

RH noted that the Hindenburg disaster, often associated with hydrogen safety concerns, was primarily a point of consideration for those directly involved in the hydrogen industry or engineering. Interestingly, the students found that the Hindenburg incident had faded from the general public's memory and was not a significant concern for most people, including non-technical individuals.

RH also mentioned a study conducted by the same American students in the United States. In that study, they found that arts students generally had no issues with hydrogen safety, while engineering students were more divided due to considerations like the Hindenburg incident.

In relation to hydrogen safety, RH provided insights from the study's findings, which suggested that, with proper regulatory approval and communication, most individuals did not perceive significant barriers to the adoption of hydrogen technology in New Zealand.

Safety	
Aspect	Key Insights
Public Perception of Safety	Public perception of hydrogen safety is influenced by historical incidents, such as the Hindenburg disaster.
Importance of Regulations	Rigorous regulations and certifications from safety bodies are critical for ensuring safety in industrial hydrogen applications.
Domestic Concerns	Domestic hydrogen use raises concerns about potential leaks and explosions in confined spaces, highlighting the need for advanced detection systems as important safety measures.
Education and Awareness	Educating the public and professionals is essential to address misconceptions and improve understanding of hydrogen safety.
Dispersal and Ventilation	Hydrogen's rapid dispersal makes large accumulations unlikely, but it still requires good ventilation and effective leak detection systems to ensure safety.
Comparative Safety	Many consider hydrogen to be safer than liquefied petroleum gas (LPG) or natural gas due to its rapid dissipation in the event of leaks.
Essential Safety Features	Pressure monitoring, flame detection, and shut-off valves are vital safety features in hydrogen systems to mitigate risks.
Storage and Transportation Protocols	The storage and transportation of hydrogen, whether in high-pressure cylinders or as liquefied hydrogen, demand meticulous adherence to safety protocols.
Responsible Implementation	With responsible implementation and adherence to safety best practices, hydrogen can play a significant role in a sustainable energy future.

Table 36: Safety

In conclusion, the experts' opinions converge on the significance of a comprehensive approach to hydrogen safety. This involves rigorous regulation, advanced detection systems, public education, and ongoing technological advancements. While acknowledging challenges, they express confidence that with the right measures in place, hydrogen can be used safely in various applications, from industrial to domestic settings, and can contribute to a more sustainable energy landscape. In summary, a multifaceted strategy involving technology, regulation, education and collaboration is key to addressing hydrogen safety for diverse applications.

4.46 Design and Installation Requirements

Participants in the interviews shared insights about the design and installation requirements of green hydrogen technologies in the built environment. The discussions focused on safety considerations, storage locations, and regulatory measures. These opinions were particularly relevant to New Zealand due to the ongoing interest in integrating green hydrogen into various settings.

According to the participants, safety is a paramount concern when designing and installing green hydrogen systems. Proper ventilation and safe distances from potential ignition sources are crucial aspects to address, as hydrogen's properties differ from heavier gases like LPG or methane. Participants highlighted the need for open spaces and outdoor storage for hydrogen due to its tendency to disperse rapidly in the atmosphere. They emphasized that hydrogen's low pressure and static

discharge risks need careful consideration. In NZ, regulatory frameworks similar to those for natural gas installations are deemed suitable for ensuring the safety of hydrogen installations.

Storage of hydrogen was a consistent topic across the interviews. The participants indicated that hydrogen storage should generally be located outdoors, favouring solutions such as outdoor cabinets or specially designed enclosures. TN shared a case from Japan where storage was placed outside with appropriate distancing and fencing to prevent hydrogen accumulation.

In terms of installation requirements, participants mentioned the importance of adhering to existing codes and standards. They highlighted the role of certified professionals familiar with safety regulations in ensuring proper installations. They suggested the possibility of implementing a hydrogen inspector for accountability and compliance checks, similar to the natural gas industry.

The unique attributes of hydrogen, such as its lightness and potential for rapid dispersion, influence design considerations. While participants emphasized outdoor storage, adequate ventilation, safe distances, and adherence to regulations, they also acknowledged the need for comprehensive engineering and planning to ensure the successful integration of green hydrogen technologies into the built environment.

RGJA emphasized the significance of proper design and installation considerations for hydrogen technologies within the built environment. Drawing from experience, RGJA noted a preference for open spaces when it comes to hydrogen storage. The rationale behind this preference lies in the inherent properties of hydrogen, which tend to cause it to disperse rapidly and ascend when released. Consequently, RGJA argued that storing hydrogen within a building is not a feasible option. Instead, RGJA advocated for the placement of hydrogen storage facilities outside buildings.

RGJA's stance aligns with safety concerns associated with hydrogen's unique properties, such as its lightweight and high dispersibility. By favouring outdoor storage, RGJA aimed to mitigate potential risks and enhance overall safety. This emphasis on safety is congruent with the careful approach required when integrating hydrogen technologies into the built environment:

“With hydrogen they prefer to use open spaces for the storage and I think it's not feasible to put inside of a building the storage. I think it should be a facility outside the building knowing that hydrogen will just go up and well, I think it should be placed outside a building” (RGJA).

Furthermore, RGJA highlighted the importance of expertise in codes and regulations within the certification process for hydrogen installations. This perspective underscores the necessity of involving knowledgeable professionals who are well-versed in safety codes and guidelines specific to hydrogen installations. By ensuring that those overseeing the certification process are familiar with the pertinent regulations, the goal is to uphold safety standards and facilitate successful deployments:

“It it's necessary for people that are involved in certification of installations to be familiar with those codes” (RGJA).

In essence, RGJA's viewpoint underscores the necessity of outdoor hydrogen storage and the essential role of regulatory expertise in the installation and certification of hydrogen technologies. These considerations are instrumental in maintaining safety, regulatory compliance, and successful integration of green hydrogen solutions within the built environment.

MR emphasized the critical importance of proper ventilation in spaces where hydrogen may accumulate. This consideration addresses the potential safety concerns associated with hydrogen's unique properties, such as its tendency to disperse quickly. By highlighting the need for effective ventilation strategies, MR underscores the proactive measures required to mitigate the risks associated with hydrogen accumulation in confined areas within the built environment.

MS highlights the dual facets of hydrogen utilization: production and storage. With a focus on hydrogen storage, he asserts the practicality of situating storage systems outdoors. He elaborates on the deployment of systems, including those in outdoor cabinets resembling standard narrow cabinets, which not only simplifies installation but also mitigates potential challenges associated with indoor placements. By advocating for outdoor cabinets and presenting them as a feasible solution, MS underscores the strategic approach to addressing safety and spatial concerns. Additionally, he emphasizes the modelling process, involving coordination, load assessment, and tailored system design, as a means to optimize hydrogen storage solutions within the built environment.

RH provides a comprehensive assessment of design and installation considerations for green hydrogen technologies within residential and commercial settings. He begins by distinguishing between the pressure levels in hydrogen systems compared to typical household gas setups, highlighting the controlled pressure regulation in residences. RH emphasizes the significance of material selection, particularly addressing potential brittleness concerns and embrittlement rates associated with certain materials. Furthermore, he underscores the necessity of vigilance regarding pressure management, particularly in external storage systems operating at higher pressures. He underscores the suitability of materials like 316 stainless steel or reinforced high-density polyethylene for pressure containment. RH's insights extend to safety measures, discussing the heightened risk of static discharge in hydrogen systems due to its lower ignition energy relative to methane. Despite the increased risk, RH offers a straightforward solution involving the design of earthed connections on both ends of the system to mitigate static discharge and potential sparks.

RH provides a comprehensive insight into the key challenges and safety considerations pertaining to the design and installation of green hydrogen technologies within the New Zealand built environment. He accentuates the potential risks associated with hydrogen's wide explosion limit and the need for prudent measures to prevent flammable mixtures. RH underscores the significance of hydrogen detection and emphasizes the development of efficient detection systems placed at strategic points within buildings. He refers to the progress in sensor technology, highlighting its affordability and role in enhancing safety measures.

RH advocates for a cautious approach in integrating hydrogen within residential structures, emphasizing the importance of locating hydrogen storage facilities outside buildings to avert potential hazards. He underscores the passive safety strategy, which involves limiting the introduction of hydrogen inside buildings and focusing on its utilization for specific purposes, such as water heating. RH further addresses the perception of hydrogen's safety, contrasting it with LPG's lingering characteristics and higher explosion risk.

RH delves into the intricacies of hydrogen flame visibility, highlighting its near invisibility in daylight and the challenges this poses for safety perception, particularly in cooking applications. He presents the use of protective gauzes to render the flame visible and manage temperature to minimize nitrogen oxides production. RH also discusses the potential role of odorizers in hydrogen systems, pointing out their toxicity and potential practical difficulties. He argues for caution and reevaluates the necessity of odorizing smaller hydrogen systems.

In summarizing RH's perspective, his comprehensive analysis elucidates various barriers and safety considerations inherent in incorporating green hydrogen technologies into New Zealand's built environment. His discourse provides valuable insights into the intricate nuances and safety protocols required for the successful integration of hydrogen systems while enhancing public safety and acceptance.

SJS offers a distinct perspective on the design and installation of green hydrogen technologies, particularly in relation to gas release and safety considerations. He highlights the unique behaviour of hydrogen compared to heavier gases, stressing its rapid dispersal rather than lingering in confined

spaces. Despite its swift dissipation, SJS advises a cautious approach, underscoring the need for careful handling. To address potential safety concerns, he cites an example of using fans and turbo lighting to accelerate the dispersion process around hydrogen storage tanks. This proactive approach aligns with safety measures to enhance the overall system's security. SJS' viewpoint enriches the discourse on green hydrogen technology installation and design, emphasizing both its distinctive characteristics and practical safety measures.

TW articulates a systematic and methodical approach to the design and installation of green hydrogen technologies within the New Zealand built environment. He underscores the importance of meticulous planning, emphasizing considerations such as the popping method and maintaining safe distances from other utilities. Drawing parallels with existing natural gas regulations, TW advocates for the adoption of similar protocols within the hydrogen domain to ensure consistent safety standards.

TW proposes a robust inspection framework to ensure the integrity of hydrogen installations. He envisions a scenario where a designated hydrogen inspector verifies critical aspects such as pressure levels, leak tests, and appropriate storage locations. This process instils a sense of accountability, shifting the focus from the fuel itself to the individuals responsible for adhering to safety protocols.

TW highlights the collaborative nature of the design and installation process, involving a multitude of professionals across disciplines. He outlines a step-by-step approach involving conceptualization, architectural drawings, electrical engineering considerations, and coordination with civil engineers to integrate services seamlessly. TW acknowledges the need for substantial engineering input at the initial stages to develop a holistic system, providing a comprehensive foundation for assessing costs, returns on investment, and engaging various stakeholders.

In summary, TW's insights underscore the structured and comprehensive approach necessary for successful design and installation of green hydrogen technologies within New Zealand's built environment. His perspective reflects the importance of meticulous planning, adherence to safety standards, and effective collaboration across disciplines to ensure the safe and effective integration of hydrogen systems.

TN provides insights into the crucial role of architecture and design in the integration of green hydrogen technologies within the New Zealand built environment. He underscores the importance of selecting appropriate locations, avoiding ignition sources, and implementing safe distancing measures. These fundamental principles serve as the cornerstone of designing hydrogen installations.

TN's perspective extends to scenarios involving the installation of small electrolyzers and hydrogen fuel cells in residential areas. He acknowledges the nuanced considerations surrounding hydrogen storage. He suggests that without storage, the risk might be relatively low. However, if storage becomes necessary due to specific residential requirements, he highlights the need for careful planning and regulations to ensure safety.

TN draws parallels with an example from Japan, where a hydrogen cylinder was placed outside a building within a retirement village. This placement was designed to minimize the risk of hydrogen accumulation and potential hazards. He anticipates similar requirements in New Zealand, emphasizing the importance of distance and containment measures to prevent hydrogen from lingering in enclosed spaces.

In summary, TN's perspective underlines the significance of architectural design and strategic placement in accommodating green hydrogen technologies in New Zealand's built environment. He recognizes the need for tailored regulations, proper distancing, and external storage solutions to ensure the safe integration of hydrogen systems.

Considering the NZ context, participants recognized the alignment between existing natural gas regulations and those that could apply to hydrogen installations. The diverse insights from these interviews underscore the importance of addressing safety and design aspects when introducing green hydrogen technologies to the built environment, both in NZ and globally. Outdoor equipment, safe distancing, ventilation and certified components will be important to manage risks and reassure occupants.

Design and Installation Requirements for Green Hydrogen Technologies in the Built Environment	
Aspect	Key Insights
Safety Concerns	Most participants emphasized safety as a paramount concern due to hydrogen's unique properties compared to other gases.
Ventilation Recommendations	Proper ventilation to avoid hydrogen accumulation and outdoor storage are commonly recommended practices to enhance safety.
Dispersal Characteristics	Hydrogen's rapid dispersal makes outdoor cabinets or enclosures preferable for storage, reducing risks associated with leaks.
Adherence to Codes and Standards	Adhering to existing codes and standards is essential, with recommendations for certified professionals to inspect hydrogen installations.
Regulatory Adaptations	Regulations for natural gas could be adapted for hydrogen use, promoting safety and compliance in installations.
Design Considerations	Careful selection of materials, pressure regulation, static discharge mitigation, and leak prevention are crucial in system design to ensure safety.
Visibility and Emission Controls	Special burners or protective gauzes are needed to address the visibility of hydrogen flames and potential nitrogen oxide emissions during combustion.
Storage Precautions	While small fuel cells may pose minimal risk, precautions for storage include distancing from buildings, with external placement preferred for safety.
Engineering and Planning	Comprehensive engineering and planning are necessary for the successful integration of hydrogen systems, requiring coordination across multiple disciplines.
Regulatory Alignment in New Zealand	Aligning with current gas installation regulations in New Zealand is sensible, emphasizing the importance of safety in gaining public acceptance for hydrogen technologies.

Table 37: Design and Installation Requirements for Green Hydrogen Technologies in the Built Environment

In summary, participants highlighted holistic planning, hazard mitigation strategies, compliance with standards, and tailored solutions as crucial in the design and installation of green hydrogen systems in the built environment.

4.47 Challenges

In the realm of hydrogen adoption, a myriad of challenges and opportunities emerge from the insights gleaned from interviews with experts across the globe. One striking consensus resonates - the journey towards a hydrogen-based economy is not without its complexities. Across various regions, including New Zealand, there are common hurdles that demand thoughtful consideration.

The interviewees also touch upon the challenges associated with hydrogen's production, distribution, and utilization. Issues related to the availability and cost of electrolyzers, supply chains, and infrastructure emerge as crucial factors affecting overall affordability. Moreover, discussions around ancillary technologies such as storage, compression, and transportation underscore the need for a holistic approach to cost optimization. These insights underscore the intricate web of factors that must be carefully balanced to achieve a competitive cost structure for hydrogen-based energy systems. The production of hydrogen, while promising, grapples with issues of efficiency and cost:

"The inefficiency challenge cannot be overcome. That's physics. You can't change physics, so you will always lose at least half in the most used case is 2/3 of the electricity you put in initially. The challenges of high costs can be overcome with scale. Same thing as in every other technology. As soon as you scale up electrolysis, production costs will go down. There's no magic" (VG).

Electrolysis, a key method for generating green hydrogen, presents challenges due to its relatively high costs and lower energy efficiency compared to conventional fuels.

Moreover, the infrastructure required for storing and transporting hydrogen poses intricate challenges:

"It's easy to make hydrogen, but it's not easy to transport it. It's tricky question of how you transport it. If you use the two trailers which use diesel, that's not entirely green. So you need to have either electric trucks which are highly uneconomical or you should have hydrogen vehicles. Those are the challenges and I indeed think that if we get around the transportation problem of hydrogen and then there is a huge potential" (DA)

"The challenges are probably going to be more related around the Achilles heel of 100, which is storage. So at the moment there are needs to be probably more done on the large scale storage and transportation of hydrogen" (MS).

"The main issue will be the storing of hydrogen in either in distribution or in the storage" (ZJ).

Balancing pressures and temperatures to contain the molecule's small yet explosive nature remains a significant concern:

"The first one is the fact that hydrogen is has very small molecule and it's also explosive. So you have to take care of how to say keep it inside something which needs to be pressurized at low temperatures. So that's the main, let's say complication. And because it's so small, then you have to find a way to contain it" (MR).

"For buildings there are sort of other additional challenges we have to address and one would be that the amount of hydrogen that would be required for the buildings, and probably would require compressing it and storing it at the pressure because of space restrictions" (MS)

"Storage, of course, is always the tricky problem to solve. You need to store hydrogen at a very high pressure in order to have a significant energy density" (VG).

In New Zealand, where the pursuit of renewable energies is fervent, challenges intertwine with opportunities. The nation grapples with the volatility of renewable energy sources, such as solar power, which necessitates innovative energy storage solutions. Storage technologies like pumped hydro, batteries, and emerging chemical storage methods are being explored to ensure a stable energy supply. Additionally, New Zealand's commitment to building hydrogen infrastructure from scratch, combined with governmental support, offers a unique advantage:

“We have to create the infrastructure now which is part of the problem. If you want to achieve the goals look at the oil and gas infrastructure which took 100 years to be developed, but the goal now is to create hydrogen infrastructure in 30 years from now to 2050. So this one of the challenges another I think it's cost we have to create a bigger factories on everything – electrolyzers, pipelines, storage tanks, fuel cells to let them get cheaper” (JAGR).

However, this clean slate also demands meticulous planning, investment, and collaboration. Despite the hurdles, New Zealand's greenfield approach holds the potential to establish a robust hydrogen ecosystem that can address energy demand and support decarbonization goals.

As the world collectively navigates these challenges, the global community's endeavours to overcome inefficiencies, cost constraints, and safety concerns pave the way for a more sustainable energy future. It is evident that while the road ahead may be arduous, the dedication of experts, governments, and stakeholders to addressing these challenges fuels the optimism that a hydrogen-powered world is on the horizon:

“The challenge starts with the opportunity is that people see it works. Yes, that's clear” (TW).

In conclusion, hydrogen adoption faces multifaceted challenges related to production, distribution and storage. But global collaboration, emerging solutions and a shared vision help overcome hurdles on the path to hydrogen-based economies.

4.48 Cost – Affordability

The issue of cost and affordability emerged as a significant concern across the interviews. A consensus resonated that the adoption of hydrogen technology, particularly in New Zealand, hinges upon its economic viability. Several participants highlighted that the cost of producing green hydrogen remains a primary challenge. Electrolyzers, a critical component of hydrogen production, were noted to be expensive due to the use of costly catalysts of Proton Exchange Membrane (PEM), leading to elevated production costs. This financial burden was seen as a barrier to widespread deployment, particularly at the residential scale:

“We've got PV on the roof and we've got an electrolyser and we can store hydrogen in the house but I think that's a really expensive way of doing it” (JH).

“It's not a very affordable technology at the moment because electrolyser and also fuel cell and the whole integration of the system into the small scale will be quite costly for the local consumers” (ZJ).

However, the Anion Exchange Membrane (AEM) offers a more cost-effective solution. It is notably less expensive to manufacture and construct, avoiding the use of costly components that are common with Proton Exchange Membrane (PEM) technology. The affordability of AEM makes it a more accessible and practical choice in comparison to PEM, offering a more sustainable and economically viable option for various applications:

“The Anion Exchange Membrane is cheaper to make. It's cheaper to build, it doesn't use expensive components for sure it doesn't” (SJS).

While some participants expressed optimism that economies of scale and advancements in technology would drive costs down over time, others emphasized that the high capital investment required for initial production facilities hindered immediate affordability:

“At the beginning, hydrogen technologies are still more expensive and then after more and more projects their cost will come down. Therefore, it's very important to use the first transit investments in an efficient way to make the companies grow and have the lower cost of production” (MR).

The interviews highlight the need for efficient scaling of hydrogen production technologies. A consensus view is that economies of scale can play a pivotal role in driving down costs:

“Challenge is that systems are still too expensive, but they are on the move getting cheaper. But they're getting cheaper only by people who do the first steps” (SJS).

“At this stage, just for quite expensive because they haven't realized their mass production cost yet” (TW).

“See affordability. I have a question mark. Yeah, unless someone does it in the big scale, including the generation of the electricity, it's not going to get cheaper. And electrolyser needs to be mass produced, then only get cheaper (TN).

Larger production facilities are envisioned to not only enhance operational efficiency but also contribute to a reduction in the capital-intensive nature of hydrogen production infrastructure. This premise is particularly significant in addressing the challenges faced by countries like New Zealand, where relatively smaller markets may necessitate innovative strategies to achieve cost-effectiveness:

“At the beginning, we can't say that it's an economic benefit because obviously it is the new technology which needs more expenses and more investment” (RGJA).

“Lots of people are looking for big scale hydrogen production because it's cheaper” (JAGR).

“There are so many companies who are working on various technologies. But the point is are they all really cost effective are they really commercially available. And that's the key question” (DA).

“The more hydrogen we make, the lower cost it will have” (DA).

The need for hydrogen to be competitively priced against existing energy sources, such as natural gas, was underscored. It was emphasized that consumers, both residential and industrial, are keenly sensitive to cost considerations, and any hydrogen-based solution must be cost-competitive to gain traction. Some participants raised concerns about the limited affordability of hydrogen, especially in the short term, leading to potential reliance on imported hydrogen from countries with more established production capacities:

“I'm talking about the countries like again, Saudi Arabia, the Middle East, where there is a vast amount of land and the availability of infrastructure to generate renewable energy and then that renewable energy can be used to generate hydrogen. And then we can at least deliver the hydrogen to the end users at more reasonable cost” (DA).

The discussions highlight the intricate interplay between technological feasibility, economic viability, and environmental sustainability. The consensus across these interviews underscores the central role of cost considerations in shaping the adoption trajectory of hydrogen technologies. Participants consistently emphasize that while the pursuit of green energy solutions is admirable, economic factors remain paramount for both individuals and industries. Notably, the prevailing sentiment revolves around the need for hydrogen production to become economically competitive with existing energy

sources, such as fossil fuels. This entails a dual focus on minimizing both capital expenditures (CapEx) and operating expenditures (OpEx) associated with hydrogen technologies:

“They’re thinking is I want to spend some money, but I want to get the return on investment in a year or two. The capital cost will be higher than a diesel generator or batteries. But you have to look at this over a five- or six-year period before you re-cap your costs, but mainly because the operating cost of these is almost zero” (MS).

“The price of the electrolyser at the moment is €8000 for a box that can produce 500 litres of hydrogen per hour consume 2.4 kilowatts of energy and consume 0.4 in the litre that that price is going to drop to over the period of maybe five years. It will be about 25% of what the cost is now” (SJS).

A prevalent theme across interviews is the significance of electricity prices in determining the economic feasibility of hydrogen production. A consistent argument emerges that the cost per kilowatt-hour (kWh) is a decisive factor, as it directly impacts the price competitiveness of hydrogen compared to conventional energy sources.

The cost dynamics of hydrogen production are intricately linked to the prevailing electricity prices. In the context of hydrogen generation methods such as electrolysis, where electricity is a primary input, the cost per unit of energy (kWh) directly shapes the overall expense associated with producing hydrogen. It is noteworthy that a reduction in electricity costs can exert a pronounced downward pressure on the overall expenditure tied to hydrogen production. This, in turn, contributes to enhancing the economic competitiveness of hydrogen as an energy source when juxtaposed with alternative energy options. The significance of this interplay underscores the importance of establishing electricity rates that are not only affordable but also sustainable. By securing a conducive environment of cost-efficient electricity, the foundation for rendering hydrogen production economically viable and fostering its widespread incorporation is significantly fortified:

“The cost to make hydrogen depends on the price you pay for electricity” (MS).

This aligns with the notion that sustainable adoption necessitates cost parity or superiority, enabling potential users to transition without incurring significant financial burden. A recurring analogy equates the “greenness” of hydrogen to its affordability, asserting that, for mainstream adoption, green technologies must align with or surpass the financial viability of conventional alternatives.

Subsequently, the discourse delves into the realm of economics. The central query pertains to cost-effectiveness, prompting consideration of divergent avenues to drive down expenses. These options hinge on either optimizing production efficiency or significantly curbing costs, thereby reducing the necessity for substantial subsidies. This strategic approach is twofold: the first involves elevating carbon pricing to notably high levels, an approach that may lead to considerable financial burdens for consumers, fostering reluctance and discontent. The second avenue involves the prospect of transitioning from conventional gas sources to hydrogen, a change catalysed by a steep carbon price tag on gas emissions. While this alternative could render hydrogen-based solutions financially viable, its implementation may be met with resistance due to the inconveniences associated with such transitions.

“When people say hydrogen is expensive, I try to convince them through the explanation of the collateral impacts fossil fuels and also the opportunity” (JAGR).

The interviewees also touch upon the challenges associated with hydrogen's production, distribution, and utilization. Issues related to the availability and cost of electrolysers, supply chains, and infrastructure emerge as crucial factors affecting overall affordability. Moreover, discussions around ancillary technologies such as storage, compression, and transportation underscore the need for a

holistic approach to cost optimization. These insights underscore the intricate web of factors that must be carefully balanced to achieve a competitive cost structure for hydrogen-based energy systems.

In the specific context of New Zealand, the interviews suggest that the cost landscape is influenced by factors such as electricity prices, grid connectivity, and the inherent challenges of a smaller market. The importance of evaluating hydrogen solutions within the local economic and energy context is evident, as the challenges and opportunities presented in New Zealand's unique setting may differ from those in larger economies. The interviews underscore that while a commitment to sustainability is essential, the economic feasibility of hydrogen adoption in New Zealand hinges on achieving a balance between technological advancements, policy support, and market dynamics.

While hydrogen's potential for addressing environmental and energy challenges was recognized, the consensus from the interviews was that overcoming the cost hurdle is crucial to unlocking its widespread adoption in New Zealand:

"People care about the costs, not about how green that" (DA).

"The major barrier for hydrogen is cost; it's too expensive" (JAGR).

As the country seeks to transition toward sustainable energy sources and achieve its net-zero targets, the challenge lies in developing strategies to drive down production costs, facilitate mass production of key components like electrolyzers, and establish pricing models that position hydrogen as a cost-effective alternative to conventional fuels. It is apparent that while technological advancements hold promise, achieving affordability remains a critical determinant of hydrogen's successful integration into the energy landscape, particularly in New Zealand

"We saw that the opportunity is to produce it in a much cheaper way and then we were calculating that when we actually produce electrolyser in masses then we could reach a price which makes hydrogen cheaper than fossil fuel" (SJS).

RH provided insights into the current and potential costs associated with the hydrogen energy system. He mentioned that the prototype system was priced at NZD80,000, but clarified that this was not a realistic market price. Instead, he expressed the goal of reducing the costs significantly for the commercial market.

According to RH's perspective, the aim is to bring down the cost of the electrolyser to around NZD10,000 and the hydrogen storage system to around NZD5,000. He specified that the current cost of the storage system is NZD9,000, which he hopes to lower. Additionally, he estimated that installation costs could be around NZD5,000.

RH noted that the system is intended to complement existing renewable energy setups. He assumed that the target audience for this system already has renewable sources and batteries in place, which sometimes lead to excess energy that could be stored as hydrogen. He emphasized that the hydrogen energy system doesn't necessarily need to augment the existing setup but can efficiently utilize excess energy.

When discussing costs, RH considered various components, including the electrolyser, storage, and water heater conversion. He indicated that converting a water heater to run on hydrogen might cost around NZD500, which he considered a relatively minor expense. Notably, RH did not factor in the costs of photovoltaic systems.

In summary, RH's opinion centred around the objective of making the hydrogen energy system economically viable by reducing costs associated with key components. He believed that achieving lower price points for the electrolyser, storage, and installation would be crucial to making the technology accessible and appealing to a wider market.

Also, it has been noticed that a significant portion of the population is burdened by the necessity to allocate a substantial portion of their income towards electricity and energy expenses. This economic strain underscores the challenges faced by individuals and families in managing their overall budgets, often leading to difficulties in meeting other essential needs. Addressing the affordability of energy sources is crucial in ensuring equitable access to basic necessities and fostering financial stability among vulnerable communities:

“Poor population that they have to spend a considerable amount of their income in electricity or in general in energy. Hydrogen will be more a cheaper option for providing energy to communities” (RGJA).

In conclusion, the amalgamation of insights gleaned from the interviews underscores the centrality of cost considerations in the path towards hydrogen energy adoption. The dialogue among diverse participants from various regions converges on the fundamental principle that affordability, driven by competitive pricing and sustainable economic models, holds the key to unlocking the full potential of hydrogen as a transformative energy source:

“It’s all doable. It’s just cost. So we’re hoping that we can get the cost of hydrogen systems down to make it as well” (RH).

Recognizing the nuances presented by individual markets, such as that of New Zealand, is imperative for formulating tailored strategies that enable the realization of a hydrogen-powered future that is both environmentally responsible and economically sound.

4.49 Cost of Producing of 1 Kilogram of Green Hydrogen

Based on insights gathered from various interviews with experts across different regions, the cost of producing 1 kilogram of green hydrogen varies significantly depending on factors such as electricity prices, regional conditions, and technological advancements. While there is a consensus that the cost of electricity constitutes a significant portion of hydrogen production expenses, estimates of hydrogen costs range widely. Some experts mention figures as low as \$0.50 per kilogram in certain favourable conditions, such as high solar irradiation or wind availability. On the higher end, figures of \$10 per kilogram are mentioned for less optimal scenarios. The general understanding is that the cost of electricity and the efficiency of hydrogen production technologies play crucial roles in determining the overall expense. It's evident that regions with abundant renewable energy resources, like Saudi Arabia where the levelized cost of electricity is around one to two cents per kWh, have a competitive edge in achieving lower hydrogen production costs, aiming at around \$1 per kilogram. In New Zealand, estimates suggest that the cost could range from \$6 to \$11 per kilogram, largely due to electricity costs which make up a significant portion of hydrogen production expenses:

“An energy price between eight cents and \$0.10 a kilowatt, which is essentially the build cost of solar and New Zealand, so it does fit. But we are kind of waiting for their cost reductions to help us get there” (TW).

“If you have a grid where there is an excess of an excessive renewable energy and you can use that renewable energy to make hydrogen at a marginal cost of almost nothing for the electricity because the price literally cost goes down. The dominant cost. 75% to 80% of the cost of hydrogen is the electricity so the dependency is really high. If you have renewable electricity generated and you haven't got a place for it to go, then the hydrogens are very good fit for that” (RH).

“When you want to produce 1 kilogram of hydrogen you need around 53 kilowatt” (SJS).

“How does it get cheap? Well, that's only with really cheap electricity. It all comes down to the electricity cost” (JH).

While there are technological innovations and cost reduction efforts in progress, green hydrogen production costs still vary widely and remain influenced by electricity prices, technology advancements, and regional characteristics. Despite variations, the common theme is that electricity cost is a key driver influencing the overall cost of producing green hydrogen.

In every context currently dominated by fossil fuels, the potential for hydrogen utilization is both compelling and inevitable. The pivot towards hydrogen is contingent upon one pivotal factor: cost. To render hydrogen an economically viable alternative, the fundamental requirement is the affordability of green energy, a cornerstone in the equation. To illustrate, producing a single kilogram of hydrogen necessitates approximately 53 kilowatt-hours of energy. If we consider electricity costs, for instance, at three to four cents per kilowatt-hour, or even as low as two cents in locales like Saudi Arabia, the calculus emerges. This computation arrives at around €1.50 per kilogram of hydrogen derived solely from the cost of generating green energy.

Yet, an essential consideration encompasses the operational expenses associated with the process. Currently, smaller systems cost approximately €1000 per kilowatt, but projections indicate a substantial drop to under €300 per kilowatt within the next five years. This reduction in capital expenditure intertwines with operational costs, thereby forming the comprehensive expense structure. Thus, the eventual cost of hydrogen production hovers around €2.00 or its equivalent in USD. When this estimate is juxtaposed with fossil fuel prices, an intriguing revelation emerges. Hydrogen becomes markedly more economical, even without accounting for the environmental benefits of reduced CO₂ emissions. It is through this lens of cost competitiveness that hydrogen emerges as an unequivocally compelling alternative to fossil fuels.

Cost - Affordability	
Aspect	Key Insights
Cost Variation	The cost of producing 1 kg of hydrogen varies significantly based on electricity prices, regional conditions, and technology.
Electricity Cost Impact	Electricity costs constitute a major portion of hydrogen production expenses, making it a critical factor in overall costs.
Cost Estimates	Estimates for hydrogen production costs range from as low as \$0.50/kg in favourable conditions to as high as \$10/kg in less optimal scenarios.
Abundant Renewable Regions	Regions with abundant renewable energy sources, like Saudi Arabia, can achieve lower hydrogen production costs around \$1/kg.
New Zealand Estimates	In New Zealand, hydrogen production cost estimates range from \$6 to \$11/kg, primarily due to higher electricity costs.
Technological Innovations	Ongoing technological innovations and cost reduction efforts aim to make hydrogen production more economically viable.
Cost Competitiveness	For hydrogen to be a viable alternative to fossil fuels, it must achieve cost competitiveness, particularly with fossil fuel prices.

System Costs	Smaller hydrogen production systems currently cost approximately €1000/kW, with expectations of reducing costs to less than €300/kW in the near future.
Renewable Electricity Pricing	With renewable electricity priced at 2-4 cents per kWh, hydrogen production costs could potentially reach €2/kg, making it competitive with fossil fuels.

Table 38: Cost and Affordability

In summary, driving down electricity costs and improving production efficiency are central to achieving affordable green hydrogen and enabling its mainstream adoption.

4.50 Conclusion

The perspectives of experts from diverse regions underscore hydrogen's versatile potential as a pivotal enabler of decarbonization across myriad industries. Green hydrogen, produced via renewable energy sources, emerges as a focal point. Experts emphasize hydrogen's adaptability as an energy carrier, from its role as a feedstock in oil refining to its integration across transportation, steel, cement, and other sectors. The concept of strategic implementation also recurs in the discourse, stressing the need to target hydrogen usage where it offers maximal emissions reduction potential through displacement of fossil fuel usage.

Several factors shape the nuanced debate around production scale. The viability of small modular systems for localized needs is weighed against the cost mitigation promised by large centralized facilities via economies of scale principles. Experts advocate for a diversified approach, tailoring scale to each application's context. The necessity of a sustainable supply chain, regardless of production scale, is consistently underscored. Scrutiny of carbon content across the entire lifecycle, encompassing raw materials, manufacturing, and transportation emissions, is deemed essential to evaluate the environmental impact holistically.

Experts note rising adoption of hydrogen solutions, particularly in heavy transport vehicles and freight, mining, computing, and healthcare – sectors with high power demands. Localized on-site production of hydrogen from renewables is also emerging as an efficiency and sustainability strategy. As hydrogen is indispensable for chemicals like ammonia, crucial across industries, green hydrogen adoption enables cleaner production pathways. With ammonia being a pivotal fertilizer ingredient, this application is especially relevant.

Apart from that, the participants provided valuable perspectives on leveraging green hydrogen and associated technologies to drive decarbonization within the built environment encompassing residential, commercial, and industrial buildings. The discourse highlights hydrogen's adaptability as a versatile energy vector that can displace fossil fuel usage across applications like heating, cooking, power generation, and more. Experts emphasize the importance of strategic implementation to maximize emissions reduction potential in the built environment.

The nuanced debate around production scale considers the merits of localized modular units versus large centralized facilities. While the latter enables economies of scale, the former may suit on-site needs. Experts stress optimizing scale to the context while ensuring supply chain sustainability. Scrutiny of carbon emissions across the production and delivery lifecycle is vital for holistic environmental impact assessments.

Experts note rising adoption in built environments to meet high power demands reliably, such as utilizing fuel cells in hospitals. Emerging on-site production of hydrogen from building-integrated renewables also promotes efficiency and sustainability. As a versatile energy carrier, green hydrogen

can enable cleaner electricity generation to replace fossil fuel reliance and support technologies like heat pumps.

In essence, the perspectives coalesce around green hydrogen’s versatility but stress that practical implementation must entail nuanced, context-specific solutions tailored to each sector’s needs. While trade-offs exist, integrating strategic deployment, supply chain sustainability, and scalability provides a pathway to unlock hydrogen’s immense decarbonization potential across the industrial landscape. With a meticulous and holistic approach, hydrogen is poised to catalyse a sweeping transformation towards carbon-neutrality across myriad sectors.

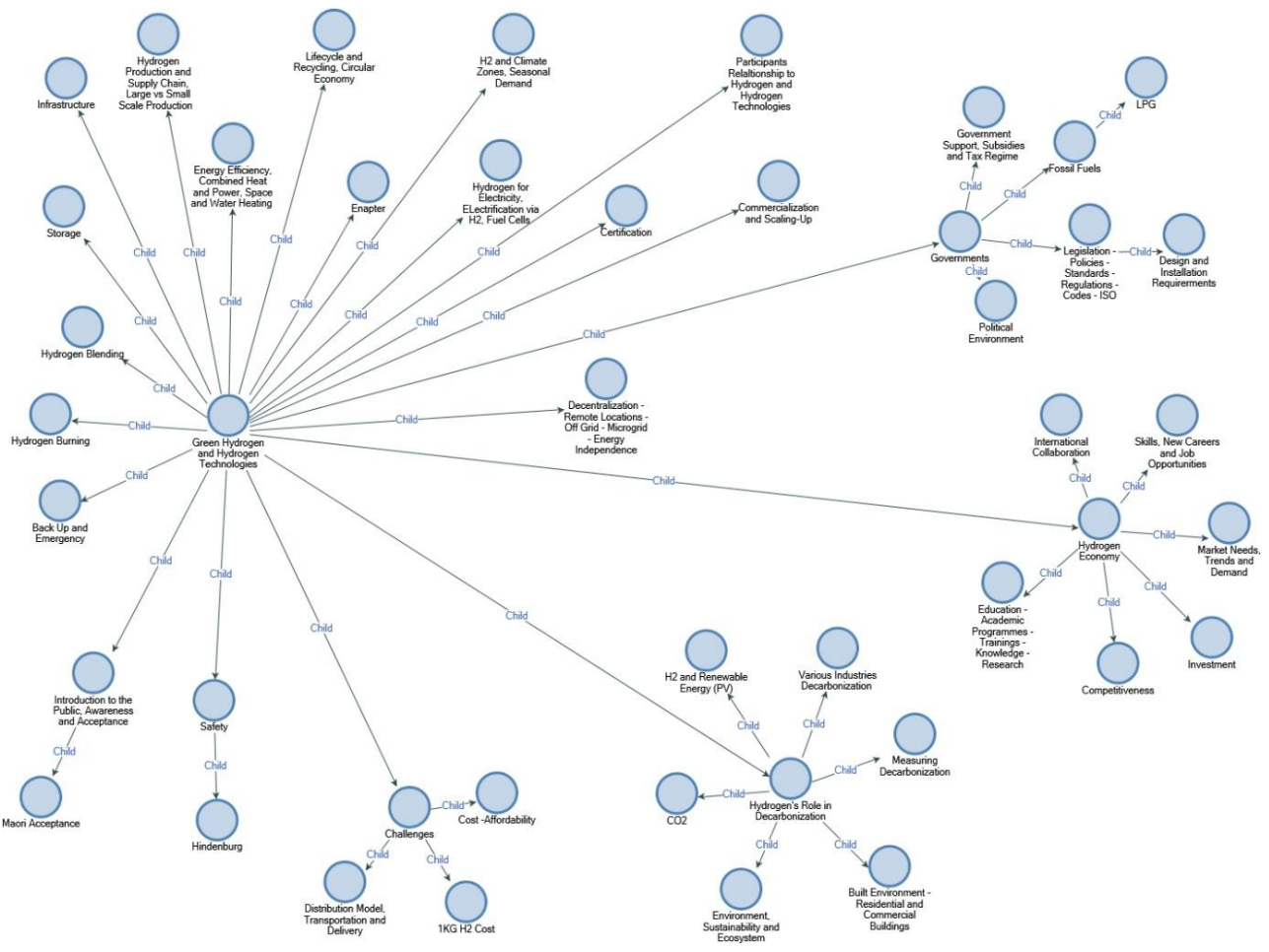


Diagram 18: Green Hydrogen and Hydrogen Technologies Ecosystem

4.67 Key Takeaways from Interviews

Key Takeaways from Interviews	
Key Aspect	Details
Diverse Backgrounds	Participants from engineering, project management, and research fields, experienced in fuel cell technologies.
Transition to Advisory Roles	Engineers leverage expertise in advisory roles for policymaking and strategic planning.
Practical Insights	First-hand knowledge helps in understanding implementation challenges.

Focus Areas	Renewable integration, electrification, decarbonization, and sustainability tailored to regional needs.
Built Environment Applications	Fuel cells envisioned for self-sufficient buildings and resilient energy hubs.
Challenges	High costs, infrastructure, and safety concerns limit adoption.
Policy Support	Government subsidies and policies are crucial for accelerating adoption.
International Collaboration	Global collaboration aids in safety standards and technological advancements.
Technological Advancements	Efficiency, storage, and cost reduction are necessary for economic viability.
Niche Applications	Hydrogen is advantageous in off-grid and remote areas.
Education and Public Awareness	Public education is key for addressing misconceptions and gaining support.

Table 39: Key Takeaways from Interviews

The transition to hydrogen technologies requires overcoming cost and infrastructure challenges. Effective policy support, international collaboration, and public education will help in advancing hydrogen solutions, especially in niche applications like off-grid settings.

Chapter 5 - Integrating Interview Insights and Literature Review

In this chapter, the focus will be on presenting the main and additional research questions posed during the semi-structured interviews, along with their corresponding answers and the themes that emerged from the discussions. The interviews provided valuable insights and perspectives that were captured in the interview transcripts and interpreted later. The responses and discussions provided by the interviewees were carefully analysed, and the main themes were extracted and interpreted from the interview transcripts.

Furthermore, after the interviews, additional comprehensive information and knowledge were sought from various literature sources. This exploration approach aimed to obtain a comprehensive understanding of the research area and the associated problems. The acquired knowledge and insights from the literature sources were then used to address the research questions, meet the research objectives and aims, and evaluate the validity of the hypotheses put forward.

1.1 Question 1. What specific hydrogen safety requirements need to be addressed to introduce hydrogen technologies to all New Zealand stakeholders? Participants' views

Question	Participant	Response
Question 1. What specific hydrogen safety requirements/standards and regulations need to be addressed to introduce hydrogen technologies to all New Zealand stakeholders?	DA	DA highlights critical safety concerns associated with hydrogen. Notably, he mentions the public fear linked to hydrogen, partly due to accidents and hydrogen-related mishaps such as Hindenburg accident. He acknowledges an explosion incident in Korea in 2018 that resulted in fatalities. People often perceive hydrogen as unsafe, drawing associations with hydrogen bombs. However, he notes that hydrogen can be stored in fibre-based tanks (Type 4 storage tanks) which, while not explosion-proof, do not cause explosions but rather tear like textile materials. DA also mentions Korea Gas Safety Corporation's rigorous safety regulations governing hydrogen technology, suggesting that with stringent safety measures, hydrogen can be handled safely. DA highlights that many hydrogen-related safety regulations, units, and standards are benchmarked from those in the US. He suggests a significant influence of US standards on safety regulations related to hydrogen and gas in various countries, including Korea. DA points out that there is not a singular approach to convince the public of the safety and viability of green hydrogen and hydrogen technologies. Building public awareness through education and training is essential. He emphasizes that historical parallels can be drawn, such as how people initially perceived liquefied petroleum gas (LPG) stations as potentially explosive. Overcoming these concerns involves a gradual process of demonstrating safety through correct handling and adhering to safety requirements. Addressing the human factor, which contributes to the majority of hydrogen-related accidents, is crucial.
	EEF	EEF emphasizes the need for specific norms and regulations for hydrogen safety, akin to existing regulations for LPG tanks. He mentions the importance of safety features like excess flow valves and emphasizes the need to follow or develop standards and norms for installing such safety devices. EEF underscores the importance of addressing safety concerns

		related to hydrogen technologies by drawing a comparison with perceptions of the Hindenburg disaster. He highlights hydrogen's long-standing presence in industrial applications and its parallel with other commonly used gases like LPG without significant safety issues. EEF explains that hydrogen technologies have advanced to a safe level comparable to conventional fuels, and the key is to adhere to established regulations and standards to ensure safety.
	SGJA	According to SGJA, to introduce hydrogen technologies in New Zealand and ensure safety, several aspects regarding hydrogen handling, transport, storage, and usage need to be addressed. Currently, there are existing international standards for handling and transporting hydrogen as an industrial gas, providing a foundation for safe practices. However, there is a notable lack of specific regulations tailored to residential and commercial buildings. In this context, it is essential to draw on international examples and best practices for hydrogen safety and usage in similar settings. By making this information publicly available, authorities responsible for regulation development can use it as a reference to shape and implement appropriate safety standards and regulations for hydrogen technologies in New Zealand. This collaborative approach ensures safety measures align with global best practices while considering local contexts and needs.
	RGJA	Accelerating public acceptance of hydrogen technologies requires addressing social concerns, particularly safety apprehensions associated with historical incidents like the Hindenburg. This perception is a significant obstacle to public acceptance. RGJA suggests addressing safety concerns as a priority. RGJA highlights potential safety concerns related to hydrogen technologies, particularly in domestic applications. He emphasizes the criticality of addressing explosion risks, given the combustible nature of hydrogen. RGJA underscores the need for specialized instrumentation to detect dangerous concentrations of hydrogen and ensure safety. Safety considerations for hydrogen technologies should prioritize the mitigation of explosion risks and implement appropriate detection systems. <i>“The main safety concern I think would be explosion risks, but they could be handled correctly with the required and specific instrumentation in order to make detection of dangerous atmospheres and dangerous concentrations of hydrogen”.</i> He highlights a common concern regarding the near invisibility of a hydrogen flame compared to a natural gas flame. This disparity in flame visibility could pose safety challenges and necessitates clear communication and education on identifying and managing hydrogen flames. Public education campaigns must emphasize the distinct characteristics of hydrogen flames to ensure safe handling and usage.
	JH	JH emphasizes the necessity of establishing clear safety standards and guidelines for hydrogen technologies to be introduced to the public. He acknowledges that New Zealand is currently lacking in this aspect and underscores the importance of developing comprehensive standards and regulations to ensure the safe integration and use of hydrogen technologies.

	JH advocates for adopting international standards rather than reinventing them in New Zealand. He argues that utilizing existing international standards is a pragmatic approach and sees no significant differences in New Zealand that would necessitate entirely unique standards for hydrogen technologies. This approach emphasizes efficiency and aligning with global best practices in the field of hydrogen technologies. <i>“New Zealand’s really lagging on. Some guidelines and standards are really needed. But it’s a waste of time reinventing the wheel. We should be using as much from overseas as possible, and I don’t really see what’s different about New Zealand compared to the rest of the world”.</i> JH emphasizes the need for adequate resources and prioritization to enhance legislation and regulations related to hydrogen technologies in New Zealand. He suggests that the existing structures need to be given higher priority and allocated appropriate resources to effectively address the lack of standards and regulations currently observed in the hydrogen sector. This approach underscores the importance of proactive steps to establish a regulatory framework that facilitates the integration of hydrogen technologies. <i>“Standards and regulations are currently lacking”.</i> In the current scenario, achieving approval for implementing hydrogen technologies in a new residential development may necessitate exemptions due to the absence of specific standards. <i>“I think it requires some sort of exemptions. I don’t think the standards are there”.</i> When it comes to hydrogen safety requirements, it is advisable not to reinvent the wheel but rather learn from and adopt existing practices from other countries. JH suggests that New Zealand should not attempt to create significantly different safety standards but rather evaluate and implement well-established international safety protocols. He recommends consulting with experts and relevant organizations, such as the Ministry of Business, Innovation and Employment, to ensure that safety measures are comprehensive and effective. He underlines the need for a strong top-level framework and proactive steps in New Zealand to prevent falling behind the global advancements in hydrogen technologies. He highlights the challenges faced by the New Zealand government in prioritizing the hydrogen roadmap and overall energy strategy amidst pressing concerns such as COVID and natural disasters like cyclones. He suggests that limited budget allocation might have affected the progress of the hydrogen program, emphasizing the need for sufficient resources and prioritization to advance hydrogen initiatives.
KQ	KQ highlights a key distinction between standards and codes. She emphasizes that product or system standards should ideally be international to ensure consistency and efficiency. These standards aim for a universal approach to ensure safe and effective implementation of technologies. However, when it comes to codes related to the built environment, they vary based on regions and local needs.

	In the US, for instance, there are different code bodies representing various aspects of safety and regulations, such as National Fire Protection Association (NFPA) codes and International Code Council standards. These codes are adopted by different authorities and regulators at the state and local levels. The NFPA, for instance, has NFPA 2 specifically dedicated to hydrogen technologies, encompassing safety requirements for diverse applications within built environments like residential and commercial buildings, repair garages, refuelling stations, and laboratory settings. Therefore, while international standards are essential for technologies themselves, codes often need to be tailored to suit the specific needs and regulations of individual countries or regions, ensuring compliance with safety and usage requirements. The integration of hydrogen technologies into various applications is progressing, and codes and standards play a crucial role in facilitating this. In the US, standards like IEEE 1547 govern the connection of these technologies to the grid. Ongoing revisions to standards, such as IEEE 1547, aim to broaden the scope of hydrogen equipment and applications, moving beyond transportation to encompass a wider range of uses. <i>“I’m seeing more of a focus on creating the standards that can then be referred to in the regulations”.</i> To introduce hydrogen technologies to New Zealand, one of the key steps is to ensure participation in ISO TC 197 (Hydrogen Technologies) where international standards for hydrogen technologies are developed and many are already published. These standards can then be adopted nationally, providing a foundation for safety and implementation. Additionally, for those specifically interested in fuel cell technology, IEC/TC 105 (Fuel Cell Technologies) has relevant standards. Starting with internationally recognized standards can help facilitate the introduction of hydrogen technologies and ensure safety requirements are met. The hydrogen technology standards are accessible to the public, although they are typically available for purchase through national bodies or directly through organizations like ISO or IEC. In the US, for instance, ANSI (American National Standards Institute) is the national body through which these standards can be obtained. However, the scope, details of the standards, the teams involved, publication information, and revision status are publicly available and can be accessed to understand the standards and their applicability. KQ also mentioned a resource that provides an extensive view of the applicable codes and standards for different hydrogen applications and regions, underlining the importance of understanding and addressing these standards to facilitate the adoption of hydrogen technologies in buildings.
MR	According to MR, to introduce hydrogen technologies to the public, specific safety requirements should address the following: 1. Ventilation for Hydrogen Leakages - MR explained that due to hydrogen’s small molecule size, there will likely be leakages. Therefore, she suggested that proper ventilation systems must be in place to disperse any accumulated hydrogen in rooms and spaces; 2. Regular Maintenance – MR emphasized

		the need for regular maintenance of hydrogen infrastructure. She advised that maintenance is essential to ensure the safe and efficient functioning of hydrogen-based systems, similar to how we maintain other devices like boilers. In the context of producing hydrogen, safety measures include having dedicated production areas specifically for testing the machines. These areas should be well-ventilated and compliant with safety regulations, allowing any potential hydrogen leakages to escape safely. Personnel working in these areas should be provided with necessary personal protective equipment (PPE), and hydrogen sensors, as well as oxygen sensors, should be in place to ensure a safe environment. Regarding hydrogen storage, similar safety measures apply, with a focus on monitoring pressure and temperature within storage facilities. It is important to have sensors in place to detect any anomalies and to have procedures for rapid evacuation in the event of a significant hydrogen leakage. When it comes to using hydrogen, maintaining the facility properly to prevent leakages is essential. This includes using the right sensors, maintaining them regularly, and providing training to the personnel responsible for operating the facility. Additionally, as hydrogen is relatively new in many applications, there should be a strong emphasis on educating users about its safe handling and operation as part of introducing hydrogen into the market.
	MS	MS emphasizes the need for clear and comprehensive safety guidelines for hydrogen technologies to introduce them to all stakeholders effectively. He suggests that similar safety guidelines to those for propane or diesel should be established for hydrogen storage and usage. Fire departments play a crucial role in ensuring safety compliance, and efforts should be made to address their concerns and provide them with necessary information. Standardized safety protocols, especially regarding hydrogen pressure, need to be collectively developed and adopted internationally. Currently, there are varying attitudes and regulations across different countries regarding hydrogen safety, underlining the necessity for a unified and standardized safety framework.
	PL	In the discussion regarding safety requirements for hydrogen technologies, it was emphasized that while hydrogen is well-known in the industry, introducing it to the mobility sector presents unique safety concerns due to public engagement and widespread usage. The key aspects of concern were identified as transport, storage, and distribution. Transport and storage were acknowledged as relatively well-mastered aspects, particularly in the context of refuelling stations where extensive safety protocols have been developed based on years of experience and hundreds of operational stations globally. The safety rules for these stations have become stringent over time, contributing to enhanced safety. Regarding vehicles, the use of high-pressure tanks was highlighted, with consideration given to public perception due to the presence of high-pressure hydrogen on board. However, it was noted that vehicle designs

		adhere to established industry standards and safety evaluations, mitigating potential risks. A critical area for improvement was identified as dealing with hydrogen leakage in enclosed spaces such as buildings, parking lots or tunnels. The importance of enhancing hydrogen detection systems, efficient ventilation, and effective mitigation strategies to prevent accidents in such environments was emphasized. Given the heightened public concern and scrutiny associated with hydrogen technologies, any incident could significantly impact public perception and acceptance. Therefore, prioritizing safety measures remains a vital focus. PL highlighted the necessity of both national and international standards and codes. He stressed the importance of international standards, particularly in the context of hydrogen fuel cells and electrolyzers, emphasizing the need for uniformity across different countries to ensure interoperability and safety. He acknowledged the existence of national regulations and variations, particularly in areas like production unit installations, based on each country's specific considerations. However, he emphasized that these differences are not significant and do not impede international collaboration or trade. The discussion emphasized the critical role of international standards in facilitating collaboration, ensuring safety, and enabling trade in hydrogen-based products. While some variations might exist at the national level, efforts are underway to establish mutual recognition platforms for certification schemes to enable international trade in hydrogen products while maintaining a level of standardization.
	RH	RH believes that introducing hydrogen technologies to all New Zealand stakeholders, especially at a domestic level, requires specific safety measures. For homes, a system to detect hydrogen should be in place, ideally resembling a smoke alarm and positioned at the highest point in the home. The hydrogen entering homes should pass through a solenoid valve, a conventional industrial component. If the hydrogen sensor detects concentrations at or above 0.5-1% of the lower flammability level, the valve should close to prevent further hydrogen intake, allowing the existing hydrogen to safely diffuse. On an industrial scale, gas sensors, flame detection systems, and pressure measurement instruments are essential. These devices can detect leaks, anomalies, and potential risks. In case of a fault or leak, these systems would prevent the release of hydrogen into the environment. For fuel cells, which use hydrogen, sensors are already integrated to monitor and ensure safe usage. In summary, accredited hydrogen monitoring systems and flame detection systems are critical for safety, and existing technology can be effectively applied to enhance hydrogen safety. To introduce hydrogen technologies to the New Zealand Stakeholders, RH suggested that: 1. Hydrogen detectors should be installed at the highest points in buildings to automatically shut off the hydrogen supply if leaks are detected.

		2. He suggested avoiding the use of odorants for small pure hydrogen systems due to toxicity risks and difficulties dosing reliably. Instead, rely on ventilation, detectors, and flame arrestors for safety. 3. RH noted the invisible flame of hydrogen could be a barrier for cooking applications. Adding heavy gauze over burners makes the heat visible and lowers flame temperatures. 4. RH stated the wider flammability range and lower ignition energy of hydrogen versus other gases necessitates avoiding flammable mixtures, not relying on odorants. 5. In RH's view, proper system design with storage kept outside buildings is crucial. Safety standards and training for personnel would also be important.
	SJS	SJS believes that the existing safety requirements for hydrogen production and storage are sufficient and do not require additional measures. He expresses confidence in the current safety standards and practices in place for hydrogen technologies, particularly in Europe.
	TW	TW mentioned that in New Zealand, the main regulatory gap lies in how electrolysis, the component generating hydrogen, is treated since it doesn't conform to existing standards like IEC or ISO 60079 due to being embedded in liquid. The rest of the regulatory aspects, including piping standards and applications in the industrial sector, are relatively established. For residential use, considering how much hydrogen is produced and storage using cylinders with appropriate standards would be essential. However, there is a lack of specific standards for residential piping systems and electrolysis components. TW opines that one of the reasons for a lack of significant regulatory changes could be concerns about the potential increase in costs for consumers. Implementing extensive changes in the regulatory framework may lead to an increase in gas prices, which could be a challenge to manage politically. TW suggests a transitional approach, such as utilizing existing carbon credit systems to incentivize the adoption of cleaner technologies. This could involve imposing additional charges on traditional energy sources while providing discounts for cleaner alternatives, aiming to balance the cost impact and drive a shift towards cleaner options. TW mentioned needing standards for residential piping, storage distances from neighbours, hazardous zone classifications where gas will go, exemptions to allow hydrogen appliances, and inspection regimes for pressure safety valves. Following something like the electrical industry with mandatory independent inspections after high-risk work was suggested.
	TN	TN emphasized that hydrogen, being lighter than air, dissipates quickly and poses minimal safety risk, provided there's no nearby ignition source or static electricity. The focus shifts to the design and architecture of hydrogen systems, ensuring safe integration. He suggested early investment in studying and adopting cleaner technologies, and promoting

		public awareness campaigns, drawing a parallel with past campaigns for liquefied natural gas safety. TN suggests importing regulations and technologies from Europe as a potential solution to address the challenge of regulations in New Zealand. This approach involves adopting regulatory frameworks and technological standards that have been proven and established in European countries, leveraging their experience and expertise in the field of hydrogen technologies to inform and shape the regulatory landscape in New Zealand. TN emphasizes several key safety measures for producing, storing, and using green hydrogen. Firstly, selecting an appropriate location and ensuring safe distancing from potential ignition sources is crucial. Additionally, implementing safety measures such as protective walls can enhance safety during hydrogen storage and use. While TN highlights these fundamental safety practices, specific safety requirements should align with industry best practices and local regulations to ensure comprehensive safety protocols.
	VG	VG emphasizes that there are numerous safety standards and regulations in place for hydrogen technologies. When these are followed diligently, hydrogen can be handled safely. He mentions that he is not aware of significant hydrogen-related accidents or explosions in Germany in recent times. He also mentions a specific incident involving a hydrogen trailer in the United States, clarifying that it was a traffic accident and not directly related to a hydrogen safety issue. However, he does not provide specific details regarding safety requirements.
	ZJ	During production through electrolysis, it is generally safe as compared to high-temperature methods like natural gas reforming. The primary safety concern lies in storing hydrogen, given its lightweight and high leakage potential. Compressed hydrogen is stored at high pressure (around 350-700 bars), making safe transportation in gas cylinders feasible. However, managing hydrogen boil-off, caused by temperature fluctuations, is crucial. Storage methods like liquefied hydrogen and a hybrid of compressed and liquefied hydrogen are also being explored for safer storage and transportation. ZJ emphasizes the importance of monitoring hydrogen leakage to ensure safety when introducing hydrogen technologies in New Zealand. Real-time monitoring of hydrogen concentration in the air is crucial to maintain levels below the threshold of explosion, prioritizing safety for stakeholders and the environment.

Table 40: Question 1. What specific hydrogen safety requirements need to be addressed to introduce hydrogen technologies to all New Zealand stakeholders? Participants' views

1.1.1 Additional inquiries pertaining to the first primary research question

Question	Participant	Response
1.1 What specific design requirements are	RGJA	RGJA highlights that ensuring safety when installing hydrogen systems within buildings involves multiplying the number of instrumentation units, notably gas detectors. The main safety measure centres on strategically placing these gas detectors to swiftly detect any potential leaks or issues. However, RGJA stresses the preference for open spaces for hydrogen

required and what safety measure should be in place to allow the hydrogen system to be installed inside of the residential and commercial buildings?		storage due to safety considerations, making it impractical to have storage facilities inside buildings.
	KQ	KQ emphasized that integrating hydrogen into buildings necessitates considering various aspects, such as adapting existing piping systems to handle hydrogen at specific pressures and ensuring that appliances are compatible with hydrogen as a fuel source. The infrastructure changes required for safe and efficient hydrogen use at the consumer level pose significant challenges.
	MR	To facilitate the installation of hydrogen systems within residential and commercial buildings, certain safety measures need to be in place. MR highlighted the key components of this infrastructure, starting with the generation of green electricity through sources such as solar panels. The generated electricity is then used to power electrolyzers, a critical component for hydrogen production. The type of application dictates the subsequent setup, which may involve storage tanks, boilers, or fuel cells for electricity distribution, all of which need to adhere to stringent safety protocols to ensure safe integration within the building premises.
	MS	MS underscores that safety measures for installing hydrogen systems in residential and commercial buildings should be akin to those for LPG or propane. While hydrogen possesses safety concerns that need addressing, treating it with a similar safety approach to other common flammable gases is essential. Safety protocols should be in place, considering factors like storage pressure levels. For instance, in public refuelling stations or garages where higher pressures are involved, specific safety measures tailored to these contexts are crucial to ensure safe hydrogen utilization.
		MS explains the requirements for installing hydrogen technologies in residential or commercial buildings. He emphasizes two aspects: hydrogen production and hydrogen storage. Hydrogen storage should always be outside the building. For hydrogen production, systems can be installed in outdoor cabinets, similar to Tesla battery farms, which simplifies safety considerations compared to enclosed spaces. However, if installed in an enclosed space like a building or garden shed, additional safety measures such as fire systems and positive pressure are necessary.
	SJS	SJS mentions that hydrogen is lighter than air, so it tends to disperse rapidly into the atmosphere. Unlike other heavier gases, it does not accumulate in confined spaces. He adds that safety measures include fans and systems to help disperse any potential release of hydrogen quickly.
	TW	TW highlighted the importance of product selection and operating at low pressures (around 0.3 bar) to mitigate hydrogen permeation. Utilizing off-the-shelf stainless-steel products and fittings, such as swage like Parker High Lock, designed for low-pressure applications, is crucial for safety. Additionally, educating plumbers on proper usage and ensuring compliance with Council approvals are essential safety measures for installing hydrogen systems inside residential and commercial buildings. In terms of safety, TW highlighted studies comparing hydrogen to natural gas, suggesting hydrogen disperses rapidly, making it safer in case of leaks. He mentioned the potential use of leakage detectors, specifically LOI sensors

		(Loss-on-Ignition Sensor), to monitor and detect any hydrogen leaks, enhancing safety measures within residential or commercial spaces. <i>“Hydrogen will disperse incredibly quickly. It’s more flammable, but if it was to be released into a room, it would be going through stuff. It would be finding every little nook and cranny to get out. Whereas if you have a natural gas leak, it will go into a house. It will hang around. It will sit near the light bulbs. It’ll sit near all your ignition sources and it will stay in that room. Trapped. Hydrogen I believe is much more safer than LPG or natural gas. Hydrogen I believe is much more safer than LPG or natural gas”.</i> TW emphasized the importance of considering the piping method and safe distances from other services when designing hydrogen technology installations in residential and commercial buildings. He suggested that the design should align with the existing natural gas regime, with material selection being a key aspect that differentiates hydrogen installations. TW highlighted the need for specific safeguards in reducing pressures, ensuring proper certification and inspection of pressure safety valves to prevent potential hazards, particularly the risk of supplying high pressure to appliances. He stressed the importance of an inspection regime to maintain safety in hydrogen installations.
	TN	TN mentioned that specific design requirements for hydrogen technology installation in residential and commercial buildings would depend on various factors, including the size of the electrolyser, presence of storage, and safety measures. Distancing requirements and strong ventilation systems might be necessary, particularly when dealing with storage of hydrogen. However, more details would be needed to provide precise design requirements. TN indicated that storage of hydrogen is typically placed outside of buildings, often within a shed with thick concrete walls to mitigate potential risks. He mentioned an example from Japan where hydrogen storage was placed outside in a secured area with a fence, emphasizing the need for proper distancing and safety precautions to prevent hydrogen accumulation in confined spaces. This approach helps ensure the safety of residential and commercial buildings.
	VS	For installing hydrogen systems inside residential and commercial buildings, it is essential to adhere to established safety standards. While specific standards should be followed, it is important to note that companies are already implementing this within buildings. Electrolysers, fuel cells, and storage systems can indeed be placed inside buildings, but it is crucial to comply with safety guidelines and adhere to appropriate regulations.

1.2 Do you think that one international standard should be applied for all countries or each single country should develop their own standards?	EEF	EEF highlights the use of international norms and standards for hydrogen technologies in Costa Rica. He recently joined the INTECO committee, the institution responsible for managing norms and standards in the country. The committee reviewed a broad spectrum of international standards, especially those from the International Organization for Standardization (ISO), adjusting them to align with Costa Rica's specific needs and conditions. Additionally, EEF mentions ongoing reviews of Chinese norms and standards within the committee due to the critical importance of hydrogen technologies. He also discusses the significance of appropriately adapting standards to local contexts, considering factors like land requirements, which can impact project feasibility. EEF elaborates on the regulatory landscape in Costa Rica concerning the adoption of hydrogen-related norms and standards. While INTECO, the institution managing norms and standards, recommends their use, there is no legal mandate to adhere to specific international standards. However, EEF points out that certain norms, such as the National Electric Code (NEC) from the US and NFPA 79 and NFPA 2, are legally binding and provide guidelines for handling explosive gases like hydrogen. He emphasizes the importance of considering factors like safety regulations and financial viability in determining which standards to follow for hydrogen projects.
	RGJA	RGJA acknowledges the existing international standards and codes for hydrogen technologies, such as ASTM and NFPA 2, which cover various industrial aspects. However, he emphasizes the need for governments to develop specific residential codes and standards to implement hydrogen technologies effectively at the residential level.
	KQ	Hydrogen technologies have several international standards and codes, including those provided by the International Organization for Standardization (ISO) and the National Fire Protection Association (NFPA) among others. ISO standards cover various aspects of hydrogen production, storage, transportation, and utilization, ensuring safety, efficiency, and interoperability on a global scale. NFPA standards, on the other hand, emphasize safety considerations and guidelines for handling hydrogen. The hydrogen technology standards are accessible to the public, although they are typically available for purchase through national bodies or directly through organizations like ISO or IEC. In the US, for instance, ANSI (American National Standards Institute) is the national body through which these standards can be obtained. However, the scope, details of the standards, the teams involved, publication information, and revision status are publicly available and can be accessed to understand the standards and their applicability.

	MR	MR emphasized the preference for international standards, particularly referencing ISO standards like those related to electrolysis production. She acknowledged that these standards may require further refinement and improvement but stressed the importance of global collaboration to gather essential data and information. MR advocated for a two-step approach: firstly, establishing international standards and then, if necessary, adapting them to local requirements. This approach ensures efficiency, facilitates technology exchange, and enables seamless international product integration, avoiding fragmentation that would occur if each country developed its own separate set of standards and regulations.
	MS	MS mentions the existence of various international standards and codes related to hydrogen technologies. Specifically, there are standards for storage and compression. In the context of fuel cells, compliance with general ISO standards is required for electrical equipment. However, specific standards related to fuel cells beyond ISO compliance were not detailed. MS suggests that manufacturers typically follow different standards based on regions like Europe and the US. However, a unifying approach involves manufacturers adhering to common certification bodies like TUV, which helps consolidate compliance across various components. The goal is to ensure the entire system complies with a specific set of standards for safety and functionality.
	RH	RH believes that a one-size-fits-all approach for hydrogen standards may not be suitable due to the complexity and diversity of applications, such as transmission, appliances, and transportation. International standards, like ISO standards, do set essential base levels, but customization based on regional or national needs should be considered. RH points out that the fundamental principles of chemistry and physics governing hydrogen are consistent worldwide, reducing the need for radically different national standards. RH also emphasizes the importance of considering factors like energy density when blending hydrogen with other gases, particularly in existing gas networks. Ultimately, creating appropriate, effective standards involves striking a balance between global consistency and local adaptability.
	SJS	Regarding international standards for hydrogen technologies, SJS recognizes the existing diversity in standards across countries, even for gas accounts. He suggests that while some standardization efforts are ongoing, a rigid, one-size-fits-all international standard may not be the ideal approach. Instead, he advocates for flexible and adaptable standards that allow for innovation and evolution within the field.
	VG	VG strongly advocates for international standards in the context of hydrogen technologies. He sees no advantages in having localized standards and emphasizes that different standards can complicate engineering efforts and hinder cross-border technology adoption. He provides an example of challenges faced in procuring hydrogen refuelling stations due to differences in standards between Europe and China. VG suggests that having consistent international standards would streamline processes and facilitate global acceptance and usage of hydrogen technologies.

	ZJ	ZJ mentioned that the UK has recently launched its own standard for low carbon hydrogen production, signalling a move toward developing specific standards tailored to the country's needs and objectives. This standard aims to limit CO₂ emissions to 20 grams per kilowatt-hour of hydrogen production. ZJ highlighted the importance for countries to have their own standards for hydrogen technologies, considering factors such as production methods, scaling, and transitioning. These standards will address a variety of sectors, including industrial, commercial, and residential, incorporating considerations like blending hydrogen into existing natural gas grids, distribution system upgrades, safety measures, and appliance adjustments. The emphasis is on meeting safety requirements and aligning with national strategies for hydrogen utilization. ZJ elaborated on the importance of having international standards, particularly regarding carbon emissions, to guide hydrogen technology development globally. However, he also emphasized the necessity for countries to adapt and develop their own standards considering their unique gas infrastructure, applications, and distribution systems. He suggested that the UK's successful hydrogen economy could serve as a valuable reference and prototype for other nations, helping them tailor their own hydrogen economies effectively. ZJ also highlighted that international standards are highly relevant and beneficial for infrastructure aspects such as production and storage.

Table 41: Additional inquiries pertaining to the first primary research question

Based on the expert opinions, the following key points emerge regarding hydrogen safety requirements and regulations needed to introduce hydrogen technologies in New Zealand:

Similar Views

1. Adhering to stringent safety protocols and regulations is crucial for safe hydrogen handling. Existing standards for industrial hydrogen usage can be a starting point.
2. Hydrogen's perception as unsafe due to historical incidents like Hindenburg poses a public acceptance barrier. Gradual demonstration of safe handling is key.
3. Tailored safety regulations are needed for new applications like hydrogen usage in buildings, since existing industrial standards may not directly apply.
4. International standards are preferred for hydrogen technologies and products to enable consistency. However, codes related to built environments often need localization.
5. Hydrogen leakage risks need special attention, especially in enclosed spaces. Appropriate ventilation, sensors, and mitigation strategies are vital.
6. Regular system maintenance and training personnel are critical to ensure continuous safe operations.
7. Gas detectors and sensors are vital safety measures to swiftly detect potential hydrogen leaks within buildings. However, open spaces are preferred for storage due to safety risks.
8. Adapting existing infrastructure like piping systems and ensuring appliance compatibility are challenges for safe hydrogen usage in buildings.
9. Safety protocols like positive pressure, fire suppression systems, proper ventilation, and outdoor storage are necessary, especially for enclosed spaces.

10. Material selection is critical, avoiding steel components prone to embrittlement. Proper grounding and pressure management are also essential.

11. Rapid dispersion of hydrogen due to its light weight reduces risks in confined spaces versus other heavier gases.

Differing Views

1. On reinventing safety regulations - Some suggest adopting existing international standards directly, while others recommend developing tailored national regulations aligned with global best practices.

2. On the current adequacy of safety regulations - Some indicate existing protocols are sufficient, while others highlight gaps, especially for new applications.

3. Some experts indicate existing residential codes are sufficient for hydrogen usage in buildings, while others highlight the lack of tailored regulations for this application.

4. Perspectives vary on the suitability of unified international standards due to hydrogen's diverse applications. While consistency can aid global adoption, customization to address regional/national requirements may be necessary.

In summary, comprehensive safety regulations and standards aligned with global best practices are essential prerequisites to introduce hydrogen technologies across all applications in New Zealand. Priority areas include new use cases like buildings, leakage mitigation strategies, maintenance protocols, personnel training, and public education to build confidence in hydrogen safety. International standards serve as a starting point, but localization may be required in codes to suit New Zealand's context. Key focus areas include leakage monitoring, infrastructure compatibility, training personnel, and developing codes aligned with global best practices but localized for New Zealand's context. Maintaining consistency where possible while allowing flexibility for innovation will enable safe and sustainable hydrogen integration.

1.1.2 What specific hydrogen safety requirements need to be addressed to introduce hydrogen technologies to all New Zealand stakeholders? Literature review in support to the primary research Question 1

In the pursuit of introducing hydrogen technologies into the New Zealand landscape, a profound emphasis on safety considerations emerges as an absolute imperative. The amalgamation of insights from an array of stakeholders, spanning policymakers to industry experts, underscores the multifaceted facets that warrant meticulous attention. Safety considerations in the realm of hydrogen technologies transcend traditional paradigms, necessitating an exhaustive and nuanced approach (Najjar, 2013).

At the forefront of these considerations lies the establishment of a rigorous regulatory framework meticulously tailored to the unique context of New Zealand. This comprehensive framework must encompass the entirety of the hydrogen deployment spectrum, encompassing not only production but also storage, transportation, distribution, and ultimate utilization. Unwavering adherence to these judiciously crafted regulations serves as the linchpin, guaranteeing the sound design, installation, operation, and maintenance of hydrogen systems.

A holistic risk assessment and management paradigm assumes paramount importance in the realm of hydrogen safety. This intricate process entails the meticulous identification of potential hazards, coupled with a rigorous evaluation of their likelihood and potential consequences. Mitigation strategies, intricately fine-tuned to address these inherent risks, play an instrumental role in ensuring the safety of hydrogen technologies throughout their lifecycle – commencing from production and

storage, traversing through transportation, and culminating in their integration within structures (Molkov, 2012).

The assurance of stakeholder competency through the implementation of structured training programs and certifications represents yet another pillar underpinning safety. Personnel spanning the spectrum, ranging from operators to maintenance personnel, emergency responders, and inspectors, must acquire an intimate proficiency in the intricate dynamics of hydrogen systems. This competence serves as the bedrock upon which seamless operations rest, while concurrently upholding the rigorous canons of safety.

The criticality of effective ventilation and leak detection mechanisms cannot be overstated. Adequate ventilation serves as a proactive safeguard, precluding the pernicious accumulation of hydrogen, a situation that could potentially precipitate hazardous scenarios. Simultaneously, the establishment of vigilant leak detection systems assumes paramount importance, endowing the ability to expeditiously identify and curtail potential leaks, thus ameliorating safety risks (Molkov, 2012; Hubert et al., 2014).

Custom-tailored fire safety protocols, harmonized with hydrogen's distinctive properties, emerge as an unassailable necessity. A profound comprehension of the unique characteristics of hydrogen fires, the deployment of suitable fire suppression methodologies, and the thorough training of personnel to adeptly respond to hydrogen-related fires represent pivotal imperatives within this realm (Saffers & Molkov, 2014).

Infrastructure design, encapsulating safety as its nucleus, plays a pivotal role in minimizing risks associated with hydrogen systems. The judicious selection of materials, the meticulous fortification of structural integrity, and the proactive institution of safeguards collectively converge to forestall prospective leaks or ruptures. The unanimous consensus among participants underscores the gravity of constructing systems imbued with the resilience to withstand potential contingencies while concurrently mitigating their potential ramifications (Saffers & Molkov, 2014).

The orchestration of preparedness for emergency response constitutes yet another pivotal facet of the safety matrix. Collaborative engagement with local emergency services, the rigorous training of responders in handling hydrogen-centric emergencies, and the formulation of meticulous protocols governing evacuation, containment, and incident management constitute non-negotiable requisites for ensuring swift and effective responses.

Simultaneously, the dissemination of knowledge and awareness pertaining to hydrogen safety among the public and communities looms as an imperative. The dispelling of misconceptions, the elucidation of safety measures, and the propagation of judicious practices collectively serve to instil trust and confidence in the embrace of hydrogen technologies.

Within this comprehensive safety framework, the formulation and adherence to codes and standards assume a foundational role. These regulatory beacons guide the secure design, installation, operation, and maintenance of hydrogen systems. However, it is paramount to recognize that safety in the realm of hydrogen technologies transcends the realm of regulatory compliance. It necessitates a profound societal commitment, a shared obligation among all stakeholders, to operate ethically and empathetically. Public acceptance hinges upon a foundation of transparent risk mitigation efforts and an unwavering commitment to fostering open communication channels capable of addressing concerns and engendering trust (Ball et al., 2016; NREL, 2023; Saffers & Molkov, 2014).

In addressing the pivotal question of what specific hydrogen safety requirements must be diligently addressed to facilitate the secure introduction of hydrogen technologies to all stakeholders across New Zealand, a multifaceted framework emerges as indispensable. The amalgamation of meticulous safety considerations and regulatory imperatives stands as the bedrock upon which the successful integration of hydrogen technologies is predicated.

Foremost among these requirements is the development of comprehensive hydrogen safety codes and standards tailored specifically to the New Zealand context. This entails a meticulous examination of factors such as seismic risks, wind loading, materials compatibility, and the seamless integration with existing gas infrastructure. Tailoring these standards to the nation's unique characteristics ensures that safety measures are attuned to the environment in which hydrogen technologies will operate.

Education and training programs constitute another pivotal facet. Engineers, technicians, first responders, code officials, and various stakeholders must be equipped with comprehensive knowledge encompassing hydrogen properties, safe handling practices, system design intricacies, maintenance protocols, and effective emergency response procedures. This knowledge dissemination empowers stakeholders with the competence necessary to navigate hydrogen technologies safely.

The regulatory framework assumes paramount importance. Regulations and approval frameworks must be meticulously devised to govern the secure siting, design, installation, operation, and inspection of hydrogen production, storage, transportation, and end-use equipment. This regulatory rigor underpins the assurance of safety across all phases of the hydrogen lifecycle.

Adequate ventilation, leakage detection, and emergency shutdown provisions are indispensable for hydrogen systems operating within buildings and confined spaces. These provisions act as pre-emptive safeguards, averting the accumulation of hydrogen, promptly identifying potential leaks, and enabling swift containment through emergency shutdown protocols.

Quantitative risk assessments hold the key to determining safe separation distances between hydrogen infrastructure and residential or commercial areas. Zoning restrictions that consider the nature of the surroundings are imperative to regulate the quantity and use of hydrogen safely.

The mandate for the use of optimal materials, joint types, valves, gaskets, and related components is crucial to mitigate hydrogen embrittlement issues that may compromise the integrity of hydrogen systems.

Classification of distinct hydrogen hazard zones is pivotal, delineating specific electrical equipment requirements intrinsic to safety considerations. These classifications ensure that electrical systems operating in proximity to hydrogen remain intrinsically safe.

Clear provisions encompassing allowable hydrogen purity levels, odorants, and contaminant limits, tailored to the specific utilization context, are vital to guarantee safety.

Stringent requirements governing storage tank, cylinder, and pipeline strength, design, maintenance, and quality control are imperative. These requirements establish the robustness of the infrastructure and its resilience in the face of potential contingencies.

Furthermore, comprehensive procedures for spill control, leak management, purification, waste handling, and disposal must be meticulously delineated. These procedures are instrumental in addressing unexpected incidents and environmental concerns associated with hydrogen systems.

Hydrogen's unique flammability characteristics necessitate the formulation of fire protection, suppression, and mitigation strategies tailored to these properties. This facet of safety is paramount in averting and mitigating potential fire-related risks associated with hydrogen technologies.

The collaborative engagement of industry stakeholders, academia, and the public plays a pivotal role in the development of well-defined safety regulations. This engagement fosters consensus-building and ensures that safety standards are universally recognized and respected. The establishment of such standards is poised to expedite the deployment of hydrogen technologies across the built environment in New Zealand.

In light of the insights garnered from experts during the interviews, here are some of the pivotal hydrogen safety prerequisites that demand attention for the effective integration of hydrogen technologies among pertinent stakeholders within the New Zealand built environment.

Key Aspect	Details
Hydrogen Safety Codes	New Zealand needs comprehensive hydrogen safety standards, considering seismic risks, wind, and gas infrastructure.
Education & Training	Training programs for engineers, architects, and stakeholders on hydrogen safety protocols, system design, and emergency response.
Regulations & Approval	Clear regulations for siting, designing, and inspecting hydrogen equipment in built environments.
Safety Measures	Adequate ventilation, leak detection, emergency systems for confined spaces.
Zoning & Separation	Safe separation distances between hydrogen infrastructure and populated areas based on risk assessments.
Material Compatibility	Assessing materials to prevent issues like hydrogen embrittlement.
Hazard Zones & Equipment	Classifying hazard zones to define electrical equipment needs for intrinsic safety.
Purity & Contaminants	Standards for hydrogen purity, odorization, and contaminant limits.
Storage & Quality Control	Strict design and maintenance protocols for storage tanks, pipelines, and cylinders.
Emergency Procedures	Detailed procedures for leak management, purification, and fire protection systems.

Table 42: Key Safety Considerations for Hydrogen Integration in the Built Environment

Overall, developing clear and robust safety regulations through collaboration with industry, academia and communities can enable universal standards for the safe integration of hydrogen technologies in New Zealand’s built environment.

In summation, the imperative to address specific hydrogen safety requirements to facilitate the introduction of hydrogen technologies to all New Zealand stakeholders entails a comprehensive and meticulously crafted framework. This framework encompasses regulatory rigor, education, risk assessment, materials selection, and stringent safety provisions, all underpinned by collaboration and engagement. Embracing these safety imperatives ensures the secure integration of hydrogen technologies and lays the foundation for their widespread adoption across the nation.

1.1.3 International Standards and Codes

The integration of green hydrogen technologies into the New Zealand built environment must be supported through the adoption of appropriate standards and codes. Recent techno-economic studies have identified green hydrogen as a promising option for decarbonizing several sectors in New Zealand, including buildings, electricity, and industry. However, the safe and effective deployment

of hydrogen solutions requires adherence to technical specifications, safety provisions, and performance requirements outlined in standards and regulations.

A review of international and local standards shows several existing documents that can enable the adoption of green hydrogen in the New Zealand context. Key international standards include ISO/TC 197's codes on hydrogen quality control, storage, transmission and safety; the NFPA 2 standard for hydrogen use in buildings (The National Fire Prevention Association); ASME's piping codes for hydrogen (American Society of Mechanical Engineers); and the IEC's fuel cell standards (International Electrotechnical Commission). These provide good baseline technical parameters and safety guidelines. Additionally, standards from organizations like CSA Group (The Canadian Standards Association) and CEN (The European Committee for Standardization) can inform the use of hydrogen tanks, cylinders and accessories.

While international standards serve as useful references, localization is necessary to align with New Zealand's specific infrastructure, materials, climatic conditions, regulations etc. In this regard, existing New Zealand documents like NZS 5259 on hydrogen gas can be leveraged. However, additional work may be required to develop complementary New Zealand standards targeting priority applications like hydrogen for heating/cooking in buildings, integration with gas distribution networks, decentralized electrolyser facilities, and fuel cell electric vehicles (NZS 5259:2015).

For regulation, the certification and compliance frameworks for gas installations, electrical safety, fire safety, and dangerous goods from bodies like Standards New Zealand, WorkSafe NZ, and the NZ Fire Service can be extended to accommodate hydrogen technologies. But amendments and new risk-based guidelines may be needed for hydrogen-specific use cases. Ongoing collaboration between government, industry, academia and standards organizations is imperative to enable timely development of fit-for-purpose technical standards and safety regulations for green hydrogen in New Zealand's built environment.

The key international standards and codes for hydrogen technologies that are relevant and potentially applicable to the New Zealand built environment:

ISO 22734:2019 provides requirements for the production of hydrogen from water electrolysis. This standard is highly relevant as electrolytic hydrogen using renewable electricity is a key route for green hydrogen production in New Zealand. The standard covers aspects like feed water specifications, control systems, safety provisions and purity parameters. Existing New Zealand standards do not adequately address electrolyser systems. Thus ISO 22734 should be adopted directly or with amendments for local electricity grid conditions and acceptable feed water quality (ISO, 22734:2019).

ISO/TC 197/SC 1 develops standards relating to hydrogen fuel specification and quality control. This includes ISO 14687 which gives quality criteria like maximum impurity levels for fuel cell applications. As New Zealand currently lacks hydrogen fuel quality standards, ISO 14687 should be implemented to ensure hydrogen purity for use in fuel cells in buildings and vehicles. Parameters may be adjusted based on local production methods (ISO/TC 197/SC 1).

ISO/TC 105 publishes international standards for fuel cell technologies across diverse applications. For example, **ISO 16110-1** specifies safety and performance of stationary fuel cell power systems, while **ISO 23274** details fuel cell road vehicle safety. These standards provide design, material, testing and safety specifications for fuel cells. New Zealand should directly reference these standards, potentially with localized air quality, materials or climate data, to enable uptake of fuel cells in buildings and EVs.

ISO/TC 197: The International Organization for Standardization's technical committee on hydrogen technologies has developed standards covering terminology, quality control, storage, transmission, safety, fuel cells, and more. These provide a good framework (ISO TC 197).

NFPA 2: The US National Fire Protection Association's hydrogen technologies code covers storage, use, handling, and generation of hydrogen in buildings and infrastructure. It provides detailed safety provisions (NFPA 2, 2020).

ASME B31: The American Society of Mechanical Engineers' piping codes include standards for hydrogen piping and pipelines that could inform similar standards in New Zealand (ASME, 2017).

CSA Group's hydrogen standards: The Canadian Standards Association has standards for fuel cell technologies, hydrogen refuelling stations, hydrogen-powered vehicles, etc. These align with international standards (CSA Group, 2023).

IEC TC 105: The International Electrotechnical Commission's standards for fuel cell technologies in stationary, portable, and transport applications are relevant for hydrogen use (IEC, 2023).

ISO TC 58: Standards for gas cylinder design, construction, inspection, etc from this ISO committee can be referenced for hydrogen cylinders and tubes (ISO TC 58).

CEN/TC 268: The European Committee for Standardization's standards on cryogenic vessels, valves, and accessories have implications for liquid hydrogen storage and handling (CEN, 2023).

ISO 22734 (all parts) is an International Standard that establishes guidelines and requirements for the safe and efficient use of hydrogen generators employing water electrolysis technology in industrial, commercial, and residential applications. It covers aspects such as design, construction, operation, maintenance, safety features, and hazard mitigation to ensure the reliable and secure deployment of these generators while minimizing risks. ISO 22734-2 establishes safety standards for residential and ISO 22734-1 for commercial and industrial applications of hydrogen generators that utilize electrochemical processes to produce hydrogen from water electrolysis. (ISO 22734, 2019; ISO 22734, 2011, ISO 22734, 2008).

The **ISO 14687:2019** standards on hydrogen fuel quality will be crucial for ensuring the purity of hydrogen used in fuel cells for stationary power and vehicles in NZ. This standard provides quality specifications for hydrogen fuel, including limits on impurities for fuel cell applications. Parameters like water content and sulfur compounds can degrade fuel cell performance. Adoption of ISO 14687 will help maintain hydrogen quality from production to end-use (ISO 14687).

ISO 16111's provisions on water electrolysis hydrogen generators will support the integration of electrolyzers for onsite renewable hydrogen production at buildings with rooftop solar PV. Aspects like electrical standards, safety distances and automatic shutdown control are relevant for safe deployment. This standard can be adopted directly or localized if needed.

ISO 22734 provides requirements for production of hydrogen from water electrolysis, a key process for onsite renewable hydrogen generation at buildings. **ISO 15916** outlines basic safety considerations for hydrogen systems in confined spaces like buildings. **ISO 19880-8** specifies hydrogen generators using fuel cells for residential/commercial sites. These ISO standards provide baselines for safe hydrogen use in the built environment.

Finally, the **ISO 19880** series on hydrogen fuelling stations contains useful codes and guidance for establishing refuelling infrastructure for fuel cell EVs in NZ. It covers station design, dispenser hoses, compression systems, etc. to enable fast and safe refuelling. This will promote uptake of FCEVs (ISO 19880, 2020).

Overall, these ISO standards provide a strong technical basis to guide the incorporation of hydrogen solutions like electrolyzers, fuel cells and refuelling stations into NZ's built environment. They will be complemented by localized NZ standards referring to specific construction practices, environmental factors, regulations and end-use cases.

Many of these international standards and codes can be adopted in New Zealand, either directly or with amendments to suit local conditions. They provide a good baseline, but New Zealand may require additional standards tailored for its own infrastructure, materials, environmental conditions, and regulations.

The deployment of green hydrogen infrastructure and technologies in the built environment will require adherence to technical standards and safety codes to ensure decarbonization objectives are achieved responsibly. International and national standards bodies have developed relevant standards that can inform New Zealand's approach.

New Zealand standards like **NZS 5259** on hydrogen gas measurement also serve as references. However, additional New Zealand-specific standards are needed to address factors like seismic risks, materials compatibility, and connection with gas distribution networks.

The Natural and Built Environments Bill could reference these standards when formulating permitting requirements for hydrogen facilities. Following recognized codes and standards, while customizing them to New Zealand conditions, will help ensure hydrogen deployment enables built environment decarbonization safely and effectively. The bill could also expedite permitting for projects adhering to approved standards.

Integrating relevant international and local hydrogen standards into New Zealand's regulatory environment through provisions in the Natural and Built Environments Bill and associated documents will provide confidence in the safe and sustainable deployment of green hydrogen solutions for low-carbon buildings and infrastructure (New Zealand 2023. Energy Policy Review, 2023).

In New Zealand, gas codes and standards are overseen by regulatory bodies and organizations to ensure the safety of gas systems. The primary authority responsible for gas safety is the Energy Safety division within WorkSafe New Zealand. While New Zealand lacks specific standards exclusively dedicated to green hydrogen, there exist a range of applicable standards and regulations. These encompass various aspects of hydrogen production, storage, transportation, and utilization, offering essential guidance and requirements. Relevant standards in New Zealand address key elements related to green hydrogen, providing a comprehensive framework for its safe integration into the energy landscape.

For example, **AS/NZS 5601.1:2022** addresses the design, installation, and commissioning of gas systems with a focus on components like appliances, piping systems, ventilation, and safety devices. While not specific to green hydrogen, it forms a foundational reference point for adapting gas standards to accommodate green hydrogen. To incorporate green hydrogen, adjustments would involve expanding definitions, updating infrastructure design guidelines, adding safety measures, and addressing installation procedures. Ventilation requirements outlined in AS/NZS 5601.1:2022 are also relevant to green hydrogen safety. Similarly, safety devices and emergency shut-off systems can be modified to suit green hydrogen installations. While dedicated green hydrogen standards may emerge, AS/NZS 5601.1:2022 provides a solid foundation for ensuring safety and compliance in the interim (AS/NZS 5601.1:2022).

AS/NZS 1596:2014 primarily focuses on the safe storage and handling of liquefied petroleum gas (LPG). While not tailored to hydrogen technologies, certain aspects of the standard can be adapted for hydrogen storage and handling. This includes guidelines for pressurized gas storage, container design, and safety measures. However, modifications are essential to account for hydrogen's unique properties, such as its lower ignition energy and wider flammability range. Additionally, considerations for hydrogen embrittlement, specialized materials, and renewable energy integration should be incorporated to align the standard with green hydrogen requirements. In essence, while AS/NZS 1596:2014 forms a foundation, adjustments are necessary to ensure safe and efficient hydrogen storage and handling practices (AS/NZS 1596:2014).

AS/NZS 1869:2012 focuses on hoses and hose assemblies in LPG systems, providing specifications for materials, construction, pressure ratings, and safety features. While it forms a foundation, its direct relevance to green hydrogen and hydrogen technologies necessitates careful adaptation. To align it with hydrogen applications, material compatibility assessments are recommended to address challenges like hydrogen embrittlement and permeation. Additionally, construction methods should be modified to accommodate hydrogen-specific considerations like permeation and embrittlement prevention. Pressure rating requirements may need revisions to suit the higher pressures in green hydrogen systems, or alternative hydrogen-specific standards may be considered. Incorporating additional safety features tailored to hydrogen, such as addressing flammability and explosion prevention, is essential for ensuring the safe use of hoses in green hydrogen and hydrogen technologies. In summary, while AS/NZS 1869:2012 provides a starting point, it requires adjustments to meet the unique demands of hydrogen applications (AS/NZS 1869:2012).

AS/NZS 5603:2009 outlines safety and performance requirements for gas appliances, including heaters, cooktops, and hot water systems, covering design, construction, installation, and maintenance aspects. While it addresses safety for gas appliances, it may not fully encompass the unique safety concerns of green hydrogen and hydrogen technologies, given hydrogen's distinct properties like high flammability and leak potential. To enhance its relevance to hydrogen applications, augmenting the standard with hydrogen-specific safety provisions is essential. These provisions should address flammability hazards, leak detection, and mitigation for safe hydrogen handling. Operational guidelines provided by AS/NZS 5603:2009, while valuable, may require supplementation to account for hydrogen's unique characteristics in production, storage, distribution, and handling. This can involve introducing specific operational guidelines tailored to hydrogen technologies or developing complementary standards. By incorporating hydrogen-specific safety measures, ventilation and installation requirements, and operational guidance into AS/NZS 5603:2009, we can ensure the safe and efficient utilization of hydrogen technologies while building upon the foundation provided by the standard (AS/NZS 5603:2009).

AS/NZS 3820:2020 establishes essential safety requirements for electrical equipment used with gas appliances and installations. To align it with hydrogen technologies, several modifications are necessary. These include introducing hydrogen-specific safety considerations like flammability hazards, leak detection, and explosion prevention. Assessing the compatibility of electrical equipment with hydrogen is crucial, considering hydrogen's reactivity and potential embrittlement. Electrical equipment ratings should be revised to meet hydrogen's unique requirements, and hydrogen-specific testing procedures and certification standards should be developed. Harmonization with other relevant hydrogen standards is essential, along with ongoing updates to accommodate evolving hydrogen technologies and safety concerns. While periodic revisions occur, dedicated green hydrogen standards remain in development as the field evolves (AS/NZS 3820:2020).

In contrast to New Zealand, where green hydrogen standards are still emerging, Australia has taken proactive steps by establishing the ME-093 Hydrogen Technologies Committee under Standards Australia. This committee plays a pivotal role in shaping and advancing hydrogen technologies within the country, focusing on safety, environmental protection, industry growth, and international alignment. Its core mission involves representing Australia's national interests in the realm of hydrogen technologies at international bodies like International Organization for Standardization and International Electrotechnical Commission. The committee's paramount goal is to ensure that the standards it develops and adopts benefit Australia while aligning with national priorities.

The establishment of the ME-093 Hydrogen Technologies Committee in early 2019 followed a forum held in October 2018, assessing the necessity of a dedicated technical committee for hydrogen technologies. The committee operates in several key areas to cater to the needs of Australian stakeholders, emphasizing safety, environmental protection, trade facilitation, and industry

upskilling. ME-093 comprises five working groups, each specializing in different aspects of hydrogen technologies, including production, storage, and applications across various sectors.

Within the ME-093 committee, five working groups are responsible for specific areas of hydrogen technologies. Working Group 1 focuses on standards related to hydrogen production, storage, and distribution, encompassing electrolysis, reforming, compression, liquefaction, storage vessel design, and transportation infrastructure. Working Group 2, known as the Safety working group, concentrates on ensuring safe hydrogen handling, storage, and utilization through activities like risk assessment, hazard identification, safety management systems, and emergency response protocols.

Working Group 3 is dedicated to applications, developing standards for hydrogen utilization in various contexts, including fuel cells, hydrogen combustion, industrial processes, and emerging technologies. This group addresses performance, efficiency, compatibility, and safety requirements specific to these applications. Working Group 4, Codes and Regulations, focuses on standards guiding regulatory frameworks, codes, and guidelines for hydrogen technologies, ensuring alignment with national and international regulations. Lastly, Working Group 5, the Environmental Impact and Sustainability group, works to develop standards assessing and mitigating the environmental impacts of hydrogen production and use, considering factors like life cycle assessments, greenhouse gas emissions, and sustainability (NERA, 2020).

ME-093 operates through close collaboration and consultation with industry stakeholders, experts, regulators, and other pertinent committees within Standards Australia. By integrating health, safety, and environmental considerations into its standards development activities, the committee aims to support the safe and sustainable growth of hydrogen technologies in Australia.

ME-093's scope encompasses the entire hydrogen value chain, spanning production, storage, handling, measurement, transport, transmission, and distribution in its pure form or as blends with other fuel gases. Additionally, it covers end-use applications such as hydrogen refuelling infrastructure, mobility applications, domestic and industrial appliances, power, and heat generation. The committee addresses diverse facets of hydrogen, including specifications, production processes, storage methods, transportation modes, safety systems, and environmental impact assessments.

Two significant working groups within ME-093, the Production, Handling, and Storage Working Group and the Pipelines and Gas Distribution Networks Working Group, address specific aspects of hydrogen technologies. The former focuses on production, purification, storage, handling, and transport systems for hydrogen. It also addresses equipment design, performance criteria, operational requirements, and safety management. The latter concentrates on the segment of hydrogen transport within the gas network, considering leak detection, hazardous areas, material compatibility, and gas quality specifications. Collaboration with existing pipeline and gas network committees is crucial to ensure comprehensive coverage.

The End Use Applications Working Group monitors advancements in end-use applications involving hydrogen or hydrogen/natural gas blends, collaborating with standards committees to develop Australian Standards for these applications. It reviews existing standards, international best practices, ongoing research, and project updates to ensure that standards remain current, effective, and aligned with industry requirements.

The Fuel Cell Applications Working Group specializes in fuel cell technologies and their applications, covering stationary power systems, transportation, auxiliary power units, portable systems, and reverse operating fuel cell power systems. The group actively reviews and recommends the adoption of international standards for fuel cell technologies, with necessary modifications to meet Australian requirements. It also engages in regulatory discussions and liaisons with other relevant Standards Australia committees to ensure a seamless integration of hydrogen technologies into Australian standards.

Through these focused working groups, ME-093 aims to advance the development, adoption, and implementation of hydrogen technologies in Australia while ensuring compliance with industry best practices and safety standards. The committee actively participates in international collaborations and stays informed about the latest developments in the field to remain at the forefront of hydrogen technology standards (ME-093, 2020; NERA, 2019).

Australia's recent adoption of nine new standards represents a significant stride toward advancing the safe and effective utilization of hydrogen technologies. These standards encompass a wide array of aspects related to hydrogen production, storage, distribution, and safety. By briefly discussing these standards, New Zealand can gain insights into Australia's approach and consider following a similar path to enhance its own hydrogen industry.

AS 16110.1:2020, Hydrogen generators using fuel processing technologies, Part 1: Safety (ISO 16110-1:2017 MOD): This standard outlines safety measures for hydrogen generators using fuel processing technologies, ensuring the secure operation of such systems.

AS ISO 16110.2:2020, Hydrogen generators using fuel processing technologies, Part 2: Test methods for performance: This standard provides test methods to assess the performance of hydrogen generators utilizing fuel processing technologies.

AS ISO 14687:2020, Hydrogen fuel quality – Product specification: Focused on hydrogen fuel quality, this standard sets product specifications to maintain consistency and reliability in hydrogen applications.

AS 22734:2020, Hydrogen generators using water electrolysis – Industrial, commercial, and residential applications (ISO 22734:2019, MOD): This standard addresses the safe use of hydrogen generators employing water electrolysis across various applications.

SA TS 19883:2020, Safety of pressure swing adsorption systems for hydrogen separation and purification (ISO/TS 19883:2017, MOD): It focuses on safety considerations for pressure swing adsorption systems used in hydrogen separation and purification.

AS ISO 16111:2020, Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride: This standard covers transportable hydrogen storage devices employing metal hydrides.

AS ISO 19881:2020, Gaseous hydrogen – Land vehicle fuel containers: It addresses fuel containers for land vehicles utilizing gaseous hydrogen, ensuring safety in hydrogen-powered transportation.

AS 19880.3:2020, Gaseous hydrogen – Fuelling stations, Part 3: Valves (ISO 19880-3:2018, MOD): This standard pertains to valves used in gaseous hydrogen fuelling stations, contributing to safety in refuelling infrastructure.

AS 26142:2020 Hydrogen detection apparatus – stationary applications (ISO 21642:2010 Ed 1.0 MOD): Focusing on stationary hydrogen detection, this standard ensures the reliable monitoring of hydrogen in various applications (ME-093, 2020; NERA, 2020).

New Zealand can consider adopting these standards as a framework to bolster its hydrogen industry. By doing so, it can align its efforts with international best practices, enhancing safety, reliability, and consistency across the hydrogen value chain. Emulating Australia's approach in standardizing hydrogen technologies can expedite the growth and sustainability of New Zealand's hydrogen sector while fostering collaboration with international stakeholders.

In practical terms, New Zealand can explore similar avenues for hydrogen utilization, mirroring Australia's initiatives in clean ammonia production, industrial heating, and remote applications like microgrids for mining, remote communities, farming, and marine sectors. Additionally, New Zealand can take inspiration from Australia's focus on ensuring backup power supply for critical

infrastructure, blending hydrogen into existing natural gas networks, and exploring various transport applications, particularly in heavy and long-range road transport, rail, and shipping.

Both nations can collaborate in the pursuit of innovative technologies to reduce the cost of hydrogen production, storage, and utilization, fostering a mutually beneficial environment for technological advancements. New Zealand, in particular, can leverage its sustainable water sources for hydrogen production, aligning with its commitment to environmentally responsible practices. Emphasizing cross-sector linkages will enable New Zealand to derive maximum value from sector coupling and integrate hydrogen seamlessly into various industries.

Regarding standards development, New Zealand can emulate Australia's approach by empowering Standards New Zealand to play a pivotal role. This involves actively participating in the development of technical standards for the hydrogen industry, promoting responsive regulation, and adopting international standards wherever applicable. By harmonizing with global best practices, New Zealand can ensure the safe, efficient, and standardized integration of hydrogen technologies, contributing to its sustainability goals and aligning with international efforts to reduce carbon emissions.

Ultimately, it is imperative for New Zealand to craft its own national hydrogen strategy, one that is finely tuned to its unique circumstances, available resources, and sustainability objectives. Simultaneously, fostering collaboration with international stakeholders will be instrumental in sharing knowledge, experiences, and standards, contributing to the growth and harmonization of the burgeoning hydrogen sector on a global scale.

Drawing parallels with Australia's approach, New Zealand has also recognized the significant potential of hydrogen as a pivotal component in its journey towards a sustainable energy future. This presents an opportunity for New Zealand to align its priorities with those identified in Australia, forging a shared vision for hydrogen development.

In conclusion, New Zealand lacks comprehensive standards for green hydrogen and should leverage these ISO standards as initial technical benchmarks. However, localized standards must supplement these with provisions tailored to New Zealand's infrastructure, environment, regulations and specific end-use cases. A collaborative approach between government, industry, academia and Standards NZ can build on these foundations to publish New Zealand hydrogen standards.

1.1.4 Summary

Based on the expert insights and literature review, a clear imperative emerges for New Zealand to develop a robust framework of tailored codes and standards to enable the safe integration of hydrogen technologies across its built environment. While international standards serve as useful references, directly adopting them in isolation runs the risk of discordance with New Zealand's unique infrastructure, materials, climatic conditions, seismic risks, and regulatory environment.

A collaborative approach, therefore, is vital - one that blends the technical rigour of international best practices with localization attuned to Aotearoa's distinctive needs. This requires proactive engagement between government, industry, academia, Standards New Zealand, and other stakeholders to formulate hydrogen-specific standards expeditiously through consensus.

The development of rigorous training programs for competent and qualified personnel also holds immense importance. Personnel must acquire intimate proficiency with hydrogen's properties, the technical nuances of associated systems, and safety protocols across the value chain. Such competence serves as the bedrock for secure system design, installation, operation, maintenance and emergency response.

Safety naturally remains paramount and standards play a pivotal role. They must encompass provisions for adequate ventilation, leakage detection, measurement and control systems, materials

compatibility, fire protection, storage distance requirements and stringent infrastructure design specifications. Quantitative risk-based methodologies can guide safe separation distances and zoning restrictions.

Overall, by blending international technical rigour with customization attuned to local conditions, New Zealand can develop a comprehensive framework of tailored standards and codes, fostering universal adherence. This will engender stakeholder confidence in hydrogen's secure deployment, laying a robust foundation for its extensive adoption across the built environment. Leadership, foresight and urgent collaboration are instrumental to realizing this vision expeditiously.

This summary directly supports Objective 1 by advocating for a global review of hydrogen projects to inform tailored safety standards in New Zealand. By integrating international best practices with local conditions, the proposed framework addresses safety challenges and identifies opportunities to enhance public acceptance of hydrogen technologies. Collaborative engagement among stakeholders is essential to build confidence in these innovations, ultimately facilitating widespread acceptance by the end of the research period.

1.2 Question 2 - How can hydrogen technologies contribute into decarbonisation of the built environment and how can this be measured? Participants' view

Question	Participant	Response
Question 2. How can hydrogen technologies contribute into decarbonisation of the built environment and how can this be measured?	DA	DA emphasized hydrogen technologies, particularly fuel cells, for decarbonizing the built environment, citing Japan's successful adoption in residences and businesses. He noted challenges of pure hydrogen PEM fuel cells for specific uses and highlighted Korea's renewable electricity mandate for large buildings. DA advocated for fuel cells as a sustainable alternative in countries like Korea, Japan, Taiwan, and New Zealand due to land constraints. His insights underscored fuel cells' crucial role in decarbonization within such constrained contexts. <i>"The only way of decarbonizing the built environment is through a fuel cells. So that's the only way that's left for carrier for countries like Korea, Japan and Taiwan where the land is quite restricted".</i> Utilizing the existing gas infrastructure, a method involves blending hydrogen into the city gas, such as the plans in Britain to incorporate 10 to 15% hydrogen into the existing gas grid, potentially reaching 20% in Korea. This approach achieves a 20% reduction in carbon emissions across the infrastructure. Another viable approach involves power plants generating green hydrogen on-site, enabling its direct use for various purposes, including cooking meals, demonstrating the versatility and potential of hydrogen technologies.
	EEF	EEF highlights hydrogen as a versatile and clean energy carrier that can significantly contribute to decarbonizing various sectors including the built environment. He underscores that hydrogen, when produced through green methods using renewable energy and water, has immense potential to decarbonize the economy. EEF notes the rapid interest of green hydrogen technologies in Costa Rica but acknowledges the limitations in residential and commercial buildings, presenting hydrogen as a promising solution for these sectors. The emphasis on hydrogen as a tool to bridge gaps in

		decarbonization aligns with the broader global movement toward a sustainable, hydrogen-powered future. EEF emphasizes that measuring decarbonization begins with establishing a baseline, often aligned with a country's national decarbonization strategy. In projects, the calculation involves assessing the CO2 emissions based on the displacement of technology. For instance, when transitioning to hydrogen-powered vehicles, the reduction in CO2 emissions over a specified period can be quantified. This measurement method is also applicable to the built environment, where carbon emissions from fossil fuel-based electricity are compared with emissions from hydrogen-based electricity. EEF stresses the importance of not just adding new technology to the built environment but also retrofitting existing systems for effective decarbonization. However, in the context of Costa Rica, where fertilizer consumption greatly exceeds the global average due to heavy rainfall and mountainous terrain necessitating substantial fertilizer use, hydrogen finds a valuable application. The significant reliance on imported, non-green fertilizers has made the agricultural sector susceptible to geopolitical shifts affecting prices. Green hydrogen offers a promising solution by enabling the production of CO2-free fertilizers locally, reducing dependency on external sources and stabilizing prices. This transformative approach presents a “Trojan horse” scenario, initiating a hydrogen economy that extends to various sectors beyond agriculture, including transportation and electricity generation. The initial focus on agriculture creates a foundation for broader hydrogen utilization without depending on uncertain events.
	SGJA	Hydrogen technologies present a promising avenue for contributing to decarbonization within the built environment, especially when sourced from renewable energy, ensuring emission-free production. This environmentally friendly approach aligns with the overarching goal of reducing carbon footprints and combatting climate change. To measure their contribution, a critical metric involves assessing the emissions mitigated or eliminated through the integration of hydrogen technologies in targeted applications focused on energy efficiency and electrification. hydrogen is employed to mitigate the CO2 footprint, particularly concerning the raw materials essential for construction, like cement and steel. In this context, hydrogen is utilized as a cleaner alternative to coal or natural gas, serving as a fuel in high-temperature processes, thus contributing to reducing carbon emission.
	RGJA	RGJA points out that hydrogen technologies can primarily contribute to decarbonization in the residential and commercial building sectors through residential heating applications. Specifically, he highlights opportunities in residential heating systems, including small capacity boilers and cooking stoves. In regions where natural gas usage is prevalent for cooking, transitioning to hydrogen-based solutions can significantly reduce carbon emissions. RGJA emphasizes that green hydrogen can play a significant role in providing emergency power and acting as a backup energy source for buildings. Additionally, it can contribute to microgrids, showcasing its potential for reliable and resilient electrification solutions within the building sector.

	JAGR	Hydrogen technologies possess a significant potential for reducing ecological footprints, particularly in terms of emissions. In comparison to conventional fossil fuels, hydrogen is markedly cleaner, offering a route to mitigating carbon footprints. However, it is important to acknowledge that the production of hydrogen still involves elements that may have adverse environmental impacts, such as the use of platinum in fuel cells and AEM technologies. The emphasis should be on further advancing and optimizing the hydrogen production process to minimize its ecological implications. Hydrogen technologies, while not exempt from the need for various minerals and metals in their supply chain, can indeed contribute to a reduction in ecological footprint. Circular economy principles, emphasizing recycling and efficient use of materials, play a crucial role in mitigating the environmental impact associated with hydrogen production. Moreover, compared to certain alternatives like batteries, hydrogen technologies generally involve a comparable or even potentially lesser demand for minerals, affirming their potential as a cleaner energy option. Striking the right balance between technological advancement, circular practices, and efficient resource management is essential for maximizing the positive environmental impact of hydrogen technologies.
	JH	Hydrogen technologies can play a vital role in decarbonizing specific challenging sectors within the built environment, particularly in hard-to-decarbonize areas like steelmaking. However, the direct use of hydrogen for heat in the built environment may not be the most efficient approach. Instead, focusing on utilizing hydrogen for critical applications like fuel cells and combined heat and power (CHP) systems could be more effective. In the United States, hydrogen has been utilized in various applications, including stationary power systems for emergency backup, particularly favoured by entities like the army and hospitals. The value of hydrogen in providing emergency backup power is acknowledged. However, incorporating hydrogen into the day-to-day operation of buildings, beyond emergency use, raises some scepticism. <i>“Well, I guess there is some stationary power stuff, like the army, they really like hydrogen... integrating it sort of. And the day-to-day running of buildings. I’m a little bit sceptical about that”.</i> JH recognizes the potential of hydrogen in industries, agriculture, and transportation due to its advantageous energy density, particularly in emergency situations and various forms of transport. However, JH remains sceptical about hydrogen's significant application in the built environment, aligning with the absence of a prevalent district heating model in New Zealand. Hydrogen technologies can significantly contribute to the decarbonization of the built environment, particularly in large office buildings and areas like Invercargill. A district heating study in Invercargill explored the potential of a district heating loop, initially considering biomass or heat pumps. However, hydrogen could serve a similar purpose, generating electricity for the city and providing heat to buildings in a combined heat and power (CHP) approach. This highlights the potential of hydrogen in district heating systems and underscores its role in reducing carbon emissions within the built environment. <i>“Hydrogen is very possibly one of the key enabling technology of the future”.</i>

	KQ	Hydrogen technologies offer a promising pathway to decarbonize the built environment, particularly by reducing emissions from natural gas appliances. Incorporating hydrogen blends into the existing infrastructure is a significant step, with established US model codes already covering pure hydrogen technologies. These technologies are presently being utilized in fuel cell applications, with economies of scale favouring larger structures like industrial buildings, certain apartment complexes, and even specialized facilities like dairy farms. The potential for broader adoption and integration into diverse building types is considerable. Measuring and calculating CO2 emissions associated with hydrogen production and usage have been done using various modelling tools and methodologies. National laboratories and research institutions have developed sophisticated models and methods to estimate CO2 emissions in the entire lifecycle of hydrogen production, from its initial production to its use in various applications. Assessing and understanding the environmental impact of hydrogen technologies, including CO2 emissions, are crucial aspects of their overall sustainability and adoption. Utilizing hydrogen-powered transportation for delivering hydrogen to end-users is a sensible approach to minimize emissions associated with transportation. There is a growing emphasis on hydrogen trucks, especially for the heavy-duty vehicle sector, where hydrogen can play a significant role in long-distance transportation with reduced environmental impact. However, it is crucial to approach the adoption of hydrogen technologies incrementally, especially in the context of transportation systems and the industrial sector. Each sector has its unique challenges and requirements, and a gradual implementation allows for practical solutions to be developed and integrated effectively. Starting with transportation, where hydrogen can have a substantial impact, lays a solid foundation for broader adoption across various sectors.
	MR	Hydrogen technologies can significantly contribute to the decarbonization of the built environment by replacing conventional fossil fuel-based heating systems, such as those utilizing methane, with hydrogen-based alternatives. For instance, hydrogen can be used in boilers for heating purposes, either on its own or in mixtures with other gases. The challenge lies in ensuring that hydrogen-based heating solutions are as efficient as traditional methods. Measuring the impact of hydrogen technologies on decarbonization in the built environment can be achieved through internationally standardized certifications for buildings. By establishing strict categorizations based on the efficiency and extent of hydrogen integration, such as Level A, Level B, or Level C standards, it becomes possible to objectively evaluate and compare the decarbonization efforts achieved with hydrogen technologies.
	MS	MS discusses how hydrogen technologies can contribute to decarbonizing the built environment by acting as substitutes for fossil fuels. Replacing fossil fuels in systems that currently depend on them is a key approach. However, this transition will take time due to the existing infrastructure heavily reliant on oil and gas, which have been established for centuries. Different sectors have varying levels of carbon dioxide emissions, with industries like steel and glass manufacturing being significant contributors.

		Additionally, transport fuels for larger vehicles like trains and ships are notable in terms of consumption. Finally, individual energy consumption in homes is a relatively smaller contributor to overall emissions. To achieve decarbonization, tailored strategies are needed for each sector. MS suggests that hydrogen technologies can aid in decarbonizing the built environment by considering the source of hydrogen. Utilizing solar panels on building rooftops to generate hydrogen is a feasible solution. This approach involves harnessing solar energy to produce hydrogen locally, which can then be directly used within the building, promoting sustainability. MS emphasizes that this approach is already being implemented by some, particularly in manufacturing companies that utilize hydrogen as a raw material. They opt to generate hydrogen on-site through solar panels, reducing the need to order and transport it in bottles, thus contributing to decarbonization. MS describes the measurement of decarbonization as assessing the energy consumption and its sources. This involves identifying the proportion of energy that comes from carbon-neutral or low-carbon sources. For instance, injecting hydrogen into a natural gas pipeline to supply a power station is a way to integrate hydrogen into the energy mix. However, this does not necessarily translate to a direct reduction in emissions based solely on the percentage of hydrogen injected. Emissions depend on the specific combustion process and the type of pollutants generated, such as CO₂, NO_x, and SO_x. To measure decarbonization, one needs to evaluate the energy input and discern the green components, determining their origin. This can include purchasing green electricity from the grid or generating electricity on-site. It is a matter of understanding the energy sources and their environmental impact through careful measurement and analysis.
	PL	According to PL, reports from organizations like IEA and IRENA outline various scenarios and perspectives on how hydrogen can contribute to decarbonization. The production of green or low carbon hydrogen is a pivotal aspect, and it is projected to contribute between 15-20% of the total efforts needed by 2050. Hydrogen, whether derived from renewables or through low carbon processes, is anticipated to be a major component of future energy production. Additionally, there is a growing focus on establishing standards, codes, and certification processes to differentiate between low carbon and renewable hydrogen. These efforts will play a crucial role in shaping the future of hydrogen technologies in the pursuit of decarbonization. PL emphasized that the definition and certification of low carbon and renewable hydrogen are critical topics gaining prominence at various international forums like the G7, G20, and COP events. They noted that low carbon includes energy sources like renewables, nuclear, and hydrogen from fossil fuels with carbon capture. Establishing a clear methodology for conveying this information is crucial to build trust and enable a hydrogen market where customers can confidently choose between low carbon and renewable options. Efforts are underway to define these methodologies and create an international legal framework to standardize and certify hydrogen based on its carbon footprint and sustainability. This standardization is seen as essential for the future of the hydrogen industry and its role in decarbonization.

	RH	Participant RH believes that hydrogen technologies can significantly contribute to the decarbonization of the built environment, particularly in replacing fossil fuels for hot water heating. The proposed method involves utilizing an electrolyser powered by solar panels to split water into hydrogen and oxygen. The produced hydrogen is then burned in an instant water heater to generate hot water for the building. This approach completely decarbonizes the operating fuel that would otherwise come from fossil fuels such as methane or LPG, resulting in a reduction of 3 kilograms of CO₂ for every kilogram of LPG used. Additionally, replacing LPG with renewable hydrogen for cooking/heating would reduce CO₂ emissions, measured by the drop in LPG use. Besides, for grid-connected buildings, RH suggested hydrogen could provide an energy buffer when electricity supply is constrained. Finally, RH proposed tracking emission reductions, increasing renewable energy percentage, and comparing performance against conventional systems to measure decarbonization impact.
	SJS	SJS believes that hydrogen technologies can significantly contribute to the decarbonization of the built environment by replacing fossil fuels in energy systems. He emphasizes that a majority of the world's energy is derived from molecules rather than electrons, and utilizing hydrogen as an energy carrier can facilitate a shift from fossil fuel-based to hydrogen-based systems.
	TW	TW emphasizes that hydrogen technologies contribute significantly to the decarbonization of the built environment. By utilizing hydrogen, which contains no carbon, the technologies effectively displace carbon emissions associated with conventional fuels such as LPG, methane, diesel, and others. This displacement directly leads to a reduction in carbon emissions, aligning with efforts to combat climate change and transition towards a low-carbon economy.
	TN	Hydrogen technologies, as highlighted by TN, offer promising contributions to decarbonizing the built environment. TN mentioned the potential of dual-fuel systems using hydrogen to power machinery at construction sites, reducing reliance on fossil fuels. Small-scale electrolysers integrated with solar panels can produce and store green hydrogen, providing clean energy for buildings, especially in remote or off-grid areas. Hydrogen-powered generators emitting only water can be eco-friendly alternatives to diesel generators, serving diverse facilities. Despite challenges like cost and public perception, the effective use of hydrogen technologies holds promise for reducing carbon emissions in specific contexts. The participant emphasized the importance of clear government initiatives and roadmaps to accelerate hydrogen technology adoption and promote sustainable change.
	VG	VG emphasizes the substantial impact hydrogen can have on reducing carbon in the built environment through its application in cement production, a major use case. This highlights the potential of hydrogen in contributing to the decarbonization of the built environment, particularly through key industries like cement production.

	ZJ	ZJ pointed out that hydrogen technologies indeed have the potential to significantly contribute to decarbonizing the built environment. He mentioned the UK government's plan to blend up to 20% of hydrogen into the national gas grid, effectively removing 20% of carbon emissions from natural gas. This move alone could make a substantial environmental impact. Additionally, the utilization of hydrogen in various sectors such as industry, transportation, and residential heating holds promise for reducing carbon footprints. High-temperature fuel cells, like solid oxide fuel cells, can improve the efficiency of combined heat and power (CHP) systems, making them an eco-friendlier alternative in regions with colder climates like Europe.

Table 43: Question 2 - How can hydrogen technologies contribute into decarbonisation of the built environment and how can this be measured? Participants' view

Question 2 - How can hydrogen technologies contribute into decarbonisation of the built environment and how can this be measured? Participants' view

Question	Participant	Response
2.1 How do you believe HT can be considered as environmentally friendly technologies?	DA	DA highlighted hydrogen production methods, stressing challenges like carbon capture in steam methane reforming. " <i>Green hydrogen</i> " from electrolysis was noted as a greener alternative, yet cost and sustainability concerns persist, especially in regions like Korea. Energy loss in production and usage, especially in high-cost green energy regions, was underscored. Transportation challenges were acknowledged, proposing solutions like using ammonia or methanol as carriers. DA shed light on crucial challenges for hydrogen tech's environmental viability: production efficiency, cost-effectiveness, and eco-friendly transportation. DA emphasizes the environmental friendliness of hydrogen technologies, particularly in contexts where a stable supply of electricity is vital for manufacturing-based economies like Korea. Due to Korea's dependence on imports for traditional energy sources like natural gas and coal, the country seeks to decarbonize its economy. However, limitations in land availability and public concerns over renewable energy options make hydrogen a more suitable solution. Korea's success in fuel cell vehicle production and fuel cell power plant installations underscores the potential of hydrogen technologies in providing a reliable and clean energy source to support the country's manufacturing needs.
	EEF	EEF highlights the key environmental advantage of hydrogen technologies, specifically the reduction or elimination of CO ₂ emissions and pollutants associated with conventional fossil fuels. Hydrogen technologies produce water as a by-product, demonstrating a cleaner and greener alternative. He acknowledges the complexities related to the materials required for constructing these technologies but emphasizes the fundamental advantage lies in their potential to significantly reduce harmful emissions, aligning with decarbonization goals for a more sustainable built environment. EEF points out the potential benefits of hydrogen technologies, including reduced or carbon-neutral operations for companies, ultimately leading to cleaner air and contributing to decarbonization. However, he also highlights the challenge in perceiving these benefits at an individual level, emphasizing that the benefits become more tangible and impactful when a

		collective shift towards a hydrogen economy occurs, demonstrating the systemic nature of the transition. This underscores the need for a broader societal and systemic perspective to fully appreciate and measure the advantages of hydrogen technologies.
	SGJA	SGJA emphasizes that hydrogen technologies can be deemed environmentally friendly if produced using renewable energy sources or biogas, thereby minimizing associated emissions. The key lies in targeting specific applications where energy efficiency or electrification is a priority. SGJA points to industries like cement production in Mexico, which have significant thermal energy needs, highlighting the potential of hydrogen to provide clean and efficient solutions in such contexts. By promoting the use of hydrogen in sectors with substantial energy demands and integrating renewable sources in its production, hydrogen technologies can play a crucial role in global decarbonization efforts.
	RGJA	RGJA asserts that while no human activity is entirely without environmental impact, hydrogen technologies can be regarded as zero-emission technologies in the broader context. Although various stages of the hydrogen technology lifecycle may involve some carbon footprint due to production processes and materials, when compared to current practices, hydrogen technologies present a superior option in terms of reduced environmental impact.
	JAGR	<i>"I think it's the magic of hydrogen. The magic of creating a fuel from water".</i> Hydrogen technologies, while not exempt from the need for various minerals and metals in their supply chain, can indeed contribute to a reduction in ecological footprint. Circular economy principles, emphasizing recycling and efficient use of materials, play a crucial role in mitigating the environmental impact associated with hydrogen production. Moreover, compared to certain alternatives like batteries, hydrogen technologies generally involve a comparable or even potentially lesser demand for minerals, affirming their potential as a cleaner energy option. Striking the right balance between technological advancement, circular practices, and efficient resource management is essential for maximizing the positive environmental impact of hydrogen technologies.
	JH	Hydrogen technologies can be considered environmentally friendly, particularly when produced from renewable energy sources. <i>"If it's from renewable energy, I think the more environmentally friendly than batteries because of the resource considerations".</i>
	KQ	Hydrogen technologies can be considered environmentally friendly primarily because hydrogen produces no pollution at the point of use and can be produced using renewable energy sources. By replacing existing or potential future technologies that are less environmentally friendly, hydrogen contributes to a cleaner and more sustainable environment. Utilizing renewable sources of energy like solar and wind to power the electrolysis process for green hydrogen production is essential to ensure the overall greenness and sustainability of the hydrogen fuel. Relying on the

		grid, which might still be powered by fossil fuels, would not align with the objective of achieving a genuinely green hydrogen production process. By integrating a higher proportion of renewables into the grid, the entire energy ecosystem becomes greener, positively impacting the greenness of hydrogen production.
	MR	MR emphasizes that hydrogen technologies can be deemed environmentally friendly when certain criteria are met. Firstly, the input energy used to produce hydrogen must be 100% green, ensuring a clean source of energy. Secondly, the application of the technology should be efficient and carefully considered, ensuring that hydrogen is the optimal choice based on a comprehensive evaluation of all aspects. Additionally, the entire production process, including the production of components needed for hydrogen technology, must also adhere to environmentally friendly practices for it to be considered truly green.
	PL	PL emphasized that assessing the sustainability of hydrogen production involves defining clear criteria. The first major criterion is the carbon content associated with hydrogen production, including assessing the carbon footprint of the entire production chain. This involves evaluating if the electricity used in hydrogen production is from renewable sources and analysing the carbon footprint throughout the entire process, including compression and transportation. However, carbon content is not the only criterion. Other considerations include the sustainable use of critical materials, addressing environmental impacts such as water use and potential atmospheric leakage, and evaluating the social implications of hydrogen production, especially in terms of equitable domestic usage in countries that both import and export hydrogen. Developing a comprehensive framework to evaluate hydrogen's sustainability based on these criteria is an ongoing endeavour, with discussions taking place at international levels. PL acknowledged that producing green hydrogen in off-grid, remote areas using solar or other renewable sources is a valid and environmentally friendly approach. However, they emphasized that while this method is compelling for areas not connected to the grid, it might constitute a minor portion of the overall hydrogen production, likely less than 1% of what is needed globally. He also emphasized the importance of considering various factors, such as land use, impact on biodiversity, water use, and energy efficiency. While it is an interesting case, addressing these parameters is crucial to ensure that the production of green hydrogen is indeed environmentally friendly and sustainable. Additionally, the energy efficiency of this process might not be very high due to the need to reconvert hydrogen back to electricity.
	TW	TW emphasizes the environmentally friendly aspects of hydrogen technologies, particularly their recyclability. He mentions that companies like Enapter have a return-to-base methodology where all parts of the hydrogen technologies, including the nano membrane, can be recycled and reconditioned. Since hydrogen technologies predominantly use metal parts, they contribute to a more sustainable approach by reusing materials and minimizing waste.

	TN	TN brought up the perception of hydrogen production, emphasizing the need for a transition to cleaner and greener methods: <i>“When we produce hydrogen, then we do also use activity then if that is from grid then it is, but it’s not 100% green. But when it is produced from renewable, then it is 100% green”.</i> TN emphasized that hydrogen technologies are considered environmentally friendly because hydrogen does not emit CO₂ when produced through electrolysis. However, he also pointed out the importance of considering the source of electricity for electrolysis; if the electricity comes from the grid, which is not entirely green in New Zealand, there is still a carbon footprint associated with hydrogen production.
	VG	VG highlighted that hydrogen technologies are environmentally friendly due to their operational phase, during which no CO₂ is emitted. He also mentioned that in the case of electrolyzes, considering the entire supply chain and production of equipment is important. Various standards, like the European regulations, ensure that hydrogen is classified as “green” based on specific criteria. The renewable energy used must be newly produced and used at the same time as hydrogen production. In summary, hydrogen technologies are considered green due to their lack of CO₂ emissions during operation.
	ZJ	Hydrogen technologies can be considered environmentally friendly through advancements in hydrogen production methods. While hydrogen production has historically relied on natural gas, the integration of carbon capture, utilization, and storage (CCUS) technologies minimizes carbon emissions associated with the process. For example, using CCUS can reduce CO₂ emissions to as low as 20 grams per kilowatt. Moreover, there's a shift towards using renewable electricity through electrolysis to produce hydrogen, further enhancing its environmental credentials. To make hydrogen more eco-friendly, efforts need to focus on storage, distribution, and policy support. Storage solutions are crucial to ensuring hydrogen can be effectively utilized across various applications. Additionally, establishing a supportive policy framework, including financial assistance from the government, is vital to driving widespread adoption, as it can help offset the current costliness of hydrogen.
2.2 How do you think GH and HT can contribute to ecological footprint reduction? What evidence do	DA	DA emphasizes the potential of green hydrogen in significantly reducing the ecological footprint. By producing hydrogen using cost-effective renewable energy, the scope of decarbonization can extend beyond just the built environment, encompassing a wide array of energy-dependent sectors. <i>“I believe that if we find a way of generating hydrogen using relatively cheap renewable energy. And then we have a solution to decarbonize not only the built environment, but everything that uses energy basically”.</i> DA discussed various types of hydrogen, particularly “blue hydrogen” with less than 5 kilograms of CO₂ emissions per kilogram of hydrogen, meeting legal criteria. This contrasts with Europe (2 kg CO₂ per kg H₂)

you have that green hydrogen producing zero or near zero-emissions?		and the USA (3 kg CO ₂ per kg H ₂), illustrating more lenient policies in Korea for considering hydrogen as “blue”.
	SGJA	SGJA notes that Green Hydrogen and hydrogen technologies can significantly contribute to reducing ecological footprints through “<i>the raw materials used in their production</i>”. According to SGJA, instead of relying on coal or natural gas for high-temperature processes and burning, the substitution involves utilizing hydrogen for combustion.
	KQ	KQ noticed that utilizing renewable sources of energy like solar and wind to power the electrolysis process for green hydrogen production is essential to ensure the overall greenness and sustainability of the hydrogen fuel. Relying on the grid, which might still be powered by fossil fuels, would not align with the objective of achieving a genuinely green hydrogen production process. By integrating a higher proportion of renewables into the grid, the entire energy ecosystem becomes greener, positively impacting the greenness of hydrogen production.
	TN	TN mentioned that for the plant in Taupo, they use geothermal power directly connected for green hydrogen production. However, for the plant being developed in Auckland, they aim to use grid electricity due to limited alternatives. They are exploring options for commercial arrangements to access renewable energy, such as supply from geothermal or solar power plants, to ensure a green energy source for hydrogen production.
2.3 Green/low carbon hydrogen is an alternative fuel; how many years do you think may it take to replace fossil fuel with hydrogen to achieve net-zero	ZJ	ZJ suggests that the emissions associated with green hydrogen can be assessed and measured through carbon counting and life cycle analysis. These methods involve examining the carbon content at various stages of production and analysing the environmental impact throughout the entire life cycle of hydrogen production. By utilizing these techniques, one can gauge and validate whether green hydrogen indeed results in minimal or near-zero emissions.
	DA	DA provides a comprehensive perspective on the timeline for green hydrogen to replace fossil fuels. He highlights the commercialization aspect, noting that for blue hydrogen, mass production could be around 4 to 5 years away, making it accessible and cost-effective for various industries. However, certain heavy industries like steel, cement, and glass manufacturing may take 10 to 15 years to transition to blue hydrogen. As for green hydrogen, he suggests it might take 20 to 30 years to achieve reasonable cost-efficiency through advancements in electrolysis technology. The involvement of politics and influential fossil fuel companies adds complexity to the transition, further affecting the pace of adoption.
	SGJA	In terms of energy, hydrogen has the potential to replace fossil fuels for energy production. It is technically viable, and advancements are being made to enhance its economic feasibility. By approximately 2040 to 2050, substantial decarbonization within the energy sector could be attainable with hydrogen playing a crucial role for energy purposes.

emissions goals	JH	JH acknowledges the possibility of achieving net-zero emissions by 2050 but raises concerns about the current trajectory and the reliance on certain approaches like carbon credits and tree planting to offset emissions. He emphasizes that the root cause of the issue lies in fossil fuels and stresses the urgency to address this fundamental challenge. Hydrogen technologies hold significant potential for remote locations and off-grid settings. Their usefulness is particularly pronounced in smaller off-grid areas compared to massive, centralized applications. The adaptability and scalability of hydrogen technologies make them well-suited for addressing energy needs in decentralized and remote contexts, offering sustainable and reliable energy solutions.
	KQ	The complete replacement of fossil fuels is a complex and long-term endeavour, contingent on various factors such as technological advancements, policy frameworks, societal adoption, and economic considerations. It is challenging to predict an exact timeline, but efforts are ongoing to transition to cleaner, more sustainable energy sources to mitigate environmental impacts and reduce dependence on fossil fuels.
	MS	MS believes that green hydrogen will inevitably replace fossil fuels due to its abundance in the universe. However, predicting the exact timeframe for this transition is challenging. Progress is already being made in various sectors, such as shipping, trains, buses, and long-duration transportation, with hydrogen-powered options emerging. MS estimates that it may take between 20 to 30 years for hydrogen to become commonplace, and in around 20 years, hydrogen modules could be as common in households as microwave ovens. However, for hydrogen to significantly impact the energy landscape, widespread adoption in industrial sectors is crucial.
	SJS	<i>“When we see the world that we understand clearly that fossil fuel area has to stop. And if we want to stop. And if you want to stop, let’s say it is the threat of global warming, then only we have to make a threat to something. Fuel. And then we understood very well that there is an infrastructure in need. And there’s a lot of things which also has to come. But the most crucial part to do this kind of change stopping fossil fuel industry is to produce hydrogen in the most efficient and the most cheapest way”.</i>
2.4 What are your insights on the integration of hydrogen technologies in the built environment? Which application do you consider most advantageous for	DA	<i>“Japan is a world champion in terms of residential and commercial building fuel cells. I can’t recall the statistics now, but they’ve got significant number of fuel cells that are applied specifically in residential buildings and commercial buildings and I see great potential”.</i>
	EEF	EEF expresses doubts about the suitability of hydrogen in stationary applications, particularly in comparison to batteries, citing their weight and complexity as potential concerns. He does not perceive hydrogen as a strong fit for stationary power applications due to these reasons. EEF expresses reservations about small-scale power-to-power hydrogen systems. He highlights concerns about the efficiency and practicality of such systems compared to battery storage solutions. EEF emphasizes that batteries offer higher efficiency and simpler system configurations without the complexities associated with hydrogen systems, such as electrolysis, tanks, and fuel cells. He points out that for stationary applications, battery systems are a more efficient and effective solution, and he questions the

decarbonizing of the built environment, and what are the respective advantages and disadvantages?		practicality of hydrogen systems in this context due to potential leakage and associated complexities. EEF suggests that centralized hydrogen may present a more viable and efficient use case for hydrogen. <i>“Hydrogen can generate heat and electricity with the only emissions being water”.</i>
	JAGR	JAGR highlights that in equatorial countries like Mexico, hydrogen may not be needed for heating water at the residential level due to the efficiency of existing technologies such as solar thermal boilers. He acknowledges the varying energy needs and contexts of different countries, noting that regions like Canada and Nordic countries might find hydrogen more relevant for specific applications. JAGR recognizes Japan as a significant proponent of using hydrogen for residential applications, particularly through combined heat and electricity power systems. This approach can enhance energy efficiency within residential contexts, showcasing the potential benefits of integrating hydrogen technologies for efficient energy use. Hydrogen stands out due to its ability to effectively store energy over extended durations, a particularly valuable attribute for countries with pronounced seasonal energy needs like Germany. This is achievable by storing hydrogen in salt caverns and subsequently utilizing it to generate electricity or provide heat, catering to diverse energy requirements. <i>“The other interesting thing of hydrogen is when it is compared to other it is a capability to efficiently store energy for long periods of time, which is something very interesting for countries like Germany that has a very seasonal energy demand because you can store the hydrogen in salt caverns and then bring it out and convert to electricity or heat or whatever you need”.</i> <i>“I couldn’t understand (Japanese people doesn’t speak good English) why Japan are pushing the hydrogen technologies in the built environment but for sure there is a good reason”.</i> <i>“The idea of creating electricity from hydrogen would be a feasible no in the economical wait, but in large scale so far”.</i> Hydrogen technologies offer a practical solution for remote areas and islands, detached from conventional power grids. The cost-effectiveness stems from avoiding the need for extensive infrastructure, making localized hydrogen production and utilization a viable option. As highlighted by JAGR, this approach is driven by the inherent expense of traditional fuels rather than a direct reduction in hydrogen costs. Developed countries prioritize decarbonization due to the acknowledged severe consequences of fossil fuels on the environment and are committed to climate change mitigation. Conversely, undeveloped countries emphasize economic development, leveraging their available resources, and decarbonization may not be their immediate priority. However, they recognize the potential of hydrogen technologies as an accessible opportunity. Hydrogen production and utilization are not overly complex, presenting a chance for these countries to embrace advancements in technology. This transition can lead to substantial economic and social

		benefits, creating job opportunities and propelling the country toward a more prosperous economic state. <i>“The collateral impacts of physical fossil fuels, a public health, a dependence of other countries to get a reliable energy supply, so when people say hydrogen is expensive, I try to convince them through the explanation of the collateral impacts fossil fuels and also the opportunity”.</i> <i>“We can migrate from being fossil fuel providers to be hydrogen providers”.</i> <i>“Technology is in a very early stage of maturity. It’s mature enough to go to the market, but I think that because I assemble it in the past electrolyzers. So I discovered it’s not rocket science. It’s very easy and everyone can do it”.</i> <i>“You can take the opportunity to industrialize your country”.</i> Green hydrogen technologies offer several benefits to users and the environment. Firstly, they contribute to a cleaner environment by reducing pollution and mitigating climate change through the production of green, emissions-free hydrogen. Green hydrogen can support a developed economy and is aligned with the global shift towards renewable and sustainable energy sources. The longer value chain associated with hydrogen technologies, compared to traditional fossil fuels, also stimulates economic growth and job creation.
	JH	<i>“Hydrogen technologies hold significant potential for remote locations and off-grid settings... smaller off-grid areas compared to massive, centralized applications”.</i>
	KQ	Hydrogen fuel cells are gaining traction in critical sectors demanding reliable power, such as banking, computing, and healthcare. Their use is expanding, with a notable trend being the blending of hydrogen with natural gas, a step toward emission reduction. Landlords have a growing interest in installing hydrogen technologies in their properties due to evolving regulations focused on reducing carbon emissions. These regulations are pushing towards lower carbon footprints, promoting cleaner energy alternatives. Hydrogen technologies are gaining traction as their safety, efficiency, and environmental benefits have significantly improved over the past few decades. Moreover, the development and implementation of relevant codes and standards ensure the safe integration of hydrogen technologies, making them an attractive option for landlords aiming to adopt more sustainable and environmentally friendly solutions. KQ highlighted that the application of hydrogen in commercial and residential buildings presents unique challenges compared to industrial and transportation sectors. The complexity arises from the distributed nature of energy consumption in households and businesses, where the primary energy sources are often distant and need to be safely integrated into local infrastructure. She emphasized that integrating hydrogen into buildings necessitates considering various aspects, such as adapting existing piping systems to

	handle hydrogen at specific pressures and ensuring that appliances are compatible with hydrogen as a fuel source. The infrastructure changes required for safe and efficient hydrogen use at the consumer level pose significant challenges. KQ also mentioned a resource that provides an extensive view of the applicable codes and standards for different hydrogen applications and regions, underlining the importance of understanding and addressing these standards to facilitate the adoption of hydrogen technologies in buildings. Hydrogen technologies demonstrate particular promise for remote, off-grid areas. Their potential becomes most apparent in these contexts, as they offer a pathway to localized energy production, storage, and utilization. In off-grid areas where traditional energy infrastructure might be lacking or impractical, hydrogen technologies present a viable solution for achieving energy self-sufficiency. Moreover, the true power of hydrogen technologies lies in their ability to facilitate the broader adoption of renewable energies. By allowing for the oversizing of renewable energy systems and leveraging excess energy to produce and store hydrogen via electrolysis, these technologies can ensure a more consistent and reliable energy supply. This approach optimizes the use of renewable sources and minimizes energy wastage, making it an ideal fit for remote, off-grid locations. Hydrogen technologies offer several benefits, including quieter systems, particularly in fuel cells where there are no moving parts. This advantage makes hydrogen-powered solutions suitable for various applications such as recreational vehicles, motor homes, and mining vehicles, enhancing safety and reducing emissions in confined spaces. Moreover, hydrogen can be a viable alternative to noisy and pollutant-emitting diesel generators. KQ elaborated on the complexities associated with integrating hydrogen into commercial and residential buildings. The challenges stem from the fact that the primary energy sources for households, such as electricity, often originate from distant locations where combustion or chemical processes occur. To enable the seamless integration of hydrogen technologies, Karen emphasized the necessity of adhering to stringent standards for connecting renewables and hydrogen to the grid. These standards must account for maintenance shut-offs, manage intermittency associated with renewable energy, and address diverse infrastructure issues. She raised critical considerations about the infrastructure within homes, questioning whether existing piping, typically designed for other fuels, can handle hydrogen at specific pressures. Additionally, KQ highlighted the potential failure of appliances designed for a different fuel, underscoring the need for careful planning and assessment when transitioning to hydrogen. In addressing these challenges, KQ referred to a valuable resource that centralizes information on the diverse codes and standards relevant to different hydrogen applications and regions, aiding in comprehensive planning and adoption strategies.

	MR	MR suggests that the strengths of hydrogen lie in its versatility as a fuel and its ease of transportation, making it a convenient energy carrier. It can be easily stored and transported, differentiating it from electricity, a major competitor. However, she acknowledges that hydrogen is not a one-size-fits-all solution and its application can vary based on specific needs and contexts. For example, she mentions hydrogen to diesel conversion as a unique application, indicating that hydrogen has diverse potential uses. MR believes that compared to electricity, hydrogen is easier to transport, highlighting this as a strength. Another strength lies in the fact that hydrogen produces no carbon dioxide emissions, only water, making it environmentally friendly when derived from clean electricity. Additionally, hydrogen serves a dual purpose as an energy vector and a crucial molecule for the chemical industry, enabling potential decarbonization in both sectors. She expressed her perspective on the use of hydrogen for electrification versus appliances traditionally powered by gas. She advocated for electrification in households, emphasizing its efficiency in heating, cooking, and water heating without requiring excessively high temperatures. Furthermore, she noted that electric technologies in households are easier to maintain and ensure safety. On the other hand, for larger complexes and industrial applications, she recommended utilizing hydrogen for gas-fired boilers or furnaces. This approach aligns with the potential for hydrogen to be a cleaner energy source for industrial processes and larger-scale heating requirements. Ultimately, her stance highlights the context-dependent suitability of hydrogen applications based on scale and purpose. MR discussed the utilization of heat, a by-product of hydrogen production, in buildings. She highlighted its potential to provide heating for buildings during the winter months. However, she noted that utilizing this heat in buildings during summer might be more challenging. For larger applications or facilities, MR suggested using the excess heat for processes that require a warm-up phase or for heating other parts of the facility, demonstrating the importance of efficient heat recovery within the overall production process. This approach optimizes the utilization of the heat by-product, promoting sustainability and resource efficiency. Electrification through hydrogen presents a promising opportunity, particularly in determining when it is more efficient to utilize hydrogen directly versus electricity. The choice depends on the scale and context of the application. For individual or single-house setups, electrification may be more suitable, given safety considerations and the need for a dedicated and secure space for hydrogen systems. On the other hand, larger complexes and buildings might find it easier to manage hydrogen, especially when there is a dedicated entity overseeing safety, efficiency, and maintenance of the hydrogen systems. MR highlights the application of hydrogen technologies in remote communities facing extreme climates. She sees potential in using hydrogen

		to reduce the load on the electricity grid, particularly in areas with harsh weather conditions. While she doesn't specifically mention New Zealand, her comments suggest that New Zealand, too, could potentially benefit from hydrogen technologies, especially in areas where reducing grid load is a priority.
	MS	MS highlights the challenges of electricity provision in remote Asian areas due to frequent grid outages and the associated cost burdens. The suggested solution involves integrating hydrogen technologies into the built environment, particularly through self-refuelling fuel cells (SRFCs), powered by renewables or the grid, allowing hydrogen production for later use. The key advantage lies in cost-effectiveness and sustainability, addressing the issues of traditional standby solutions like batteries and diesel generators. Modular electrolyser technology plays a crucial role, enabling scalability and efficient implementation, making SRFCs a promising application, especially in telecommunications. However, challenges remain in the widespread adoption and integration of hydrogen technologies, necessitating further advancements and infrastructure development.
	PL	PL shared an innovative approach involving a unit with a reversible fuel cell and an electrolyser, designed for residential and building applications. This unit could ensure a certain degree of energy autonomy for a group of buildings by effectively managing hydrogen levels and addressing intermittency issues.
	RH	RH believes that small-scale projects involving electrolysers, storage, and hydrogen fuel cells are indeed viable. An Australian project by a company called Lava demonstrates the potential for a hydrogen battery, essentially a reversible fuel cell, providing 40 kilowatt-hours of storage. However, the cost may currently be higher than battery solutions like Tesla Powerwalls. In terms of efficiency, burning hydrogen directly can achieve higher efficiency compared to converting it back to electricity. Utilizing hydrogen for cooking, hot water, and space heating, which constitute a significant portion of energy usage, can be an efficient approach, especially when considering the high efficiency achievable through combustion. RH suggests that for emergency power needs or vital energy applications, a small fuel cell could be valuable. RH believes that electrification is effective as long as rapid heat control is not a crucial requirement. For process heat, particularly in industries like rotomolding, achieving the same level of controllability with electricity can be considerably more expensive - three times the cost of using gas burners. The decision between electrification and gas often comes down to a trade-off between capital cost and running cost. He also mentions the importance of rapidly deploying renewable energy sources like wind turbines to ensure a sustainable energy supply. RH believes that it's not about New Zealand accepting hydrogen, but rather about the use cases and economic viability of hydrogen technologies. He suggests that the current use cases for hydrogen, such as producing ammonia for fertilizers, are well-established and moving forward. However, he does not see a compelling use case for using hydrogen as a

		residential storage medium in urban centres, considering it not a smart energy or cost-effective solution. He mentions that the focus has been on fringe off-grid applications where the use case has been made more thoroughly due to the unique circumstances of those applications. In terms of commercial use, he notes that there are cases where hydrogen begins to make sense, especially for controllable process heat, but emphasizes that the market and practicality, not just subsidies, should drive the adoption of hydrogen technologies.
	SJS	SJS explains that the requirements for heating or cooling in a household can vary based on the climate zone. In Europe, heating is typically required, making hydrogen useful for providing this heat. Conversely, in warmer regions like Asia and Australia, the need for heat is lower, making the utilization of hydrogen for this purpose less relevant. SJS highlights that hydrogen systems, like home power solutions, generate heat as a by-product during the electrolysis and fuel cell processes. In regions where energy is already abundant and inexpensive, the utilization of hydrogen primarily for heat may not be as economically beneficial.
	TW	TW suggests that adopting European methods of heating, such as using boilers and radiated hot water systems, can be a viable approach for integrating hydrogen in heating applications. Additionally, he highlights high-temperature heat pumps as a potential technology to incorporate hydrogen. The two primary areas where hydrogen can be prominent are hot water systems and cooking appliances (hobs). These applications represent clear front runners for integrating hydrogen into residential and commercial heating systems. According to TW, small cities or even micro-communities within larger cities can indeed be taken off the grid and made self-sufficient in terms of energy. He points to initiatives like the one by LIA and ATCO in Western Australia, where they have already started exploring this concept. Trials have been conducted, such as building a small neighbourhood with centralized energy hubs equipped with hydrogen blending and fuel cell systems, along with batteries and inverters. This centralized hub then distributes energy to the surrounding neighbourhood, showcasing a potential model for energy self-sufficiency on a smaller scale. Hydrogen technologies (electrolyser) can be connected to photovoltaic (PV) systems, direct DC voltage or 230 Volt AC voltage, making it compatible with various renewable energy sources. TW and his company can work with PV systems, but they prefer not to focus on a specific generation method, aiming to be adaptable to any renewable source that may be installed. They can connect to the inverter side and manage the loads as needed, ensuring flexibility in their system's integration with renewables. TW mentions that while they have considered the idea of launching pilot projects in collaboration with architects and engineers to demonstrate viability, they have been primarily focused on their first pilot project and seeking opportunities to assist ongoing projects with technology integration. They are also working on marketing to increase their brand

		visibility and welcome inquiries from potential partners to develop concepts and provide suitable hydrogen systems for various scenarios. TW believes that the hydrogen system (electrolyser) could be beneficial for New Zealand, especially in the residential space where individuals aspire to achieve energy self-sufficiency. However, they point out that going fully hydrogen may not be the most efficient approach, so a hybrid system involving hydrogen and batteries is suggested. This approach aims to optimize efficiency by using solar and batteries for low-end loads and employing hydrogen for high-end loads like cooking, hot water, and space heating. The combination of hydrogen and batteries allows for a well-balanced energy arrangement, ensuring a consistent power supply even during days with limited sunlight. TW sees potential in utilizing grid-connected hydrogen to manage the increasing energy demand and prevent overloading of existing electricity infrastructure. This approach involves using hydrogen technologies as a form of demand response. When the demand for electricity spikes, the electrolysers connected to the grid can temporarily reduce their power usage, helping to balance the load on the network. This effectively acts as a distributed storage mechanism, storing energy at various end-user points and making it accessible to consumers. By strategically managing energy distribution and storage, grid-connected hydrogen can play a role in addressing the challenges of increasing energy demand and supporting a more sustainable energy infrastructure.
	VG	VG describes the primary application of green hydrogen, emphasizing that while a portion may be allocated for energy storage, the significant focus is on exportation. The highest demand and price for hydrogen are anticipated from international markets, particularly Europe. Local use cases (Saudi Arabia) include mobility, green steel production, and various industrial applications. However, the overarching strategy revolves around capitalizing on the international market for green hydrogen due to its substantial demand and potential economic benefits. VG acknowledges that heating in buildings is not a significant concern for their region (Saudi Arabia), but they point out that a notable use case for hydrogen in buildings could be heating. He mentions the use case known as waste to energy or waste to heat. This involves utilizing local environments, especially in larger industries, to harness waste heat for various purposes. It's seen as a great approach if there is an appropriate local setup to make use of this waste heat effectively. This approach essentially repurposes waste heat for beneficial applications like heating spaces or water. VG outlined the extensive applications of hydrogen technologies within the Neom Project, a significant undertaking aiming to transform Saudi Arabia's economic dependency on oil. The hydrogen ecosystem being developed at Neom encompasses hydrogen production through a 2.2 GW electrolyser, transportation via a regional pipeline system, local use cases including mobility, green steel, and cement, and even export of hydrogen. Neom is at the forefront of building a future powered by renewable energies, addressing various global challenges. Specifically, in hydrogen mobility, efforts are focused on establishing hydrogen refuelling

		infrastructure, particularly for heavy-duty vehicles like trucks and buses, recognizing the efficiency benefits hydrogen offers in such applications. Additionally, the adoption of hydrogen vehicles is expected to be a mixed approach alongside electric vehicles at the national level.
	ZJ	<i>“So with the reasonable sum, some light resources and it is doable for the residential scale hydrogen production and then using enough fuel cells combined in the CHP units in the residential houses or you just using the PEM fuel cells for generating electricity only it is a viable technology, but it’s not a very affordable technology at the moment because electrolyser and also fuel cell and the whole integration of the system into the small scale will be quite costly for the local consumers”.</i>
2.5 What challenges, problems & drawbacks do the hydrogen technologies have that may affect the decarbonisation?	DA	DA highlights several challenges and drawbacks associated with hydrogen technologies. Firstly, green hydrogen produced through electrolysis is expensive, posing a barrier to widespread adoption, especially in countries with high energy costs like Korea. Secondly, the green hydrogen production and hydrogen technologies are not yet fully commercialized. The disparity in the cost of electricity production, particularly from renewables like solar power, between different regions further contributes to the challenge of cost-effective hydrogen production. The issue of hydrogen transportation is another significant hurdle, with limited availability of hydrogen vehicles and concerns about the environmental impact of transportation methods like diesel-fuelled trucks. He underscores the current inefficiency of existing technologies, specifically pointing out the efficiency levels of prominent fuel cell types. He draws attention to the energy-intensive nature of hydrogen production, highlighting the substantial electricity and water required to generate one kilogram of hydrogen. This inefficiency raises concerns about sustainability and the environmental impact of the production process. Additionally, DA discusses the need for substantial advancements in technology to enhance efficiency, aiming for 100% efficiency in electrolysis systems. Moreover, he emphasizes the importance of cost-effective and commercially available solutions for effective deployment, underscoring the need for readily accessible technologies to drive widespread adoption. DA deems hydrogen production energy-extensive due to high electricity and water requirements. Solution: 1. Optimizing electrolysis efficiency is a crucial step toward enhancing energy efficiency in hydrogen production, potentially revolutionizing the sustainability of hydrogen technologies. 2. <i>“The more hydrogen we make, it’s a rule of thumb in the economics, right. The more you make something the lower cost, it will have. We need to make as much harder than as possible, and it will eventually decrease the cost of delivered hydrogen”.</i>
	EEF	EEF identifies the primary challenge in hydrogen technologies as high capital expenditure (CapEx) related to production processes and supply chains. He emphasizes that the hydrogen industry is still in a relatively early stage, and it takes a considerable amount of time, possibly decades, for supply chains and production lines to mature and for costs to decrease significantly. While efforts are being made to address this issue and bring down costs, the pace of progress is not as rapid as desired, underscoring the

		need for sustained investment and advancements in technology to overcome this hurdle. <i>“It should go down just not as fast as we wish”.</i>
	SGJA	SGJA highlights that the main challenge facing green hydrogen production in Mexico is more political than technical. The current administration is heavily focused on supporting state-owned companies involved in fossil fuels, which hinders the prioritization and advancement of green hydrogen technologies. He does not explicitly mention specific technical challenges related to production and storage of hydrogen.
	RGJA	RGJA identifies two primary issues within hydrogen technologies: industrial capacity for production, especially in the early stages of the value chain, and the supply of critical materials, particularly for electrolyzers. Regarding critical materials, the development of AEM technology, which utilizes noncritical materials, is seen as a positive step. However, its technological advancement is still in its early stages, making it less comparable to existing technologies like PEM or alkaline electrolyzers.
	JAGR	JAGR highlighted two key points. Firstly, in regions with milder or warmer climates, hydrogen adoption might not be necessary as photovoltaic systems can effectively provide sufficient energy. Secondly, the cost-intensive nature of hydrogen transportation is a significant factor affecting its feasibility and adoption. The current economic challenges, as large-scale hydrogen production is often seen as more cost-effective due to economies of scale. these technologies face significant challenges. One major obstacle is the need to develop a comprehensive infrastructure for hydrogen, which requires substantial investment and planning. Creating cost-effective solutions by scaling up production, improving efficiencies, and reducing manufacturing costs is essential. Additionally, addressing technical challenges related to system behaviour, energy density, and overall efficiency is crucial to enhance the adoption and effectiveness of hydrogen technologies.
	JH	JH highlights two significant hurdles in the adoption of hydrogen technologies, primarily the cost and the need for judicious utilization of key resources. He underscores the importance of choosing technologies with lower resource intensity and emphasizes the effectiveness of managing building envelopes for increased efficiency. While cost is a notable obstacle, JH emphasizes the need to consider broader systemic approaches and avoid relying solely on technological solutions. The key challenge for green hydrogen and hydrogen technologies lies in infrastructure development and the need to transition from existing fossil fuel-dependent infrastructure to hydrogen-ready systems. The vast investment and subsidies directed towards fossil fuels create an uneven playing field for hydrogen technologies. It is crucial to strategically select applications where hydrogen can excel, such as forklifts in enclosed spaces or long-distance transport decarbonization. Additionally, focusing on decarbonizing industries like petroleum refining through the use of green hydrogen and ammonia production is imperative for successful adoption and implementation of hydrogen technologies.

		The investment and substantial subsidies directed towards fossil fuels pose a significant challenge when transitioning to greener alternatives like hydrogen. The existing infrastructure and the financial interests associated with fossil fuels often hinder the rapid adoption of cleaner technologies. These investments and subsidies maintain a dependency on fossil fuels and create an uneven playing field for emerging sustainable solutions. Addressing this issue and redirecting investments and subsidies towards green technologies is crucial for a successful transition to a more sustainable energy future.
	KQ	KQ highlighted that the application of hydrogen in commercial and residential buildings presents unique challenges compared to industrial and transportation sectors. The complexity arises from the distributed nature of energy consumption in households and businesses, where the primary energy sources are often distant and need to be safely integrated into local infrastructure. There are challenges and drawbacks to consider. One significant challenge is the need to adapt existing infrastructure primarily designed for natural gas to accommodate hydrogen. Transitioning to hydrogen requires an incremental approach, gradually increasing hydrogen integration rather than an immediate overhaul. Additionally, the unfamiliarity with hydrogen technologies and their readiness for widespread adoption pose hurdles. Overcoming these challenges will require a phased and strategic approach, emphasizing the benefits while addressing concerns.
	MR	The safety concerns associated with hydrogen primarily revolve around its small molecular size, its explosive nature, and the need for specialized containment and transportation methods. Hydrogen's small molecule size makes it challenging to contain and store, necessitating high-pressure and low-temperature storage solutions. Addressing these challenges involves leveraging existing experience with gases like methane and adapting infrastructure to safely handle hydrogen. Additionally, considering hydrogen's unique explosion limits and optimizing transportation methods are key safety measures. <i>"I think that a big challenge also is to have bigger scale electrolyzers which become affordable".</i> In terms of weaknesses, MR points out the need for multiple transformations and careful consideration to minimize losses and leakages in various applications. Safety is also highlighted as a concern, requiring more investments compared to other fuel types. Additionally, the versatility of hydrogen, while a strength, can be a weakness if not optimally utilized for specific applications, potentially leading to inefficiencies and misplaced investments. MR identifies two primary problems with hydrogen technologies. Firstly, the requirement for clean water for the hydrogen production process is a challenge, emphasizing the necessity of a readily available clean water supply. Secondly, the production processes need further optimization, which is vital before scaling up the technology too rapidly. To address these issues, there is a collective effort in the industry to improve production processes, optimize resource usage, and find innovative solutions to ensure a more efficient and sustainable production

		of hydrogen. The focus is on careful optimization and addressing challenges step by step to ensure a successful and sustainable deployment of hydrogen technologies.
	MS	MS identifies challenges associated with using hydrogen technologies, particularly in buildings. One significant challenge is addressing the volume of hydrogen needed for a building. This necessitates compression and storage of hydrogen, often facing space restrictions within the building or the surrounding area. Managing safety concerns is another important challenge. While hydrogen is no more dangerous than LPG or propane, safety issues and precautions must be carefully addressed. MS emphasizes the importance of adhering to safety regulations and treating hydrogen storage similarly to other flammable gases, considering appropriate pressure levels for storage, especially in public refuelling stations or confined spaces. The primary challenges in hydrogen technologies revolve around storage, transportation, and efficiency. Storage poses a significant challenge, especially at large scales. High-pressure gas storage is effective on a smaller scale but becomes impractical for powering entire cities or industries. Alternative storage solutions like hydrogen absorption technologies are being explored to enable efficient transportation and storage. Transportation of hydrogen is also challenging. While liquefying hydrogen is an option, it involves significant energy loss due to the need for extremely low temperatures. Moreover, transporting hydrogen as a gas in high-pressure vessels faces practical limitations. Efficiency is another concern. The process of liquefying hydrogen or converting it back to a gas for use can result in energy losses. Additionally, energy efficiency during the production of hydrogen needs improvement to maximize the benefits of green hydrogen. To overcome these challenges, research and development efforts should focus on advancing storage technologies, exploring efficient transportation methods, and enhancing production processes. Innovation in storage, such as hydrogen absorption technologies or advancements in liquefaction methods, is crucial. Moreover, developing efficient and sustainable methods for hydrogen production is essential for widespread adoption and achieving the desired environmental benefits. MS highlights storage as a significant challenge for hydrogen technologies, especially at a large scale. The current Achilles heel is the storage and transportation of hydrogen. While steel vessels can store hydrogen at a small scale, larger applications pose challenges in terms of storage and transport, especially for powering entire cities or industrial facilities. High-pressure gas storage has limitations and alternative storage technologies need to be explored. One potential solution is to investigate alternative storage technologies beyond high-pressure gas. For instance, research is underway on substances that can absorb hydrogen, allowing for transport in normal pipelines. Another method is liquefying hydrogen, but this process involves extreme

		cold temperatures and results in some loss of hydrogen during transportation. Efficient storage and transportation solutions need to be developed to ensure the widespread use of hydrogen as a clean energy source. Producing green hydrogen on-site and using it as needed could be a more efficient approach.
	RH	RH suggests that while a residential project focused on self-sufficiency with hydrogen energy produced from solar power is technically possible in New Zealand, there are potential obstacles in terms of building consent due to current regulations. He acknowledges that exemptions may be granted for single houses but emphasizes the need for a strong economic case for such projects. The participant points out that the economics of using hydrogen for residential energy may not be favourable compared to battery storage and using the grid, particularly due to the inefficiencies in the hydrogen production and usage process. However, he notes that in specific contexts with a consistent need for high-quality heat, hydrogen may have a role. Ultimately, he concludes that while it is technically possible, the current economic viability and regulatory landscape may not support widespread implementation of such projects.
	SJS	According, to SJS, high initial cost is the main challenge. Hydrogen systems are still relatively expensive, although they are steadily becoming more affordable, especially with ongoing advancements and increasing adoption. SJS emphasizes the importance of removing unnecessary hurdles and barriers imposed by regulations to allow for a more rapid and smoother transition to hydrogen technologies. He draws parallels to the historical evolution of various industries, urging for a proactive approach to embrace advancements rather than being hindered by overregulation. SJS emphasizes the urgency of addressing climate change, likening it to a war where swift action is necessary. He underscores the need for collective willingness and urgency to combat climate change effectively.
	TW	Based on the conversation, some of the key challenges that TW discussed regarding introducing hydrogen technologies and green hydrogen in New Zealand include: Lack of clear regulations and standards specifically for hydrogen - there are gaps around how electrolyzers are treated, piping standards for residential use, storage standards, etc. This makes it difficult to get council approval. Lack of hydrogen-ready appliances like boilers and hobs that are certified for use in New Zealand. Major manufacturers are waiting to see confirmed hydrogen demand before certifying appliances. High upfront costs of around NZ\$70,000 for a full hydrogen system for a household, including solar, electrolyser, storage and appliances. This is not affordable for most homes currently. Getting government support and incentives has been difficult so far due to bureaucracy and reporting requirements. The government also seems hesitant to push hard on hydrogen over other energy options. Educating the public and building confidence in hydrogen's safety will take time, given historical incidents like the Hindenburg disaster. Proper

		standards, inspection regimes, and accountability measures will be important. Working across so many areas like regulations, appliances, infrastructure, and public perception means there are many roadblocks to coordinate and align to get hydrogen projects underway. Starting small with exemptions may be the way forward initially. The emissions trading scheme so far has just encouraged tree planting rather than new clean energy tech. New incentives like green certificates may be needed.
	TN	TN emphasizes that the main drawbacks of green hydrogen and hydrogen technologies are the cost and lack of ready regulations. These challenges can be addressed through efforts to reduce the cost of hydrogen production, which includes optimizing electrolyser technology and scaling up production. Additionally, developing and implementing clear and supportive regulations will provide a framework for the efficient and safe adoption of hydrogen technologies. These measures will contribute to overcoming the challenges and realizing the potential of hydrogen as a clean and sustainable energy solution.
	VG	According to VG, hydrogen for heating remain a critical drawback. Challenges of inefficiency in hydrogen production and utilization are inherent due to the physics involved, resulting in losses of at least half the initial electricity input. These challenges are difficult to overcome fundamentally. However, addressing cost challenges can be achieved through scaling up the hydrogen technology. As the scale increases in electrolysis, hydrogen vehicle production, and other applications, the production costs decrease due to economies of scale, similar to other technologies. These scaling efforts can significantly contribute to making hydrogen technologies more viable and accessible.
	ZJ	ZJ highlights several challenges in reducing carbon emissions through the application of hydrogen technologies. First, policy support from governments is crucial to encourage and facilitate hydrogen adoption across various sectors. While the UK is optimistic about hydrogen's role and provides substantial funding, the technology side presents challenges. For instance, the production of green hydrogen using electrolyzers can be expensive, especially with newer, more efficient low-temperature electrolysis methods. These methods often require costly catalysts, contributing to the overall cost of hydrogen production. ZJ identifies significant challenges in hydrogen technologies. Regarding production, issues lie in large-scale distribution and storage. If aiming to replace natural gas entirely with hydrogen, existing gas pipelines may need modification for safety. Distribution logistics, especially in offshore wind farm scenarios, present logistical and infrastructure challenges. The transportation of compressed gas or the construction of undersea pipelines necessitates substantial investments.
2.6 How much energy is	DA	<i>"You will have to use 50 kWh of electricity" and "10 litres of water".</i>
	RGJA	<i>"56-57 kilowatts hour per kilogram of hydrogen"</i>

needed to produce 1kg of green hydrogen?	JAGR	The amount of renewable energy required to produce 1 kilogram of green hydrogen varies based on the scale of the electrolyser. For small-scale electrolysers in the kilowatt range, it typically ranges from 60 to 65 kilowatt-hours (kWh) per kilogram of hydrogen. In larger electrolysers, the energy requirement reduces to approximately 50 to 53 kWh per kilogram due to improved efficiency at a larger scale.
	MR	MR mentioned that determining the exact amount of renewable energy required for the production of 1 kilogram of green hydrogen varies based on the specific technology being utilized. As such, she didn't provide a precise numerical value, emphasizing the variability associated with different hydrogen production methods and technologies. MR mentioned that the efficiency of different electrolysers for producing green hydrogen could be around 50%, emphasizing the variability based on technology and system design. Given this rough estimation, to produce 1 kilogram of green hydrogen, you would need approximately twice the amount of solar energy, considering the 50% efficiency of the electrolyser. However, specific values would depend on the efficiency and design of the electrolyser being used.
	MS	53.3 Kilowatt hours of electricity to produce 1 kilogram of hydrogen.
	TW	Approximately 43 kilowatts of energy are required to produce 1 kilogram of green hydrogen using the Enapter system. This energy consumption translates to approximately 33 kilowatt-hours of stored energy, considering an operating efficiency of around 70%.
	TN	TN mentioned that it takes about 60 to 70 kWh of renewable energy to produce 1 kilogram of green hydrogen. The actual amount can vary based on the size and efficiency of the electrolyser used in the production process.
	ZJ	In terms of renewable energy requirements, it is crucial to ensure an adequate supply of renewable energy to power the electrolysis process for hydrogen production. For instance, in the UK, the availability of wind resources significantly impacts wind power generation, which, in turn, affects the production of green hydrogen. Similarly, regions with varying solar or wind resources will experience fluctuations in green hydrogen production based on their renewable energy availability.
2.7 How much does it cost to produce 1 kg of green hydrogen?	RGJA	According to RGJA, the cost to produce 1 kilogram of green hydrogen is approximately \$6 USD.
	JAGR	The cost of producing 1 kilogram of green hydrogen can vary based on several factors. In Mexico, the national average cost was approximately \$4.75 USD per kilogram in 2020. However, the cost can range depending on various conditions. In optimal locations with abundant solar or wind resources, the cost can be around \$7-8 USD per kilogram. Conversely, in less favourable locations, the cost can rise to as much as \$10 USD per kilogram. Generally, achieving a cost of less than \$6 USD per kilogram is considered favourable at present.

JH	The cost of producing 1 kilogram of green hydrogen in New Zealand is primarily determined by the electricity cost. Typically, it could range from around \$6 to \$9, but this is heavily influenced by the cost and availability of electricity, the type of electricity generation (dedicated or grid-based), and additional charges related to transmission and distribution. The cost can vary based on these factors, making it a dynamic and evolving aspect of hydrogen production.
KQ	The cost of producing 1 kilogram of green hydrogen in America varies based on production scale, transportation, and on-site production factors. If the production facility is located close to the point of use, the cost is relatively lower. However, transportation methods, whether it is through pipelines or trucks, can influence the overall cost. The cost of producing green hydrogen using a standard photovoltaic system would depend on various factors such as the size of the photovoltaic system, the capital cost of the equipment, and the efficiency of the electrolyser used to produce hydrogen. Without specific numbers, it is challenging to provide an exact cost for this scenario.
MR	As of the current moment, the cost to produce 1 kilogram of green hydrogen is approximately between 4 to €6 on average, according to MR. However, it's important to note that this cost is significantly higher compared to grey hydrogen production. Ongoing advancements and efforts in technology are aimed at reducing this cost gap and making green hydrogen more economically competitive.
MS	MS highlights that determining the cost of producing 1 kilogram of green hydrogen is challenging due to various factors. He refers to a study by Enapter, suggesting a price of around €15 per kilogram or approximately \$0.53 per cubic meter. However, he emphasizes that the ultimate cost heavily depends on the price of electricity. The key factor in cost calculation is the amount of electricity required, and the price of electricity has a significant impact on the overall production cost.
PL	PL mentioned that the cost of producing 1 kilogram of green hydrogen varies depending on the size and type of the project. In France, there are two main types of projects: large-scale industrial projects connected to the grid (e.g., 50, 100, 200 megawatts) and smaller projects at the local level, often focused on hydrogen for mobility. The factors influencing the cost of green hydrogen include the cost of electricity and the cost of electrolysers, which can be relatively expensive. Public support is aimed at significantly reducing the cost of electrolysers by providing funding until 2030. However, the cost of electricity, which varies by region, remains a significant factor affecting the overall cost of producing green hydrogen. PL explained that the cost of producing 1 kilogram of green hydrogen depends on various factors, including the cost of electricity and the cost of electrolysers. Public funding is aimed at reducing the cost of electrolysers significantly by providing financial support until 2030. However, the cost of electricity remains a significant factor affecting the overall cost of producing green hydrogen.

	RH	RH discussed the cost of producing 1 kilogram of green hydrogen. The cost varies, and quoted prices have been as low as 5 U.S. dollars per kilogram. However, the actual cost depends on various factors such as capital investment, operational costs, and the source of energy. Achieving a cost of around 1 to 1 1/2 dollars per kilogram is possible, but this also depends on the efficiency and availability of renewable energy. Renewable energy surplus can significantly reduce the electricity cost, and hydrogen becomes a suitable option for utilizing excess renewable energy. Ultimately, the cost of hydrogen production is heavily influenced by the cost of electricity, making renewable energy an essential factor in cost considerations.
	TW	In 2023, the estimated cost to produce 1 kilogram of green hydrogen at domestic sizes (stored at 35 bar, the standard output pressure of the El 4.0 S system) is around \$9 to \$11.00. The predominant factor influencing this cost is the energy cost. However, if you have already installed renewables, you can reduce this cost by about \$2 to \$3.00 per kilogram by utilizing the excess energy from the renewable system to run the hydrogen system. The aim is to eventually achieve a cost of around \$1.50 US per kilogram of hydrogen through advancements in technology and system efficiency. Achieving this cost reduction involves making the system slightly larger, extending its lifespan, and potentially reducing the output pressure to improve efficiency. These efforts are aligned with the goal of attaining a competitive cost for green hydrogen production.
	TN	TN estimates the cost of producing 1 kilogram of green hydrogen in New Zealand to be approximately \$5-6. This calculation considers obtaining electricity at a rate lower than the market price, assuming collaboration with a partner for hydrogen production. It's important to note that hydrogen production costs may vary based on specific circumstances, electricity prices, technology efficiency, and other factors. For example, TN mentioned that the assumption for the current electricity tariff is \$0.11 per kWh, which is lower than the market standard price of about \$0.17 per kWh. However, they noted that the specific context of Auckland might present challenges despite the lower assumed tariff.
	VG	VG specified that the cost of producing 1 kilogram of green hydrogen is primarily determined by the levelized cost of electricity, constituting about 80-90% of the total hydrogen production cost. This cost varies significantly based on the specific region and its associated electricity prices. In Saudi Arabia, the estimates for levelized costs of electricity range from about one to two cents per kWh using solar energy. This translates to a hydrogen production cost close to the goal of \$1.00 per kilogram. This affordability is a significant factor driving heavy investment in hydrogen technology within Saudi Arabia and other Gulf countries.
	ZJ	Currently, the cost to produce 1 kilogram of green hydrogen in the UK using alkaline electrolysis is as low as 50 pence per kg, which is approximately 40-70 cents in US dollars. However, typically, the cost ranges from about 3 to 5 US dollars per kg, making it relatively expensive. Given the supportive government policies and the potential for wider deployment of electrolysis technologies, the cost of green hydrogen is expected to decrease significantly. Currently, the high cost is attributed to substantial capital investments in production facilities. However, with a 10-fold or hundred-fold increase in production capacity, the cost could

		potentially drop to 20-30% of the current prices. As nations strive for net-zero emissions, hydrogen's competitiveness with natural gas and other fossil fuel options is likely to improve. To produce 1 kilogram of green hydrogen, the cost currently ranges from about \$0.5 to \$5, depending on the facility and application. This cost is associated with the production of 1 kilowatt-hour of hydrogen for the stack. It's important to note that the cost can vary based on factors such as the efficiency of the electrolysis process and the renewable energy availability in the region.
2.8 How can a lifecycle analysis of hydrogen technologies be linked to the principles of a Circular Economy?	EEF	EEF advocates for a pragmatic approach to addressing concerns related to the life cycle analysis and materials used in hydrogen technologies. He highlights that while there may be challenges associated with the supply chain and environmental impact of certain materials used, it is essential to focus on solutions and advancements that address these issues. EEF encourages viewing these challenges as opportunities for improvement and emphasizes the importance of pushing for sustainability and cleaner supply chains to ensure that hydrogen technologies become more environmentally friendly and viable in the long run. He also draws a parallel with batteries, suggesting that as demand for hydrogen technologies grows, solutions to recycle materials will likely emerge, promoting a more sustainable life cycle for these technologies.
	KQ	The materials used in electrolyzers and hydrogen fuel cells can be recycled at the end of their technology life cycle. There are established standards and processes for recycling these materials, ensuring that valuable components can be recovered and reused, promoting sustainability and reducing the environmental footprint associated with hydrogen technologies.
	MS	MS discusses the lifespan of green hydrogen technologies and the potential for recycling. The production and conversion of hydrogen into electricity involve chemical reactions with membranes and catalysts. The membranes in these systems eventually wear out, typically lasting around 35,000 hours for electrolyzers and 20-30 thousand hours for fuel cells. However, their actual lifespan can extend to 10-15 years due to intermittent usage. Regarding recyclability, the components often involve expensive materials like platinum, and the extraction may not be practical, yielding less than what was initially used. Recycling may not be the most viable option, especially as technology evolves rapidly, making replacements more efficient and effective. While some companies claim their modules can be recycled for noble metals, it is limited to certain components, and the overall balance of plant may not be practically recyclable. While recycling certain materials is possible, expecting a complete recycling Nirvana for these technologies may not be realistic due to evolving technology and challenges in material extraction and reuse.
	SJS	SJS emphasized a precise CO2 approach and are actively working on publishing detailed information about their system's carbon footprint. They also highlight their efforts to use recyclable and eco-friendly materials.

	TW	TW emphasizes the environmentally friendly aspects of hydrogen technologies, particularly their recyclability. He mentions that companies like Enapter have a return-to-base methodology where all parts of the hydrogen technologies, including the nano membrane, can be recycled and reconditioned. Since hydrogen technologies predominantly use metal parts, they contribute to a more sustainable approach by reusing materials and minimizing waste.
	ZJ	ZJ mentions key materials used in hydrogen technologies. Platinum and Palladium are crucial for PEM fuel cells, while nickel is vital for high-temperature fuel cells. Recycling initiatives, particularly for nickel oxide elements, are in progress to reuse waste materials in fabricating fuel cell stacks.

Table 44: Question 2 - How can hydrogen technologies contribute into decarbonisation of the built environment and how can this be measured? Participants' view

Drawing upon expert perspectives, the salient elements regarding the role of hydrogen technologies in mitigating carbon emissions within the built environment and evaluating their effect are delineated as follows:

Similar views among participants:

1. Replacing natural gas/fossil fuels with hydrogen for heating and cooking in buildings can reduce carbon emissions. Blending hydrogen into existing gas grids is a transitional step.
2. Hydrogen technologies offer a means to significantly reduce or eliminate CO₂ emissions and pollutants associated with conventional fossil fuels. For example, hydrogen fuel cells, using hydrogen instead of fossil fuels, are a promising technology for clean power generation and heating in buildings.
3. Participants emphasize the importance of using renewable energy sources, particularly in green hydrogen production through electrolysis, as a critical factor in ensuring the overall environmental friendliness and sustainability of hydrogen technologies. For example, solar PV electricity paired with electrolyzers enables onsite green hydrogen production for buildings. This displaces grid electricity emissions.
4. Applications like CHP, microgrids, backup power and district heating are areas where hydrogen can play a role in reducing building emissions.
5. Measuring the CO₂ impact involves comparing emissions from hydrogen systems versus conventional fossil fuel-based systems they displace in buildings.
6. There is a consensus that the benefits of hydrogen technologies become more tangible and impactful when there is a collective shift towards a hydrogen economy.
7. Participants universally acknowledge the potential for recycling and reusing materials in hydrogen technologies, aligning with Circular Economy principles and sustainable resource use.

Differing Perspectives among participants:

1. Some experts are very positive about the potential of hydrogen for decarbonizing buildings across heating, cooking and power generation. Others are more sceptical and see applications in industry, agriculture and transport as more suitable.
2. Views vary on the extent to which hydrogen should be directly used in buildings versus focusing on key applications like fuel cells or district heating.

3. There are differing takes on the significance of establishing certification systems to measure decarbonization versus simply calculating emission reductions.
4. While participants agree on the importance of energy efficiency, there are differing views on how to address energy loss during production and usage of hydrogen. Some stress the need to address energy loss, especially in regions with high-cost green energy, while others emphasize the efficiency of application.
5. Views vary regarding the sustainability of materials and resources used in hydrogen technology. Some stress the need for an eco-friendly production process, considering the entire production chain's carbon footprint and the sustainable use of critical materials. Others focus on the recyclability of materials, promoting a more sustainable approach by reusing materials and minimizing waste.

The unanimous agreement on emissions reduction and the role of renewable energy in hydrogen production reflects a strong consensus on the potential of hydrogen technologies to contribute to decarbonization. It signifies a common understanding of the environmental benefits and aligns with the overarching goal of reducing carbon footprints in the built environment.

The differing views on energy efficiency and material considerations highlight a need for nuanced strategies in integrating hydrogen technologies sustainably. Balancing energy efficiency concerns, cost considerations, and material sustainability is essential for ensuring the long-term viability and effectiveness of hydrogen technologies in achieving decarbonization.

The emphasis on recyclability and reusability aligns with Circular Economy principles, indicating a shared understanding of the importance of a sustainable lifecycle for hydrogen technologies.

In summary, hydrogen technologies can contribute to decarbonizing the built environment primarily by displacing fossil fuel usage in applications like heating, cooking, backup power, and distributed generation. Quantifying the carbon reduction impact involves comparing emissions from conventional systems versus new hydrogen-based systems. But perspectives vary on the extent of hydrogen's direct role within buildings themselves versus enabling decarbonization through other applications. While there are differences in perspectives, the overall consensus is that hydrogen technologies hold significant potential for decarbonizing the built environment. Key areas of focus should include enhancing energy efficiency, ensuring sustainable material use, and establishing supportive policy frameworks. A holistic approach that integrates these factors will be crucial in maximizing the positive impact of hydrogen technologies on decarbonization.

1.2.1 How can hydrogen technologies contribute into decarbonisation of the built environment and how can this be measured? Literature review in support to the primary research Question 2

Upon inquiry about the potential contributions of hydrogen technologies to the decarbonization of the built environment and the corresponding measurement approaches, the respondents articulated a range of responses and concepts and discussed the potential of hydrogen technologies to contribute to the decarbonization of New Zealand's built environment and measurement approaches to quantify their impact.

The built environment, encompassing residential, commercial, and industrial buildings, constitutes a significant portion of global energy consumption and associated greenhouse gas (GHG) emissions. In New Zealand, the building sector accounts for 20% of national carbon dioxide emissions, with residential buildings comprising 60% of this share (Vickers & Fisher, 2018). Decarbonizing the built environment is therefore imperative to curb emissions and mitigate climate change aligned with New

Zealand's net-zero 2050 target under the Climate Change Response Act 2002 (New Zealand Legislation, Ministry for the Environment, 2023).

Buildings are carbon-intensive across their lifecycles – from construction using energy-demanding materials like steel and cement, to everyday lighting, heating, and appliance usage. In New Zealand, space and water heating constitute the bulk of residential emissions, largely met through gas and woody biomass (Dodds et al., 2015). Decarbonization requires displacing fossil fuel usage across these applications by integrating renewable energy technologies.

While electrification via renewables presents a decarbonization avenue, intermittency challenges persist with solutions like solar photovoltaics. Batteries can address variability to an extent but remain limited in storage capacity. Herein lies an opportunity for hydrogen – as an energy carrier, it can provide flexible storage to overcome intermittency and enhance resilience. When produced via electrolysis using renewable electricity, green hydrogen presents a compelling emissions-free fuel choice.

Hydrogen technologies, encompassing production, storage, distribution and end-use solutions, offer diverse decarbonization pathways for buildings. Green hydrogen, for instance, can replace natural gas usage in boilers and cooktops, while fuel cells can provide efficient co-generation of heat and power (Dodds et al., 2015). Such technologies are gaining traction globally. Korea and Japan demonstrate early leadership, with substantial deployments of hydrogen fuel cells in buildings driven by government policies. As DA notes, Japan's residential fuel cell adoption exemplifies their potential:

“Our neighbouring country Japan is a world champion... significant number of fuel cells that are applied specifically in residential buildings and commercial buildings”.

In New Zealand's context as well, hydrogen promises to enhance resilience and achieve renewable energy targets in larger buildings. TW discusses how integrating fuel cells and hydrogen storage can address intermittency:

“They use a small fuel cell to top up batteries, and then the island essentially uses it. That's been gone for a very long time. It's a very good use case of what's happening and how to do it”.

Such solutions must be tailored to building-specific loads. As RH explains, the high share of thermal energy usage makes direct hydrogen utilization preferable to conversion losses.

A key appeal of hydrogen is its modularity and stacking capability to match demand. As MS notes, this facilitates gradual adoption aligned with needs:

“And the technology provider who makes an electrolyser, where I can buy one and I can modularly add more like networking PCs and has really been instrumental towards this being successful”.

Hydrogen technologies hold a multifaceted and promising potential for facilitating the decarbonization of the built environment. The diverse perspectives provided by experts collectively underscore the significant role hydrogen can play in this transformative journey, even though viewpoints diverge on the specifics and challenges.

At the core of these expert opinions lies the recognition of hydrogen's versatility. Numerous experts emphasize its capability to serve as an energy storage and utilization solution in regions with sporadic grid access. This aligns seamlessly with the overarching objective of shifting away from carbon-intensive practices, enabling greater self-sufficiency and resilience in energy supply for areas susceptible to disruptions.

Deploying hydrogen for seasonal energy storage, especially during extended periods of unfavourable weather conditions, emerges as a strategic response to address concerns regarding intermittency. By incorporating hydrogen-powered heating systems, several experts envision a transition from traditional fossil fuel-based heating, thus contributing to the broader aspiration of curbing carbon emissions.

The role of hydrogen technologies in the decarbonization of the built environment is a complex subject that evokes diverse perspectives from various participants. While some emphasize hydrogen's potential to significantly reduce emissions across sectors, including challenging industries like steel and cement, others express reservations about its direct applicability within built environments. A consensus emerges that hydrogen can indeed play a pivotal role in decarbonizing sectors that pose substantial challenges for alternative solutions, such as heavy transportation and industrial processes.

The feasibility of hydrogen adoption varies regionally, influenced by factors like the availability of renewable energy sources, resource utilization, and economic considerations. Participants underscore the importance of assessing the entire hydrogen value chain's environmental impact and highlight the necessity of robust government policies, carbon pricing, and global collaboration to facilitate sustainable hydrogen integration.

Various perspectives shed light on hydrogen's multifaceted potential. DA highlights the transformative capacity of hydrogen across industries, noting its relevance for oil refineries and its role as a versatile energy carrier. Emphasizing the importance of clean hydrogen extraction from renewables, this viewpoint navigates challenges faced by countries with limited renewable land, advocating for stable electricity supply and the potential of fuel cells.

EEF underscores hydrogen's remarkable potential in revolutionizing multiple sectors. The focus is on green hydrogen produced through renewable sources, particularly relevant in regions with substantial renewable energy capacity. EEF identifies the challenge of extending decarbonization to transportation and industry, pointing to opportunities in sectors like transportation where hydrogen could complement electrification.

SJGA highlights the viability of hydrogen adoption in resource-intensive sectors like cement and steel manufacturing. They outline the economic competitiveness of renewable energy sources in regions like Mexico, emphasizing the potential for hydrogen in high-temperature processes, even in industries with limited low-carbon alternatives. Moreover, this perspective acknowledges the importance of strategic resource allocation, spotlighting hydrogen's role in critical infrastructure scenarios.

While these viewpoints converge on hydrogen's potential for sectors such as heavy transportation and industry, RGJA adopts a more cautious stance regarding its direct integration within the built environment. The emphasis is on hydrogen's role in hard-to-decarbonize sectors, considering factors such as resource efficiency and responsible resource utilization. This viewpoint underscores hydrogen's pragmatic use in specific applications, highlighting its potential for emergency power situations and transportation use cases.

Ultimately, these perspectives underscore the multifaceted and context-dependent nature of hydrogen technologies' contributions to decarbonization in the built environment. The viewpoints resonate with varying degrees of optimism, scepticism, and strategic consideration, reflecting the intricate balance between technological potential, regional dynamics, economic feasibility, and environmental impact in driving the transition towards a low-carbon future.

Although optimism prevails, practical challenges cannot be ignored. The implications of cost loom large, as hydrogen technologies demand further refinement and scalability to achieve competitive cost profiles. Nevertheless, localized pilot projects provide tangible evidence that hydrogen can indeed be effectively harnessed, given a context-specific approach.

A thought-provoking avenue that surfaces from these insights revolves around the potential symbiosis between hydrogen and renewable energy sources. The prospect of hybrid systems, harmonizing hydrogen with battery storage, emerges as a viable strategy for optimizing energy usage, particularly in energy-intensive domains such as cooking and space heating. This cooperative approach underscores the need for a comprehensive strategy where diverse renewable technologies coalesce to maximize efficacy and resilience.

Although a spectrum of opinions exists regarding the precise role of hydrogen within the built environment, consensus holds that it should be integrated hand in hand with renewables. Be it for enhancing energy security, addressing off-grid scenarios, or enabling seasonal energy storage, hydrogen assumes a pivotal role in fostering sustainable urban living. Nonetheless, it remains crucial to address economic barriers, safety apprehensions, and the dissemination of precise knowledge to ensure hydrogen meaningfully contributes to the global mission of establishing cleaner and more sustainable urban lifestyles.

The amalgamation of insights from these knowledgeable experts collectively unveils the adaptable nature of hydrogen technologies in spearheading the decarbonization of the built environment. These technologies usher in solutions for energy storage, heating, and power generation while bolstering energy resilience in remote locales. Despite the challenges of cost and safety, small-scale pilot initiatives substantiate the potential benefits of localized hydrogen generation. The integration of hydrogen with renewable energy sources surfaces as a prudent pathway for optimized energy utilization. Overall, the role of hydrogen in decarbonization hinges upon meticulous strategizing, inclusive public engagement, and persistent innovation.

Energy carrier - The participants in the discussion fervently underscored the pivotal role of green hydrogen in addressing the challenge of surplus renewable energy, which often occurs during periods of abundant solar or wind power generation. This surplus of renewable energy can be harnessed effectively by converting it into green hydrogen through a process known as electrolysis. This method entails splitting water molecules into their constituent parts, hydrogen and oxygen, utilizing electricity. The resulting green hydrogen can then be stored for subsequent use, particularly during periods of low renewable energy generation. This practice ensures a consistent and sustainable energy source for the built environment, effectively mitigating the intermittency concerns typically associated with renewable energy sources (Clegg & Mancarella, 2016).

Leveraging green hydrogen as an energy carrier carries manifold advantages for the built environment, ushering in a more balanced and stable energy supply. It guarantees a continuous and dependable power source, even when renewable energy generation experiences fluctuations due to varying weather conditions. Furthermore, green hydrogen stands out as a clean and versatile energy

carrier with the capability of being reconverted into electricity through the use of fuel cells. This capability extends to powering diverse applications within the built environment, ranging from residential and commercial buildings to transportation and even high-temperature industrial processes. The application of green hydrogen as an energy storage medium also contributes substantially to the overarching decarbonization endeavour within the built environment. By efficiently storing and utilizing surplus renewable energy, instead of relying exclusively on fossil fuel-based power sources, the carbon emissions linked to energy consumption can be significantly curtailed. This alignment with global endeavours to transition toward a low-carbon and sustainable energy system is paramount (Dodds et al., 2019).

The burgeoning field of power-to-gas technologies introduces a realm of possibilities by bridging the electrical and gas sectors, thereby presenting new avenues for seasonal energy storage. In essence, power-to-gas involves the conversion of electrical energy into hydrogen, which can subsequently be injected, transported, stored, and eventually utilized within the gas network for purposes such as heating or electricity generation. This integration of power-to-gas with seasonal storage introduces a promising dimension by incorporating an additional form of energy storage characterized by seasonal dynamics. Consequently, it expedites the assimilation of low-carbon energy generated from renewable sources, culminating in noteworthy reductions in carbon emissions within both the electricity and heating sectors (Clegg & Mancarella, 2016).

In summation, the participants in the discussion resoundingly acknowledged that the exploration and adoption of green hydrogen as an energy storage medium present a hopeful avenue for mitigating the intermittency challenges inherent in renewable energy sources. By adeptly harnessing and utilizing surplus renewable energy, green hydrogen emerges as a pivotal player in ensuring a consistent and sustainable energy supply for the built environment. It effectively bolsters decarbonization efforts and steers us closer toward a cleaner and more sustainable future (Osman et al., 2022; Kalpin et al., 2021; Cho, 2021).

Natural gas substitution - The participants conveyed that the substitution of natural gas with green hydrogen in heating systems has emerged as a prominent strategy for mitigating carbon emissions associated with conventional fossil fuel-based heating practices. This transition entails replacing traditional heating systems that rely on natural gas combustion with hydrogen-based alternative:

“Hydrogen can substitute the other gases, or it can be mixed with other gases” (MR)

Moreover, participants acknowledged the potential of hydrogen fuel cells for combined heat and power generation, presenting an efficient and environmentally friendly solution for fulfilling heating and cooling requirements in buildings. Hydrogen fuel cells enable the conversion of hydrogen into electricity and heat through an electrochemical process, allowing for simultaneous production of both energy forms. This combined heat and power generation approach ensures optimal energy utilization and reduces energy waste typically associated with separate electricity and heat generation systems.

It has been said that the utilization of green hydrogen and hydrogen fuel cells in heating systems offers several advantages one of which is enabling of a significant reduction in carbon emissions because hydrogen combustion or fuel cell operation produces only water vapor as a by-product. By eliminating or minimizing the release of greenhouse gases, the adoption of hydrogen-based heating systems contributes to the decarbonization of the built environment. Also, green hydrogen and hydrogen fuel cells provide a versatile and scalable solution for meeting various heating and cooling demands and they can be integrated into existing building infrastructure, allowing for retrofitting or incorporation into new construction projects. This flexibility makes hydrogen-based heating systems

suitable for both residential and commercial buildings, as well as different heating applications such as space heating and water heating.

Furthermore, the adoption of hydrogen-based heating systems aligns with the growing emphasis on energy efficiency and sustainability in the built environment. Hydrogen fuel cells exhibit high electrical efficiency and can achieve overall system efficiencies greater than conventional separate heat and power generation methods. This improved efficiency translates into reduced energy consumption and operating costs, contributing to resource conservation and cost-effectiveness.

In general sense, the substitution of natural gas with green hydrogen and the utilization of hydrogen fuel cells for combined heat and power generation present promising strategies for reducing carbon emissions and enhancing energy efficiency in the built environment because these advancements offer sustainable alternatives to conventional heating systems, aligning with the goals of decarbonization and promoting a cleaner and more sustainable future (Osman et.al. 2022; Douglas, 2015; Fleming & Kreeft, 2020; Dodds et al., 2019; Ernst & Young, 2023).

Assessing **the energy efficiency** of hydrogen technologies within the built environment stands as a crucial aspect in quantifying their contribution to the overarching decarbonization endeavour. Conversant within this discourse universally acknowledge the imperative nature of meticulously measuring the energy yield vis-à-vis the energy input within hydrogen-based systems. Energy efficiency, within this specific sphere, denotes the capability of a given system or technology to efficiently transmute the input energy into valuable output energy. Within the realm of hydrogen technologies, this entails a meticulous scrutiny of how effectively these systems harness hydrogen to cater to the requisites of heating, cooling, and electricity generation (New Zealand 2023. Energy Policy Review, 2023).

In the context of the built environment, hydrogen-based systems serve multifarious functions, encompassing building heating, hot water provision, and electricity generation. The evaluation of energy efficiency in these systems mandates the quantification of the energy generated or dispensed relative to the energy input requisite for their operation. To illustrate, consider the scenario of a hydrogen fuel cell deployed for combined heat and power generation. In this instance, energy efficiency can be computed by ascertaining the ratio of the electrical and thermal energy generated to the quantity of hydrogen consumed. This metric offers invaluable insights into the overall effectiveness of the system in harnessing hydrogen to fulfil the heating and electricity needs (Nasser, 2023).

Furthermore, the assessment of energy efficiency within hydrogen-based heating systems necessitates a comparative analysis with traditional fossil fuel-based heating systems. This holistic assessment encompasses various facets, including energy conversion efficiency, heat dissipation during distribution, and the aggregate energy consumption. By diligently scrutinizing the energy efficiency of hydrogen technologies, stakeholders, encompassing policymakers, researchers, and industry experts, can identify areas warranting refinement and optimization. This discernment plays an instrumental role in guiding the development of more efficient and efficacious hydrogen-based systems tailored to the built environment, thereby making a substantial contribution to the materialization of decarbonization objectives (Energy Technology Perspective, 2023).

A wealth of resources exists, providing valuable insights and research findings pertinent to the energy efficiency of hydrogen technologies within the built environment. For instance, the Hydrogen Strategy report issued by the U.S. Department of Energy expounds upon ongoing initiatives directed at hydrogen production from diverse sources, including water, concurrently endeavouring to augment

energy efficiency. This report underscores the paramount importance of advancing technologies capable of simultaneously generating hydrogen and electricity to enhance energy efficiency (U.S. Department of Energy, 2020). Additionally, the Hydrogen and Fuel Cell Technologies Office within the U.S. Department of Energy furnishes a comprehensive overview of hydrogen technologies, with a pronounced emphasis on the imperative of cost-effective and efficient electrolyzers to amplify energy efficiency. This document highlights a myriad of initiatives and consortia diligently working towards advancing the energy efficiency of hydrogen production technologies (Stetson, 2021; World Energy Outlook, 2022).

The International Renewable Energy Agency (IRENA) and international Energy Agency have also made substantial contributions to this discourse by disseminating comprehensive reports on hydrogen. These reports delve into hydrogen's potential as a renewable energy source and underscores the urgent need to scale up technologies to bolster energy efficiency. They accentuate hydrogen's pivotal role in addressing pressing energy challenges and issues a call to action for cost reduction and expanded deployment to foster broader adoption (IRENA, 2019; Energy Technology Perspectives, 2023; World Energy Outlook, 2022; Global Hydrogen Review, 2022; Hydrogen Patents for a Clean Energy Future, 2023).

However, it is imperative to acknowledge a notable distinction that exists between the production of green hydrogen and the generation of solar or wind energy. While the latter predominantly hinges on capital expenditure, the production of green hydrogen is primarily influenced by operational costs, with approximately 80% of the total cost being contingent on electricity prices. It is noteworthy that reducing the cost of electrolyzers through subsidies aimed at widespread implementation may not inherently translate into a cheaper production of green hydrogen (Van Renssen, 2020). This distinction underscores the intricate economic dynamics at play in the domain of hydrogen production and reinforces the necessity for a nuanced approach in promoting energy-efficient hydrogen technologies.

H2 vs Fossil Fuels - Furthermore, the assessment of the economic viability of hydrogen technologies in contrast to conventional fossil fuel-based systems emerges as a pivotal metric. Examination encompassing capital expenditure, operational outlays, and potential cost reductions associated with the integration of hydrogen technologies within the built environment yields valuable insights into their fiscal feasibility.

Concerning capital costs, it is noteworthy that the initial investment pertaining to hydrogen infrastructure and equipment can be substantial. However, it is incumbent upon us to cast a discerning eye on the long-term advantages and prospective cost savings that hydrogen technologies may yield. For instance, systems powered by hydrogen exhibit the capacity to ameliorate operational expenses by diminishing reliance on fossil fuels and cushioning the impact of volatile fuel pricing. Furthermore, it is imperative to duly acknowledge the potential for economized maintenance and operational expenses resulting from the adoption of hydrogen technologies.

It becomes evident that the cost-effectiveness of hydrogen technologies is inherently subject to fluctuations contingent on a medley of factors. These include local energy tariff structures, the accessibility of renewable energy resources for hydrogen production, and the extent of system deployment. Consequently, a comprehensive evaluation accounting for distinct local nuances and circumstances emerges as a prerequisite for gauging the fiscal feasibility of hydrogen technologies within a specific context of the built environment.

For an in-depth exploration into the cost-effectiveness of hydrogen technologies, the document outlining the Department of Energy's hydrogen strategy proffers invaluable insights into ongoing research and development endeavours revolving around hydrogen technologies and their pivotal role in orchestrating a transition towards a low-carbon paradigm. This repository of knowledge aids in comprehending the potential fiscal ramifications of hydrogen technologies within the ambit of the built environment (U.S. Department of Energy, 2020).

It is imperative to evaluate the alignment of hydrogen technologies with government policies and carbon reduction targets as a fundamental gauge of their role in advancing decarbonization efforts within the built environment. This assessment entails a comprehensive examination of how hydrogen technologies are integrated into existing policy frameworks and the diligent monitoring of progress vis-à-vis established targets. Such scrutiny is instrumental in tracking the actual impact of these technologies on carbon reduction.

Furthermore, monitoring progress against predefined targets emerges as another critical facet in assessing alignment. This entails the systematic tracking of the implementation and deployment of hydrogen technologies, coupled with the quantification of the tangible carbon reduction achieved as a direct consequence. This endeavour necessitates the meticulous collection and rigorous analysis of pertinent data concerning hydrogen production, utilization, and carbon emissions in the built environment. Regular and transparent reporting and evaluation of progress play a pivotal role in identifying potential gaps or areas warranting improvement. This, in turn, empowers policymakers to make well-informed decisions regarding policy adjustments and the formulation of supplementary support measures.

These methodological approaches not only offer valuable insights but also foster a deeper comprehension of the contribution of hydrogen technologies to the overarching objective of decarbonizing the built environment. Additionally, they serve as effective tools for pinpointing domains ripe for further enhancement and optimization, thereby facilitating more sustainable and eco-friendly practices within our built environments.

Quantifying the decarbonization enabled by hydrogen requires a life cycle approach accounting for emissions across the production-to-utilization value chain (Hydrogen Council, 2021). For green hydrogen pathways, verifying the renewable origins and carbon footprint of the input electricity is essential, as JAGR explains:

“Producing electricity splitting water and no connection to the grid”.

Where grid electricity is used, hourly marginal emissions data allows accurate quantification of electrolysis emissions (Jenkin et al., 2022).

For utilization, the displaced emissions compared to conventional fuels must be analysed. TW notes the potential to:

“Displace that exist exact carbon content of the fuel that you’re using. So compared to LPG, you can drop by however many carbon atoms are in there or methane or diesel or any of those other fossil fuel sources”.

Indirect savings from enhanced renewable energy utilization should also be incorporated where applicable.

Regarding the measurement of hydrogen technologies' impact on decarbonization of the built environment, participants proposed several metrics and indicators. Primarily, quantifying the reduction in carbon emissions resulting from the displacement of fossil fuel-based energy sources with hydrogen technologies was recommended. This involved comparing the carbon emissions of traditional energy sources against hydrogen-based systems, following established norms and fuel consumption equivalencies.

“We take the equivalent consumption of whatever fuel we are substituting; there’s a carbon content based on the norms, and then from there we quantify in a certain period of time how much CO₂ emissions we are reducing” (EEF).

One of the primary metrics proposed is the quantification of carbon emissions reduction achieved through the substitution of fossil fuel-based energy sources with hydrogen technologies. This approach involves comparing the carbon emissions associated with traditional energy sources, such as natural gas or coal, to those of hydrogen-based systems. This comparison can be conducted based on established norms and fuel consumption equivalencies. The International Renewable Energy Agency (IRENA) guide on green hydrogen provides insights into the methodologies and calculations involved in assessing carbon emissions reductions.

“If you just blend hydrogen 20% into the existing grid, you have just decarbonized your entire infrastructure by 20% (DA).

Additionally, lifecycle analysis has been suggested as a valuable tool for evaluating the environmental impact of hydrogen technologies. This analysis takes into account various stages of the hydrogen value chain, including production, transportation, and utilization, and assesses the energy and resource requirements, as well as the potential emissions associated with each stage. By conducting a comprehensive lifecycle analysis, researchers and policymakers can gain a holistic understanding of the environmental implications of hydrogen technologies. Furthermore, evaluating the energy efficiency of hydrogen technologies is crucial for assessing their contribution to decarbonization. Measuring the energy output versus the energy input of hydrogen-based systems can provide insights into their overall efficiency and effectiveness in delivering heating, cooling, or electricity generation (Stolten & Emonts, 2016).

Based on the data provided by National Renewable Energy Laboratory (NREL) and considering the power consumption of electrolyzers within the range of 48-58 kWh per kilogram of hydrogen produced, the carbon footprint per kilogram of generated hydrogen has been estimated. It should be noted that these calculations do not take into account emissions associated with hydrogen transportation, compression, or subsequent conversion into hydrogen derivatives. Furthermore, emissions resulting from the manufacturing of electrolyzers and other related equipment, as well as emissions from the deployment of electrolyser facilities, have been excluded from these calculations. Therefore, it is important to acknowledge that these figures may actually be higher when considering the full lifecycle analysis of hydrogen production (World Economic Forum, 2023).

The topic of low-carbon hydrogen certification, which considers the carbon footprint of hydrogen throughout the value chain, is currently under discussion and undergoing development. It is not sufficient to solely assume that hydrogen derived from renewable energy sources through water electrolysis will always be categorized as green or low-carbon. Instead, it is crucial to comprehensively assess the carbon footprint of hydrogen at each stage of its production and utilization.

Certification schemes for hydrogen are still in their early stages and have not been widely tested in real-world applications, primarily due to a limited number of available projects. As the hydrogen industry progresses and matures, these certification schemes will evolve to align with the requirements and expectations of producers, customers, and regulatory bodies. This evolution will aim to ensure that the certification schemes effectively address the diverse needs and concerns of all stakeholders involved in the hydrogen value chain.

The Green Hydrogen Organisation sets a conservative threshold of 1.0 kg CO₂e (carbon dioxide equivalent) per kilogram of hydrogen (kg H₂), which represents the lowest acceptable carbon emissions for hydrogen production. Under the most favourable conditions, all renewable energy sources are capable of meeting this stringent threshold, ensuring that the carbon footprint of hydrogen production remains below 1.0 kg CO₂e per kg H₂. However, in the most challenging scenarios, no single technology can achieve this requirement.

On the other hand, the China Hydrogen Alliance adopts a more lenient CO₂ emissions threshold of 4.9 kg CO₂e per kg H₂. Even under the most extreme circumstances, this threshold can still be met by renewable energy sources such as hydropower, wind, and ocean energy generation. These sources have the potential to produce hydrogen with carbon emissions within the acceptable range of 4.9 kg CO₂e per kg H₂ (World Economic Forum, 2023).

The government has launched the “*Building for Climate Change*” program to reduce emissions from new and existing buildings. However, there is still a lack of detailed strategies and official policies to mandate zero carbon requirements in the building code and regulations.

The use of green hydrogen technologies, produced from renewable energy, provides a major opportunity to help decarbonize New Zealand’s built environment. Hydrogen can be used for zero-emission heating, cooking, and power generation in buildings to eliminate fossil fuel use. The government can encourage adoption of hydrogen technologies in its public housing and buildings to lead by example. Stronger policies mandating zero carbon standards, potentially utilizing green hydrogen, are vital to achieve national net zero goals. Public-private partnerships can also accelerate demonstration and deployment of hydrogen solutions for the residential and commercial building sector. Overall, green hydrogen has significant potential to be integrated into a comprehensive policy approach to achieve deep decarbonization of New Zealand’s existing and new building stock (Wilkinson et al., 2021).

The latent capacity of hydrogen and fuel cell technologies in the realm of low-carbon heating, spotlighting both advancements and impediments. The evolution of fuel cell combined heat and power (CHP) systems is underscored, progressing into dependable and economically viable technologies, particularly evident in Japan’s burgeoning deployment landscape. These systems manifest impressive electrical efficiencies of 40-60%, and when synergistically coupled with waste heat utilization, overall system efficiencies can ascend to 80-90%. Consequently, this culminates in diminished CO₂ emissions relative to conventional heating frameworks, particularly in jurisdictions where electricity generation is carbon-intensive (Staffell et al., 2019).

Hydrogen, a carbon-neutral gaseous fuel, emerges as a potential surrogate for natural gas in heating applications. Repurposing segments of the existing natural gas grid to distribute hydrogen offers substantial economic advantages compared to establishing novel infrastructure. Notwithstanding, pivotal challenges endure concerning the twin facets of ensuring hydrogen’s safety and optimizing its performance.

The inquiry attests that government policies exert a seminal influence on propelling the uptake of low-carbon heating technologies. Fostering regulations hastens the demonstration phase, drives cost amelioration, and accelerates commercial deployment. Mandating augmented energy efficiency benchmarks within building codes and integrating hydrogen technologies into national energy system models emerge as pivotal tactics (Staffell et al., 2019; Dodds, 2015).

With regard to New Zealand, the viability of producing green hydrogen from renewable sources could potentially yield a zero-emissions alternative to supplant fossil natural gas for heating edifices. Transforming segments of the extant natural gas distribution network to dispense green hydrogen, coupled with the stipulation of hydrogen-ready boilers or fuel cells in novel constructions, could pave the way for a profound decarbonization of the building sector. The amplification of policies and fiscal incentives, earmarked for piloting initiatives and technology showcases, could catalyse the commercialization drive and precipitate cost reductions. Collectively, the potential of hydrogen and fuel cell technologies to usher New Zealand into a zero-carbon built environment is robust and promising (New Zealand 2023. Energy Policy Review, 2023).

Measuring the impact of decarbonization in the built environment through the implementation of hydrogen technologies is a complex endeavour, as revealed by the diverse perspectives shared by participants. A consensus emerges around the necessity of establishing a baseline against which the effectiveness of hydrogen initiatives can be evaluated. This entails quantifying the reduction in CO₂ emissions achieved by substituting conventional technologies with hydrogen-based alternatives. Notably, the focus lies on the displacement effect, wherein emissions reduction is calculated based on the carbon content of the fuel being replaced.

The viewpoints underscore the multifaceted nature of this assessment process. It involves intricate calculations to gauge CO₂ emissions reduction within specific time frames. The role of variables such as displacement technologies, vehicle types, and travel distances is acknowledged. Practical examples, such as introducing hydrogen-powered vehicles, offer tangible case studies to project potential emission reductions.

However, the viewpoints collectively stress that quantification is not solely quantitative. Qualitative approaches are also essential, as participants emphasize the significance of understanding the energy equivalency and subsequent emissions reduction. This entails comprehensive insights into the carbon content of different fuels and the emissions produced during their combustion. The discussions further highlight the need for holistic assessments that consider a broader range of pollutants beyond CO₂ emissions.

Overall, the participants' perspectives underscore the intricate and context-sensitive nature of measuring decarbonization through hydrogen technologies. This involves a comprehensive grasp of energy consumption, carbon content, displacement effects, and potential environmental implications. These viewpoints contribute to the broader discourse on assessing the efficacy of hydrogen integration in advancing sustainable and low-carbon environments, reflecting a thorough understanding of the complexities inherent in such endeavours.

Hydrogen technologies hold noteworthy potential to reduce carbon emissions within New Zealand's built environment by displacing fossil fuel usage for thermal and electrical needs. However, their impact must be quantified through meticulous life cycle assessments accounting for production origins and utilization pathways. With strategic implementation tailored to buildings' energy profiles and diligent measurement of displaced emissions, hydrogen can pave the path to meeting New Zealand's decarbonization goals.

This discussion provides diverse expert perspectives on the potential for hydrogen technologies to enable decarbonization of the New Zealand built environment. It highlights hydrogen's versatility as an energy carrier to store and utilize renewable energy to address intermittency challenges. Substituting natural gas with green hydrogen for heating systems and deploying fuel cells for combined heat and power are discussed as pathways to displace fossil fuel use and emissions. The importance of life cycle assessments and quantifying displaced emissions compared to conventional technologies is emphasized to evaluate impact.

Experts note hydrogen allows better integration of renewables, provides seasonal storage capabilities, and can be produced locally using electrolysis if renewable electricity supply is sufficient. This aligns with New Zealand's high share of renewable electricity. Hydrogen is seen as an enabler for hard-to-decarbonize sectors like industrial processing and heavy transport as well. But views differ on the magnitude and timeline of its contribution within buildings. Overall, experts concur that with supportive policies, falling technology costs and localized solutions, hydrogen has notable potential to assist New Zealand's decarbonization, but its impact must be rigorously measured.

1.2.2 Summary

The insights gathered from participants' opinions and the comprehensive literature review have played a pivotal role in addressing the core research inquiry: *"How can hydrogen technologies contribute to the decarbonization of the built environment, and how can this contribution be effectively measured?"*

The integration of qualitative insights with empirical data provides a multifaceted perspective on hydrogen's future role in decarbonizing New Zealand's built environment. It reveals hydrogen as a versatile energy vector that can displace fossil fuel usage across applications from heating to transport, provided its production and use achieves sufficient emissions reductions compared to incumbent technologies. Quantifying its impact requires robust life cycle analyses and monitoring of displaced emissions. Strategic deployment tailored to New Zealand's energy context and resources in synergy with strong decarbonization policies can enable hydrogen technologies to meaningfully contribute to reducing the building sector's carbon footprint. But their cost-competitiveness and safety considerations remain challenges to be addressed.

The assimilation of expert insights unveils hydrogen's adaptable nature and its potential to facilitate decarbonization across diverse facets of the built environment. As an energy carrier, hydrogen offers a pathway to surmount the intermittency limitations of renewable power generation. By effectively harnessing and storing surplus renewable energy, hydrogen technologies can mitigate the variability in solar and wind resources, fostering consistent clean energy availability. This capacity for energy storage and flexible utilization enables hydrogen systems to displace conventional fossil fuel-based technologies for thermal and electrical needs in buildings.

The substitution of natural gas with green hydrogen in heating systems, and the deployment of fuel cells for combined heat and power generation, emerge as promising decarbonization strategies. By displacing greenhouse gas emissions linked to the combustion of natural gas and other fossil fuels, these technologies can make substantive contributions to reducing the carbon footprint of the built environment.

However, experts note that the scale and timeline of hydrogen's penetration within buildings remain contingent on advancements in technology, policy support, falling costs, and strategic implementation tailored to specific energy demands and resources. To ascertain hydrogen's tangible impact on decarbonization, meticulous life cycle assessments and measurements of displaced emissions are indispensable.

Although perspectives differ regarding the magnitude of hydrogen's potential, there is broad acknowledgement of its versatility and capability to facilitate the integration of renewable energy to meet the multifaceted energy requirements of the built environment. The synthesis of expert insights dispels notions of hydrogen being a panacea, emphasizing instead the need for judicious and context-sensitive deployment aligned with broader decarbonization policies. With concerted efforts to quantify emissions reductions and continuing innovation, hydrogen technologies can undoubtedly accelerate the decarbonization of buildings and infrastructure across New Zealand.

This summary aligns with Objective 2 by emphasizing the need to assess the techno-economic performance of hydrogen technologies in the built environment. It highlights hydrogen's potential to replace fossil fuels, offering significant energy outcomes and measurable economic benefits. Strategies like using green hydrogen in heating systems and deploying fuel cells for combined heat and power are presented as effective ways to enhance energy efficiency and reduce carbon emissions. The focus on life cycle assessments and emissions monitoring further supports the goal of quantifying the economic advantages of hydrogen deployment. Overall, the insights underscore the necessity of a strategic, innovation-driven approach to hydrogen technologies that addresses cost and safety challenges, ultimately fostering sustainable energy solutions in New Zealand.

5.3 Question 3: How to accelerate the hydrogen technologies acceptance by the public to bring the New Zealanders out of fuel poverty and to achieve the economic growth goals? Participants view

Question	Participant	Response
3. How to accelerate the hydrogen technologies acceptance by the public to bring the New Zealanders out of fuel poverty and to achieve the economic growth goals?	DA	DA provides a nuanced approach to accelerate public acceptance of hydrogen technologies, acknowledging the multifaceted nature of this endeavour. He emphasizes the importance of raising public awareness about hydrogen's safety through education and training. Drawing on his experience, DA mentions how initial concerns and misconceptions about other gases like LPG were eventually dispelled through public education and proper handling procedures. He underscores that addressing the human factor, through educating and engaging the public, is critical in changing perceptions and fostering acceptance of hydrogen technologies. This multifaceted approach, involving safety education and awareness campaigns, aligns with his view that there is no singular solution to drive public acceptance.
	EEF	EEF highlights a critical obstacle in accelerating hydrogen technology acceptance - the financial aspect, particularly the high capital expenditures (CapEx) associated with hydrogen technologies. He explains that in many developing countries like Costa Rica, there is a lack of sufficient funding and subsidies compared to more developed nations. EEF points out that subsidies in countries like the US, Europe, and China significantly influence technology costs. In the absence of such subsidies, accessing technologies at affordable prices becomes challenging. To overcome this barrier, EEF suggests a reliance on concessional funds to make hydrogen technologies more accessible and viable for addressing fuel poverty and achieving economic growth goals. EEF acknowledges the chicken-and-egg problem in the adoption of hydrogen technologies, emphasizing the need for a simultaneous approach to both technology availability and demand. He raises a critical concern regarding the practicality and motivation for individuals to

		adopt hydrogen technologies, whether for transportation or residential use, without a reliable and accessible source of hydrogen. EEF emphasizes that the commercialization and mass production of hydrogen technologies could potentially drive down costs, making them more affordable and attractive to the public. However, he underscores the importance of developing a comprehensive ecosystem that addresses both supply and demand aspects, ensuring a viable and sustainable transition to hydrogen-based energy vectors.
	RGJA	To alleviate energy-related financial burdens on vulnerable populations, RGJA proposes implementing communal power generation units, fostering energetic communities, and leveraging microgrids powered by renewables. Drawing on successful models in Colombia and Chile, where local communities are responsible for power generation and plant operations, RGJA advocates for a similar approach in New Zealand to empower communities and improve access to affordable and sustainable energy.
	JAGR	Accelerating public acceptance of hydrogen technologies involves addressing both social perceptions and policy-driven barriers. Regarding public acceptance, it is essential to dispel misconceptions about hydrogen's safety by emphasizing its familiarity and managing concerns through clear and accurate information. Parallely, engaging policymakers is critical, showcasing the potential of hydrogen technologies despite current costs. By highlighting the collateral impacts of fossil fuels, showcasing the opportunity for economic transformation, and emphasizing the technology's maturity for market entry, it's possible to shift policy perspectives. This approach positions hydrogen as a pathway to industrialization and technological advancement, aligning with the economic goals of developing nations like those in Latin America. Thus, a comprehensive strategy encompassing education, awareness, and economic positioning is vital for widespread acceptance.
	JH	JH highlights two significant hurdles in the adoption of hydrogen technologies, primarily the cost and the need for judicious utilization of key resources. He underscores the importance of choosing technologies with lower resource intensity and emphasizes the effectiveness of managing building envelopes for increased efficiency. While cost is a notable obstacle, JH emphasizes the need to consider broader systemic approaches and avoid relying solely on technological solutions. JH emphasizes the need for effective education and dissemination of accurate information to the public. He suggests that creating platforms to share resources and knowledge, such as through the International Energy Agency Hydrogen Technology collaboration program, can help provide a balanced understanding of hydrogen technologies. By addressing misconceptions and promoting factual insights into the advantages and safety aspects of hydrogen compared to fossil fuels, it can accelerate public acceptance. Māori, with their deep connection to nature and environmental values, are likely to support the introduction of green hydrogen technologies within their communities, especially in off-grid and remote areas. Their pragmatic approach, long-term view, and consideration of sustainability

		align well with the potential benefits of green hydrogen. While respecting their cultural values and ensuring responsible water use is crucial, they are open to embracing solutions that are environmentally sound and contribute to the well-being of their communities.
	KQ	To expedite the acceptance of hydrogen technologies by the public, it is essential to focus on local resources and needs. In the US, for example, the aim is to enhance energy independence by utilizing hydrogen produced from local feedstocks. States like California have set a precedent by emphasizing hydrogen as a solution to combat air pollution and promote clean air and water. They have taken a lead with a significant number of hydrogen fuelling stations and initiatives to lease hydrogen-powered vehicles. Similar efforts are being replicated in other states to establish refuelling station corridors, encouraging broader adoption of hydrogen technologies in the built environment. Tailoring solutions to local contexts and emphasizing the benefits for the community can enhance public acceptance. Green hydrogen can play a pivotal role in addressing the energy trilemma encompassing affordability, energy security, and sustainability. The concept of H2@Scale, pioneered by the US Department of Energy, provides a blueprint demonstrating the multifaceted benefits of hydrogen and renewables across various energy sectors. Many states and countries have developed their own hydrogen roadmaps, underlining the global recognition of hydrogen's potential in achieving a balanced and sustainable energy future. The core idea behind H2@Scale is to leverage hydrogen's versatility as an energy carrier and feedstock to decarbonize multiple sectors. It explores how hydrogen can be integrated into existing infrastructure and processes to enhance energy security, reduce greenhouse gas emissions, and foster sustainability while ensuring economic viability. This initiative aligns with the broader goals of promoting a clean energy transition and unlocking the full potential of hydrogen in a low-carbon future.
	MR	Accelerating the acceptance of hydrogen technologies by the public can be achieved through education, starting from schools and teaching chemistry. It is crucial to dispel any misconceptions and emphasize that with proper safety measures, hydrogen is a viable and safe option. Highlighting its extensive use in various industries, such as refineries, for decades can demonstrate its practicality and familiarity. Explaining the lessons learned and the additional precautions taken in civilian contexts will contribute to building public trust and understanding of hydrogen technologies.
	MS	MS suggests several strategies to accelerate public acceptance of hydrogen technologies. He highlights the importance of showcasing the financial benefits, emphasizing that people are motivated by cost-effectiveness. Governments can play a role by offering subsidies to offset the initial high capital costs associated with hydrogen technologies, making the transition more financially appealing. Additionally, MS mentions leveraging government intervention to redirect subsidies from traditional fuels to hydrogen technologies, steering users towards cleaner options. Finally, he recommends targeting significant users of diesel generators, like Telcos, and

		encouraging them to adopt fuel cells, demonstrating the advantages of hydrogen technologies in terms of efficiency and environmental impact.
	PL	PL emphasized the importance of creating awareness and visibility for hydrogen technologies among the public. Governments and organizations have launched extensive programs and initiatives focused on hydrogen, leading to increased awareness in recent years. In terms of applications, while hydrogen will have significant utilization in industries and energy management, its visibility and acceptance among the public are often tied to transportation. Initiatives like hydrogen-powered taxis, such as the 200 hydrogen taxis in Paris, make the technology more visible and accessible to the public, fostering acceptance and understanding of its potential benefits.
	RH	RH believes that accelerating the acceptance of hydrogen technologies by the public, particularly in New Zealand, involves addressing two key aspects. Firstly, ensuring public assurance regarding the safety and certification of the technology is vital. Research conducted by RH has shown that people are more likely to accept hydrogen technologies if they are properly certified by New Zealand authorities. Providing clear information about certification and standards can boost public confidence. Secondly, highlighting the positive impact of hydrogen technologies on decarbonization and economic growth is essential. It's important to express the benefits in terms that the public can easily relate to, such as demonstrating the equivalent amount of emissions saved over the lifespan of the product. Economic considerations are also crucial, and efforts should be made to reduce the initial cost of hydrogen technologies to make them more affordable for consumers. This can be achieved through both cost reduction strategies and utilizing carbon pricing mechanisms to incentivize the adoption of cleaner alternatives. Balancing direct cost reduction with indirect incentives like carbon taxes can effectively drive public acceptance and encourage responsible resource usage. <i>“You can put the carbon price really high, which basically means people still pay a lot and they hate that. If the price of gas was such that the carbon from our gas was \$200.00 a ton, we burnt gas like I do at home and natural gas and then that would make almost certainly make it cost effective to rip out my existing boiler and put in a hydrogen boiler”.</i> RH believed hydrogen’s potential affordability could help address energy poverty if capital costs can be overcome. Systems like Lava for energy storage may have a role. RH suggested public awareness campaigns, demonstrations, and emphasis on economic opportunities like job growth could accelerate public acceptance. Finally, RH thought government incentives, developing regulations and standards, and industry collaboration would also facilitate acceptance.
	SJS	To accelerate public acceptance of hydrogen technologies, SJS emphasized several strategies. One important step is debunking misconceptions. People tend to perceive hydrogen as dangerous due to

		its nature as a gas that can explode and needs proper containment. However, it is less dangerous than other gases and not poisonous. Educating the public about hydrogen's actual safety profile and dispelling myths is vital. Furthermore, he highlighted the need for safety regulations and certifications. Just like the automotive industry continuously improved car safety over time, the hydrogen industry needs rigorous safety measures to build public trust. Institutions should focus on certifying and making hydrogen technologies safer rather than spreading unnecessary fear. Overall, accurate information, targeted education, improved safety measures, and a broader perspective on risks are essential components to enhance public acceptance of hydrogen technologies.
	TW	TW identifies a critical aspect of adopting hydrogen systems in New Zealand: utilizing hydrogen as a thermal energy source in appliances. To achieve this, it's important to showcase the availability of hydrogen and gain confidence in the cost-effectiveness of using hydrogen. This confidence will empower advocates to push for the necessary regulations to incorporate hydrogen technology into thermal applications. The goal is to demonstrate the viability and safety of hydrogen in appliances, ultimately paving the way for widespread adoption in the New Zealand market. On public acceptance, TW said hydrogen needs to be de-risked for consumers through demonstrations, education, and publicity around successful pilots. Offering maintenance plans can also help alleviate concerns around new technology. Transitioning areas using bottled LPG to hydrogen was suggested as an early focus.
	TN	The key, TN mentioned, is long-term education and awareness efforts to assure people of hydrogen's safety, especially compared to other conventional fuel options. <i>"In New Zealand, I think perception needs to be changed. We should do something to give people to understand hydrogen and safe".</i>
	VG	The challenge of public perception regarding hydrogen technologies, particularly concerning historical accidents like the Hindenburg disaster, is acknowledged. VG suggests showcasing successful implementations and demonstrating the safety and efficiency of hydrogen technologies in various countries, using Germany as an example where hydrogen is generally perceived positively. Providing clear, factual information and emphasizing successful applications could help alleviate concerns and build public trust in hydrogen technologies. However, there's no specific strategy outlined to accelerate public acceptance.

Table 45: Question 3: How to accelerate the hydrogen technologies acceptance by the public to bring the New Zealanders out of fuel poverty and to achieve the economic growth goals?

Participants view

5.3.1 Additional inquiries pertaining to the third primary research question

Question	Participant	Response

3.1 How do you think Green hydrogen can solve an energy trilemma around affordability, energy security and sustainability of the energy?	DA	DA outlines a nuanced perspective on how green hydrogen can address the energy trilemma involving affordability, energy security, and sustainability. He emphasizes the critical role of cost-effective transportation in achieving these goals. Using the example of a steel manufacturer striving for cost competitiveness, he highlights the importance of making hydrogen production economically efficient by generating higher volumes. The key lies in maximizing hydrogen production, particularly in regions with ample renewable resources like the Middle East, to ultimately lower the delivered hydrogen's cost. This, in turn, facilitates affordable access to green hydrogen, addressing energy security concerns while advancing sustainability objectives by encouraging its widespread use.
	RGJA	RGJA suggests that green hydrogen offers potential solutions to the energy trilemma of affordability, energy security, and sustainability. Affordability is seen as the most pressing concern, but utilizing green hydrogen in countries with renewable resources can potentially provide cost-effective energy solutions. Sustainability, on the other hand, is attainable by incorporating sustainable practices in the entire lifecycle of green hydrogen projects. Energy security is bolstered by countries without oil and gas reserves utilizing green hydrogen to gain energy independence.
	JH	Navigating the energy trilemma of affordability, energy security, and sustainability with green hydrogen is indeed complex. Hydrogen tends to be more expensive than electricity, necessitating a strategic approach to finding applications where hydrogen brings distinct benefits. Direct electrification often remains the more cost-effective choice. Although hydrogen offers the advantage of decoupling production and utilization, this comes at a notable efficiency cost. The key to cost-effectiveness lies in having a surplus of very affordable electricity. However, managing a hydrogen system entails additional infrastructure compared to electrification, particularly in remote areas. <i>“Yeah, that’s a tough one because fundamentally, the hydrogen’s got to be more expensive than electricity... compared to electrification and remote absolutely”.</i>
	MR	MR highlights that green hydrogen can address the energy trilemma by tackling affordability, energy security, and sustainability. She mentions that advancements in technology can drive down the cost of green hydrogen compared to grey hydrogen, making it more affordable and accessible. In terms of energy security, hydrogen allows communities, especially those off the grid, to become self-reliant by utilizing renewable sources like solar panels and converting excess energy to hydrogen. Lastly, she emphasizes that hydrogen is a versatile element crucial for various sectors, presenting an opportunity to create a green economy and connect renewable energy sources to hydrogen production.
	RH	RH believes that green hydrogen offers strong potential to address the energy trilemma concerning affordability, energy security, and sustainability. In terms of sustainability, hydrogen offers a circular energy economy as it utilizes water, and the resulting water vapor goes

		back into the natural water cycle, creating a closed loop with minimal environmental impact. Regarding decarbonization, green hydrogen is a viable solution as it eliminates the need for fossil fuels to power systems. However, RH emphasizes the importance of managing nitrogen oxides (NOx) to ensure a low environmental impact. In terms of affordability and energy security, the economics of hydrogen generation play a crucial role. The choice of hydrogen generator, efficiency, capital costs, materials, and scaling strategies are all factors that impact the cost-effectiveness and overall success of implementing green hydrogen technologies.
	TW	TW emphasizes that addressing the energy trilemma involving affordability, sustainability, and reliability requires a careful balance and understanding of how to prioritize these elements. While current conventional fuels are cheaper, the goal is to transition towards what is environmentally sustainable and beneficial for the user in the long run. He suggests that waiting for a significant event or crisis may not be the best approach, and proactive steps should be taken to ensure energy independence and resilience, which can, in turn, tackle issues like fuel poverty. Balancing financial considerations with environmental and resilience aspects will be crucial in determining the transition timeline.
	TN	TN mentioned that in terms of affordability, there is a question mark, as mass production and scaling of electrolyzers are crucial to reduce costs. However, in the context of sustainability and energy security, green hydrogen is promising. It can be produced locally with water and electricity, providing a more sustainable and environmentally friendly option with no CO2 emissions. <i>“See affordability. I have a question mark. Yeah, unless someone does it in the big scale, including the generation of the electricity, it’s not gonna get cheaper. And electrolyser needs to be mass produced, then only get cheaper. But in terms of sustainability and energy security wise, it makes sense because it can be produced anywhere as long as there’s water and electricity. So it’s easier than getting the fossil fuel out from Middle East. Then sustainability wise, let’s see what too. I mean, no CO2 basically. So it is sustainable environmentally friendly, yeah”.</i>
	VG	VG highlighted that green hydrogen and hydrogen technologies contribute significantly to sustainability by providing a clean energy solution across various sectors, such as mobility, steel production, and cement. However, when considering the energy trilemma of affordability, energy security, and sustainability, hydrogen may not directly address affordability. The initial capital costs (CapEx) for hydrogen equipment can be high, and hydrogen production incurs energy inefficiencies. In terms of energy security and sustainability, hydrogen can contribute by serving as an energy storage solution. Excess energy during periods of high renewable energy production can be used to produce and store hydrogen for later use, enhancing supply stability. Nevertheless,

		utilizing hydrogen for energy storage comes at a relatively high cost. Therefore, while hydrogen significantly addresses sustainability and can aid in energy security, it may not be the most cost-effective solution for achieving affordability.
	ZJ	ZJ elaborates on how green hydrogen can address the energy trilemma of affordability, energy security, and sustainability. Regarding energy security, as the world shifts toward renewable energy, managing the intermittent nature of renewables becomes crucial. Hydrogen stands out as an excellent candidate for large-scale energy storage, allowing for medium to long-term storage, from months to even a year. It can be stored in various forms, including gas or liquefied hydrogen, providing a secure and reliable energy storage solution. Moreover, utilizing hydrogen for domestic energy supply can enhance energy security by reducing dependence on energy imports from interconnectors or fossil fuel resources. This dual application of hydrogen, for large-scale energy storage and domestic energy supply, contributes to energy security by ensuring a reliable and consistent energy supply.
3.2 What do you think about the Government support for installation and maintenance of hydrogen technologies in residential and commercial buildings? What kind of support it could be?	DA	DA notes that there is substantial government support for the introduction of hydrogen technologies, not limited to green hydrogen, in Korea. The main short to medium-term goal is to make hydrogen affordable for the public, particularly for use in cars. The emphasis is on scaling up hydrogen availability and reducing costs to cater to the preferences of ordinary individuals concerned about affordability. The Korean government is actively providing subsidies for hydrogen infrastructure development, such as hydrogen refuelling stations and hydrogen vehicles, to encourage their widespread adoption. <i>“There’s a lot of support of introducing ... green hydrogen so Korea has short to medium term plan is to make hydrogen at cheap enough so that people could use it...”</i>
	EEF	EEF emphasizes the crucial role of government support and concessional funding in driving the adoption of hydrogen technologies. He underscores the financial challenges faced by many countries, particularly in terms of accessing affordable technologies without sufficient government support. EEF expresses concern about the potential reliance on fossil fuels, like natural gas, in the absence of financial backing for hydrogen technologies. He stresses the need for concessional funding to accelerate the transition to hydrogen and avoid getting stuck in non-renewable fuel alternatives. EEF emphasizes that government support and financial assistance are vital to making hydrogen technologies a viable and sustainable option for the public.
	RGJA	RGJA emphasizes the need for a balanced approach to government subsidies for green hydrogen projects. While subsidies are necessary to facilitate adoption and ensure affordability, RGJA advocates for an accompanying responsibility from users. He believes that granting subsidies without any responsibilities may lead to a dependency mentality rather than encouraging accountability and improved quality

		of life. RGJA underlines the importance of balanced subsidies with associated responsibilities to achieve sustainable outcomes. He highlights the support provided by the Colombian government for hydrogen projects, including financial support for pre-feasibility studies and incentives such as tax benefits, accelerated depreciation for goods, and reduced import fees. Additionally, he emphasizes the importance of legal security, ensuring long-term policy consistency to instil confidence in private investors. He underscores the importance of governments creating a special tax regime or incentives to promote hydrogen technologies effectively. He believes that offering financial support and reduced taxes is crucial for encouraging investments in this sector.
	JAGR	According to JAGR, government support primarily comes in several forms. First and foremost, having a stable regulatory environment is crucial, ensuring contracts are respected and providing a clear framework for operations. Secondly, supportive regulations that outline the permissions and restrictions within the ecosystem are essential for a smooth functioning of projects. This includes mechanisms for tax reduction and financial incentives. Lastly, financial support in the form of grants or investment plays a vital role, especially for ambitious projects like those involving the development of green hydrogen. While direct financial support is less common in Latin American countries, it is more prevalent in regions like Europe and the US, where governments are actively encouraging and funding green hydrogen projects.
	KQ	Government support for hydrogen technologies is multifaceted, involving various mechanisms and policies to promote its adoption and development. These include tax rebates, incentives, grants, carbon reduction acts, and environmental regulations. In the context of transportation, support may manifest through tax credits for clean energy production and incentives for hydrogen-powered vehicles.
	MR	MR discussed her organization's engagement in various government funding competitions to secure support for their initiatives. They actively participate in competitions related to energy transition and technological development, accessing funds at national, regional, and international levels across their operations in Germany, Italy, and Thailand. While not her primary area of expertise, she acknowledged the significant effort involved in the application process, including extensive documentation to demonstrate the value and alignment of their projects with the criteria set by the respective funding bodies. This approach involves a thorough and transparent process to access the necessary financial support for their endeavours.
	MS	MS mentioned that there is some government support, especially in Germany, where organizations like H2 PPP help German companies do business abroad. These organizations arrange events and seminars to promote German sales overseas, including in the hydrogen sector. Additionally, the German government may provide financial support for specific projects, although this support is rare and often involves complex paperwork. However, it is not advisable to depend solely on this kind of funding.

	PL	PL highlighted the government support in France for hydrogen projects, part of a broader national strategy. The strategy is not exclusive to France and is seen in other countries like Germany and Thailand as well. This strategy is backed by a substantial €10 billion fund, allocated to various areas including the built environment. The fund supports the creation of Gigafactories and plants for hydrogen, fuel cell, and electrolyser production. A significant focus is on job creation in the sustainable sector, contributing to both decarbonization and economic growth. The government aims to decarbonize sectors while fostering job opportunities, making both objectives equally significant. Additionally, the fund supports the industry in bridging the cost gap for green hydrogen in the current market. There are different parts of the national plan in France to support hydrogen projects. One part is focused on bridging the cost gap between the market price of hydrogen and the production cost, ensuring competitiveness. Another part is directed towards supporting local territories and promoting the development of Hydrogen Valleys, integrating various applications. The final part involves funding research and innovation to further enhance the hydrogen sector.
	SJS	SJS emphasized the need for government facilitation, making the process of adopting renewable energy technologies like solar panels and wind power to produce hydrogen more streamlined and efficient. SJS suggests that the government should provide fair support for hydrogen technologies by not favouring other technologies. He mentions a simple support scheme where a specific amount is allocated for each produced green hydrogen, incentivizing its use. Drawing from historical examples, he points out that support has been given to fossil fuels in the past and advocates for a shift towards supporting green hydrogen today.
	TW	Currently, PV and hydrogen systems are experiencing greater adoption in Germany due to the favourable funding regime. In Germany, approximately 50% of the cost of installing a PV and hydrogen system is funded, boosting its uptake among the population. This financial support incentivizes the integration of these sustainable energy solutions and contributes to their widespread implementation, as stated by TW. TW suggests that a similar approach could be implemented in New Zealand to incentivize the adoption of PV and hydrogen systems. By establishing a funding regime or financial incentives, akin to what is seen in Germany, where approximately 50% of the installation cost is funded, New Zealand could encourage a higher uptake of these sustainable energy solutions among its residents. TW suggests that providing support for hydrogen systems, similar to the support for electric vehicles and solar PV installations, could garner significant public backing. People often appreciate being in control of their energy generation, storage, and consumption, contributing to energy independence and resilience. However, there might be concerns about maintenance, which could be addressed through maintenance plans or services.

	TN	TN pointed out various potential approaches for subsidies to promote hydrogen technologies, including subsidizing hydrogen equipment, generators, vehicles, or providing subsidies directly to customers or service providers. He mentioned tax reductions as another method that has been implemented in the U.S. The objective is to alleviate the additional costs associated with adopting hydrogen technologies, ensuring that end-users are not burdened with extra expenses while transitioning to hydrogen-based solutions. TN provided insights into a potential subsidy approach in Japan, where the government plans to provide subsidies over the next 10 years to cover the difference between the actual cost and the alternative cost of conventional methods. However, looking ahead 20 to 30 years, as the cost of hydrogen production is expected to decrease due to mass production, individuals or entities benefiting from this reduction will repay the saved amount to the government. This strategy aims to balance financial support in the early stages while promoting cost-efficiency in the long run as hydrogen production becomes more economical.
	VG	To garner government support for introducing hydrogen technologies into the country, potential investors should consider countries that are already actively encouraging and subsidizing such initiatives. Many governments are taking steps to attract investors in the hydrogen sector, offering incentives, subsidies, and favourable conditions. Therefore, investors may find it advantageous to focus on regions where the government is already aligned with and supportive of hydrogen technology, making the process smoother and more conducive to successful implementation.
	ZJ	ZJ mentioned several forms of government support for hydrogen technologies in the UK. First and foremost is policy support, outlined in the UK Hydrogen Strategy, specifying goals for hydrogen production by 2030. Additionally, in 2021, the UK released an Energy Security report, which increased the production capacity ambition for hydrogen in 2030. The UK government also offers funding competitions to support feasibility studies and demonstration projects focused on low-carbon technologies, particularly green hydrogen. These financial supports are provided through various investment programs, competitions, and funding initiatives.
3.3 Do you believe decentralized on-site hydrogen production is superior to centralized production and subsequent distribution to end-users?	EEF	In the present scenario, the focus appears to be on generating green hydrogen through large-scale electrolyzers and subsequently distributing it to end-users for various applications, including powering hydrogen fuel cells. This approach aligns with existing demand for hydrogen, particularly in sectors such as ammonia and fertilizer production. The envisioned future may see advancements in technology and storage methods, potentially altering the optimal approach for green hydrogen production. However, at present, the established strategy of centralized production and distribution seems to offer a viable and pragmatic path towards green hydrogen utilization.
	JH	The successful delivery of green hydrogen to end-users would depend on the chosen production and distribution models. A mix of both centralized and distributed production models might be necessary to

		efficiently deliver green hydrogen to end-users. The complexity of the delivery process would be influenced by the logistics and infrastructure involved in getting the hydrogen from production facilities to the intended consumers.
	KQ	The trend is not necessarily a complete decentralization of large power stations but rather a shift towards adding new energy to the system that is increasingly carbon-free. The emphasis is on incorporating renewables and associated technologies, like electrolysis, hydrogen storage, and fuel cells, into the existing power grid. This transition aims to accommodate intermittent energy sources, improve grid resilience, and reduce carbon emissions. However, complete decentralization is not yet widespread, and efforts are primarily focused on integrating decentralized renewable energy sources effectively within the existing grid infrastructure. Utilizing hydrogen-powered transportation for delivering hydrogen to end-users is a sensible approach to minimize emissions associated with transportation. There is a growing emphasis on hydrogen trucks, especially for the heavy-duty vehicle sector, where hydrogen can play a significant role in long-distance transportation with reduced environmental impact.
	MS	MS explains that the superiority of decentralized on-site hydrogen production versus centralized production and distribution depends on various factors. Transportation costs are a significant consideration - if hydrogen is produced on-site, transportation costs are saved. Additionally, the cost-effectiveness of central systems versus multiple decentralized systems servicing different locations is dependent on the specific application. For MS, producing hydrogen where and when it's needed provides more control and cost-effectiveness, particularly when considering utilizing renewable energy sources. Decentralized production allows for hydrogen generation when energy sources like the sun are readily available, making it a favourable option. Ultimately, the choice between centralized and decentralized production depends on the specific use case and the associated cost-benefit analysis.
	SJS	To make hydrogen technologies cost-effective, SJS highlights the need for affordable green energy production, such as cheap wind and solar power. He asserts that the cost of producing hydrogen can be substantially reduced, making it competitive with fossil fuels. SJS predicts a decline in the cost of hydrogen production systems, paving the way for hydrogen to be a cheaper alternative. <i>“Hydrogen can be produced decentralized. You can put solar or wind you can produce hydrogen and this changed there and this changed the energy systems.</i> <i>Because it becomes more decentralised and this is what central governments do not want. So you can clearly say that most of the governments in the world do not like it. If you want to make strong systems for the future, we have to allow decentralization also because Decentralization reduce the amount of bringing energy to the endpoint.</i>

		<i>When you see how much transportation of energy is involved in this kind of lines, and then it shows clearly that it's not really working”.</i> SJS advocated for decentralization in the energy sector, citing benefits such as increased efficiency and improved resilience. SJS likened this to the functioning of the internet, highlighting the advantages of decentralized systems in routing and efficiency. SJS criticized the bureaucracy and complications surrounding energy systems, illustrating how even surplus energy from wind and solar farms is often underutilized due to centralized power preferences. He underscored the importance of decentralization, suggesting that countries should focus on maximizing locally harvested energy for increased energy independence. However, he criticized the tendency of governments to support large companies and maintain centralized systems, even when there are opportunities for decentralized growth. In summary, SJS stressed the need to streamline regulations, encourage the adoption of efficient technologies, and shift towards decentralized systems to promote advanced technologies and tackle climate change effectively.
	TW	TW believes that in the next 5 to 10 years, investments should be directed towards making certain areas energy-independent or off-grid, particularly those at the far end of power lines. He suggests that it could be more cost-effective to install fully renewable systems at individual houses in remote areas rather than maintaining lengthy power lines. By starting at the edges and working back, it is possible to scale down the regular grid infrastructure and create opportunities for renewable technologies, which can contribute to community sustainability and reduce reliance on extensive horizontal infrastructure. This approach can be a counterbalance to the challenge posed by the increasing demand for power associated with electric vehicles. To encourage widespread adoption, TW emphasizes the need to decentralize energy generation, moving away from heavy reliance on major energy companies. This decentralization could pave the way for virtual power plants, hydrogen integration, and efficient utilization of surplus or curtailed energy, ultimately fostering hydrogen technologies and addressing energy storage challenges.
3.4 Do you think that it is more cost effective to produce a green hydrogen in a large scales or small scales through large scale electrolyzers or small-scale electrolyzers?	JH	Producing green hydrogen is likely more cost-effective on a large scale using large-scale electrolyzers. Economies of scale come into play, particularly in ancillary aspects such as compression and storage. While the scaling of electrolyzers may not be entirely linear, the overall cost per kilogram of hydrogen is likely to be lower with larger-scale production due to the benefits of scale in various components and processes within the hydrogen production system.
	MS	MS discusses the cost-effectiveness of producing green hydrogen on different scales using electrolyzers. They draw an analogy to computing, where initially, people networked PCs instead of using mainframes. Similarly, in hydrogen production, small-scale electrolyzers, analogous to networked PCs, could be cost-effective. However, as the demand increases to a certain scale, practicality becomes a concern. MS proposes modular electrolyzers, resembling centralized PC servers, where components are centralized and streamlined, reducing costs akin to

		mass-producing computer components. The approach of modularizing electrolyzers ensures cost reduction through standardized manufacturing processes, akin to the drop in component costs observed in the computing industry.
	SJS	SJS suggests that the cost-effectiveness of producing green hydrogen depends on the scale and the specific use case. For large-scale production, there are advantages in terms of efficiency and economies of scale. However, one must consider the additional costs associated with transportation and distribution on a larger scale. In contrast, for smaller-scale production, particularly in remote areas or for localized consumption, a distributed energy system is often more cost-effective. The suitability of the scale depends on the energy demands of the application and the logistics of distribution. Ultimately, the decision should be based on the unique requirements and circumstances of the given situation.
	TW	TW emphasized that the distributed production of green hydrogen at a smaller scale, utilizing small-scale electrolyzers installed at individual households, is the more cost-effective and viable option. This approach not only provides redundancy to the system but also promotes energy independence and resilience, aligning with the need for a more self-sufficient energy infrastructure.
	TN	TN mentioned that for green hydrogen production, it seems more efficient to use a minimum of a 1 MW class electrolyser, and doubling it to a two MW setup could increase efficiency, although the increase might not be significant.
	ZJ	ZJ suggests that small-scale applications, particularly solar-based hydrogen production, hold promise. In regions with abundant solar resources like the South Coast of the UK and Australia, residential-scale hydrogen production using solar energy is feasible. However, the current cost of electrolyzers, fuel cells, and system integration makes it less economically viable for individual consumers. Affordability remains a challenge, but advancements and further research may enhance the commercial viability of small-scale hydrogen production in the future.
3.5 Do you know any of the places that have been taken off grid and powered with Hydrogen?	RGJA	RGJA expresses the belief that achieving autonomy and self-sufficiency through green hydrogen for off-grid areas is possible. However, the viability of this concept depends on the specific context of each country. In the case of Colombia, where RGJA is focused, the challenges of transporting diesel fuel to isolated areas make renewable alternatives, despite their current costs, more affordable and attractive.
	KQ	There are a limited number of places powered by hydrogen technologies, typically owned by individuals or entities with a specific interest in these technologies. KQ discussed the concept of producing, storing, and utilizing green hydrogen on-site, disconnected from the main electric grid and gas pipelines. She drew parallels to a time before extensive grid infrastructure when localized energy solutions were prevalent.

		However, she also acknowledged the challenges inherent in detaching entirely from centralized energy grids. She emphasized that this approach might resonate with individuals or locations seeking to operate off the grid. KQ provided examples of some homes powered by hydrogen following this off-grid model, relying on their hydrogen storage, as well as solar and wind energy production. Nonetheless, these setups remain isolated from the broader grid network.
	MS	MS provides insights into the feasibility of going off the grid and highlights a notable case in Thailand - the Phi Suea housing project - as a significant deployment. The project, initiated in 2014, represents a microgrid example that operates independently and optimizes energy resources through a combination of solar power and efficient software management. The integration of batteries is essential for ensuring continuity. MS emphasizes the role of Enapter, a company resulting from the Phi Suea project, which now focuses on producing modular hydrogen-generating units. The required hydrogen capacity varies based on the specific application, whether it's powering a small town or an individual house or vehicle. Flexibility in building the necessary capacity is crucial, analogous to adjusting the size of IBM mainframe computers based on requirements. When aiming to remove a building from the grid, integrating hydrogen on-site and using fuel cells to convert hydrogen into electricity is a viable alternative.
	SJS	Participant SJS outlined a case where they built a private home in northern Thailand aiming for complete off-grid sustainability. He recognized the necessity of energy storage, particularly for extended periods without sufficient sunlight, like during the rainy season. Batteries were considered a logical choice for daily energy storage but posed a challenge for seasonal storage when energy needs surpassed what batteries could store for longer periods. To address this, they opted for a battery storage system that could cater to their energy needs for a day. For longer durations without adequate energy, they implemented hydrogen storage as an additional solution to ensure energy availability.
	TW	According to TW, small cities or even micro-communities within larger cities can indeed be taken off the grid and made self-sufficient in terms of energy. He points to initiatives like the one by LIA and ATCO in Western Australia, where they have already started exploring this concept. Trials have been conducted, such as building a small neighbourhood with centralized energy hubs equipped with hydrogen blending and fuel cell systems, along with batteries and inverters. This centralized hub then distributes energy to the surrounding neighbourhood, showcasing a potential model for energy self-sufficiency on a smaller scale.
	TN	TN suggests that it is possible to power specific places off the grid using green hydrogen, especially in detached areas like islands or remote locations. For instance, installing solar or wind plants along with electrolyzers in such areas can provide sustainable energy solutions without the need for grid connectivity, making hydrogen a viable option for powering residential or commercial buildings in such regions.

		<i>“It depends on the stays and the purpose of where that energy will be used. I think it's possible, for example maybe a factory somewhere. It can be all residential. Yeah, I think it's possible. Say if we build maybe a solar or wind in, say, middle of CBD, Auckland is the one consuming the activity, right? So why not build the wind turbine in the CBD, then use that for a residential there?”</i> <i>I was thinking like an island. Maybe Waihiki Island put the solar or wind plans there together with the electrolyser. Then we can power the residential or commercial buildings there.</i> <i>So it's detached area then it makes sense. That's some people are trying in Japan, they are small islands. It's more costly to connect the grid. Then why not just use hydrogen?”</i>
	VG	VG noted that using hydrogen technologies to go off-grid can be expensive, especially when compared to traditional grid electricity. Hydrogen can increase the cost further. However, he mentioned a shift from diesel off-grid to hydrogen off-grid in some cases, primarily for environmental reasons, despite the increased cost. Overall, hydrogen technologies are seen more as a way to supplement existing off-grid solutions, particularly those reliant on fossil fuels according to VG.
	ZJ	ZJ said that in the UK, there is the Coney Island project near the country's largest wind farm, generating hydrogen from renewable sources to supply Glasgow's energy system. Another initiative is being planned in Wales to produce hydrogen from wind resources. In China, more than 100 megawatts of alkaline electrolyzers are being used to produce hydrogen, supporting local heating and domestic use.

Table 46: Additional inquiries pertaining to the third primary research question

Drawing from expert insights, the principal viewpoints on expediting public endorsement of hydrogen technologies in New Zealand can be summarized as follows.

Similar ideas:

1. Education campaigns to increase awareness, address misconceptions about safety, and provide accurate information on hydrogen technologies. This includes highlighting successful pilots and real-world applications and communicating sustainability, energy security, environmental and economic benefits.
2. Engaging and reassuring the public by emphasizing hydrogen's extensive existing applications in industries like refining and its comparability to familiar fuels like LPG in terms of safe handling.
3. Governments playing a lead role through policy initiatives, subsidies, and incentives to reduce costs and steer adoption of hydrogen technologies over conventional options.
4. Emphasizing local benefits like energy independence, clean air and water, and supporting economic growth to motivate adoption.
5. Collaboration with Māori communities by aligning hydrogen's sustainability with their values.
6. Financial incentives like subsidies, tax rebates, reduced import duties, and grants are crucial, especially in the initial stages, to offset high costs and drive adoption.
7. Supportive regulations and policies like carbon reduction acts and environmental regulations help redirect focus towards clean technologies.
8. Stable, long-term policy environments provide confidence to potential investors and project developers.

9. Funding for feasibility studies enables project conceptualization, while support for pilot projects facilitates real-world validation and awareness.
10. Government leadership in its own operations, through public housing and building integration, can demonstrate benefits and mainstream hydrogen.
11. Smaller scale electrolyzers located at point of use like individual buildings can optimize renewable energy usage compared to reliance on the grid.
12. Modular electrolyzers with some degree of centralization allow standardized manufacturing, enhancing cost-effectiveness.
13. Decentralized production avoids transportation/distribution costs associated with centralized production.
14. Decentralized systems promote self-sufficiency and energy resilience, aligning with sustainability goals.

Differing Views:

1. Some experts emphasized the criticality of addressing both technology supply and demand simultaneously through an ecosystem approach, while others focused more unilaterally on increasing adoption.
2. Perspectives varied on the comparability of hydrogen with other fuel options, with some strongly positioning it as safer and more familiar versus others urging caution about differentiating properties.
3. While all highlighted information dissemination, some experts focused on digital platforms for sharing knowledge versus others prioritizing school education and community engagement.
4. Some experts strongly advocate extensive subsidies and incentives to accelerate affordability, while others warn against dependency and urge user responsibility.
5. While funding for research and innovation has backing, direct project investments garner more diverse views.
6. Perspectives vary on the viability and ease of securing financial support, with some indicating complex processes.
7. Some experts strongly favour decentralized for most applications, while others see centralized large-scale as more cost-effective.
8. Perspectives vary on the tipping point scale where centralized becomes favourable - some indicate a few MW while others point to much larger scales.
9. While decentralized has advantages, fully disconnecting from the grid has complications and might only suit remote locales.

In summary, multi-pronged efforts are needed to accelerate public acceptance encompassing awareness, education, government leadership, local contextualization, safety assurance, cost reductions, and ecosystem development. While perspectives differ on strategies, the overarching emphasis is on actively engaging people by highlighting hydrogen's benefits aligned with values, disseminating accurate information to correct misconceptions, and judiciously adopting supportive policies and financial incentives to facilitate adoption. A collaborative yet tailored approach can effectively enhance public acceptance and realize hydrogen's potential in addressing New Zealand's energy trilemma.

In terms of public acceptance and economic growth, decentralized production and utilization of hydrogen enhances localization and community self-reliance. By empowering people to become producers through technologies like small-scale electrolyzers, adoption can accelerate. This aligns with values like independence and environmental stewardship. Decentralized systems also create job opportunities in installation, operation and maintenance - contributing to economic growth. However, perspectives vary based on unique local contexts and needs. Overall, decentralized production and

utilization emerge as an important avenue, but likely complementing some degree of centralized systems, to expand hydrogen acceptance and economic development.

5.3.2 How to accelerate the hydrogen technologies acceptance by the public to bring the New Zealanders out of fuel poverty and to achieve the economic growth goals? Literature review in support to the primary research Question 3

In order to answer the research question of how to accelerate the acceptance of hydrogen technologies by the public in New Zealand and bring New Zealanders on board with this innovative energy source, the insights from discussion participants offer valuable strategies and perspectives. The multifaceted challenge of enhancing public awareness and trust in hydrogen technologies was a recurring theme, with a focus on overcoming misconceptions and fostering informed opinions. Education and public engagement emerged as essential tools, with an emphasis on gradual introduction, cost-effectiveness, and transparent communication.

Furthermore, participants underscored the pivotal roles of government and industry in shaping public perception. They highlighted the need for strong policy frameworks, regulations, and certification processes to instil confidence. The importance of showcasing hydrogen's historical uses and safety record, along with regulatory endorsement, was emphasized.

Additionally, the discussion emphasized that public perception is a complex issue that varies across countries and regions. Nonetheless, consistent efforts across academia, industry, and government were deemed essential to bridge the knowledge gap and garner public trust.

The strategies and perspectives outlined by the participants provide valuable insights into how New Zealand can accelerate the acceptance of hydrogen technologies among its citizens, ultimately contributing to the nation's sustainable energy future. Based on participant feedback, expediting the integration of hydrogen technologies into the public sphere in New Zealand necessitates a multifaceted strategy encompassing public awareness, affordability, accessibility, incentives, pilot projects, infrastructure development, collaboration and partnership, and regulatory framework establishment and policy reinforcement. The following strategies are worth considering:

Public Awareness: Elevating public awareness and comprehension of green hydrogen and associated technologies is pivotal to their successful adoption. To achieve this, comprehensive educational campaigns, public forums, and accessible information resources should be launched to actively engage the general populace and address their concerns. Educational campaigns should prioritize dispelling misconceptions and inaccuracies surrounding hydrogen technologies. By furnishing precise information and accentuating advantages like reduced greenhouse gas emissions and energy security, these campaigns can instil public confidence and garner support (Ates, 2023).

Community Engagement: Inclusivity is paramount, and public forums and community involvement initiatives can serve as platforms to foster open dialogues and knowledge exchange concerning hydrogen technologies. These forums should strive for diverse stakeholder participation, including Māori communities, given their distinctive cultural and environmental values, as well as their roles as kaitiaki (guardians) of land and resources. Collaborating with Māori organizations, incorporating traditional knowledge systems, and engaging Māori leaders and influencers in educational endeavours can augment the efficacy and relevance of these initiatives.

Accessible Information: Providing accessible, user-friendly information resources tailored to different audiences is crucial. These resources should elucidate the science and technology underpinning green hydrogen, its potential applications, and its contribution to New Zealand's

decarbonization objectives. Addressing concerns linked to safety, reliability, and affordability of hydrogen technologies should be a central focus. Employing case studies, success stories, and practical examples can effectively illustrate the viability and applicability of these technologies.

Māori Collaboration: Collaborative partnerships with Māori communities that integrate Te Ao Māori (Māori worldviews) and honour the principles of kaitiakitanga (guardianship) and manaakitanga (hospitality) are essential for building trust, respect, and ownership among these communities. Meaningful engagement and input from Māori communities during decision-making processes can ensure their perspectives and aspirations are taken into account, facilitating more inclusive and sustainable outcomes.

Affordability and Incentives - both play a pivotal role in making hydrogen technologies appealing and accessible to the public. Mitigating initial financial barriers is crucial. Financial incentives, such as subsidies or tax incentives, are effective tools to encourage investments in hydrogen-based systems. These subsidies can extend to individuals investing in photovoltaic (PV) systems, electrolyzers, and fuel cells for household energy generation. By rendering these technologies economically viable, adoption is incentivized. Additionally, financial support for installing hydrogen-based heating systems in residential and commercial buildings promotes clean energy usage and offsets initial costs compared to traditional fossil fuel-based heating systems (Nasser, 2023; MBIE, 2022).

Economies of Scale can be achieved by extending subsidies and support to the production and distribution of hydrogen-related products, including fuel cells, electrolyzers, and other hydrogen generation or storage technologies. Market incentives, such as feed-in tariffs or long-term purchasing agreements for hydrogen energy, stabilize and encourage investment, driving economies of scale as the hydrogen technology market grows (IRENA, 2020).

From an academic perspective, evaluating the impacts and effectiveness of these incentives is crucial. **Research studies** can analyse cost-benefit aspects, including factors like subsidy levels, duration, and overall market impact. Socioeconomic implications, such as job creation, technological innovation, and environmental benefits, provide insights into the long-term sustainability of incentivizing hydrogen technologies (MBIE, 2022).

Pilot projects are instrumental in accelerating public acceptance. These real-world demonstrations showcase the practical applications and benefits of hydrogen technologies, addressing scepticism or apprehension. These projects can be strategically implemented in selected communities or buildings, allowing for a focused evaluation of their impacts on energy costs, carbon emissions, and air quality. Transparency in sharing outcomes and lessons learned from pilot projects fosters trust and knowledge dissemination, paving the way for broader hydrogen technology adoption (Thomas et.al., 2020).

Infrastructure development is vital for supporting the widespread adoption of hydrogen technologies. This includes facilities for hydrogen production, storage, distribution, and an expanded network of refuelling or recharging stations for hydrogen-powered vehicles. Collaboration with industry stakeholders, local governments, and private investors accelerates infrastructure development, ensuring accessibility and availability. By working collaboratively, these entities can pool resources, share expertise, and leverage their respective networks to accelerate the deployment of hydrogen infrastructure. Additionally, a comprehensive and strategic approach should be taken to identify and prioritize locations for infrastructure development, considering factors such as population density, transportation hubs, and existing energy infrastructure.

Collaboration and partnerships among industry players, research institutions, and community organizations unlock valuable synergies, facilitating knowledge exchange and innovative solutions. These partnerships lead to joint investment opportunities, enabling financial support for hydrogen infrastructure scaling and economic growth.

Establishing a robust **regulatory framework and standards** is essential for creating an enabling environment. Clear safety, performance, and interoperability standards across the hydrogen value chain ensure compliance and reliable operations. Streamlining permitting processes and addressing regulatory barriers reduce obstacles to hydrogen technology adoption. The regulatory framework must adapt to technological advancements and industry developments to remain relevant.

Finally, highlighting the potential **economic benefits** of hydrogen technologies can generate public support. Emphasizing the creation of new job opportunities, local manufacturing and supply chain development, and the overall economic growth potential can help garner public enthusiasm and support for hydrogen technologies.

In summation, advancing public awareness and education regarding green hydrogen and hydrogen technologies in New Zealand calls for comprehensive educational initiatives, active community engagement, accessible informational resources, a comprehensive approach addressing affordability, pilot projects, infrastructure development, collaboration, and regulatory framework establishment. Meaningfully involving and consulting with Māori communities is integral to securing their support and participation. By implementing these measures diligently, New Zealand can cultivate an informed and engaged public that embraces hydrogen technologies as a cornerstone for a sustainable future (Wilcox et.al., 2008).

5.3.3 Summary

The integration of hydrogen technologies into New Zealand's energy landscape necessitates a thoughtful, collaborative approach to garner public acceptance. As the discussions have illuminated, accelerating public endorsement requires comprehensive educational initiatives, accessible informational resources, meaningful community engagement, strategic financial incentives, pilot demonstrations, infrastructure development, industry collaboration, and robust policy frameworks. Fundamentally, it entails actively empowering people to make informed decisions regarding these technologies by transparently communicating potential benefits aligned with values like sustainability, energy security, clean air and water, and economic resilience. Strategic government support through subsidies, streamlined regulations, and public sector adoption can stimulate market growth. Meanwhile, decentralization enhances localization and self-sufficiency. Overall, a nuanced strategy tuned to the distinctive needs and perspectives of New Zealand's diverse communities, integrating insights from all stakeholders, provides the most promising avenue for expediting public acceptance of hydrogen technologies. This can enable New Zealand to harness hydrogen's immense potential in addressing the pressing energy trilemma and securing an equitable, prosperous zero-carbon future.

This summary aligns with Objective 3 by emphasizing the need for a comprehensive framework to guide the introduction of hydrogen energy systems in New Zealand. It underscores the importance of a collaborative approach that integrates educational initiatives, community engagement, financial incentives, and infrastructure development. By fostering public understanding and support, the framework aims to ensure that hydrogen technologies align with social, economic, and environmental security objectives. The focus on transparency and alignment with community values - such as sustainability, energy security, and economic resilience - demonstrates a commitment to public well-being. Strategic government support and decentralized solutions further enhance the framework's potential to enable New Zealand to effectively harness hydrogen's capabilities, addressing the energy trilemma and promoting a prosperous, equitable zero-carbon future.

5.4 Question 4 - What factors may influence the Government's decision to accelerate development of new energy vectors and how to provide the Government with confidence to invest in advanced hydrogen technologies? Participants' view

Question	Participant	Response
4. What factors may influence the Government's decision to accelerate development of new energy vectors and how to provide the Government with a confidence to invest to advanced hydrogen technologies?	DA	DA highlights that convincing governments, especially those without existing regulations and frameworks, depends on their economic dependencies and energy needs. For developed nations heavily reliant on a single source, like Russia for gas, diversifying energy sources becomes crucial. Proposing hydrogen as a viable alternative helps mitigate geopolitical risks associated with over-dependence. Additionally, for manufacturing-driven economies like Korea, Japan, and China, emphasizing the sustainability and efficiency of hydrogen as a replacement for coal and natural gas can make a persuasive argument. However, the transition will require time and consistent effort. <i>"But how do you convince those governments to changing to hydrogen? You just are taking a just give the example of Germany. So if you are dependent on one country, if you are too much dependent on one country. In terms of like energy, then you are doomed. Basically, you need to find ways of alternative energy. You need to find exactly as United Arab Emirates doing exactly as Saudi Arabia, doing exactly the countries like Japan and Korea doing so. This is one way of kind of convincing them to diversify their energy sources like hydrogen. But also the other way is if they have economies that are based on manufacturing like Korea and Japan, or even China, then you can tell them listen, making all those cars, all those ships, all those products, there's an unsustainable with coal and natural gas. And what can really replace the call in natural gas? Basically the full size is a hydrogen, so you can and a lot of countries who are in the same position as Korea, Japan, Taiwan. They are currently convinced that hydrogen is probably the only way they can decarbonize their whole economy. And that's exactly why they're betting big on this type of fuel. But it can take years. It will take, of course, it's not gonna happen overnight and it will take time. A lot of time".</i>
	EEF	The critical factor that can drive government action in accelerating the development of a new energy vector like hydrogen is external pressure, particularly in terms of decarbonization. Many countries, including Costa Rica, face the dilemma of balancing decarbonization efforts with economic development. External pressure, perhaps from international agreements or global initiatives, can incentivize governments to prioritize decarbonization, providing the necessary confidence to invest in advanced hydrogen technologies. The urgency to address climate change and meet international commitments pushes governments to explore and invest in innovative solutions like hydrogen to align with global sustainability goals. EEF believes that there often exists a tension between environmental concerns and development, especially in the short term. Striking a balance between the two is challenging, as immediate development goals may clash with the long-term environmental sustainability needed to combat climate change. Governments often grapple with finding solutions that promote both development and environmental well-being. While it is difficult to

		harmonize these objectives in the short run, long-term planning and sustainable policies can bridge this gap, allowing for a more interconnected and mutually beneficial approach in the future. The key lies in envisioning development that is sustainable and environmentally responsible. EEF underscores that Costa Rica's lack of natural gas and fossil fuel resources has provided an impetus for exploring and harnessing alternative and renewable energy sources. The absence of abundant fossil fuel reserves has encouraged the pursuit of indigenous solutions, such as the development of hydrogen technologies, to meet the country's energy needs. However, he also notes that while this context initially facilitated early initiatives, sustaining and scaling these efforts requires addressing increasing opportunity costs associated with maintaining a carbon-intensive approach. This illuminates the complex trade-offs and considerations involved in aligning development choices with decarbonization objectives.
	SGJA	SGJA believes that convincing the government to switch to green hydrogen production might be challenging due to their entrenched stance. If the government is inclined towards promoting renewable energy, they could facilitate the transition without extensive regulatory changes. Allowing the regulators and independent system operators to function effectively in promoting renewable energy can be a pivotal step towards encouraging the production of green hydrogen.
	RGJA	RGJA suggests that the primary motivation for governments to accelerate new energy vector development is the long-term goal of achieving a decarbonized economy. This strategic shift aligns with global demands for environmentally responsible practices, enhancing international trade prospects by meeting stringent CO2 footprint standards. Moreover, for countries lacking direct access to oil and gas reserves but possessing renewable energy resources, investing in hydrogen offers a pathway towards energy self-sufficiency, reducing dependence on external energy providers. Green hydrogen presents a promising opportunity for countries rich in renewable resources but lacking in oil and gas reserves. The affordability of green hydrogen is contingent on finding viable business models and suitable application cases. The participant sees potential in leveraging the global carbon market to ensure the true cost of emissions is reflected, further enhancing the affordability of green hydrogen. Sustainability is regarded as achievable by integrating sustainable practices throughout the lifecycle of green hydrogen projects. This includes assessing impacts in social, environmental, economic, and governmental domains, guided by effective government regulations. He acknowledges that the production scale of hydrogen technologies, especially AEM electrolyzers, may not be at the optimal level yet. However, he believes that private investors will readily invest in projects to expand production capacity and meet the demand for hydrogen technologies if they see a viable market.
	JAGR	Accelerating the development of a new energy vector like hydrogen requires government confidence and investment. JAGR emphasizes the importance of presenting facts and numbers to quantify the benefits of hydrogen technologies. Demonstrating tangible advantages, such as job creation, improved public health due to reduced respiratory illnesses, and increased tax revenues from a thriving hydrogen market, can speak the government's language of economics and incentivize their investment. The

		key lies in tailoring the approach to each country's context and identifying the appropriate actors, whether private sector entities, civil associations, or international cooperation agencies, to effectively advise and influence the government in favour of hydrogen technology development. <i>“When you can quantify the amount of employees, you can create full time employment.</i> <i>When you can quantify how much you will save for the public health service by avoiding illness from the respiratory system”.</i>
	JH	To accelerate the development of the new energy vector, key factors include the completion and effective utilization of a comprehensive roadmap, proper resourcing, and active engagement with stakeholders, especially potential users and industry experts. It is vital to collaborate with entities like the New Zealand Hydrogen Council and involve various interested parties in shaping the future of hydrogen technologies in New Zealand. Building strong relationships and open communication with government bodies like the Ministry of Energy and Resources can instil confidence and provide the necessary impetus for government investment in hydrogen technologies. <i>“I think they need to develop this road map and I think that's really important that they actually do the thinking...”.</i> He underlines the need for a strong top-level framework and proactive steps in New Zealand to prevent falling behind the global advancements in hydrogen technologies. He highlights the challenges faced by the New Zealand government in prioritizing the hydrogen roadmap and overall energy strategy amidst pressing concerns such as COVID and natural disasters like cyclones. He suggests that limited budget allocation might have affected the progress of the hydrogen program, emphasizing the need for sufficient resources and prioritization to advance hydrogen initiatives.
	MR	Various factors can influence the government's decision to accelerate the development of a new energy vector like hydrogen. Economic viability is a crucial consideration, with a focus on technologies that can reduce costs and compete effectively with existing energy sources. Private sector involvement and functional, comprehensive solutions are also essential. Having a coordinated approach, where different technologies and infrastructure pieces align effectively, is seen as pivotal. Technology plays a central role in bringing all the components together, enabling the government to strategically invest and advance the development of the new energy vector. To instil confidence in government investment into advanced hydrogen technologies, it's crucial to maintain transparency and honesty about the challenges and limitations of the technology. Acknowledge both the strengths and weaknesses, and openly discuss unresolved questions. Demonstrating a clear understanding of the technology's capabilities and areas for improvement helps set realistic expectations. By doing so, trust can be built between the government and the technology developers, ensuring that investments are informed and effective.
	MS	MS points out that global commitments and agreements, like the G8 summit, play a crucial role in influencing governments to accelerate the

		development of new energy vectors such as hydrogen technologies. Governments are collectively committed to reducing CO2 emissions, which drives the need to invest in cleaner and more sustainable energy solutions. However, the approach can vary for countries based on their economic reliance on oil and gas exports. For instance, countries like Indonesia need to find a balance between reducing CO2 emissions while considering their oil and gas export industry. The overarching goal is to align their energy strategies with international commitments and environmental sustainability.
	RH	RH suggests that governments may find it challenging to accelerate the development of advanced hydrogen technologies due to the perception of risk associated with new and advanced technologies. Companies involved in electrolyser production, and importers of electrolysis technology like Enapter, can provide assurance to the government. Rather than driving the process, the government should create supportive regulations to facilitate the adoption of these technologies. To encourage government investment in advanced hydrogen technologies, highlighting the potential for hydrogen as a backup during dry periods alongside other storage systems like pumped hydro can be beneficial. Additionally, showcasing projects such as storing hydrogen in exhausted oil wells, like the endeavour project at the University of Canterbury, can demonstrate the viability of hydrogen storage solutions. If such projects prove successful, the government can consider investing in the necessary equipment and infrastructure to support hydrogen storage and utilization.
	SJS	To convince governments to invest in green hydrogen and hydrogen technologies, SJS suggested to reduce subsidies for the fossil fuel industry, providing hydrogen with a level playing field for fair competition. Governments should focus on fostering free competition, allowing people to naturally gravitate towards the most economical and sustainable energy options. SJS underscored the influence of major oil companies and their massive marketing budgets, advocating for greater transparency and accurate information dissemination. He emphasized that reducing reliance on fossil fuels is critical, urging governments to transition to renewable energy sources and incentivize their adoption. Furthermore, he criticized Germany's energy choices, pointing out the contradiction of halting Russian gas purchases while opting for expensive fracked gas from the US. He stressed the importance of prioritizing renewables and investing in solar panels, encouraging a decentralized and localized energy system. In summary, SJS urged governments to level the playing field by reducing fossil fuel subsidies, prioritize renewables, and promote fair competition to boost confidence and investments in hydrogen technologies. SJS criticized bureaucratic hurdles that individuals face when trying to adopt renewable energy solutions. He stressed the importance of simplifying permit processes and eliminating unnecessary complications, enabling faster and easier adoption of technologies like hydrogen.
	TW	TW suggests that the government could be motivated to introduce hydrogen technologies to the public, especially if they recognize the potential for these technologies to produce zero or near-zero emissions. The emissions trading scheme was initially seen as a mechanism to encourage the adoption

		of low or no-carbon energy sources. However, recent discussions indicate that it may not have achieved the desired outcomes, potentially prompting a need to explore other avenues for promoting sustainable and low-emission technologies like hydrogen. TW emphasizes the importance of political will in driving the adoption of hydrogen systems in New Zealand. He suggests that the transition to hydrogen may not immediately make financial sense from an efficiency perspective and will require exemptions to existing regulations, such as the Gas Act. Integration will also depend on supporting systems like batteries. Wiseman suggests identifying use cases, focusing on where bottled LPG is currently used, as a starting point for cost-effective hydrogen adoption. He particularly sees potential for replacing bottled LPG with hydrogen in domestic applications before 2025. On government confidence, TW suggested the government needs to see energy independence and resilience benefits for consumers rather than just financial incentives. Enabling rooftop solar, virtual power plants, and better use of curtailed renewable energy were ideas to build the case for hydrogen. Removing perceived risks of change was noted as important.
	TN	TN outlined several factors that could influence the government's decision to accelerate the development of a new energy vector like hydrogen. He highlighted the global commitment to decarbonize by 2050, emphasizing the need for effective investments and a long-term strategy. Comparing strategies of other countries and understanding that hydrogen can play a crucial role, especially in challenging areas of decarbonization, could drive the government's interest. He stressed the importance of a holistic approach, considering the pros and cons of various methods without excluding options. TN noted the necessity for a sense of urgency, driven by the need to achieve decarbonization goals by 2050, and highlighted the role of financial considerations as a significant factor. TN expressed the challenge of providing confidence to the government for investing in hydrogen technologies. He mentioned conducting financial analysis on hydrogen production and refuelling facilities, highlighting the cost factor associated with electricity. He implied that the current cost of converting electricity to hydrogen and back to electricity may not be competitive with traditional fuels like diesel or petrol. He suggested that in order to instil confidence, the government might need to allocate more funding or enact policy changes to support the transition to hydrogen technologies. <i>"I don't see much road map or initiative from the government toward hydrogen. Not only subsidies, but I don't see the leadership there at all. So that is critically missing here. Then when I look at, say not only Japan but Australia or US, they have clearer picture of where a country is heading. So that's what has been missing here in New Zealand".</i>
	ZJ	The UK government is making significant efforts to transition to clean energy and shift away from fossil fuels. Their aim is to generate 80% of the electricity from renewable sources by 2030, demonstrating a strong commitment to this transition. something similar can be adopted by the NZ government.

Table 47: Question 4 - What factors may influence the Government's decision to accelerate development of new energy vectors and how to provide the Government with confidence to invest in advanced hydrogen technologies? Participants' view

5.4.1 Additional inquiries pertaining to the fourth primary research question

Question	Participant	Response
4.1 What would be your recommendation to the NZ government agencies and how to convince the government agencies to adopt the hydrogen technologies?	MR	MR suggested a strategic approach for the New Zealand government agencies regarding green hydrogen and hydrogen technologies. She recommended conducting local evaluations to identify specific regions or areas where hydrogen could be effectively utilized. Implementing pilot projects in different communities, focusing on applications such as heating buildings or grid balancing using hydrogen, would provide valuable insights into the most suitable technologies for each application. Based on the outcomes of these pilot projects, the government could then make informed and targeted investments to promote the widespread adoption of hydrogen technologies across the country.
	MS	MS believes that in the case of New Zealand, there might not be a need to convince the government regarding the benefits of green hydrogen technologies. New Zealand is already inclined towards renewable energy due to its lack of oil and gas production and its status as a net importer. The key focus should be on highlighting how adopting green hydrogen technologies can help reduce dependence on imported resources and align with the country's renewable energy goals.
	SJS	Simplify government permit processes, reduce bureaucracy, eliminating unnecessary complications and shift towards decentralized energy systems to enable faster and easier adoption of technologies like hydrogen. SJS highlighted the paradox where governments encourage advanced technologies to reduce CO2 emissions but simultaneously create barriers for the public. He noted that people tend to appreciate more complex solutions, perceiving simplicity as inadequate.
	TW	TW recommends that the New Zealand government should provide clarity in the political space to facilitate the adoption of new technologies. He acknowledges the government's caution in pursuing specific fuel types and suggests focusing on enabling energy independence and resilience for domestic users. Encouraging domestic solar adoption can be a crucial step, as it provides additional energy that can be utilized for hydrogen production. Building step by step and enabling the community to be more energy-independent is key to driving progress in the energy sector. TW suggests that while bureaucracy and paperwork can make accessing government support challenging, he emphasizes the importance of having physical demonstrations and tangible experiences with the technology. He believes that having a university or polytechnic to showcase and work with these products can be sufficient for learning and educating people about hydrogen technologies. He envisions that one institution in the country could effectively serve this purpose, given New Zealand's size and existing educational infrastructure.

		TW expresses concerns about the current approach, suggesting that simply planting trees to offset carbon emissions from fossil fuel consumption may not adequately address the climate change problem. He points out that the prevailing strategy is geared towards utilizing mechanisms like green energy certificates and carbon credits to encourage the adoption of cleaner technologies rather than relying solely on tree planting. This approach aims to incentivize the use of cleaner and low-carbon energy sources like hydrogen by penalizing high-emission energy consumption. By shifting the focus from merely offsetting emissions to actively reducing emissions through technological advancements, TW believes that more effective solutions can be achieved to mitigate climate change. TW emphasizes the importance of reducing perceived risks associated with transitioning to hydrogen technologies. To achieve this, he advocates for a multifaceted approach involving pilot projects, public demonstrations, and educational initiatives. These efforts can help build trust in hydrogen as a fuel source and increase public acceptance, especially by addressing historical incidents like the Hindenburg disaster, which often shape public perception of hydrogen. By mitigating risks and demonstrating the safety and viability of hydrogen technologies, TW believes that the transition to hydrogen can be facilitated successfully.
	TN	TN recommends approaching government authorities at higher levels, particularly the central government and influential local government figures, to expedite the process of gaining support and approvals for pilot projects related to green hydrogen technologies. Emphasizing the positive aspects of green hydrogen, such as its environmentally friendly nature and potential to address the trilemma of energy affordability, security, and resilience, can help in convincing decision-makers. TN also suggests engaging with ministers or officials responsible for relevant sectors, like transportation, as they can act as channels to advocate for and support innovative projects in the energy sector. This strategy aims to streamline the approval process and ensure timely consideration of pilot projects.
	ZJ	ZJ offers insightful recommendations for New Zealand's adoption of green hydrogen. He suggests initiating a consultation program involving key stakeholders from industrial sectors and national energy providers to gather input on how hydrogen can integrate into the existing energy system. Additionally, conducting techno-economic assessments of the technology is vital. ZJ also advises considering the import of hydrogen from countries like Australia if local production is initially expensive, particularly focusing on solar-based hydrogen production. However, for long-term energy security, New Zealand should develop its own hydrogen supply chain, encompassing production, storage, and utilization facilities.
4.2 What qualifications and skills are required for working with hydrogen	EEF	EEF emphasizes the importance of qualifications and skills related to the hydrogen sector. He highlights that foundational knowledge and expertise in areas such as gas handling, safety regulations, and operational protocols are crucial. EEF suggests that qualifications and skills akin to those in the natural gas sector are valuable for working with hydrogen, given their similarities as gaseous fuels. Understanding relevant codes, norms, and

technologies and What types of educational programs should academic institutions design to equip specialists for the hydrogen industry?		standards is deemed paramount, especially as hydrogen transitions from an industrial gas to a key player in decarbonization efforts. EEF also underscores the significance of continuous learning and staying updated with the evolving hydrogen landscape.
	RGJA	RGJA suggests two pathways for training installers in hydrogen technologies. Firstly, existing professionals can undergo retraining or additional education through academic programs to gain the required knowledge and skills for these technologies. Secondly, new educational programs can be designed to create a technical foundation for careers involving installation, operation, and maintenance of hydrogen equipment. These programs should cover relevant technical codes like NFPA 2, which is essential for certification of hydrogen installations.
	JAGR	In addressing the qualifications and training required to engage with hydrogen technologies, JAGR emphasizes the need for tailored educational programs and a shift in focus from traditional oil and gas-centric curricula. He advocates for nurturing expertise in electrical engineering, materials science, and digitalization, essential in the evolving landscape of hydrogen technologies. JAGR highlights the adaptability of existing knowledge in energy systems, emphasizing the importance of retraining professionals to grasp the nuances of hydrogen systems compared to natural gas. Ultimately, he underscores the necessity of being agile and responsive to emerging trends, swiftly crafting educational initiatives to align with the evolving demands of the hydrogen sector. <i>“There is a deficit of electrical engineers”; “that people who has knowledge on energy system and gas and other stuff, we can retrain them to understand the differences between natural gas and hydrogen. We have to also create new programs on that kind of trending topics for materials, digitalization”.</i>
	JH	To work with hydrogen energy, professionals should possess a range of skills encompassing both practical implementation and a deep understanding of the broader energy context. JH suggests that professionals in the oil and gas industry already possess practical talents applicable to hydrogen energy implementation. However, in academia, he emphasizes the need to provide students with a comprehensive understanding of energy systems and technologies. JH advocates for educational programs, like sustainable energy systems, that equip students with the knowledge required for working with hydrogen. He also raises concerns about potential cuts to such programs due to restructuring in universities. <i>“We need to develop that human capital”.</i>
	MR	In order to embark on a career involving green hydrogen and hydrogen technologies, several key skills are essential. Individuals should possess a strong foundation in relevant engineering and technology, particularly focusing on renewable energy systems, electrochemistry, and chemical engineering. Familiarity with digitalization, automation, and control systems is crucial for effectively managing and optimizing hydrogen technologies.

		Moreover, expertise in chemistry, especially as it pertains to hydrogen production, storage, and safety, is fundamental. Professionals need to understand the intricacies of hydrogen behaviour, its interaction with various materials, and safety protocols associated with its production, handling, and utilization. MR emphasized the need for an updated curriculum in universities to incorporate education about hydrogen technologies. This update should include a broad understanding of hydrogen, its applications, associated challenges, and its role in the energy transition. Encouragement for students to explore and specialize in these areas is crucial to meet the growing demand for skilled professionals in the field of hydrogen technologies.
	RH	RH suggests that existing gas fitter teaching programs cover about 90-95% of the skills needed for working with green hydrogen and hydrogen technologies. He proposes an endorsement for hydrogen knowledge and skills, building on the foundation of gas fitter qualifications. This endorsement would encompass knowledge specific to hydrogen, including material considerations, odorization alternatives, buoyancy, and dealing with an invisible hydrogen flame. For individuals seeking a more comprehensive qualification, a short training course to obtain this endorsement could be pursued. RH believes that New Zealand professionals can easily adapt their existing skills for the hydrogen industry with a little extra training, making the transition feasible and not overly challenging. Additionally, he suggests that institutions might consider incorporating this endorsement or specific hydrogen-related subjects into a curriculum to prepare future professionals for the emerging green hydrogen economy.
	SJS	According to SJS electrochemistry, mechanical engineering, software engineering are the main required qualifications. SJS emphasizes the need for a strong foundation in electrochemistry and related sciences for individuals working with green hydrogen technologies. He highlights the importance of specialized training and education in these domains. He also raises concerns about the development of electrochemistry expertise being more pronounced in countries like China, emphasizing the need for Western countries to prioritize and enhance their educational programs in these areas. SJS further encourages hands-on learning through practical demonstrations and workshops. He emphasizes that starting with a demo system, integrating it with software, and understanding the intricacies of hydrogen-related components are valuable learning experiences. He suggests that organizations and individuals should proactively invest in training, workshops, and learning centres to equip themselves with the necessary skills and knowledge to work effectively with green hydrogen technologies. He mentions that their electrolyser system is designed to be cost-effective, allowing interested individuals and organizations to start working with it without significant financial barriers.
	TW	According to TW, engineers looking to work with green hydrogen and hydrogen technologies should have skills in electrical engineering, particularly in managing additional loads. In the case of mechanical engineering or process perspectives, a strong focus should be placed on

		careful material selection due to the flammable nature of hydrogen. He believes that New Zealand professionals already possess the skills necessary to work with green hydrogen and hydrogen technologies, particularly in the electrical and mechanical engineering domains. According to TW, there is a need for additional training and certifications to ensure professionals are equipped to work with hydrogen systems due to the unique hazards and controls associated with this energy vector. He mentioned the idea of micro credentials, a form of certification, which could be implemented to ensure professionals have the necessary qualifications and knowledge to work safely with hydrogen systems. TW emphasizes the need for universities to adapt their curricula to include a focus on hydrogen safety, efficiency, and its application within the regulatory and architectural domains. He suggests educating professionals about the strengths and limitations of hydrogen, ensuring they understand when and where it is the most suitable solution. This aligns with a balanced approach, helping professionals make informed decisions regarding hydrogen adoption.
	TN	TN highlighted that individuals with a background in the oil and gas industry possess valuable skills for working with hydrogen technologies due to their familiarity with plant operations. However, he emphasized the need for training programs to enhance these skills and bridge any knowledge gaps specific to hydrogen technologies. While he acknowledged the presence of potential resources and skills in New Zealand, he indicated the necessity of specific training and educational programs tailored to hydrogen technologies.
	VG	VG emphasizes that hydrogen, like any industry, requires a variety of skill sets beyond highly specialized hydrogen knowledge. While a fraction of the workforce needs deep technical understanding, the majority of jobs in the hydrogen sector encompass a range of roles such as project managers, sales managers, and accountants, which are industry-independent and can be filled by individuals with diverse backgrounds and experiences. Specific technical roles may require engineering degrees with a focus on hydrogen, but extensive retraining initiatives might not be necessary. Having a broad understanding of the energy sector is valuable for comprehending how hydrogen fits into the larger energy landscape. Adaptability and on-the-job learning play crucial roles in filling roles within the hydrogen economy.
	ZJ	ZJ emphasizes the importance of an engineering background, particularly in chemical, mechanical, and electrical engineering, for a career in hydrogen technologies. The specific skills needed may vary based on the sector within hydrogen technologies. For production, knowledge of chemical engineering principles is crucial. However, for distribution and storage, skills related to mechanical engineering and electrical engineering become more pertinent. Training should focus on hydrogen properties, safety aspects, and the specific requirements of the chosen sector within hydrogen technologies. ZJ suggests that educational institutions, including universities and research institutions, should design programs to ensure the industry

		attracts appropriately skilled professionals. One approach is the development of training courses tailored to the needs of industrial partners, varying in duration from two to four weeks based on specific goals and requirements. Additionally, longer programs such as master's degrees can provide a more in-depth and comprehensive understanding of hydrogen technologies. These initiatives help in upscaling the skills of professionals and ensuring a pipeline of talent in the hydrogen sector. Universities play a critical role in providing relevant education and training to prepare individuals for careers in the hydrogen industry.

Table 48: Additional inquiries pertaining to the fourth primary research question

The expert insights reveal several key factors that can influence government confidence and decisions to accelerate new energy vectors like hydrogen:

Similar Perspectives:

1. Emphasizing energy security and diversification benefits, reducing over-reliance on limited energy sources.
2. Quantifying decarbonization and emissions reduction potential aligned with climate commitments.
3. Demonstrating economic viability and cost competitiveness with conventional energy.
4. Highlighting job creation, tax revenues, and other tangible economic benefits from hydrogen adoption.
5. Showcasing successful pilot projects as proof points and building collaborative relationships.
6. Reducing bureaucratic hurdles and streamlining adoption of renewable energy technologies.
7. Pilot projects and local demonstrations to validate applications and build evidence for decision-makers.
8. Streamlining bureaucratic processes for renewable energy technology adoption.
9. Emphasizing alignment with renewable energy goals and reduced import dependency.
10. Highlighting economic benefits like job creation and tax revenues.
11. Recommending consultation with industry stakeholders for integration strategies.
12. Advocating for foundational engineering skills, especially around renewable systems, electrochemistry, and hydrogen properties.
13. Promoting hands-on learning and continuous education to stay updated.

Differing Views:

1. Some experts warn entrenched government stances may be resistant to change, while others are more optimistic about convincing governments.
2. Perspectives vary on the ease of securing direct project funding from governments - some indicate significant challenges.
3. While hydrogen's potential is acknowledged, instilling full confidence in governments to invest heavily remains a complex challenge.
4. Some experts warn of resistance to change from entrenched interests, while others express optimism about government adoption.
5. Perspectives vary on the need for extensive retraining versus adaptability of existing oil and gas skills.
6. Recommendations range from comprehensive university programs to short endorsement courses for qualifications.

In summary, multifaceted efforts are required to provide governments the confidence to accelerate new energy vectors like hydrogen. Quantifying sustainability and economic benefits while reducing adoption barriers is key. But overcoming entrenched interests and scepticism about cost viability

persists as challenges. Ongoing collaboration and showcasing local success stories to convey potential can contribute to driving government investment and leadership in enabling energy transitions aligned with global climate commitments.

In terms of providing government confidence to invest, the overarching emphasis is on showcasing evidence and quantifying benefits through localized demonstrations. Skilling professionals for hydrogen deployment will further instil confidence. But managing expectations realistically and incrementally building evidence remains prudent, given uncertainties around adoption barriers. Ongoing collaboration with government and industry partners can reinforce hydrogen's merits and contribute to strategic policy and education for its sustainable integration into New Zealand's energy landscape.

5.4.2 What factors may influence the Government's decision to accelerate development of new energy vectors and how to provide the Government with confidence to invest in advanced hydrogen technologies? Literature review in support to the primary research Question 4

Various factors were expressed by the participants that can influence a government's decision to expedite the development of innovative energy vectors like advanced hydrogen technologies. These considerations encompass environmental objectives, economic prospects, technological readiness, market dynamics, research endeavours, stakeholder engagement, and regulatory frameworks.

Firstly, a government's commitment to environmental goals and carbon emissions reduction significantly impacts its stance on advanced hydrogen technologies. If these technologies align with sustainability targets, decarbonization strategies, and international climate commitments, they become an attractive investment choice for the government. Demonstrating hydrogen's potential to decarbonize New Zealand's building stock can motivate government support. With buildings contributing approximately 20% of national emissions, largely from fossil fuel usage, analysing hydrogen's application for low-carbon heating and power generation is crucial (MBIE, 2019).

Demonstrating the economic advantages of advanced hydrogen technologies is another pivotal factor. This entails highlighting the potential for job creation, economic growth, and enhanced energy security. Offering comprehensive techno-economic analyses, cost-benefit assessments, and demonstrating the long-term sustainability of hydrogen technologies can inspire government confidence in making investment decisions and technology adoption (IEA, 2019).

Techno-economic assessments can compare the costs of transitioning to hydrogen boilers and fuel cells in residential and commercial buildings under different adoption scenarios. Life cycle emissions studies verify net reductions from displacing natural gas. Viability depends on factors like carbon pricing, gas network repurposing, renewable electricity capacity and technology cost trajectories (MBIE, 2023).

Assessing the maturity and potential of advanced hydrogen technologies is vital. This involves conducting feasibility studies, technology assessments, and presenting successful pilot projects or demonstrations. Such actions are critical for illustrating the technical viability and scalability of these technologies. As indicated, there's a substantial opportunity to reduce costs associated with advanced hydrogen technologies, such as electrolysis, by increasing the module size and adopting innovations. Scaling up from 1 MW to 20 MW plants, for instance, can lead to cost reductions of over a third. Such cost efficiencies can make hydrogen technologies more economically attractive, aligning with the Government's fiscal objectives (IRENA, 2020).

Achieving economies of scale, especially through automated production in gigawatt-scale manufacturing facilities, can result in a step-change cost reduction. A critical threshold for cost

savings appears to be around 1,000 units per year for 1 MW stacks. This scalability not only makes production more cost-effective but also contributes to greater confidence in the feasibility of mass adoption (IRENA, 2020).

The availability of materials, particularly scarce ones like iridium and platinum, can influence the feasibility and cost-effectiveness of hydrogen technologies. Developing solutions that reduce or eliminate the need for such materials, as seen in some alkaline electrolyser technologies or Anion Exchange Membrane (AEM) electrolyzers, aligns with sustainability and can instil confidence in the Government regarding resource availability (IRENA, 2020).

Efficient operation of hydrogen technologies, especially in terms of power supply and flexibility, is vital. Efforts to address efficiency losses at low loads, modular plant designs, and integrated solutions for electricity and hydrogen storage can enhance the economic appeal of these technologies. Recognizing the value of green hydrogen in providing flexibility to the power system can further strengthen the case for investment (IRENA, 2020).

Closely monitoring international and domestic market trends is essential. A growing global demand for hydrogen technologies and a supportive market ecosystem can substantially influence government investment decisions. Evaluating market opportunities, industry partnerships, and export potential helps in establishing the commercial viability of advanced hydrogen technologies (IRENA, 2020).

Tailoring the design and operation of electrolysis systems to specific residential and commercial applications can be a key driver. Different sectors may have varying requirements, such as off-grid facilities, hospitals or decentralized production. Optimizing hydrogen technologies to meet these diverse needs can attract Government interest, especially if it aligns with national industrial and economic strategies.

A robust research and development landscape is another influential factor. Strong efforts in this domain, coupled with partnerships with academia and research institutions, can bolster confidence in the government to invest further in the innovation and development of hydrogen technologies.

Engagement with industry stakeholders, including energy companies, technology providers, and investors, is paramount. Demonstrating industry support, collaborative initiatives, and public-private partnerships conveys the presence of a strong network of stakeholders vested in the success of hydrogen technologies.

Learning rates in the hydrogen sector, while not as rapid as solar PV, still show potential for significant cost reduction. Demonstrating that hydrogen technologies can follow a cost reduction trajectory, akin to 1.5°C climate targets, can provide confidence in the long-term economic viability of these technologies (IRENA, 2020).

Furthermore, the establishment of a supportive policy and regulatory framework is crucial for government investment. Crafting clear policies, incentives, and long-term strategies offers a stable and predictable environment for investment. Engaging with experts, industry representatives, and stakeholders for the development of comprehensive policies enhances government confidence in hydrogen technology investments (MBIE, 2023).

In conclusion, the path to accelerating the development and widespread adoption of advanced hydrogen technologies hinges on the concerted efforts of stakeholders. By conducting comprehensive feasibility studies, sharing success stories, providing sound economic analysis, and engaging in constructive dialogues with policymakers, we can pave the way for the government to invest with confidence in these innovative energy vectors.

Furthermore, recognizing that the government's decision is influenced by factors like cost reduction, economies of scale, materials procurement, efficiency, industrial applications, and cost projections,

it becomes imperative for stakeholders to align their efforts with these considerations. Presenting robust, evidence-based arguments that underscore the economic and environmental advantages of hydrogen technologies is key. Additionally, addressing crucial aspects such as materials scarcity and operational efficiency demonstrates our commitment to overcoming challenges.

Ultimately, by aligning the development of hydrogen technologies with national goals, showcasing their cost-effectiveness, and providing a clear roadmap for their implementation, we can inspire the government to embrace these transformative energy solutions. Together, we can usher in a cleaner, more sustainable, and economically vibrant future.

5.4.3 Summary

The path to securing government investment and leadership in advanced hydrogen technologies requires a multidimensional approach. Comprehensive techno-economic analyses quantifying sustainability and economic benefits can reveal hydrogen's alignment with net-zero goals. Meanwhile, collaborative local demonstrations and global best practices provide evidence of technical viability and scalability. Streamlining adoption frameworks and emphasizing export opportunities convey market readiness. Ultimately, an ecosystem-wide commitment to incremental innovation, transparent communication, and showcasing hydrogen's merits through localized trials offers the most promising avenue. This can progressively nurture government confidence and strategic policy support for hydrogen's integration, facilitating the transition to diverse and decentralized energy systems capable of delivering secure, affordable and low-carbon energy aligned with community expectations and national interests.

This summary aligns with Objective 4 by outlining a multidimensional approach for formulating detailed hydrogen policy recommendations for the Government. It emphasizes the importance of comprehensive techno-economic analyses to quantify sustainability and economic benefits, which can inform safety regulations, codes, and standards essential for a robust regulatory framework. Collaborative local demonstrations and adherence to global best practices will provide evidence of hydrogen's technical viability, informing policy development. Streamlining adoption frameworks and highlighting export opportunities will showcase market readiness, guiding the creation of effective policies. Ultimately, fostering an ecosystem-wide commitment to innovation and transparent communication will nurture government confidence, leading to strategic policy support that ensures safe integration of hydrogen technologies within a diverse, decentralized energy system that meets community expectations and national interests.

5.5 Conclusion

This chapter has undertaken an extensive literature review and synthesized expert perspectives to illuminate the pivotal role of hydrogen technologies in enabling the decarbonization of New Zealand's built environment. It has delved into four key aspects - safety requirements, quantifying decarbonization impact, public acceptance, and factors influencing government support - that emerge as central determinants of the successful adoption of hydrogen technologies.

The literature review and expert insights reveal the necessity for robust safety regulations, training programs, ventilation provisions, risk-based infrastructure siting, and fire mitigation strategies to facilitate the secure deployment of hydrogen. Quantifying the decarbonization enabled by displacing fossil fuel usage requires meticulous life cycle analyses and displacement emission measurements tailored to the local context. Strategies like education campaigns, financial incentives, pilot demonstrations, and emphasis on localization are underscored to accelerate public acceptance.

Factors like emphasis on economic benefits, collaborative projects, policy incentives and managing realistic expectations can spur government investment.

While literature and experts provide valuable perspectives, capturing insights from a broader cross-section of stakeholders within New Zealand through surveys can uncover crucial nuances. Surveys allow wider engagement with groups like engineers, architects, developers, policymakers, industry specialists, investors, and the general public. This elicits multifaceted views on opportunities and barriers for hydrogen adoption while gauging confidence levels across various aspects. The quantitative and qualitative data garnered can affirm or counter perspectives from literature and experts. By integrating these diverse inputs, pragmatic roadmaps can be formulated to advance the adoption of hydrogen technologies securely and sustainably across New Zealand's built environment.

The next phase will administer comprehensive surveys to diverse stakeholders connected to New Zealand's building and construction ecosystem. This primary data collection will generate pivotal insights to clarify aspects requiring attention to expeditiously yet safely advance hydrogen technology integration. The surveys will address knowledge levels, risk perceptions, technology preferences, policy expectations, and other factors that influence the adoption of hydrogen technologies within New Zealand's residential and commercial buildings. By blending literature, expert opinions, and nationwide stakeholder surveys, this research endeavours to devise practical recommendations that contribute meaningfully to the policy discourse surrounding hydrogen's role in charting a sustainable built environment future for New Zealand.

Chapter 6 – Survey – Findings

6.0 Introduction

This chapter serves to unveil the discoveries derived from a meticulously conducted questionnaire survey, distributed among professionals within the extensive New Zealand network. While certain participants were geographically abroad during the survey, their invaluable insights pertained directly to the context of New Zealand.

The questionnaire was meticulously structured to address pivotal inquiries outlined in the table below, meticulously designed to align with the overarching objectives of this study. Through this survey, the aim was to glean comprehensive insights that contribute substantively to the central objectives of this research endeavour.

The formulation of the survey questions was meticulously tailored to align with the overarching research aims and objectives, aiming to systematically address the research inquiries and assess the validity of the research hypothesis. The insights gathered during the interview phase significantly informed the construction of the survey questionnaire, ensuring its comprehensive coverage and relevance.

The strategic design of these survey inquiries was aimed at eliciting precise responses that could serve as empirical evidence to substantiate or challenge the established research inquiries and hypotheses. These questions were structured in a manner that allowed for a comprehensive exploration of the research themes while aligning with the research's underlying objectives. The detailed list of survey questions is provided in Appendix XXX. The survey incorporated multiple-choice responses along with an open-ended section, affording participants the opportunity to provide their own qualitative responses. This dual approach facilitated the collection of both quantitative and qualitative data, enabling comprehensive analysis in the subsequent phases of the study.

6.1 Survey Distribution Methodology

The survey was facilitated through the utilization of the online survey platform, Qualtrics, which was made available through AUT. This instrumental tool facilitated the seamless collection and organization of data, streamlining its transfer for further analysis in SPSS software.

Participants were strategically approached through email correspondence and outreach via the LinkedIn platform. Deliberate selection criteria were employed, targeting individuals within professional networks possessing pertinent knowledge relevant to the study. Invitations to participate were disseminated via email and LinkedIn posts. These communications included a succinct yet comprehensive outline, encompassing the purpose of the survey, the study's objectives, participant information sheets, survey duration, and contact details of the researcher. Attached below is the invitation for participation in the study. Notably, the survey link was prominently shared across LinkedIn groups, including “Women in Green Hydrogen”, “Renewable Energy Experts”, and “Hydrogen News”, aiming to engage professionals with expertise in the field of study.

Participants were duly informed about the timeframe allocated for survey completion, ensuring ample time for their thoughtful consideration and participation. Additionally, select participants were directly contacted on LinkedIn, where all pertinent survey details and information were shared via the chatbox. This approach mirrored the methodology employed during the initial interview stage, fostering direct and personalized communication to encourage their involvement in the survey. The participants' invitation is attached in Appendix 4.

6.2 Survey Duration and Response Rate

The survey commenced on November 3rd, 2023, and concluded on December 26th, 2023, spanning a comprehensive duration of 53 days. During this period, a total of 258 responses were garnered, comprising 104 electronic mail-based responses and 154 responses obtained through the LinkedIn platform. Notably, out of these responses, 180 were deemed fully completed, surpassing the predetermined population threshold of 155 responses necessary for analytical rigor.

In the pursuit of a comprehensive participant engagement strategy, this research initiative deployed a combination of email invitations and LinkedIn outreach to solicit responses for a survey. A total of 109 email invitations were dispatched, culminating in 104 responses. Among these, 70 responses were deemed “true” and deemed usable for subsequent analyses, while 34 were categorized as “false” and subsequently rejected. The response rate for email-based responses was calculated with precision, revealing a noteworthy 67.3% response rate, reflecting the proportion of “true” responses to the overall email responses.

Simultaneously, the research leveraged LinkedIn as a pivotal platform for survey dissemination. A survey link was strategically embedded in posts across three distinct LinkedIn groups and on the personal page of the researcher. Additionally, a targeted outreach effort involved the transmission of approximately 1000 personal requests directly through the LinkedIn chat box to the researcher’s connections. As of January 20, 2024, the researcher’s network on LinkedIn, boasts 5900 connections. The scope and magnitude of response rates from these posts, however, pose challenges due to the expansive and diverse audience.

LinkedIn, being a platform of considerable magnitude, presented varied group memberships as of January 20, 2024, with “Women in Green Hydrogen” comprising 5,245 members, “Hydrogen News” boasting 76,884 members, and “Renewable Energy Experts” encompassing a substantial 213,010 members. The amalgamated responses from LinkedIn participants, inclusive of those emanating from personal invitations and link-based group posts, amounted to 157. The intricacies of response attribution within the LinkedIn platform make it challenging to precisely estimate response rates, given the diverse origins of responses.

The visibility metrics associated with the survey posts on various platforms further elucidate the reach and impact of the researcher’s outreach efforts. Specifically, the post on the personal researcher page garnered substantial attention with 5400 views, underscoring the resonance of the survey within the researcher’s immediate professional network.

The group-based dissemination strategy on LinkedIn, targeting specialized audiences, exhibited varying levels of engagement. The post within the “Women in Green Hydrogen” group accrued 117 impressions, indicating a discernible interest within this niche community. Similarly, the post in the “Hydrogen News” group garnered 111 impressions, reflecting an audience intrigued by current developments and news within the hydrogen sector. Notably, the post in the “Renewable Energy Experts” group achieved a notable 6415 impressions, affirming a robust engagement within a substantial and expert-centric LinkedIn community.

	Group Members	Number of Views
Women in Green Hydrogen	5,245	117
Hydrogen News	76,884	111
Renewable Energy Experts	213,010	6415
Post on the Personal Page	5900	5400
Number of Invitations Sent via LinkedIn Personal Chat Box	1000	1000

Total	301,039	13043

Table 49: LinkedIn Platform Engagement Metric

The determination of response rates and the subsequent categorization of responses as “true” or “false” constitutes a nuanced evaluation within the context of this research endeavour. While the quantification of responses from the LinkedIn platform encounters inherent challenges related to the discernment of respondents’ origin, whether through posted links or direct invitations via the personal chat box, a meticulous analysis has been undertaken to derive insightful estimations.

Considering a total of 12,043 individuals who viewed the posts and an additional 1,000 personal invitations disseminated through LinkedIn’s chat box, an approximate outreach of 13,043 individuals is inferred. Within this cohort, a total of 154 participants engaged with the survey, contributing valuable insights to the research endeavour. Among these respondents, 114 were deemed “true” and deemed instrumental for research purposes, while 40 responses were categorized as “false” and subsequently excluded from the analytical framework.

Consequently, the indicative rate of responses from the LinkedIn platform, based on the number of “true” responses, stands at 0.9%. This metric reflects the proportion of substantive and relevant responses in relation to the total LinkedIn engagement. Conversely, positing that all 154 responses emanated from direct personal invitations via LinkedIn’s chat box elevates the overall response rate to 15.4%, with the rate of “true” responses concurrently reaching 74.0%. This theoretical scenario underscores the potential impact of targeted and personalized LinkedIn outreach on response quality.

In aggregate, the overall response rate encompassing both email and social platform avenues is calculated at 70.9%, with the true response rate specifically pertaining to “true” responses identified as 74.0%. Importantly, these rates are articulated within the context of mitigating sample biases, thereby fortifying the robustness of the derived insights.

	Number of questionnaires distributed	Number of responses	False	True	Responses Rate (%)	True Responses Rate (%)
Electronic Mail-Based Responses	109	104	38	66	95.4	63.5
LinkedIn Platform – Chatbox Responses	1000	154	40	114	15.4	74.0
LinkedIn Platform	13043	154	40	114	1.2	74.0
Total		258	78	180	-	70.0

Table 50: Survey distribution and response rate

The response rate is computed by dividing the number of completed responses by the total invitations or survey distribution attempts and expressing the result as a percentage. The formula for response rate is articulated as follows:

$$\text{Response Rate} = (\text{Number of Completed responses} / \text{Total Invitations or Distribution Attempts}) \times 100$$

Similarly, the true response rate is determined by dividing the number of "true" responses by the total number of responses and representing the outcome as a percentage:

$$\text{True Response Rate} = (\text{Number of True Responses} / \text{Total Number of Responses}) \times 100$$

The presented data encompasses the distribution of questionnaires through various channels and details the responses received, distinguishing between “false” and “true” responses. The analysis integrates the observed response rates with reference to the literature, drawing upon established benchmarks and considerations.

A total of 109 questionnaires were distributed via email, yielding 104 responses. Of these, 66 were classified as “true” and usable for analysis, while 38 were deemed “false” and excluded. The response rate of 95.4% exceeds conventional expectations, aligning with the recommendations of AAPOR (2016) and emphasizing the effectiveness of email-based survey distribution (AAPOR, 2016).

Leveraging the LinkedIn platform, 1000 invitations via the chatbox elicited 154 responses. Among these, 114 were categorized as “true”, constituting a notable true response rate of 74.0%. Despite a comparatively low overall response rate of 15.4%, this aligns with findings by Singer and Ye, who underscore the positive impact of incentives on response quality (Singer & Ye, 2013).

A broader outreach effort on the LinkedIn platform, combining both group posts and personal invitations, reached approximately 13,043 individuals. The overall response rate of 1.2% presents a challenge in estimating due to the diverse origins of responses. However, the true response rate of 74.0% among those who participated reinforces the effectiveness of personalized LinkedIn outreach, echoing the recommendations of Groves and emphasizing quality over quantity (Groves, 2006).

Combining responses from both email and LinkedIn platforms, the overall response rate stands at 70.0%, emphasizing a substantial engagement level. The prominence of “true” responses, constituting 74.0% of total responses, aligns with the assertions by Fowler that, even with lower response rates, valid findings can be obtained when systematic differences between responders and non-responders are minimal (Fowler, 2014).

In conclusion, the observed response rates in this study align with or surpass established benchmarks, emphasizing the importance of quality responses over sheer quantity. The nuanced approach to outreach on different platforms, supported by literature-informed methodologies, has yielded a robust dataset for analysis. The utilization of incentives on the LinkedIn platform and the meticulous consideration of potential biases and non-response factors contribute to the methodological strength of the study.

6.3 Demography of Respondents

The analysis of occupational engagement in the survey data offers valuable insights into the diverse expertise contributing to the academic community. Engineers emerge as the predominant group, comprising 21.1% of respondents, followed closely by Architects at 8.3%. Project Managers also play a significant role, contributing 5% to the survey. Additionally, Consultants and Mechanical Engineers each represent 5% and 3.9% of respondents, respectively, underscoring the varied expertise within the academic landscape.

Beyond these established roles, the survey underscores the importance of specialized professions such as Hydrogen and Power Systems Developers, Solar Electricians, and Policy Advisors (Energy), highlighting the multidisciplinary nature of the field. This diverse array of expertise enriches discussions and initiatives aimed at green hydrogen adoption and decarbonization of the built environment.

The quantitative analysis provides a nuanced understanding of each professional category's proportional contribution, guiding targeted strategies for interventions and collaborative efforts. By acknowledging and leveraging the breadth of expertise within the academic community, stakeholders can foster more comprehensive approaches to address the challenges of sustainability and energy transition effectively.

6.4 Section 1 - Hydrogen Safety Requirements

Section 1 of the survey aimed to address the first research question: *“What specific hydrogen safety requirements need to be addressed to introduce hydrogen technologies to all New Zealand stakeholders?”*

6.4.1. Section 1 Question 2

A range of responses was received, encompassing various aspects of safety considerations, regulations, and standards associated with hydrogen technologies. The survey asked respondents to identify crucial safety requirements for introducing hydrogen technologies in New Zealand. Percentages of respondents selecting each requirement are reported.

- 74.4% chose adequate ventilation and leak detection systems. This emphasizes the need to monitor and control hydrogen leaks and accumulation risks.
- 81.1% identified proper hydrogen storage and handling guidelines. Stringent procedures for safe storage and usage are viewed as highly important.
- 72.2% selected comprehensive fire safety and emergency response measures. Hydrogen's flammability necessitates robust emergency and fire response preparedness.
- 71.1% chose strict training and certification requirements for personnel. Appropriately qualified staff are critical for safely managing hydrogen systems.
- 67.2% identified adherence to international safety standards. Compliance with codes and best practices is valued but seen as relatively less crucial.

Case Processing Summary							
Questions		Cases					
		Included		Excluded		Total	
		N	Percent	N	Percent	N	Percent
What specific safety requirements do you believe are crucial for the introduction of hydrogen technologies in New Zealand?	2_1. Adequate Ventilation and Leak Detection Systems	134	74.40%	46	25.60%	180	100.00%
	2_2. Proper Hydrogen Storage and Handling Guidelines.	146	81.10%	34	18.90%	180	100.00%
	2_3. Comprehensive Fire Safety and Emergency Response Measures.	130	72.20%	50	27.80%	180	100.00%
	2_4. Strict Training and Certification Requirements for Personnel.	128	71.10%	52	28.90%	180	100.00%

2_5. Adherence to International Safety Standards.	121	67.20%	59	32.80%	180	100.00%

Table 51: Safety Requirements for Hydrogen Technologies in the New Zealand Built Environment

The data indicates consensus on the paramount importance of prudent storage/handling, ventilation, leak detection, fire/emergency preparedness, training and certification for safe hydrogen integration. Prioritizing these areas in regulations and policies is viewed as vital by most respondents.

While all listed aspects received majority endorsement, storage/handling procedures and ventilation/monitoring systems stand out as the most universally recognized safety imperatives according to the survey sample. Adoption of international best practices, while still valued, was perceived as relatively less imperative.

In addition, respondents were given the opportunity to write in other safety requirements they deem important for introducing hydrogen technologies in New Zealand.

Several key themes emerged from the open-ended responses:

- Adoption of international standards was emphasized by 27% of respondents. This aligns with 67.2% selecting this option in the multiple choice question.
- Public education and awareness was highlighted by 22% of respondents. This underscores the perceived need to inform the public on hydrogen safety.
- Proper training and certification of personnel was mentioned by 19% of respondents, reinforcing its importance alongside the 71.1% choosing it in the multiple choice.
- Robust risk assessment practices were noted by 16% of respondents. Thorough evaluation of risks appears vital.
- Code compliance was highlighted by 13% of respondents. This supports adherence to health and safety regulations.
- Other areas like materials compatibility, first responder protocols, storage regulations, and process safety protocols were cited less frequently but provide additional context.

The open-ended responses largely reinforced the safety priorities identified through the quantitative data, emphasizing international standards, training, public education, risk assessment, and regulatory compliance. Notably, a consensus emerged around the need for:

Key Aspect	Details
NZ specific standards	Recommendation against NZ-specific standards
	Emphasis on demonstrating applied safety practices rather than relying on set standards
	Recognition that expertise might not solely reside in regulators for dictating guidelines
Adoption of international safety standards	Suggestion to adopt international standards, drawing parallels with the approach taken for Liquefied Petroleum Gas (LPG)
Awareness among final users	Highlighted the importance of safety awareness among end-users
Certification	Certification of green and low carbon hydrogen

	Certification according to the AS/NZS IEC 60079 series of standards for equipment
	Certification of installation and repair personnel, akin to gas charge discharge restrictions for air conditioning systems
Changes to H&S regulations	Proposal for changes to Health and Safety regulations, particularly in relation to gas storage, emphasizing energy rather than water volume
Wider limits	Suggestion for wider limits in gas regulations (e.g., NZ5442)
Commercial and retail use	Safety protocols and measures for commercial and retail use by the general public
	Emphasis on compliance with international codes and standards
Public awareness and education	Advocacy for public awareness and education initiatives regarding hydrogen technologies, their benefits, and safety measures
	Highlighted the need for comprehensive design guidance
Education initiatives	Suggested education at trade/apprenticeship levels
Market establishment	Advocacy for establishing markets and making fuels available, especially for remote locations
	Collaboration with expertise from other countries for Front-End Engineering Design (FEED) studies
Green Hydrogen	Emphasis on technology advancements and increased efficiency in green hydrogen production
Small Scale Hydrogen generation	Belief that small-scale, localized hydrogen generation is key to reducing the need for large storage facilities
Logical compliance pathways	Suggested the need for logical compliance pathways for green hydrogen storage
Peer reviewed safety standards	Proposal for peer-reviewed safety and implementation standards inspired by international best practice
Periodic certification	Suggestion for periodic certification of both storage facilities and containment (tanks)
Process safety awareness	Emphasis on process safety awareness and methodology for users dealing with large volumes of hydrogen
Proper maintenance	Stressed the importance of proper maintenance for equipment that could pose hazards
Proper materials understanding	Highlighted the need for a proper understanding of materials to avoid hydrogen embrittlement, especially in welds, connections, and piping
Regulatory framework	Advocacy for a clear regulatory framework

Risk assessment	Suggested a risk assessment written from the ground up, anchored in practical measures to manage actual risks
Safe distancing	Highlighted the importance of safe distancing from residential/commercial buildings, especially for small-scale production
Update to existing standards	Advocacy for updating existing Health and Safety at Work Act standards to reflect energy in storage vessels rather than simple volumes
Use of proper PPE	Emphasis on the use of proper Personal Protective Equipment (PPE) such as face shields and masks

Table 52: Recommendations for Safety Standards and Practices in Hydrogen Technologies

This provides greater confidence in the validity of these key findings and the importance placed on prudent management, qualified personnel, community awareness, and clear regulations when introducing new hydrogen applications. To integrate hydrogen technologies within the built environment safely, a multilayered approach addressing competence, attitudes, procedures, and compliance appears prudent based on synthesis of both the qualitative and quantitative data. Adoption of global best practices adapted for the New Zealand context will likely provide an effective foundation.

6.4.2. Section1 Question 3

Respondents were asked to identify other organizations beyond a provided list that should be involved in hydrogen safety standards and regulation. The table below summarizes response frequencies and percentages for a multiple choice survey question asking “Which organizations should play a significant role in setting and enforcing hydrogen safety standards in New Zealand?”.

Case Processing Summary							
Which organizations or authorities should play a significant role in setting and enforcing hydrogen safety standards in New Zealand?	3_1. Ministry of Business, Innovation and Employment (MBIE)	92	51.10%	88	48.90%	180	100.00%
	3_2. Energy Safety, WorkSafe New Zealand	156	86.70%	24	13.30%	180	100.00%
	3_3. Environmental Protection Authority (EPA)	94	52.20%	86	47.80%	180	100.00%
	3_4. Standards New Zealand	103	57.20%	77	42.80%	180	100.00%

Table 53: Organizations for Setting and Enforcing Hydrogen Safety Standards in the New Zealand Built Environment

- 86.7% of respondents selected Energy Safety, WorkSafe NZ. This indicates overwhelming agreement they should have a lead role.
- Standards NZ was chosen by 57.2% of respondents. A majority see them playing an important standard-setting function.
- MBIE was identified by 51.1% of respondents. This suggests they are seen as having a more moderate, though still significant, involvement.
- 52.2% of respondents chose EPA. This implies a split view on whether they should have a major role.

- The frequencies reveal Energy Safety and WorkSafe NZ are viewed as the clear leaders, which aligns with their mandate. Standards NZ and MBIE also garnered majority support for contributing. The verdict was more divided on EPA's role.
- Industry associations were frequently mentioned, including Master Plumbers (16% of respondents) and Plumbers, Gasfitters, and Drainlayers Board - 18%. This emphasizes engagement from skilled trades.
- Standards development organizations like Standards NZ were noted by 13% of respondents. Aligning with standards development in Australia was also highlighted. This reinforces the role of technical standard-setting bodies.
- The Hydrogen Council of NZ was cited by 11% of respondents. This points to the advisory and advocacy role the industry council can play.
- WorkSafe NZ and regulatory groups like Electrical Licensing were each mentioned by 8% of respondents. Continued safety regulator involvement is valued.
- Fire and emergency services like FENZ were highlighted by 5% of respondents. Including first responders is deemed important.
- Respondents emphasized that operators and end-users should help inform standards based on their expertise.
- Some noted replicating the collaborative approach used for LPG adoption could be beneficial.
- Close coordination with Australian groups setting hydrogen standards was advised by several respondents.

EECA - Energy Efficiency & Conservation Authority	Suggested as a potential organization playing a significant role in setting and enforcing hydrogen safety standards.
Transpower	Mentioned as a potential authority involved in hydrogen safety standards.
Accredited Inspection Bodies	Highlighted for certifying high hazard and other industrial operations.
BRANZ - the Building Research Association of New Zealand	Indicated multiple times as a relevant organization.
Hydrogen Council	Repeatedly mentioned as a significant entity in shaping hydrogen safety standards.
Civil Defence Department	Identified as a potential authority in the context of hydrogen safety.
Electrical Licensing/Regulation under AS/NZS60079	Proposed as a relevant framework for hydrogen safety.
Energy Council	Mentioned as an organization with potential involvement.
Engineering New Zealand	Acknowledged for potential contribution to hydrogen safety standards.
FENZ (Fire and Emergency New Zealand)	Recognized for its potential role in ensuring safety.
Gas NZ	Identified as a relevant entity in the context of hydrogen safety.
Master Plumbers Association	Mentioned as a potential stakeholder in hydrogen safety.

GIC - Gas Industry Company	Noted for its potential contribution to hydrogen safety.
IPENZ - Institution of Professional Engineers New Zealand	Identified as a potential contributor to hydrogen safety standards.
Fabrum and Hiringa Energy (Hydrogen Refuelling Infrastructure)	Mentioned in association with the Hydrogen Council, indicating potential collaboration.
Australian Bodies	Suggested for knowledge exchange with Australian counterparts. Learn and have close affiliations with existing bodies in Australia
Master Plumbers Gasfitters and Drainlayers NZ; Plumbers Gasfitters and Drainlayers Board (PGDB)	Mentioned as a potential contributor to hydrogen safety and their involvement in safety regulations. Acknowledged, particularly regarding gasfitters installing end-user products.
GANZ (Gas Association of New Zealand)	Mentioned as a relevant organization in the context of hydrogen safety.
RICS (Royal Institution of Chartered Surveyors)	Proposed as a potential entity involved in hydrogen safety.
ACE NZ (Consulting and Engineering)	Suggested as a relevant organization contributing to hydrogen safety.
SAE (Society of Automotive Engineers), TUV SUD (Fire Protection Code Compliance), NFPA 2 (The National Fire Protection Association)	Identified as industry groups providing potential standards.
National Road Carriers NZ, National Courier Association, FENZ, and Civil Contractors NZ	Recognized as industry groups representing end-users and transporters of hydrogen.
WorkSafe	Acknowledged as a key authority for ensuring safety.
BCA (Building Consent Authority)	Mentioned for potential involvement in hydrogen safety.
Energy Safety GOVT	Highlighted as part of WorkSafe, emphasizing government involvement.
Site Safe	Mentioned in the context of safety regulations.
Standards NZ	Recognized for its role in developing and aligning standards, collaborating with the Standards Australia committee.
WA (Western Australia)	Suggested for close affiliations due to its potential role in decarbonization.

Waka Kotahi (NZTA) for Motor Vehicle Hydrogen Systems	Identified as a relevant authority for motor vehicle hydrogen systems.
Individual and Collective Responsibility	Emphasized the importance of personal and collective responsibility for safety.

Table 54: Stakeholders in Setting and Enforcing Hydrogen Safety Standards in New Zealand

6.4.3 Section1 Question 4

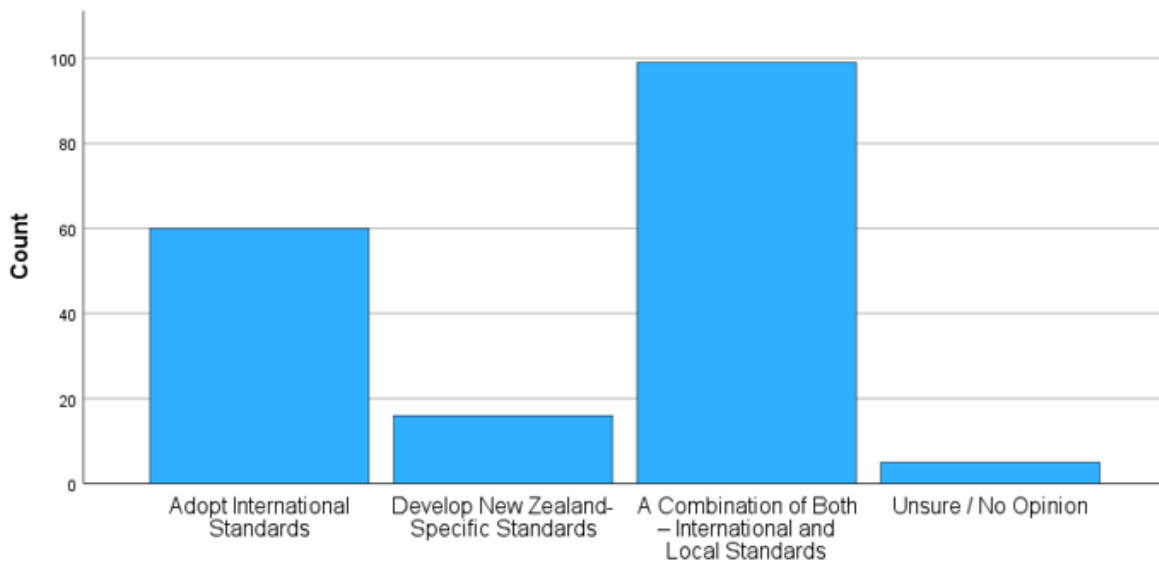
In Section 1 Question 4, the survey asked respondents “*Should New Zealand adopt international hydrogen safety standards or develop its own specific standards?*”. The responses were as follows:

- “Adopt International Standards” - 60 people (33.3%)
- “Develop New Zealand-Specific Standards” - 16 people (8.9%)
- “A Combination of Both – International and Local Standards” - 99 people (55%)
- “Unsure / No Opinion” - 5 people (2.8%)

Q4. Should New Zealand adopt international hydrogen safety standards or develop its own specific standards?				
	Frequency	Percent	Valid Percent	Cumulative Percent
Adopt International Standards	60	33.3	33.3	33.3
Develop New Zealand-Specific Standards	16	8.9	8.9	42.2
A Combination of Both – International and Local Standards	99	55	55	97.2
Unsure / No Opinion	5	2.8	2.8	100
Total	180	100	100	100

Table 55: Preferences Regarding Adoption of Hydrogen Safety Standards in the New Zealand Buildings

This distribution of opinions provided insight into stakeholders’ perspectives on this foundational regulatory issue for New Zealand’s emerging hydrogen sector. A majority supported either outright adopting international standards or developing a hybrid model incorporating global norms. Only a small minority favoured exclusively bespoke national standards.



Bar Chart 1: Participants opinions on Implementing Hydrogen Safety Standards in NZ Buildings

These survey results suggest certain approaches were viewed as more pragmatic than others. Adopting well-established international standards promises efficiency, while purely domestic rules face challenges. A combined solution gained the most support as balance. The preferences also have implications for maximizing benefits from cross-border harmonization and network effects, important for scaling clean hydrogen internationally. They further indicate preferences around priorities like leveraging overseas expertise versus autonomy.

6.4.4 Section 1 Question 5

In response to Section 1, Question 5 “*In your opinion, what specific design requirements should be in place to ensure safe installation of hydrogen systems in residential and commercial buildings?*”, participants provided valuable insights into specific design requirements to ensure the safe installation of hydrogen systems in residential and commercial buildings.

In your opinion, what specific design requirements should be in place to ensure safe installation of hydrogen systems in residential and commercial buildings?	5_1. Secure Hydrogen Storage Facilities	145	80.60%	35	19.40%	180	100.00%
	5_2. Automated Hydrogen Leak and Shutdown Valves	155	86.10%	25	13.90%	180	100.00%
	5_3. Use of Fire-Resistant Building Materials	102	56.70%	78	43.30%	180	100.00%
	5_4. Adequate Ventilation and Exhaust Systems	137	76.10%	43	23.90%	180	100.00%
	5_5. Emergency Hydrogen Release Systems	115	63.90%	65	36.10%	180	100.00%

Table 56: Design Requirements for Safe Installation of Hydrogen Systems in Buildings

The table shows response frequencies for a multiple choice question asking respondents to identify important hydrogen system design safety requirements.

- 86.1% selected automated leak and shutdown valves, indicating this is seen as the most critical requirement.
- 80.6% chose secure storage facilities, emphasizing prudent storage as imperative.

- 76.1% identified adequate ventilation/exhaust systems, highlighting the need to mitigate gas accumulation risks.
- 63.9% selected emergency hydrogen release systems, suggesting this is valued but less universally essential.
- 56.7% chose use of fire-resistant materials, showing some difference of opinion on its necessity.

In open-ended responses, key themes included:

- 25% mentioned proper zoning/separation from ignition sources and occupied spaces. This aligns with storage, leak controls, and ventilation priorities.
- 13% referenced the need for safety systems tailored to specific applications and environments. This underscores a case-by-case approach.
- 10% highlighted licensing/standards for qualified design and installation businesses, emphasizing specialist competence.
- 6% questioned the appropriateness of residential hydrogen applications, indicating scepticism.

Other issues like fire suppression, signage, and sensor technologies were cited less frequently.

Classification of Zones	Suggested the adoption of zones classification based on hydrogen release risks, akin to the ATEX (ATmosphères EXplosibles) European regulation.
Clear Indication of Hydrogen Equipment	Emphasized the need for clear marking and signage on hydrogen equipment for easy identification.
Fire Suppression Systems	Recommended the installation of fire suppression systems compatible with hydrogen to mitigate potential risks.
Placement Criteria	Highlighted the importance of criteria for placement locations, considering spacing from potential ignition sources.
Ex II C (the Gas Group ratings)	Mentioned the importance of adhering to the Ex II C classification, a standard for electrical equipment in explosive atmospheres.
Site-Specific Systems	Advocated for site-specific systems tailored to the use case and environment, with a focus on hazard and risk assessment.
Residential Viability/ Negative Expression	Expressed concerns about the financial and safety viability of using hydrogen residentially, suggesting limitations on commercial applications to those that can be electrified. Suggested alternatives like electric heat pumps for space/water heating and induction for cooking, expressing scepticism about the need for hydrogen in residential or most commercial buildings.
Storage Outside Buildings	Proposed measures such as solenoid valves outside dwellings to prevent hydrogen entry if detected above safety thresholds.
High-Risk Volume Storage	Recommended the exploration of systems similar to fire detection (e.g., VESDA system) for high-risk volume storage.
Detection Technologies	Proposed the use of infrared cameras and ultrasonic detectors for enhanced safety.

Licensing Requirements	Called for licensing requirements for hydrogen design and installation businesses.
Standards Reflecting Actual Hazards	Advocated for standards reflecting actual hazards from hydrogen, based on energy, pressure, explosion risks, and fire risks.
Safe Location Selection	Emphasized the safe selection of locations away from entry and exit points to properties.
Separation Distances and Setback Requirements	Recommended the consideration of separation distances from storage to public exposure, integrating setback requirements into national and local zoning rules.
Specialized Buildings and Infrastructure	Highlighted the need for additional specific standards for specialized buildings and infrastructure like gas pipelines, vehicle refuelling stations, and hydrolysis facilities.
Fuel Usage Rate and Storage Size Relevance	Suggested that requirements and standards should be relevant to fuel usage rate and storage size.
Safe Transport and Handling	Advocated for safe transport and handling practices for hydrogen.

Table 57: Recommendations for Safe Installation of Hydrogen Systems in Buildings

The qualitative insights largely reinforced the quantitative data trends on the paramount importance of prudent system design, leak control, zoned separation, and ventilation. Respondents consistently identified these areas as vital for installation safety. The findings will help inform building code development and system design best practices as hydrogen applications emerge.

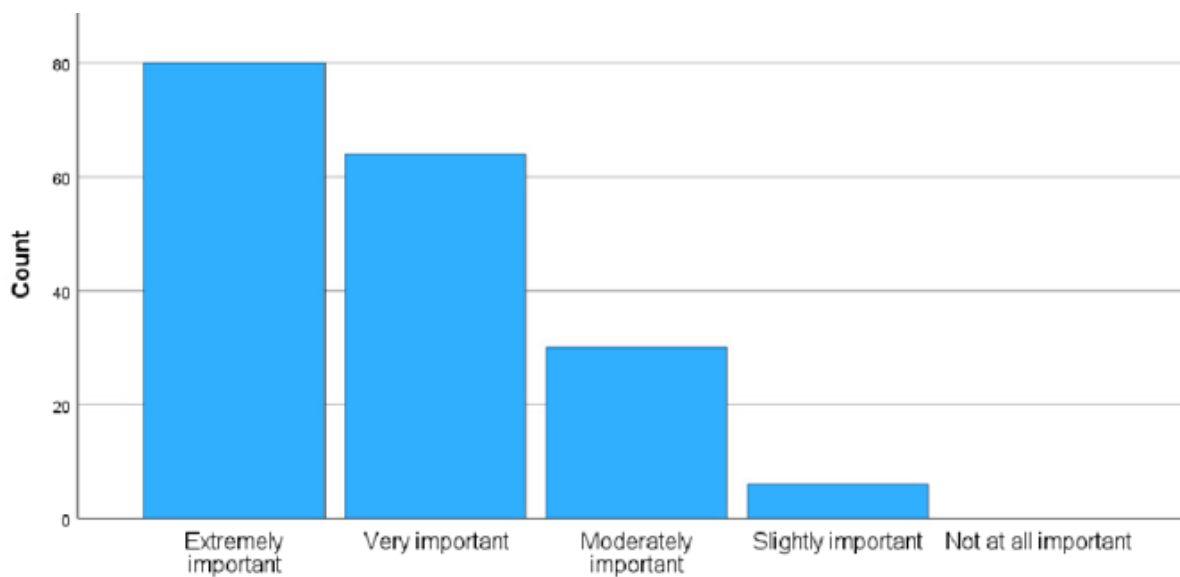
6.4.5 Section 1 Question 6

The survey sought to gain stakeholders' insights by asking them to consider the question 6 in Section 1 - *"How important do you think public awareness and education regarding hydrogen safety are in the successful implementation of hydrogen technologies in New Zealand?"*. Respondents were provided a 5-point Likert scale to indicate their views.

- Extremely Important
- Very Important
- Moderately Important
- Slightly Important
- Not Important

An analysis of the responses suggests stakeholders perceived public outreach on safety as having considerable significance. The clear majority selected either "Extremely important" (44.4%) or "Very important" (35.6%), signalling accord that community acceptance relies on engaging the public domain. Additionally, a sizable proportion (16.7%) believed such engagement was "Moderately important", even if they ascribed less decisive weight. Taken together, over 96% therefore viewed awareness-raising somewhat positively. Only a small minority deemed it a "Slightly important"

concern. Notably, unanimity existed in that none selected “Not important” - a lack of dissent that contrasts with heterogeneous policy debates. The uniformity of affirmative viewpoints reinforces recognition that societal perspectives factor crucially into technological change.



Bar Chart 2: Participants opinions about importance of public awareness and education regarding hydrogen safety for successful implementation of hydrogen technologies in New Zealand

Q6. How important do you think public awareness and education regarding hydrogen safety are in the successful implementation of hydrogen technologies in New Zealand?				
	Frequency	Percent	Valid Percent	Cumulative Percent
Extremely important	80	44.4	44.4	44.4
Very important	64	35.6	35.6	80
Moderately important	30	16.7	16.7	96.7
Slightly important	6	3.3	3.3	100
Total	180	100	100	

Table 58: Importance of Public Awareness and Education Regarding Hydrogen Safety in New Zealand

This consensus implies stakeholders anticipate public risk perception as pivotal for deploying an unfamiliar concept. Continued multi-directional communication may help consolidate already supportive stances as experience expands. Ultimately, participants emphasized the human dimension’s importance for adoption success.

6.4.6 Section 1 Question 7

The table shows response frequencies for a question 7 in Section 1 asking “*What factors would increase your confidence in the safe use of hydrogen technologies?*”

New energy vectors like green and low	7_1. Comprehensive Safety Regulations and Building Codes	137	76.10%	43	23.90%	180	100.00%

carbon hydrogen may gain wider public acceptance if hydrogen safety concerns are adequately addressed. What factors would increase your confidence in the safe use of hydrogen technologies?	7_2. Rigorous Personnel Training Requirements	103	57.20%	77	42.80%	180	100.00%
	7_3. Public Awareness Campaigns about Hydrogen Risks	112	62.20%	68	37.80%	180	100.00%
	7_4. Selected Choice Government Oversight and Industry Standards Enforcement	119	66.10%	61	33.90%	180	100.00%
	7_5. Demonstration of Safe Hydrogen Use in Other Jurisdictions	92	51.10%	88	48.90%	180	100.00%
	7_6. Independent Safety Testing and Certification Regimes	113	62.80%	67	37.20%	180	100.00%

Table 59: Factors Increasing Confidence in the Safe Use of Hydrogen Technologies

- 76.1% selected comprehensive safety regulations and building codes. This indicates robust governance is the top priority for most respondents.
- 66.1% chose government oversight and standards enforcement. Aligned with the above, official supervision provides assurance.
- 62.8% identified independent safety testing and certification regimes. Third-party validation is valued for verifying safety.
- 62.2% chose public awareness campaigns. Educating the public on hydrogen risks is deemed important.
- 57.2% selected rigorous personnel training requirements. Properly qualified professionals also provide confidence.
- 51.1% chose demonstration of safe use elsewhere. While still valued by half, this was less universally essential.

In open-ended responses, the following responses were provided:

Demonstration of Environmental Impact	Encouraging the idea of how hydrogen can positively impact the environment and achieving possible environmental goals.
Modify Existing Legislation	Suggested modifying existing legislation for LPG (Liquefied petroleum gas) and CNG (Compressed natural gas) to include hydrogen, drawing attention to the successful nationwide network of fuel stations for CNG and LPG.
Transition Expertise	Expressing a desire for a smoother transition, utilizing the existing expertise of LPG-certified technicians and mechanics for adapting to hydrogen.
Industrial Focus	Proposing to initially keep hydrogen focused on essential industrial needs before widespread public use.
Address Compliance and Training	Highlighting the need to address compliance issues and ensure adequate training for hydrogen installers, technicians, and building managers, particularly considering New Zealand's culture around industry regulations.

Piloting and Demonstration	Recommending piloting or applied technology demonstrations within New Zealand to showcase the practical and safe use of hydrogen.
Global Safe Use History	Gaining confidence through the safe use history of hydrogen technologies in other places around the world.
Cost-Effective Compliance Processes	Stressing the importance of developing cost-effective and science-based compliance processes to make hydrogen more accessible to residents and businesses.
Engineering and Design Expertise	Emphasizing the need to focus on engineering and design expertise for Front-End Engineering Design (FEED) studies, Return on Investment (ROI) cases, and aligning with Australian standards.
Showcasing Successful Use Cases	Advocating for the presentation of successful use cases that highlight the value and safety of hydrogen technology.

Table 60: Factors Contributing to Confidence in Hydrogen Technology Adoption

While providing qualitative insights, respondents emphasized compliance and enforcing regulations will be critical, noting this has been an issue with other fuels historically in NZ. Also, leveraging existing governance frameworks for LPG was advised by 25% of respondents to build on proven models, while 19% highlighted the need for demonstrated use cases and pilot projects to showcase real-world safety and value.

The data indicates comprehensive regulations, enforcement, training requirements, public education, independent validation, and oversight bodies would provide the greatest collective confidence in safe hydrogen systems. While learning from international experience is useful, locally tailored governance and NZ-specific demonstrations appear most likely to drive acceptance based on these findings. Ensuring robust frameworks, compliance, and public awareness will be pivotal.

6.4.7 Key Fundings and Conclusion for Section 1

This chapter examined the survey findings related to hydrogen safety requirements for the successful introduction of hydrogen technologies in New Zealand. The key findings are:

1. Respondents identified several crucial safety requirements, with the top priorities being:
 - Proper hydrogen storage and handling guidelines (81.1%)
 - Adequate ventilation and leak detection systems (74.4%)
 - Comprehensive fire safety and emergency response measures (72.2%)
 - Strict training and certification requirements for personnel (71.1%)
2. There was strong consensus that Energy Safety and WorkSafe NZ should play a lead role in setting and enforcing hydrogen safety standards, with support also for involvement from Standards New Zealand, MBIE, and the Environmental Protection Authority (EPA).
3. A majority of respondents (55%) favoured a combination of adopting international standards and developing New Zealand-specific standards, rather than solely relying on international or purely domestic standards.
4. Key design requirements identified for safe installation of hydrogen systems in buildings included automated leak/shutdown valves, secure storage, adequate ventilation, and emergency release systems.

6. Respondents overwhelmingly viewed public awareness and education on hydrogen safety as important (80% said it was “extremely” or “very” important) for the successful implementation of hydrogen technologies.

7. To increase confidence in the safe use of hydrogen, the top factors were comprehensive safety regulations/codes, government oversight and standards enforcement, independent safety testing and certification, public awareness campaigns, and rigorous personnel training.

Conclusion:

The survey results highlight the paramount importance of addressing hydrogen safety through a multifaceted approach encompassing robust regulations, competent personnel, public engagement, and international alignment. There is a clear consensus among stakeholders that prudent management of hydrogen’s unique safety considerations is vital for successful adoption in New Zealand. A hybrid model incorporating global best practices and local adaptations appears to be the preferred path forward. Continued multi-stakeholder collaboration to develop comprehensive safety frameworks will be essential as hydrogen technologies advance in the built environment. The further discussion regarding hydrogen safety requirements for the built environment will be elaborated upon in Chapter 8.

6.5 Section 2 - Decarbonization Potential

Section 2 of the survey was designed to address the second research question: ***“How can hydrogen technologies contribute to the decarbonization of the built environment, and what methodologies can be employed to quantify and assess this contribution?”***

6.5.1 Section 2 Question 8

Section 2 of the Survey is dedicated to addressing the second research question: *“How can hydrogen technologies contribute to the decarbonization of the built environment, and how can this be measured?”*. For this purpose, a series of questions was addressed, starting from Question 8, which inquired, *“In your opinion, how can hydrogen technologies contribute to the decarbonizing of the built environment?”*

In your opinion, how can hydrogen technologies contribute to the decarbonizing of the built environment?	8_1. Hydrogen as a Clean Energy Source for Heating Buildings Instead of Natural Gas	115	63.90%	65	36.10%	180	100.00%
	8_2. Hydrogen-Powered Fuel Cells for Electricity in Buildings	96	53.30%	84	46.70%	180	100.00%
	8_3. Hydrogen-Based Combined Heat and Power Systems	109	60.60%	71	39.40%	180	100.00%
	8_4. Hydrogen as an Energy Storage Solution for Renewable Energy	117	65.00%	63	35.00%	180	100.00%

Table 61: Contributions of Hydrogen Technologies to Decarbonizing the Built Environment

The table shows response frequencies for a question on how hydrogen can enable decarbonization.

- 63.9% chose hydrogen for heating instead of natural gas. This was the top selection, indicating hydrogen’s potential for displacing fossil fuel heat.
- 60.6% selected hydrogen combined heat and power systems. Integrated systems are seen as impactful.

- 65% identified hydrogen as renewable energy storage. Its storage capacity to enable cleaner grids was recognized.
- 53.3% chose hydrogen fuel cells for electricity. More modest support, but still a majority, see benefits here.

In open-ended responses, key themes included:

- 24% discussed hydrogen for displacing fossil fuel reliance and empowering renewable energy systems in remote locations.
- 19% mentioned hydrogen's role in decarbonizing heavy industry like steel and cement production through high temperature heating.
- 13% highlighted hydrogen for powering heavy transportation like shipping and trucks to reduce diesel use.
- 12% emphasized ensuring hydrogen production is based on renewables when assessing merits.
- 6% questioned if buildings are the most viable application given efficiency challenges and alternatives like electrification.

Replacement of LPG and Diesel	Hydrogen can contribute to decarbonizing by replacing traditional fuels like LPG and Diesel in various applications, including remote renewable power support, hospitals, cooking, and continuous hot water.
Reducing Dependence on Fossil Fuels	Any use case that minimizes fossil fuel use and reduces New Zealand's dependence on external sources is seen as a positive initiative.
Backup Power and Industrial Uses	Hydrogen is considered for backup power, particularly in remote areas, medical facilities and data centres. However, some express concerns about its efficiency compared to electricity.
Heat Pumps vs. Hydrogen for Heating	There is a divergence of opinions on the efficiency of hydrogen for direct electrification of the heating in the built environment. Some suggest heat pumps as an alternative, emphasizing the need for a nuanced approach based on specific use cases.
Challenges in Building Applications	Some participants express scepticism about the economic feasibility of hydrogen in building applications, emphasizing its high cost compared to electric alternatives. This highlights the importance of considering economic viability alongside technical feasibility.
Renewable Hydrogen in Remote Locations	Locally produced hydrogen is suggested as an alternative to LPG for rural areas, promoting cleaner energy options and decentralised energy production. This insight is supported by many participants.
Energy Carrier and Storage Mechanism	It is emphasized that hydrogen is an energy carrier and a storage/transport mechanism rather than an energy source, underlining the importance of public understanding.
Economic Considerations	Challenges are acknowledged in economically justifying certain hydrogen applications, indicating a need for a balanced consideration of costs.

Clean Fuel in Construction	Hydrogen is seen as a clean fuel in the production process of steel and cement for the construction industry, emphasizing its potential for the built environment.

Table 62: Perspectives on the Role of Hydrogen in Decarbonizing the Built Environment

The data indicates hydrogen is primarily viewed as an enabler for displacing natural gas heating, integrating cleaner combined heat/power systems, and supporting renewable energy storage and grid stability. Secondary benefits in industry and transportation were also acknowledged. Renewable production methods for hydrogen emerged as an important consideration. Some scepticism exists around efficiency and alternatives.

6.5.2 Section 2 Question 9

Question 9 in Section 2 asked: “Which aspect do you consider the most impactful in decarbonizing the built environment using hydrogen technologies?”.

Which aspect do you consider the most impactful in decarbonizing the built environment using hydrogen technologies?	9_1. Reducing Carbon Emissions	128	71.10%	52	28.90%	180	100.00%
	9_2. Enhancing Energy Efficiency	102	56.70%	78	43.30%	180	100.00%
	9_3. Enabling Widespread Adoption of Renewable Energy	95	52.80%	85	47.20%	180	100.00%
	9_4. Reducing Reliance on Fossil Fuels	121	67.20%	59	32.80%	180	100.00%

Table 63: Impact of Hydrogen Technologies on Decarbonizing the Built Environment

- 71.1% of respondents selected reducing carbon emissions, indicating this direct emissions reduction impact is viewed as most important.
- 67.2% chose reducing fossil fuel reliance, again emphasizing displacing carbon-intensive existing practices.
- 56.7% identified enhancing energy efficiency, suggesting efficiency merits are also valued.
- 52.8% selected enabling renewable energy adoption, showing this is seen as impactful but less critical than direct carbon replacement.

While expressing qualitative insights, the participants’ responses were the following:

- 19% discussed integrating intermittent renewable power and providing grid stability through energy storage and load shifting.
- 13% emphasized displacing natural gas use for heating as a key opportunity to reduce emissions.
- 10% highlighted the resilience benefits of having a diversified energy system less reliant on single sources.
- 6% noted hydrogen’s role in reducing lifecycle emissions through construction, transportation.
- 3% questioned if hydrogen provides efficiency gains compared to electrification.

Carbon Emission Reduction	Recognition of all listed aspects as impactful but prioritizes the reduction of carbon emissions as the most significant.
Flattening Load Curve	Importance of storing off-peak electricity to reduce peak demand during high electricity usage times.

Total Footprint Impact	Influence of hydrogen on the total footprint of the built environment, including reducing embedded emissions in construction and transport.
Increasing Resilience and Energy System Efficiency	Need for increased resilience by having green hydrogen as energy carrier and fuel option and enhancing energy system efficiency through utilization and storage of the produced energy.
Integration of Renewable Power Sources	Advocacy for integrating renewable power sources into the existing network to manage the inconsistencies of supply and suggests hydrogen creation and storage as a reliable alternative.
Energy Network Resilience	Support for the idea of providing energy network resilience in the built environment by using green hydrogen source independent of environmental conditions.
Displacing Fossil Fuels	Specific mentions the role of hydrogen in displacing fossil fuels in ‘hard-to-abate’ sectors and applications.
Substitution for Stationary Gaseous Fuels	Identification green hydrogen as a substitution for stationary gaseous fuels, particularly natural gas (scope 1).
Energy Efficiency Comparison	Energy efficiency of heat pumps for building space heating compared to hydrogen.
	Scepticism about hydrogen’s energy efficiency compared to natural gas.

Table 64: Key Aspects Impacting the Decarbonization of the Built Environment with Hydrogen Technologies

The data indicates directly supplanting fossil fuel usage and emissions through hydrogen is viewed as the most significant decarbonization pathway in buildings. However, respondents also recognize indirect benefits for renewable energy systems, energy resilience, efficiency, and lifecycle emissions. Some remain uncertain if hydrogen offers efficiency advantages. The findings suggest that while direct carbon displacement is the priority, the complementary benefits of hydrogen are also valued.

6.5.3 Section 2 Question 10

In section two, the tenth question queried: *“How do you think the impact of hydrogen technologies on decarbonization can be measured effectively?”*

How do you think the impact of hydrogen technologies on decarbonization can be measured effectively?	10_1. Reduction in Carbon Emissions (measured in CO2 equivalents)	129	71.70%	51	28.30%	180	100.00%
	10_2. Increased Renewable Energy Utilization Ratio	83	46.10%	97	53.90%	180	100.00%
	10_3. Reduction in Natural Gas/Fossil Fuel Consumption	117	65.00%	63	35.00%	180	100.00%
	10_4. Energy Efficiency Improvement Metrics	71	39.40%	109	60.60%	180	100.00%

	10_5. Comparative Analysis with Conventional Systems	77	42.80%	103	57.20%	180	100.00%

Table 65: Metrics for Effectively Measuring the Impact of Hydrogen Technologies on Decarbonization

- Direct carbon reduction - 71.7% selected tracking CO2 emission decreases. As the foremost priority, directly substituting and displacing carbon-intensive processes appears the most intuitive metric.
- Increased renewable share - 46.1% chose measuring raised renewable utilization. Indicates this is relevant but secondary to direct carbon displacement.
- Reduction in natural gas/fossil fuel consumption - 65% chose measuring natural gas/fuel consumption decreases. Aligns with the priority of supplanting gas for heating/power.
- Efficiency improvements - 39.4% identified tracking efficiency gains. Suggests this is valued but not the prime objective.
- Comparative analysis - 42.8% selected benchmarking against conventional systems. Demonstrating advantages over incumbent technologies is useful politically.

In the open-ended section, the following themes were highlighted.

Energy Efficiency Improvement	Perceiving improvement in energy efficiency through hydrogen technologies.
Comparison of Energy Values	Compare energy values related to green hydrogen use with alternative emissions from non-hydrogen sources, considering both scope and scope 2 GHG emissions.
Energy Sovereignty	Evaluate the impact on energy sovereignty, understanding the degree to which green hydrogen contributes to national energy independence.
Flattening of Maximum Demand Curve	Assess the impact on the maximum demand curve, examining how hydrogen technologies contribute to flattening the curve.
Life Cycle Analysis	Conduct comprehensive life cycle analysis, accounting for all stages of hydrogen production, transport, and utilization, including environmental impacts associated with raw material extraction, manufacturing, operation, and decommissioning.
Input into the Main Grid	Evaluate the contribution of hydrogen technologies to the main grid, considering the input and integration into existing energy infrastructure.
Lifecycle Cost of Carbon	Analyse the lifecycle cost of carbon associated with hydrogen technologies, considering economic factors alongside environmental impacts.
EROI or EROEI	Measure Energy Return on Investment (EROI) or Energy Return on Energy Invested (EROEI) to gauge the efficiency and effectiveness of hydrogen technologies.
Installed Hydrogen Storage Capacity	Monitor the installed capacity of hydrogen storage as an indicator of the technology's impact on energy storage.

MACC Modelling:	Utilize Marginal Abatement Cost Curve (MACC) modelling to understand the cost-effectiveness of hydrogen technologies in relation to carbon abatement.
Economic Metrics	Consider economic metrics, including the financial aspects such as dollars per ton of carbon abatement, to assess the commercial viability and economic impact.
Robust Monitoring System	Implement a robust monitoring system to continually measure the reduction in other utilities and ensure the effectiveness of the hydrogen system.
Reduction in NZU Obligations	Assess the reduction in New Zealand Units (NZU) obligations and associated spending as an indicator of the impact of hydrogen technologies on decarbonization.

Table 66: Metrics for Effectively Measuring the Impact of Hydrogen Technologies on Decarbonization (Open-ended responses)

The question explores effective metrics for measuring the impact of hydrogen technologies on decarbonization. Respondents prioritize tracking direct carbon emission reductions (71.7%) and reducing natural gas/fossil fuel consumption (65%). Themes from open-ended responses include assessing energy efficiency improvements, comparing energy values, and evaluating the impact on energy sovereignty. Other considerations include life cycle analysis, contribution to the main grid, economic metrics, and implementing robust monitoring systems.

6.5.4 Section 2 Question 11

In section two, Question 11 inquired: *“In your opinion, what challenges do you foresee in measuring the impact of hydrogen technologies on decarbonization effectively?”*

In your opinion, what challenges do you foresee in measuring the impact of hydrogen technologies on decarbonization effectively?	11_1. Lack of Standardized Measurement Metrics	110	61.10%	70	38.90%	180	100.00%
	11_2. Difficulty in Data Collection and Analysis	106	58.90%	74	41.10%	180	100.00%
	11_3. Variability in Regional Infrastructure and Energy Mix	92	51.10%	88	48.90%	180	100.00%
	11_4. Technological Advancements Outpacing Measurement Approaches	71	39.40%	109	60.60%	180	100.00%

Table 67: Challenges in Measuring the Impact of Hydrogen Technologies on Decarbonization

- Lack of standardized measurement metrics - 61.1%. This indicates establishing consistent methodologies is viewed as the most critical need by a majority. As the survey results indicate, the top challenge chosen was the lack of standardized ways to measure the emissions impact of hydrogen across different applications and regions. Without consistent measurement methodologies, it will be difficult to compare and aggregate the decarbonization impact of various hydrogen projects. Establishing internationally accepted standards and protocols will be crucial.
- Difficulty in data collection and analysis - 58.9%. This highlights issues with availability and processing of comprehensive data on hydrogen as a substantial obstacle. This stems from hydrogen applications being in early development stages across many sectors. Tracking data

like production sources, transportation, storage, and end-use will require coordination across multiple stakeholders.

- Variability in regional infrastructure and energy mix - 51.1%. While still a majority, the lower percentage compared to the top two challenges shows accounting for regional differences is seen as significant but manageable. The emissions impact of hydrogen is greatly dependent on how it is produced and the energy mix it displaces in a given region. As the moderate choice rate for this challenge shows, developing customized baseline models and impact accounting for different areas is an obstacle. A nuanced approach taking local contexts into account is needed.
- Technological advancements outpacing measurement approaches - 39.4%. The markedly lower selection rate suggests rapidly evolving technologies are not seen as a prime hurdle in impact quantification. As hydrogen technologies rapidly evolve, keeping measurement methodologies current can be difficult. However, this challenge received the lowest selection rate, indicating it is likely manageable with sufficient foresight in designing adaptive frameworks.

An open-ended response yielded the following valuable insights:

Adoption Strategy and Network Reduction	The adoption strategy involving small to medium plant installations may result in challenges, especially when such plants drop off the nationwide network, leading to the measurement as a network reduction only.
Lack of Clear Base-Case Data	Challenges may arise from the absence of clear base-case data sets, hindering the establishment of reference data against which the impact of hydrogen can be effectively measured.
Accounting for Energy Lose	Difficulties in accounting for energy losses during the production, transport, and utilization of hydrogen can pose a challenge in accurately measuring its impact on decarbonization.
Cultural Reluctance to Change:	Cultural resistance to change can impede effective measurement, as societal attitudes and behaviours may influence the acceptance and integration of hydrogen technologies.
Lack of Central Investment in Baseline Models	The absence of central investment to develop and maintain baseline models, along with monitoring the impact of change, can hinder effective measurement efforts.
Verification of Hydrogen Source	The challenge of verifying the source of hydrogen, distinguishing between fossil fuel-derived and alternative sources, adds complexity to impact measurement.
Misinformation Campaigns	Misinformation campaigns stemming from legacy systems may create challenges in objectively assessing and communicating the effectiveness of hydrogen technologies in decarbonization.
Time Constraints for Hydrogen Production Plants	Concerns about insufficient time to build a significant number of hydrogen production plants by 2030 and 2050 pose a practical challenge in achieving decarbonization goals.
Political, Industry, and Personal Biases	Biases in political agendas, industry perspectives, and personal interests can distort data and narratives related to the effectiveness of decarbonization using hydrogen technologies, emphasizing the need for a

	fair and unbiased assessment to fully appreciate the potential of hydrogen in sustainable solutions.
Regulatory Framework	Regulatory issues related to the framework defining commercial deployment models may present challenges in establishing standardized benchmarks for impact measurement.
Early Stage Benchmarking	Benchmarking at an early stage across industries can complicate the collection of starting points to demonstrate reductions, making it challenging to assess the impact of hydrogen technologies.
Unrealistic Carbon Neutrality Goals	Perceptions of the country's ambition to achieve carbon neutrality by 2030 may be seen as unrealistic, potentially affecting the commitment and implementation of hydrogen-based decarbonization.
Emission Measurement Comparison	While emissions from hydrogen are measurable, the challenge lies in determining a meaningful comparison, emphasizing the importance of using guarantee of origin for accurate measurement in decarbonization efforts.

Table 68: Challenges in Measuring the Impact of Hydrogen Technologies on Decarbonization (open-ended responses)

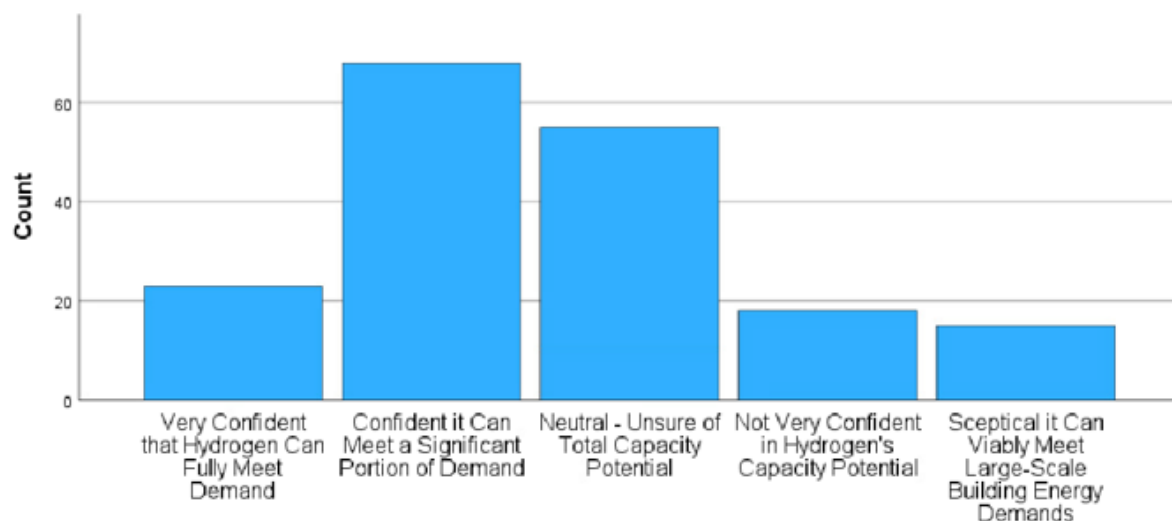
In summary, a lack of standardized practices, data availability issues, variability across regions, and adapting to new developments are key foreseeable hurdles. A collaborative effort between industry, policymakers and research institutions will be essential to establish robust impact quantification. But overcoming these challenges is feasible with strategic initiatives.

6.5.5 Section 2 Question 12

In Section 2 Question 12, the participants were asked to indicate their level of confidence in the ability of hydrogen technologies to meet building energy demands and displace fossil fuels. They were given the following response options:

- Very Confident That Hydrogen Can Fully Meet Demand
- Confident It Can Meet a Significant Portion of Demand
- Neutral - Unsure of Total Capacity Potential
- Not Very Confident in Hydrogen's Capacity Potential
- Sceptical it Can Viably Meet Large-Scale Building Energy Demands

The results showed mixed perspectives, with the largest group - 42.2% - expressing confidence hydrogen could meet a significant portion of demand. However, a sizable minority of 32.2% remained neutral. Notably, the most optimistic stance of being “Very Confident” in full displacement was only held by 12.2%. And a collective 13.3% expressed doubts about hydrogen's capacity in some form through lack of confidence or scepticism.



Bar Chart 3: Level of confidence in the ability of hydrogen technologies to meet building energy demands and displace fossil fuels

Q12. Confident it Can Meet a Significant Portion of Demand				
	Frequency	Percent	Valid Percent	Cumulative Percent
Very Confident that Hydrogen Can Fully Meet Demand	22	12.2	12.2	12.2
Confident it Can Meet a Significant Portion of Demand	76	42.2	42.2	54.4
Neutral - Unsure of Total Capacity Potential	58	32.2	32.2	86.7
Not Very Confident in Hydrogen's Capacity Potential	13	7.2	7.2	93.9
Sceptical it Can Vially Meet Large-Scale Building Energy Demands	11	6.1	6.1	100
Total	180	100	100	

Table 69: Confidence in Hydrogen's Capacity to Meet Building Energy Demands

These responses ranged from the most confident view that green hydrogen could replace fossil fuels entirely, to the least confident perspective that doubts hydrogen's feasibility at meeting energy needs on a large scale for buildings.

On average, respondents indicated being moderately confident (mean score of 2.53 out of 5) that hydrogen technologies can provide sufficient capacity to displace fossil fuels for building energy demands. On the proper 1-5 scale, this falls between 1 (Very Confident) and 2 (Confident it Can Meet a Significant Portion). This indicates most believe hydrogen has good potential to meet at least a major part of building energy demand.

Respondents across various occupations expressed a moderate level of confidence in the capacity of hydrogen technologies to contribute to decarbonization efforts in the built environment. The mean confidence level of 2.53 out of 5 indicates a cautious optimism, with respondents acknowledging both the potential opportunities and existing barriers associated with hydrogen adoption. While some occupations, such as Engineers, Project Managers, and Architects, exhibited higher confidence levels, others, like Delivery Managers and professionals in general occupations, showed lower confidence. Despite differences in confidence levels, all occupational groups recognize the importance of

hydrogen technologies in decarbonization initiatives. Engineers, particularly Electrical Engineers, displayed higher confidence levels, likely due to their direct involvement in hydrogen projects and technologies. Similarly, Project Managers expressed moderate confidence, reflecting their role in assessing feasibility and overseeing technology adoption. Architects demonstrated a balanced perspective, recognizing the potential of hydrogen technologies while acknowledging integration challenges within building systems. On the other hand, Delivery Managers exhibited lower confidence levels, reflecting concerns about infrastructure readiness and operational challenges. Respondents in more general occupations, such as Digital Solutions Lead and Commercial Manager, also showed lower confidence levels, possibly due to a lack of direct involvement or expertise in hydrogen-related projects.

While statistical analysis highlighted variations in confidence levels between occupations, the focus should remain on the overall consensus regarding the potential of hydrogen technologies in decarbonizing the built environment. Despite differing levels of confidence, respondents collectively recognize hydrogen's role in transitioning towards cleaner energy sources and mitigating carbon emissions.

6.4.6. Key Findings and Conclusion for Section 2

This chapter examined the potential for hydrogen technologies to contribute to decarbonizing the built environment. The key findings are:

1. The survey results indicate hydrogen is viewed as a promising solution, with strong support for its use in:
 - Displacing natural gas heating
 - Enabling renewable energy integration through storage
 - Powering efficient combined heat and power systems
2. Respondents saw hydrogen's ability to directly reduce carbon emissions and fossil fuel reliance as its most impactful decarbonization benefits.
3. Respondents highlighted significant challenges in quantifying and measuring hydrogen's real-world impact. Lack of standardized metrics, data availability issues, and regional variability were cited as major obstacles to effectively assessing hydrogen's decarbonization potential.
4. Respondents expressed moderate overall confidence in hydrogen's capacity to meet building energy demands, reflecting both enthusiasm for its possibilities and pragmatic concerns about technical and practical hurdles.

Conclusion:

The findings in this chapter underscore both the promise and the complexity of leveraging hydrogen technologies for built environment decarbonization. While hydrogen is widely seen as a critical enabler, realizing its full potential will require concerted efforts to establish robust measurement frameworks, improve data collection, and address regional implementation challenges. Collaborative work between industry, policymakers, and researchers will be essential to develop the necessary standards, tools, and evidence base to guide hydrogen's integration into sustainable building energy solutions. With a balanced approach to assessing both the benefits and barriers, hydrogen can become a key component of decarbonization strategies for the built environment. Further details will be thoroughly discussed in Chapter 8.

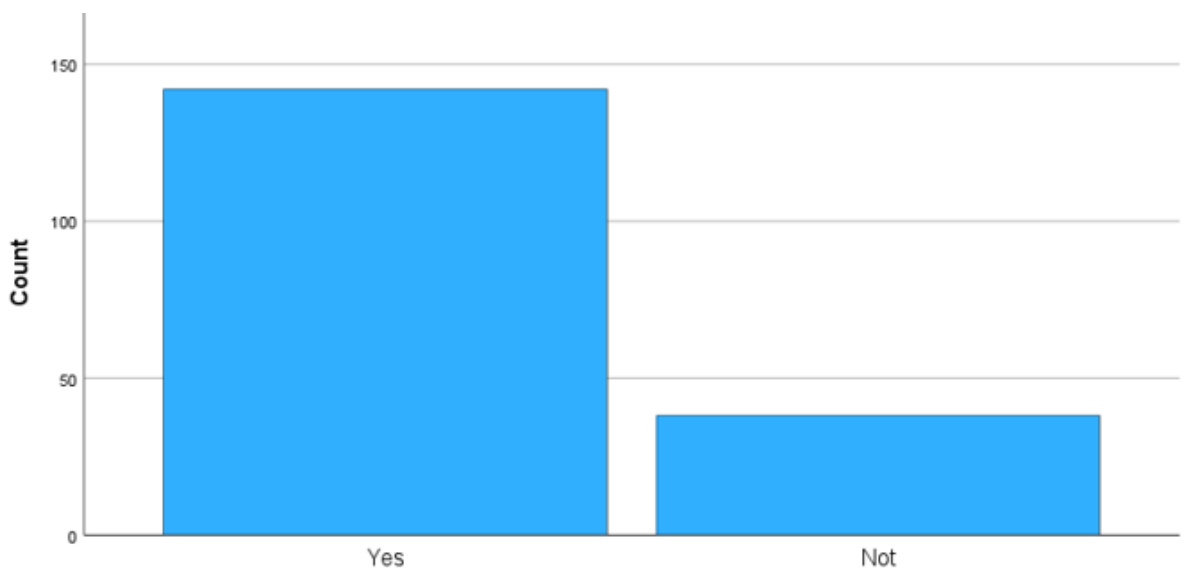
6.5 Section 3 - Public Acceptance

Section 3 of the survey aims to address the third research question: *“How to accelerate the hydrogen technologies acceptance by the public to bring the New Zealanders out of fuel poverty and to achieve the economic growth goals?”*

6.5.1 Section 3 Question 13

The survey in Section 3 Question 13 asked respondents *“Are you aware of hydrogen technologies and their potential benefits in addressing energy affordability and economic growth in New Zealand?”*.

- Yes
- No



Bar Chart 4: Participants’ awareness of hydrogen technologies and their potential benefits in addressing energy affordability and economic growth in New Zealand

An overwhelming majority (78.9%) responded “Yes” when presented with the options of “Yes” or “No”, demonstrating awareness amongst stakeholders of hydrogen’s role in key domestic issues. However, over one-fifth (21.1%) answered in the negative, indicating knowledge gaps still exist for some regarding opportunities afforded by these emerging technologies.

Q 13. Are you aware of hydrogen technologies and their potential benefits in addressing energy affordability and economic growth in New Zealand?				
	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	142	78.9	78.9	78.9
Not	38	21.1	21.1	100
Total	180	100	100	

Table 70: Awareness of Hydrogen Technologies and Their Potential Benefits in Addressing Energy Affordability and Economic Growth in New Zealand

As a relatively new domain, this level of unfamiliarity was not unexpected, but highlights the need for continued education and engagement initiatives to disseminate understanding more broadly.

Tracking shifts over time may help assess developments in hydrogen literacy as discussion proliferates. Factors like organizational roles or regional representation could provide insight for customizing outreach. The open-ended nature of the question also precluded determining the depth of respondents' cognizance. Overall, while the positive response of most stakeholders is encouraging, there remains potential to enhance knowledge given hydrogen's economic and environmental value propositions for New Zealand's energy landscape.

6.5.2 Section 3 Question 14

The participants provided the following data in response to Question 14 in Section 3 “*What aspects of hydrogen technologies, in your opinion, can help in alleviating fuel poverty and promoting economic growth?*”, expressing their opinions on the aspects of hydrogen technologies that can contribute to mitigating fuel poverty and fostering economic growth.

What aspects of hydrogen technologies, in your opinion, can help in alleviating fuel poverty and promoting economic growth?	14_1. Affordability of Hydrogen as an Energy Source	105	58.30%	75	41.70%	180	100.00%
	14_2. Job Creation and Economic Opportunities in the Hydrogen Sector	108	60.00%	72	40.00%	180	100.00%
	14_3. Diversification of Energy Sources Leading to Economic Resilience	118	65.60%	62	34.40%	180	100.00%
	14_4. Supporting Local Industry and Businesses, and Supply Chain	74	41.10%	106	58.90%	180	100.00%

Table 71: Aspects of Hydrogen Technologies Contributing to Alleviating Fuel Poverty and Promoting Economic Growth

- The top selection was diversification of energy sources leading to economic resilience at 65.6%. This indicates that hydrogen's ability to provide an additional clean energy option beyond just electricity is seen as its most valuable economic attribute. A more diverse energy mix protects against shocks and reduces reliance on any single source.
- The second highest choice was job creation and economic opportunities in the hydrogen sector at 60%. This highlights the potential for hydrogen to drive employment and overall economic growth, especially as a new industry. Developing this emerging sector can create many direct and indirect jobs.
- Affordability of hydrogen as an energy source was picked by 58.3%. Though a majority, this lower percentage suggests cost reductions may need to come from further technological development and scale for hydrogen to become truly affordable. It is not yet seen as the cheapest option.
- Supporting local industry and supply chain was selected the least at 41.1%. While viewed as beneficial, building localized hydrogen facilities appears considered less critical than sector-wide job creation and overall energy diversification.

In response to the open-ended section, participants offered the following insights.

Certainty in Clean Energy Creation	Assurance that hydrogen is produced using clean energy approaches rather than petrochemical byproducts adds credibility and aligns with environmental goals.

Technological Advancement	The degree of technological advancement in hydrogen technologies influences their effectiveness in addressing fuel poverty and fostering economic growth.
Hydrogen Export Utilizing Existing Infrastructure	Enabling the export of hydrogen to other countries through existing yet adjusted gas infrastructure presents economic opportunities and contributes to global energy trade.
Export Earnings	The export of hydrogen can generate earnings for the country, enhancing economic growth and trade balance.
Cost Reduction at Scale	Hydrogen at scale has the potential to lower certain energy costs, particularly in heavy transport, contributing to economic efficiency.
Viable Alternative in Specific Cases	In specific cases where hydrogen is the only viable alternative to fossil fuels, it may increase energy costs, but its adoption becomes crucial for decarbonization.
Marginal Abatement Cost Curves (MACC)	MACC analysis can guide the identification of cost-effective measures, optimizing the economic impact of hydrogen technologies.
Decarbonization in Remote Communities	For remote communities with local renewable energy, hydrogen can assist in decarbonization, reducing costs, and promoting economic growth while enhancing energy resilience.
Energy Storage Medium	Hydrogen, as an energy storage medium, reduces the overprovisioning costs of intermittent renewable electricity, benefiting grid-level efficiency.
Efficient and Cost-Effective Delivery	If hydrogen can be delivered to the point of use efficiently and cost-effectively, it can play a role in alleviating fuel poverty and supporting economic growth.
Reduction in Infrastructure and Deployment Costs	Initial roll-out and adoption may be more feasible if the costs associated with infrastructure and deployment are minimized.
Cost Dynamics and Renewable Energy	The cost of hydrogen is linked to the affordability of renewables; as renewable costs decrease, hydrogen becomes more economical, fostering economic growth.
Resource Resilience and Economic Growth	Hydrogen produced and stored in regions and remote locations enhances resilience, reduces reliance on external resources, and supports economic development.
Long-Term Cost and Efficiency Advancements	Hydrogen, being a sustainable alternative, can become more cost-effective and efficient over time, contributing to economic advancement.
Energy Access for Remote Communities	Hydrogen used for energy storage facilitates energy access in remote communities, addressing fuel poverty and promoting economic development.
Global Uptake and Market Maturity	While sceptical about short-term impact, global uptake and market maturity could eventually lead to lower hydrogen costs, potentially alleviating fuel poverty.

Job Creation and Economic Development	Green hydrogen has the potential to create jobs and contribute to economic development, although trade-offs with other decarbonization opportunities should be considered.
Information Accessibility	The lack of easily accessible usage and demand information may pose a challenge in optimizing the economic benefits of hydrogen technologies.

Table 72: Factors Influencing the Economic Impact of Hydrogen Technologies

In conclusion, the multifaceted benefits of hydrogen technologies extend beyond energy considerations, encompassing economic growth, trade, and environmental sustainability. Successful integration relies on addressing technological challenges and optimizing economic factors in alignment with broader decarbonization goals.

6.5.3 Section 3 Question 15

In response to question 15 in Section 3 *“What factors, if any, do you believe hinder the public acceptance of hydrogen technologies in New Zealand?”*, participants offered insights into factors they perceive as hindrances to the public acceptance of hydrogen technologies in New Zealand.

What factors, if any, do you believe hinder the public acceptance of hydrogen technologies in New Zealand?	15_1. Lack of Awareness and Education	120	66.70%	60	33.30%	180	100.00%
	15_2. Perception about High Costs of Hydrogen Technologies	95	52.80%	85	47.20%	180	100.00%
	15_3. Safety Concerns and Lack of Information	108	60.00%	72	40.00%	180	100.00%
	15_4. Uncertainty About Hydrogen's Effectiveness and Reliability	102	56.70%	78	43.30%	180	100.00%
	15_5. Lack of Government Incentives and Policy Support	84	46.70%	96	53.30%	180	100.00%

Table 73: Factors Hindering Public Acceptance of Hydrogen Technologies in New Zealand

- Lack of awareness and education - 66.7% selected this, indicating it is seen as the most significant barrier. Low understanding of how hydrogen works and its benefits creates scepticism. Targeted education campaigns could help address this.
- Safety concerns and lack of information - 60% chose this. Hydrogen's perceived riskiness due to incidents like the Hindenburg disaster contributes to negative public sentiment. Providing safety data could help alleviate uncertainty.
- Perception about high costs - 52.8% picked this. Though costs are dropping, the perception of expensiveness persists. Communicating accurate cost comparisons and projections could counter this narrative.
- Uncertainty about effectiveness and reliability - 56.7% chose this. Unfamiliarity with real-world hydrogen applications likely contributes to doubts about viability. Demonstration projects could demonstrate capabilities and build confidence.

- Lack of government incentives and policy support - 46.7% selected this. While not the prime factor, greater policy mechanisms and funding to encourage adoption were seen as needing improvement by close to half.

The open-ended responses yielded the following perspectives.

Clean Energy Certification	Ensuring hydrogen production aligns with clean energy approaches enhances credibility and supports environmental goals.
Technological Advancement	The effectiveness of hydrogen technologies in addressing fuel poverty and fostering economic growth is influenced by their degree of technological advancement.
Hydrogen Export Opportunities	Utilizing existing gas infrastructure for hydrogen export presents economic opportunities and contributes to global energy trade.
Export Earnings and Trade Balance	Hydrogen export has the potential to generate earnings, enhancing economic growth and positively impacting the trade balance.
Cost Reduction at Scale	The scalability of hydrogen technologies can lead to lower energy costs, especially in heavy transport, contributing to overall economic efficiency.
Viable Alternative in Specific Cases	Hydrogen becomes crucial in cases where it is the only viable alternative to fossil fuels, even if it may increase energy costs, supporting decarbonization goals.
MACC Analysis for Cost Effectiveness	Marginal Abatement Cost Curves (MACC) analysis guides the identification of cost-effective measures, optimizing the economic impact of hydrogen technologies.
Decarbonization in Remote Communities	Hydrogen can assist in decarbonization efforts in remote communities, reducing costs, and fostering economic growth.
Energy Storage Efficiency	Hydrogen, as an energy storage medium, reduces overprovisioning costs of intermittent renewable electricity, benefiting grid-level efficiency.
Efficient Delivery for Economic Impact	Efficient and cost-effective delivery of hydrogen to the point of use contributes to alleviating fuel poverty and supporting economic growth.
Reduction in Infrastructure Costs	Minimizing infrastructure and deployment costs during initial roll-out facilitates widespread adoption of hydrogen technologies.
Cost Dynamics Linked to Renewables	The cost of hydrogen is linked to renewable affordability; decreasing renewable costs make hydrogen more economically viable, fostering economic growth.
Resource Resilience and Local Production	Hydrogen produced and stored locally enhances resilience, reduces reliance on external resources, and supports economic development.

Long-Term Cost and Efficiency Gains	Hydrogen's sustainability as an alternative enables long-term cost-effectiveness and efficiency gains, contributing to economic advancement.
Energy Access for Remote Communities	Hydrogen used for energy storage facilitates energy access in remote communities, addressing fuel poverty and promoting economic development.
Global Uptake Potential	While sceptical about short-term impact, global uptake and market maturity could eventually lower hydrogen costs, potentially alleviating fuel poverty.
Job Creation and Economic Development	Green hydrogen has the potential to create jobs and contribute to economic development, with considerations for trade-offs in decarbonization opportunities.
Challenges of Information Accessibility	The lack of easily accessible usage and demand information poses a challenge in optimizing the economic benefits of hydrogen technologies.

Table 74: Factors Influencing the Economic Impact of Hydrogen Technologies

In conclusion, the widespread acceptance of hydrogen technologies in New Zealand faces impediments rooted in awareness, cost perception, and infrastructure concerns. While factors such as clean energy creation, technological advancement, and global market integration present promising economic opportunities, challenges lie in addressing cost dynamics, ensuring efficient delivery, and reducing infrastructure expenses. The potential for hydrogen to alleviate fuel poverty and foster economic growth, particularly in remote communities, hinges on advancing renewable energy affordability, enhancing resource resilience, and realizing long-term cost efficiencies. As global uptake and market maturity progress, coupled with job creation potential, hydrogen's role in New Zealand's economic landscape could evolve positively, yet comprehensive information accessibility remains crucial for optimizing its economic benefits.

6.5.4 Section 3 Question 16

Participants provided perspectives in answer to question 16 in Section 3 *“How do you think public awareness about hydrogen technologies can be increased?”*

How do you think public awareness about hydrogen technologies can be increased?	16_1. Public Education Campaigns and Workshops	98	54.40%	82	45.60%	180	100.00%
	16_2. Showcasing Successful Case Studies and Demonstrations .	124	68.90%	56	31.10%	180	100.00%
	16_3. Involvement of Schools and Educational Institutions	100	55.60%	80	44.40%	180	100.00%
	16_4. Media Campaigns and Informational	100	55.60%	80	44.40%	180	100.00%
	16_5. Engaging Hydrogen Industry Experts for Public Talks	81	45.00%	99	55.00%	180	100.00%

Table 75: Strategies to Increase Public Awareness of Hydrogen Technologies

- The most selected option was showcasing successful case studies and demonstrations at 68.9%. This suggests that highlighting real-world examples of hydrogen applications within the built environment, especially locally, is seen as the most impactful awareness building approach. Seeing tangible implementations can make hydrogen technologies more relatable.
- The second highest choice was public education campaigns and workshops at 54.4%. This indicates more generalized educational outreach is also viewed as an important awareness raising mechanism. Traditional public campaigns can provide foundational knowledge.
- Involvement of schools and educational institutions and media campaigns tied for third at 55.6% each. Educating students through academic institutions is seen as equally effective as utilizing media for outreach. Both allow communicating with broad segments of the population.
- The least picked option was engaging hydrogen industry experts for public talks at 45%. While still substantial, this direct expert outreach is considered relatively less critical compared to demonstrations, school-based learning, and media campaigns.

The open-ended responses added additional viewpoints to the conversation.

Relevant Overseas Studies	Highlighting relevant overseas studies, such as ENE (Energy and Environment) installations in Japan, to showcase successful implementations in similar markets and assess economic viability for New Zealand.
Targeting the Youth	Focusing on children and youth as the target generation for awareness campaigns, recognizing their potential to drive societal change and acceptance.
Incentive-Free Case Studies	Demonstrating case studies without government incentives to showcase the economic feasibility of hydrogen technologies in real-world applications.
Economically Feasible Prototypes	Developing and showcasing economically feasible prototypes to provide tangible examples of hydrogen technologies in action.
Community Education	Conducting educational initiatives that reach all communities, both rural and urban, ensuring widespread awareness and understanding.
Incorporating Hydrogen Education in Schools	Integrating hydrogen education into school curriculums, spanning from years 6 to 13, to foster awareness and understanding from an early age.
Funding for Proof of Concept	Providing funding support for proof-of-concept projects to encourage practical demonstrations and applications of hydrogen technologies.
Alternative and Cost-Effective Energy Source	Positioning hydrogen as a viable alternative and cost-effective energy source through awareness campaigns and educational programs.
Targeted Campaigns and Workshop	Implementing public and industry-targeted campaigns and workshops tailored to specific audiences, avoiding a one-size-fits-all approach.
Showcasing Successful Projects	Highlighting successful hydrogen projects globally, emphasizing their relevance and potential impact, even if they are not specific to New Zealand.

Realistic Environmental Benefits	Providing realistic examples of how hydrogen technologies can benefit the environment, coupled with an emphasis on affordability and accessibility.
Replacing Traditional Energy Sources	Demonstrating how hydrogen can effectively replace traditional energy sources, perhaps using examples like replacing a significant project such as Lake Onslow.
Addressing Public Concerns	Acknowledging public indifference and addressing concerns by ensuring transparency from suppliers and providing clear information on the benefits and safety of hydrogen technologies.

Table 76: Strategies to Increase Public Awareness of Hydrogen Technologies

Increasing public awareness of hydrogen technologies in New Zealand requires leveraging overseas success stories, targeting youth education, and showcasing economically feasible case studies. Community-wide education, funding for projects, and transparent supplier communication play crucial roles. Tailored campaigns, workshops, and emphasizing realistic benefits contribute to building public understanding and acceptance.

6.5.5 Section 3 Question 17

Question 17 in Section 3 inquired “*What role should the government play in accelerating the acceptance of hydrogen technologies in New Zealand?*”.

In your opinion, what role should the government play in accelerating the acceptance of hydrogen technologies in New Zealand?	17_1. Providing Financial Incentives for Hydrogen Adoption	101	56.10%	79	43.90%	180	100.00%
	17_2. Establishing Clear Regulatory Framework and Standards	129	71.70%	51	28.30%	180	100.00%
	17_3. Funding Research and Development in Hydrogen Technologies	131	72.80%	49	27.20%	180	100.00%
	17_4. Collaborating with Industry to Promote Hydrogen Use	117	65.00%	63	35.00%	180	100.00%

Table 77: Government Roles in Accelerating Hydrogen Technology Acceptance in New Zealand

- Establishing a clear and supportive regulatory framework. Over 70% agreed this is important to provide long-term certainty for industry planning and investment. International collaboration can help streamline regulations.
- Funding research and development. Nearly three-quarters saw this as a key government function, especially to lower technology costs over time. Co-funding trials and demonstration projects was also highlighted.
- Providing financial incentives. A majority (56%) supported incentives to boost early adoption, recognizing upfront capital costs are currently high. Tax incentives and building code support were some suggestions.
- Collaborating with industry. Two-thirds saw value in the government partnering with private sector to undertake promotions and awareness initiatives to educate on viability and benefits.
- At the same time, several respondents cautioned against open-ended subsidies and instead favoured letting market forces determine the most cost-effective low-carbon technologies.

Most agreed government should take a strategic and technology-neutral approach to encourage multiple solutions.

The ensuing responses from open-ended queries were as follows.

International Alignment	Aligning with international partners, such as Australia, to save on development and implementation costs and increase awareness.
Technology Agnosticism	Government support for decarbonization technologies should be technology agnostic, treating each solution fairly.
Financial Incentives	Providing financial incentives like GST tax breaks, customs tax breaks, and building levy fee reductions to encourage the installation of hydrogen-related plants in new builds.
Information Dissemination	Informing the public about hydrogen technologies, showcasing international successes, and providing transparent cost/benefit analyses.
No Subsidies	Some believe that hydrogen should not be subsidized and should only progress if economically viable.
Community Reinvestment	Ensuring profits from new energy technologies are reinvested into local communities.
Regulatory Alignment	Creating a systematic regulatory framework for hydrogen, aligning with existing compliance paths for natural gas and LPG.
External Cost Pricing	Pricing in the negative externalities of fuels to reflect the total societal cost in customer pricing.
Private Sector Leadership	Government should not act as venture capitalists but reduce barriers to adoption and support private sector initiatives.
Demonstration Support	Government support for demonstration or trials of green hydrogen, co-funding where industry projects are potentially viable.
Economic Opportunity	Involvement of the government in supporting the hydrogen industry beyond regulation should be based on clear economic opportunities.
Market-Driven Approach	Government should be technology agnostic, letting the market drive technology preferences through high NZU prices.

Table 78: Government Roles in Accelerating Hydrogen Technology Acceptance in New Zealand (open-ended responses)

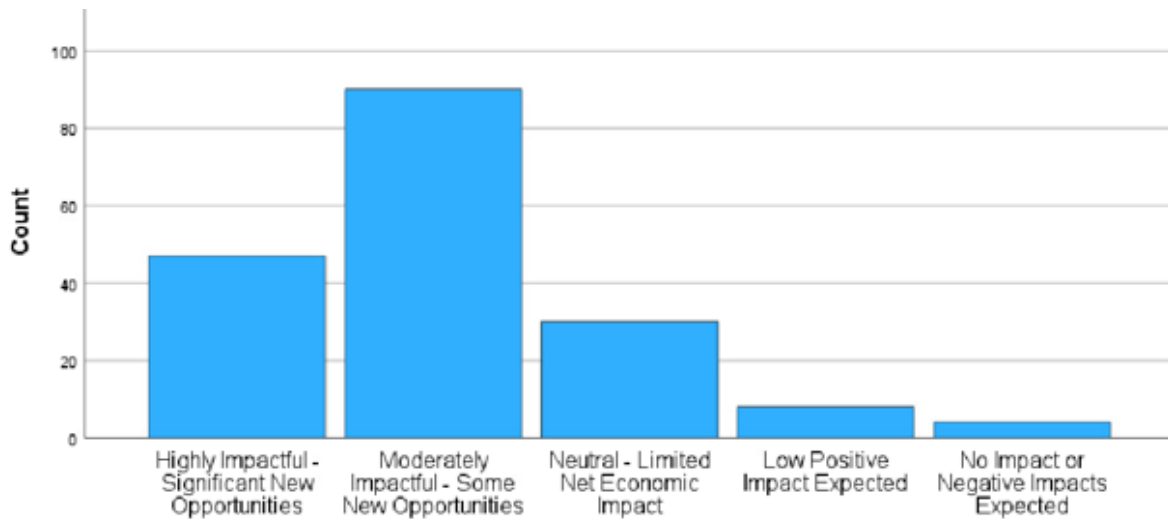
Overall, the results suggest New Zealanders view regulatory and R&D support as appropriate roles for now, with less need for long-term demand subsidies once hydrogen is proved.

6.5.6 Section 3 Question 18

The survey presented respondents with the question 18 in Section 3: *“Development of a robust regulatory framework with a risk-based approach for hydrogen could enable new economic opportunities and jobs growth. In your view, how impactful would hydrogen sector job creation and growth opportunities be for the NZ economy?”*

Respondents were then given a 5-point scale to rate the potential impact:

- Highly impactful - significant new opportunities
- Moderately impactful - some new opportunities
- Neutral - limited net economic impact
- Low positive impact expected
- No impact or negative impacts expected



Bar Chart 5: Assessment the Impact of Hydrogen Sector Job Creation on the New Zealand Economy

The results showed:

- 26.1% believed the impact would be “Highly impactful”
- 50% saw it as “Moderately impactful”
- 17.2% were “Neutral”
- 4.4% expected “Low positive impact”
- 2.2% anticipated “No impact or negative impacts”

Q 18. Development of a robust regulatory framework with a risk-based approach for hydrogen could enable new economic opportunities and jobs growth. In your view, how impactful would hydrogen sector job creation and growth opportunities be for the NZ economy				
	Frequency	Percent	Valid Percent	Cumulative Percent
Highly Impactful - Significant New Opportunities	47	26.1	26.1	26.1
Moderately Impactful - Some New Opportunities	90	50	50	76.1
Neutral - Limited Net Economic Impact	31	17.2	17.2	93.3
Low Positive Impact Expected	8	4.4	4.4	97.8
No Impact or Negative Impacts Expected	4	2.2	2.2	100
Total	180	100	100	

Table 79: Impact Assessment of Hydrogen Sector Job Creation on the New Zealand Economy

This suggests stakeholders generally viewed hydrogen's development as having a positive economic impact for New Zealand through job and growth opportunities, with over three-quarters seeing at least some degree of impact. Overall, respondents indicated moderate optimism regarding the economic opportunities from hydrogen development in New Zealand. The mean response was 2.04 on the 5-point scale, between "Moderately impactful - some new opportunities" and "Neutral - limited net economic impact". The most common perspective at 50% was that hydrogen would bring moderately impactful opportunities and benefits. Meanwhile, 26.1% felt the impact could be highly significant. At the other end, only 6.4% expected low or no positive impacts. This distribution reflects cautious optimism around hydrogen's economic potential. It aligns with research suggesting emerging clean energy can catalyse job creation and growth, but realization depends on factors like policy support, private investment, and training programs (Vona et al., 2018). Specific opportunities could arise across production, storage, distribution, and end-use segments. However, competitive advantage and maximizing local benefits would require strategic development of specialized capabilities and intellectual property. The diversity of sentiments shows there are still unknowns and differing outlooks. 17.2% remained neutral, underscoring the need for further assessment of concrete impacts. The moderately positive mean suggests potential if the industry can mature. More robust scenario modelling could elucidate likely outcomes under different policy and investment conditions. Additionally, research on labour markets and skills could better match workforce development to expected needs (IRENA, 2022).

6.5.7 Key Findings and Conclusion for Section 3

Chapter 3 of the survey focused on addressing the third research question: *"How to accelerate the acceptance of hydrogen technologies by the public to alleviate fuel poverty among New Zealanders and achieve economic growth goals in the context of decarbonizing the built environment through green hydrogen technologies"*. The results in Section 3 provide valuable insights into how hydrogen acceptance can be accelerated through public education, demonstration projects, policy incentives, and emphasizing sustainability benefits.

1. Public education and awareness campaigns were seen as imperative by over 60% of respondents. Outreach to increase basic literacy and positive associations can pave the way for smooth adoption. Events, media, and transparent communication of risks/benefits are key vectors.
2. Demonstration projects: well-designed pilot projects can also build acceptance by showcasing real-world feasibility. Government co-funding pilots across applications like heating and powering of the built environment can catalyse private investment. Success stories reduce perceived risk.
3. Policy Incentives: Measures such as capital subsidies, tax credits, and preferential electricity rates can help achieve lifecycle cost parity with conventional fuels during market maturation. Emphasizing emissions reductions and environmental gains leverages public values. This resonates with New Zealand's clean/green brand.
4. Emphasizing Sustainability Benefits: Quantifying and communicating sustainability benefits through verified impact measurement provides motivation.
5. Strategic workforce development and training will ensure the required expertise to maximize economic opportunities and self-reliance.
6. Concerns were raised about the efficiency challenges of hydrogen applications in buildings, with some respondents questioning the viability of such an approach compared to electrification. Cost competitiveness is crucial.

In summary, public acceptance can be accelerated through multifaceted efforts to educate, demonstrate, incentivize, and quantify hydrogen’s alignment with values. Prudent policymaking has a strong enabling role across these fronts. With sound strategies grounded in public insights, hydrogen can positively contribute to sustainable development goals in the built environment and beyond. The findings from this section will be further elaborated upon in Chapter 8 for a more in-depth discussion.

6.6 Section 4 - Government Investment

Section 4 of the survey was formulated to tackle the fourth research question: *“What factors may influence the Government’s decision to accelerate the development of new energy vectors, and how can confidence in investing in advanced hydrogen technologies be provided to the Government?”*.

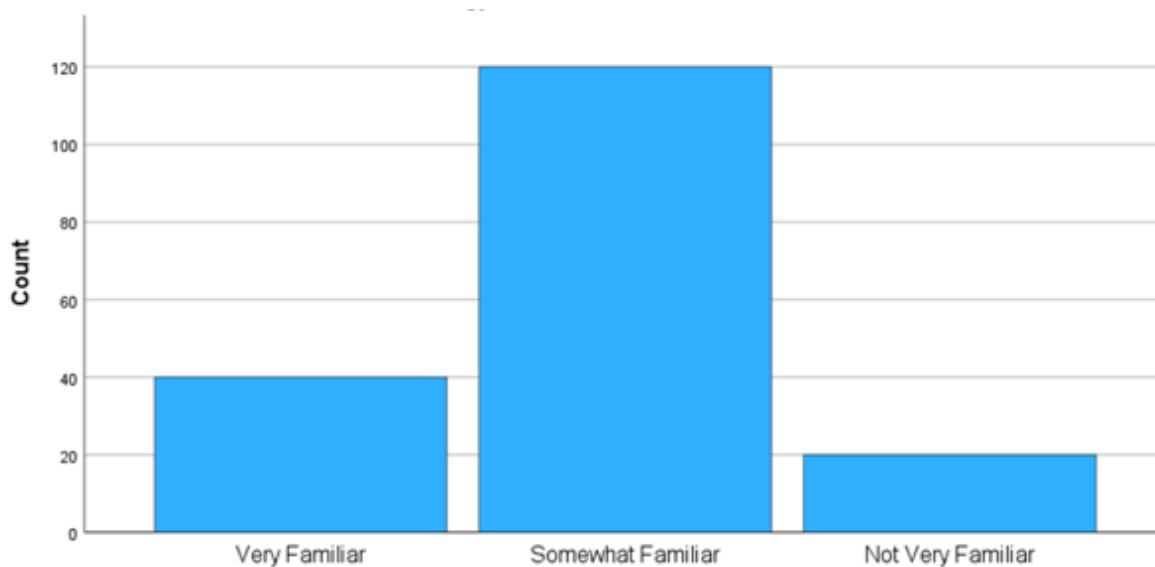
6.6.1 Section 4 Question 19

In Section 4 Question 19, the participants were asked to indicate their level of familiarity with advanced hydrogen technologies and their potential as a new energy vector in New Zealand.

The response options were:

- Very familiar (1)
- Somewhat familiar (2)
- Not very familiar (3)

The survey used a 3-point inverse Likert scale to assess familiarity with advanced hydrogen technologies, where 1 = Very familiar, 2 = Somewhat familiar, and 3 = Not very familiar (Dalton, 1993; Jamieson, 2004).



Bar Chart 6: Level of Familiarity with Advanced Hydrogen Technologies and Their Potential as a New Energy Vector in New Zealand

- Very Familiar (22.2%): This portion of respondents shows a relatively lower level of deep familiarity with advanced hydrogen technologies. While a smaller percentage, these individuals are likely to possess a more comprehensive understanding of the subject.
- Somewhat Familiar (66.7%): The majority of respondents fall into this category, indicating a moderate level of familiarity with advanced hydrogen technologies. This suggests that a significant portion of the surveyed population has some knowledge about these technologies, although it may not be as extensive as the “Very Familiar” group.

- **Not Very Familiar (11.1%):** A smaller percentage of respondents admitted to having limited familiarity with advanced hydrogen technologies. This group may lack detailed knowledge or may be less informed about the potential of hydrogen as a new energy vector in New Zealand.

Q19. Are you familiar with advanced hydrogen technologies and their potential as a new energy vector in New Zealand?				
	Frequency	Percent	Valid Percent	Cumulative Percent
Very Familiar	40	22.2	22.2	22.2
Somewhat Familiar	120	66.7	66.7	88.9
Not Very Familiar	20	11.1	11.1	100
Total	180	100	100	

Table 80: Level of Familiarity with Advanced Hydrogen Technologies in New Zealand

The survey findings reveal disparities in familiarity with hydrogen technologies across various occupations in New Zealand. Engineers and technical roles generally exhibit a higher level of familiarity, which is expected given their direct involvement in developing expertise in this field. On the other hand, non-technical professionals such as consultants tend to show lower levels of familiarity, despite their significant influence on energy policymaking.

The overall mean familiarity score was moderate, indicating a reasonable level of familiarity on average. However, a closer look at the data by occupation reveals some interesting trends. Engineers, architects, and construction managers scored relatively well, reflecting the increasing integration of hydrogen technologies in building practices and educational curricula.

Consultants demonstrated moderate familiarity, while policy analysts exhibited lower levels of familiarity. This suggests that although these professionals play crucial roles in energy transitions, they may lack the deep technical expertise required for effective decision-making regarding emerging technologies like hydrogen. Thus, targeted educational initiatives for these groups are recommended to bridge knowledge gaps.

Project managers showed moderate familiarity, but with more variability compared to other occupations, indicating inconsistent levels of familiarity within this group. Similarly, while solar electricians and sustainability experts showed some level of familiarity, there were gaps compared to technical specialists like electrical engineers.

Interestingly, students displayed a high level of familiarity, likely due to the increasing prominence of hydrogen in technical curricula. However, translating this theoretical knowledge into practical roles remains a challenge.

Overall, while there are occupational disparities in hydrogen familiarity, addressing these gaps through tailored engagement and training programs can support more informed decision-making across all key roles. It is crucial to bridge these divides to ensure a holistic understanding of hydrogen technologies, which is vital for effective policymaking and successful implementation of decarbonization strategies.

6.6.2 Section 4 Question 20

Question 20 in Section 4 asked: *“What do you perceive as the main benefits of investing in advanced hydrogen technologies for New Zealand’s energy landscape?”*

What do you perceive as the main benefits of investing in advanced hydrogen technologies for New Zealand's energy landscape?	20_1. Reduction in Carbon Emissions and Environmental Impact	138	76.70%	42	23.30%	180	100.00%
	20_2. Potential for Energy Independence and Security	115	63.90%	65	36.10%	180	100.00%
	20_3. Economic Growth and Job Creation in the Hydrogen	79	43.90%	101	56.10%	180	100.00%
	20_4. Facilitating Transition to Renewable Energy Sources	120	66.70%	60	33.30%	180	100.00%
	20_5. Enhancing Energy Storage and Grid Stability	88	48.90%	92	51.10%	180	100.00%

Table 81: Benefits of Investing in Advanced Hydrogen Technologies for New Zealand's Energy Landscape

- Reduction in carbon emissions and environmental impacts. Nearly 77% selected this as a primary benefit, reflecting New Zealand's clean, green image and climate change commitments.
- Facilitating transition to renewable energy sources. Two-thirds saw hydrogen enabling greater penetration of wind and solar by providing long-term storage and electricity sector decarbonization.
- Potential for energy independence and security. Over 63% recognized hydrogen could reduce reliance on imported fuels. Offshore wind generation coupled with domestic hydrogen production was highlighted.
- Enhancing energy storage and grid stability. While less than half chose this currently, hydrogen energy storage likely becomes more important as distributed renewable capacity grows.
- Additional benefits mentioned include fuel optionality in transportation, industry and exports; economic diversification and jobs as oil/gas roles decline; reduced diesel consumption improving trade balances; and enabling decarbonization of strategic sectors like steel and transport to maintain export market access and premiums.

The open-ended responses introduced the following themes into the discussion.

Flexibility in the Energy Landscape	Creating a green hydrogen energy option for increased flexibility in the energy landscape.
Export Earnings	Generating export earnings through the production and export of green hydrogen.
Heavy Transportation	Addressing the energy needs of heavy transportation, contributing to a more sustainable and efficient transport sector.
Offshore Electricity Generation	Aligning with the trend for offshore electricity generation, making overprovision more economically attractive through local and decentralised hydrogen generation.

Maintaining Export Market Access	Decarbonizing the supply chain emissions in heavy road transport, marine, and aviation to maintain access to premium export markets.
Job Creation	Providing new job opportunities as roles in oil and gas are likely to phase out, potentially transitioning labour forces.
Reduction in Diesel Consumption	Contributing to a reduction in diesel consumption, improving the balance of payments.
Emissions Reduction in Steel Production	Addressing emissions from steel production, particularly from New Zealand Ironsand.
Minimal Downsides	Participants perceive minimal downsides, with the transition of non-renewable labour forces being the main challenge.

Table 82: Advantages of Advanced Hydrogen Technologies in New Zealand's Energy Landscape (open-ended responses)

In summary, hydrogen is seen as crucial to maximizing environmental and climate benefits from New Zealand's natural resources base while managing long-term energy transition challenges around infrastructure, storage and stable grid operations to maintain economic competitiveness. Early investment can help realize these strategic opportunities.

6.6.3 Section 4 Question 21

Question 21 in Section 4 asked: *“What factors, in your opinion, may influence the government's decision to invest in advanced hydrogen technologies?”*

What factors, in your opinion, may influence the government's decision to invest in advanced hydrogen technologies?	21_1. Scientific Research and Technological	81	45.00%	99	55.00%	180	100.00%
	21_2. Economic Viability and Cost-Effectiveness	130	72.20%	50	27.80%	180	100.00%
	21_3. International Trends and Agreements on Hydrogen Adoption	95	52.80%	85	47.20%	180	100.00%
	21_4. Pressure from Environmental Groups and Public Opinion	58	32.20%	122	67.80%	180	100.00%
	21_5. National Energy Security Concerns	73	40.60%	107	59.40%	180	100.00%

Table 83: Factors Influencing Government Investment in Advanced Hydrogen Technologies

- Economic viability and cost-effectiveness was selected as the top factor by over 72% of respondents. This aligns with the reality that governments operate within fiscal constraints and must consider value-for-money of priorities. Demonstrating hydrogen's costs can compete without long-term subsidies will be crucial.
- International trends and agreements on hydrogen adoption ranked second highest at 52.8%. As a small, trade-reliant country, New Zealand may wish to participate in emerging global markets and contribute to international climate commitments.

- Scientific research and technological progress garnered 45% support. Continued R&D lowering the costs of production, storage and use could strengthen the business case over the long-run as technologies mature.
- National energy security concerns and pressure from environmental/public opinion were viewed as less immediately influential factors by around 40-32% respectively. However, growing domestic awareness of climate change risks coupled with fuel import dependence enhancing energy insecurity could elevate their importance in the future.
- Notably, over half saw public and environmental group pressure as unlikely to sway government investment at this stage. Cost-effectiveness remains the paramount consideration. International cooperation also ranked above domestic lobbying, signalling New Zealand's open economy outlook.

Furthermore, the open-ended responses introduced additional themes into the discussion.

Climate Change Obligations	Alignment with climate change obligations and commitments, emphasizing the importance of green hydrogen in achieving sustainability goals.
Corporate Lobbying	Influence from corporate lobbying efforts advocating for hydrogen technologies, potentially reflecting industry interests.
Economic Security	Consideration of economic security, with some participants suggesting that economic factors may either support or deter government investment.
Industry-Led Initiatives	The impact of industry-led initiatives, especially in high-volume requirement sectors such as mining or construction, influencing the decision to invest.
Impact on Hard-to-Abate Industries	Recognition of the potential for hydrogen technologies to make significant advancements in hard-to-abate industries, like the production of green steel for the construction.
Pressure from Environmental Groups	Acknowledgment of the negative pressure from environmental groups on green hydrogen and the preference for greater direct electrification of the energy system.
Proven Overseas Case Studies	Consideration of proven case studies and successful implementations of hydrogen technologies within the built environment overseas, providing a basis for decision-making.
Paris Agreement Commitment	The potential influence of commitments made under the Paris Agreement, possibly driving government support for hydrogen initiatives.
Government-Supported Initiatives	Government-Supported Initiatives: Reference to existing government support, such as the support for the Hiringa H2 station rollout and the introduction of hydrogen trucks.

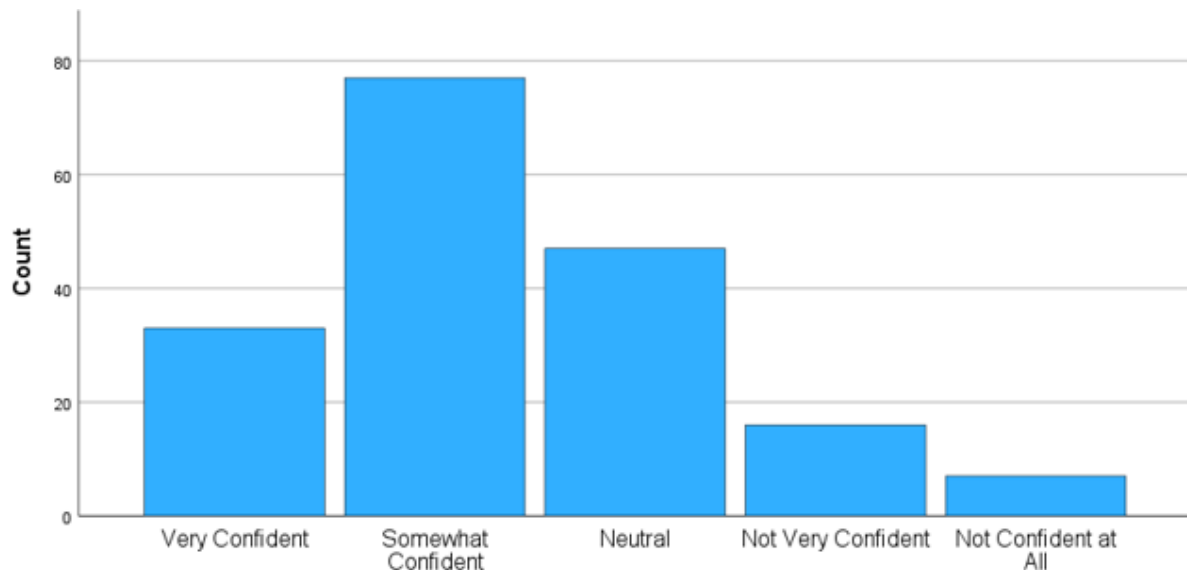
Table 84: Factors Influencing Government Investment in Advanced Hydrogen Technologies

In summary, hydrogen is seen as crucial to maximizing environmental and climate benefits from New Zealand's natural resources base while managing long-term energy transition challenges around infrastructure, storage and stable grid operations to maintain economic competitiveness. Early investment can help realize these strategic opportunities.

6.6.4 Section 4 Question 22

In section 4 Question 22, the survey asked respondents “How confident are you in the potential of advanced hydrogen technologies to address New Zealand’s energy needs?”. A 5-point scale was provided:

- Very Confident
- Somewhat Confident
- Neutral
- Not Very Confident
- Not Confident at All



Bar Chart 7: Level of Confidence in the Potential of Advanced Hydrogen technologies to address New Zealand’s Energy Needs

The results demonstrate a diversity of perspectives but an overall tendency towards positivity. Specifically:

- 18.3% selected “Very Confident”, indicating optimism in hydrogen’s capabilities.
- A plurality (42.8%) chose “Somewhat Confident”, representing cautious support.
- A further 26.1% adopted a neutral stance through the mid-point option.
- Only 8.9% expressed lack of confidence to some degree as “Not Very Confident”.
- The remaining 3.9% selected the most doubtful rating of “Not Confident at All”.

Q22. How confident are you in the potential of advanced hydrogen technologies to address New Zealand’s energy needs?				
	Frequency	Percent	Valid Percent	Cumulative Percent
Very Confident	33	18.3	18.3	18.3
Somewhat Confident	77	42.8	42.8	61.1
Neutral	47	26.1	26.1	87.2
Not Very Confident	16	8.9	8.9	96.1
Not Confident at All	7	3.9	3.9	100

Total	180	100	100	

Table 85: Confidence in Advanced Hydrogen Technologies to Address New Zealand’s Energy Needs

In aggregate, over three-fifths conveyed confidence levels towards the affirmative end of the scale, suggesting many stakeholders anticipate hydrogen proving able to address a portion of New Zealand’s energy demands. Continued deployment may consolidate viewpoints over time.

6.6.5 Section 4 Question 23

Question 23 in Section 4 inquired: “What actions or measures, if any, do you believe the government should undertake to instil confidence in investing in advanced hydrogen technologies?”.

What actions or measures, if any, do you believe the government should take to gain confidence in investing in advanced hydrogen technologies?	23_1. Collaborating with Hydrogen Industry Experts and Institutions	107	59.40%	73	40.60%	180	100.00%
	23_2. Conducting Pilot Projects and Demonstrations	119	66.10%	61	33.90%	180	100.00%
	23_3. Offering Grants and Funding for Research and Development	114	63.30%	66	36.70%	180	100.00%
	23_4. Establishing Regulatory Frameworks and Standards	118	65.60%	62	34.40%	180	100.00%
	23_5. Engaging in International Collaborations and Knowledge Sharing	104	57.80%	76	42.20%	180	100.00%

Table 86: Government Measures to Gain Confidence in Investing in Advanced Hydrogen Technologies

- Conducting pilot projects and demonstrations was the top selected action, with over 66% support. This aligns with the viewpoint that tangible, local proof points are important to validate technical and economic feasibility.
- Establishing regulatory frameworks and standards closely followed at 65.6%, indicating clear guidelines are desired to de-risk investments and long-term planning.
- Offering grants and funding for R&D gained 63.3% support, reflecting the need to subsidize initial innovation costs that lower technology prices over the lifespan.
- Collaborating with industry experts and institutions ranked fourth at 59.4%, emphasizing the value of co-developing strategic roadmaps with on-the-ground stakeholders.
- Engaging in international knowledge sharing and partnerships received 57.8% support, underscoring New Zealand’s open economy and the global nature of industry developments.

Moreover, the open-ended feedback brought forth supplementary topics for consideration in the discourse.

Learn from Successful Projects	Emphasizing the importance of observing and learning from successful projects, both locally and internationally, to build confidence in the viability of hydrogen technologies.

Tax Break Incentives	Implementing various tax break incentives to encourage the use of hydrogen technologies, making them more economically attractive for investors.
Avoiding Excessive Compliance Cost	Ensuring that the industry does not become an expensive compliance proposition, minimizing regulatory burdens that could hinder investment.
Consistent Approach and Framework	Establishing a consistent approach, including a clear strategy and framework, to encourage investment confidence while minimizing risks associated with changing frameworks and priorities.
Immediate Action	Urging the government to initiate hydrogen projects promptly, as the technology is available and regulations are close to being fit for purpose, with a focus on encouraging the first energy users to take the initial steps.
Exploring All Options	Encouraging the exploration of all available options to support and promote advanced hydrogen technologies within the built environment.
Learning from Australian Pilot Projects	Drawing insights and lessons from pilot projects in Australia, with an offer of assistance and collaboration.
Private Sector Initiative	Expressing the viewpoint that if private companies cannot make hydrogen technologies successful, the government's role should be limited, and any government involvement should follow the lead of other countries.

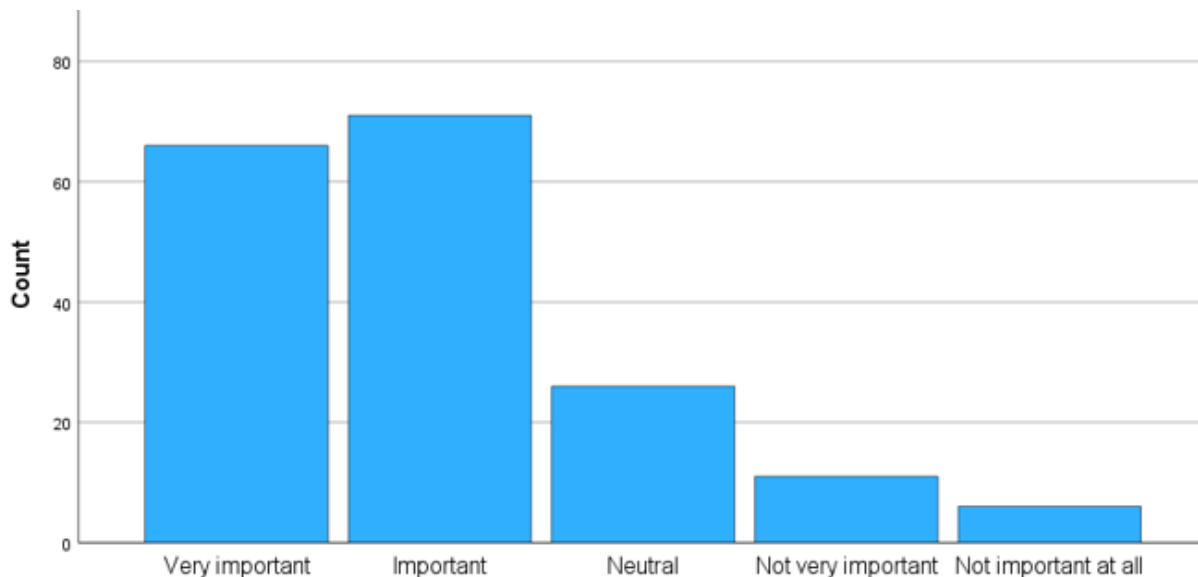
Table 87: Government Measures to Instil Confidence in Advanced Hydrogen Technologies (open-ended responses)

Notably, no single measure achieved overwhelming consensus, instead requiring a balanced portfolio approach incorporating evidence generation, capacity building, and strategic policymaking done in partnership with sector leaders. This comprehensive strategy reflects participants' calibrated view of de-risking such a transformative transition. Early yet targeted actions across these fronts could progressively validate long-term hydrogen confidence.

6.6.6 Section 4 Question 24

The survey asked stakeholders to consider *“How important is it for the government to actively promote and support the development of advanced hydrogen technologies in New Zealand?”* in Question 24, Section 4. A 5-point scale was provided to indicate views:

- Very Important
- Important
- Neutral
- Not Very Important
- Not Important at All



Bar Chart 8: The Importance of Government in Actively Promoting and Supporting the Development of Advanced Hydrogen Technologies in New Zealand

The results demonstrate clear consensus around the crucial role of governmental support and promotion. Over a third (36.7%) selected “Very Important” and another sizable portion (39.4%) chose “Important” - a strong majority accord of 76.1%. The views clustered toward affirmative positions, with neutral sentiments comprising a moderate 14.4%. Only a narrow minority deemed support “Not Very Important” (6.1%) or opted for neutral non-commitment. This clustering suggests stakeholders appreciate hydrogen’s advancement relies substantially on state impetus given industry infancy. However, a small minority (3.3%) believed it was “Not Important at All” to controversial perspectives that warrant consideration to gain fuller perspective.

Q24. How important is it for the government to actively promote and support the development of advanced hydrogen technologies in New Zealand?				
	Frequency	Percent	Valid Percent	Cumulative Percent
Very important	66	36.7	36.7	36.7
Important	71	39.4	39.4	76.1
Neutral	26	14.4	14.4	90.6
Not very important	11	6.1	6.1	96.7
Not important at all	6	3.3	3.3	100
Total	180	100	100	

Table 88: Importance of Government Support for Advanced Hydrogen Technologies in New Zealand

The unified call for active government promotion underscores recognition transitioning emerging technologies requires long-term policy vision and targeted initiatives to de-risk initial investments. Continued facilitating measures will likely cement already affirmative stances as deployment proceeds.

6.6.7 Key Findings and Conclusion for Section 4

Chapter 4 of the survey focused on understanding stakeholder perceptions of the government’s role in supporting the development of advanced hydrogen technologies in New Zealand. Key findings:

1. **Knowledge Gaps:** While a majority of respondents (66.7%) reported being “somewhat familiar” with hydrogen technologies, significant knowledge gaps exist, especially among non-technical professionals involved in policymaking. Only 22.2% were “very familiar” with the technology.
2. **Perceived Benefits:** Respondents identified key benefits of investing in hydrogen, including reduction in carbon emissions (76.7%), facilitating the transition to renewable energy sources (66.7%), and potential for energy independence and security (63.9%). The open-ended responses also highlighted economic diversification, job creation, and decarbonization of hard-to-abate industries.
3. **Factors Influencing Investment:** The top factors seen as influencing government investment were economic viability and cost-effectiveness (72.2%), international trends and agreements on hydrogen adoption (52.8%), and scientific research and technological progress (45%). Public and environmental pressure were viewed as less immediately influential (32.2%).
4. **Confidence in Hydrogen:** Over 60% of respondents expressed confidence in hydrogen’s ability to address New Zealand’s energy needs, with 18.3% being “very confident” and 42.8% being “somewhat confident”, suggesting a generally positive outlook.
5. **Recommended Government Actions:** Respondents identified key actions the government should take, including conducting pilot projects and demonstrations (66.1%), establishing regulatory frameworks and standards (65.6%), offering grants and funding for R&D (63.3%), and collaborating with industry experts (59.4%).

The extensive analysis in Chapter 4 sheds light on several key factors that appear likely to influence the New Zealand government’s decision to accelerate the development of green hydrogen technologies for decarbonizing the built environment. Economic viability and cost-competitiveness will be paramount, requiring demonstrations that hydrogen solutions can achieve emissions reductions targets for buildings and infrastructure at affordable costs without long-term subsidies.

Continued technological progress lowering the levelized cost of using green hydrogen, as well as rising public concern about climate change, may also heighten the government’s prioritization of decarbonizing strategic sectors. Demonstration of technical and commercial feasibility through well-designed pilot projects can provide real-world evidence to validate green hydrogen’s potential in the built environment.

Confidence in green hydrogen for buildings and construction can be strengthened through local pilots, regulatory frameworks, research funding, and industry-academic collaboration. Engagement in international knowledge exchange also allows New Zealand to capitalize on global growth. Overall, the findings suggest a data-driven, multi-stakeholder approach balancing costs and emissions outcomes is most likely to gain the confidence required for government investment and policy support. The detailed findings from this section will be further explored and analysed in Chapter 8.

Chapter 7 – Observations, Data Validation, Discussion and Recommendation

Chapter 7 of the report delves into observations, data validation, discussion, and recommendations regarding the acceptance and integration of advanced hydrogen technologies in New Zealand's energy landscape. This chapter provides a comprehensive analysis of the survey data collected, validates key findings, discusses correlations between various variables, and offers recommendations based on the insights gathered. By critically examining the survey results and discussing their implications, this chapter aims to provide valuable insights and guidance for policymakers, industry stakeholders, and researchers interested in advancing hydrogen technologies in New Zealand.

7.1 Correlation between questions 12, 13, 19 and 22

Q12 Transitioning to new energy models like green and low carbon hydrogen has the potential to meet building energy demands while reducing environmental impacts. How confident are you that hydrogen technologies can provide sufficient capacity to displace Fossil Fuels

Q13 Are you aware of hydrogen technologies and their potential benefits in addressing energy affordability and economic growth in New Zealand?

Q19 Are you familiar with advanced hydrogen technologies and their potential as a new energy vector in New Zealand?

Q22 How confident are you in the potential of advanced hydrogen technologies to address New Zealand's energy needs? here is information related to correlation. analyse please and produce good academic passage as previously with relevant references if required.

The original survey question on familiarity most aligned with conventional 3 to 5-point scale design based on the mean score observed. The mean, median, and mode compose a survey item's central tendency describing the centre of responses distribution (measuring what is average) (Taherdoost, 2016). For familiarity measurement, the mean familiarity rating of 1.89 skewed above the exact midpoint, indicating more collective positivity towards the higher end of the underlying agreement scale (Lantz & Nebenzahl, 2016). This suggests a degree of convergence towards reasonably high familiarity on average.

On a 3-point scale, a mean of 1.89 indicates that on average, respondents rated themselves between "Very familiar" and "Somewhat familiar" in terms of their familiarity with advanced hydrogen technologies. Since the mean cannot exceed the maximum value of 3.00 for a 3-point scale, a score of 1.89 skews positively towards more familiarity rather than less.

If every respondent selected "Very familiar", the mean would be 1.00. If every respondent selected "Somewhat familiar", the mean would be 2.00. And an exactly even split across the 3 options would give a mean of 2.00. In the context of a 3-point scale, a mean of 1.89 suggests respondents in aggregate view themselves as more toward the "Very familiar" side, but not exclusively. With 180 respondents, if it was split evenly between 60 "Very familiar", 60 "Somewhat familiar", and 60 "Not very familiar" then the mean familiarity would have equalled 2.00. Therefore, a mean of 1.89 indicates more people rated themselves as "Very familiar" than the other two options, dragging down the mean. There was a smaller portion of "Not very familiar" responses to produce that aggregate mean statistic.

A modest standard deviation (SD=0.568) indicates scores did not widely differ or stray from the mean (Sullivan & Artino, 2013; Lantz & Nebenzahl, 2016). To illustrate spread, 68% fell within 0.568

points of the mean (1-SD range in normal distribution). Though compressed by scale endpoints, responses varied noticeably across familiarity levels. The SD coupled with upper-end mean shows collective familiarity distributions were skewed positively while exhibiting divergence in individual assessments.

Correlational analysis assesses the relationship between variables, revealing if changes in one coincide with changes in the other (Field, 2018). A strong positive correlation exists when higher scores in one variable associate with higher scores in the other. Therefore, the data analysed if self-reported familiarity with hydrogen technology (variable one captured in Question 19) has a positive correlation with confidence in its viability as an energy option (variable two captured in Questions 12 and 13).

The mean familiarity score ($M = 1.89$) skewed towards higher familiarity. If those rating themselves as more familiar also expressed greater confidence in subsequent survey questions, this positive correlation would demonstrate familiarity ties to recognition of hydrogen's promise. Statistically this relationship can be measured by Pearson's R coefficient to determine correlation strength on a -1 to +1 scale (Sullivan & Artino, 2013).

Correlational analysis calculates correlation coefficients (r) determining the strength and direction of linear relationships between variables; values range from -1 to +1 (Everitt & Skrondal, 2010).

A coefficient near ± 1 indicates a very strong positive or negative correlation, while a coefficient near 0 shows little to no correlation (Field, 2018). A positive coefficient signifies an upward linear trend between variables, while a negative value marks an inverse relationship.

Multiple medium positive r values were calculated between awareness, familiarity, capacity confidence, and government support importance related to hydrogen technology integration. For example, the correlation between familiarity (Q19) and capacity confidence (Q12) was $r = +0.529$. This medium positive correlation suggests those more familiar with hydrogen and hydrogen technologies potential were more confident in its ability to displace fossil fuels at scale.

Likewise, correlation between capacity confidence (Q12) and awareness of economic benefits (Q13) was $r = +0.558$. Those perceiving higher capacity are also more conscious of affordability/growth opportunities.

Awareness of benefits (Q13) and confidence in addressing energy needs (Q22) have a correlation of 0.594. Those more conscious of potential benefits also tend to be more confident in hydrogen's ability to address overall energy requirements.

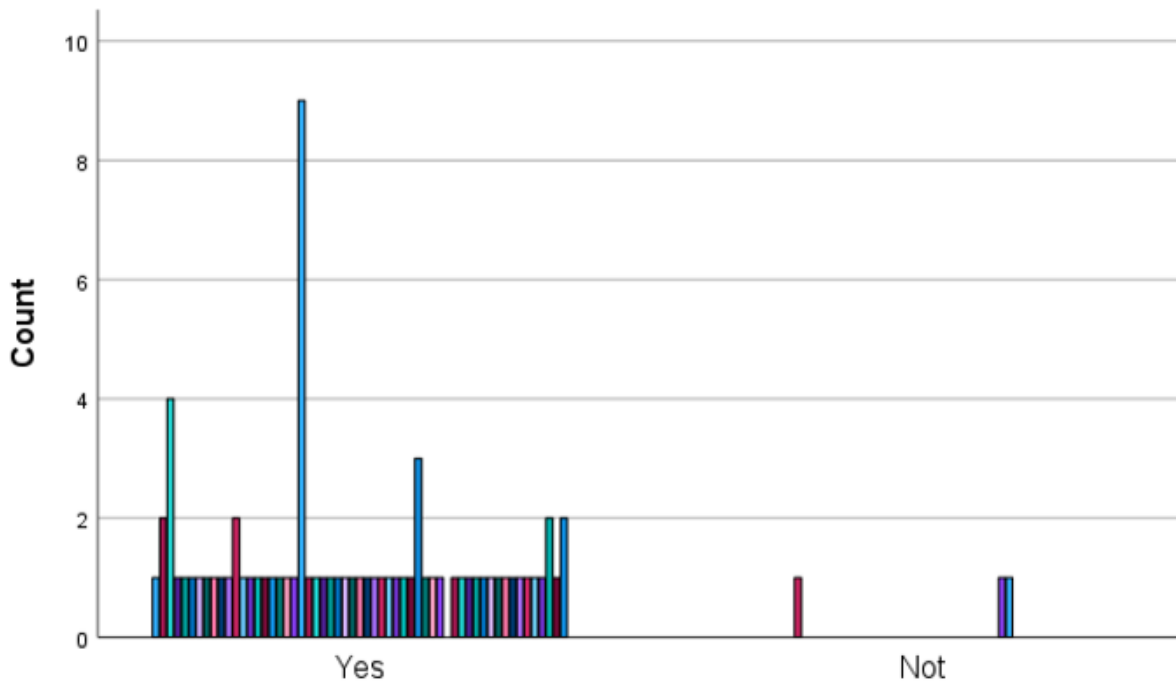


Diagram 19: Correlation between Awareness of Hydrogen Technologies and Confidence in Meeting New Zealand's Energy Needs

Familiarity (Q19) and confidence in energy needs (Q22) have a correlation of 0.541. More familiarity associates with higher confidence, though the relationship is slightly weaker.

Perceived government investment importance (Q25) and importance of active government promotion (Q24) have the highest correlation of 0.667. Those that see government financial support as more important also tend to place greater importance on active policy advocacy and engagement.

The consistent positive correlations indicate survey participants recognizing greater promise and benefits of hydrogen technology integration (across dimensions of potential, awareness and importance) tended to be more familiar with hydrogen systems.

As correlations do not imply causation (Aldrich, 1995), heightened familiarity cannot be shown to directly influence perceptions. However, the robust positive correlations suggest familiarity associates strongly with viewing hydrogen favourably across assessed dimensions.

Correlational analysis revealed significant positive correlations between familiarity with hydrogen technologies and confidence in their capacity to displace fossil fuels, awareness of their potential benefits for energy affordability and economic growth, confidence in addressing energy needs, and the perceived importance of government support in promoting hydrogen technology development. These correlations suggest that individuals who are more familiar with hydrogen technologies tend to hold more positive views regarding their potential benefits and the need for government intervention to support their development.

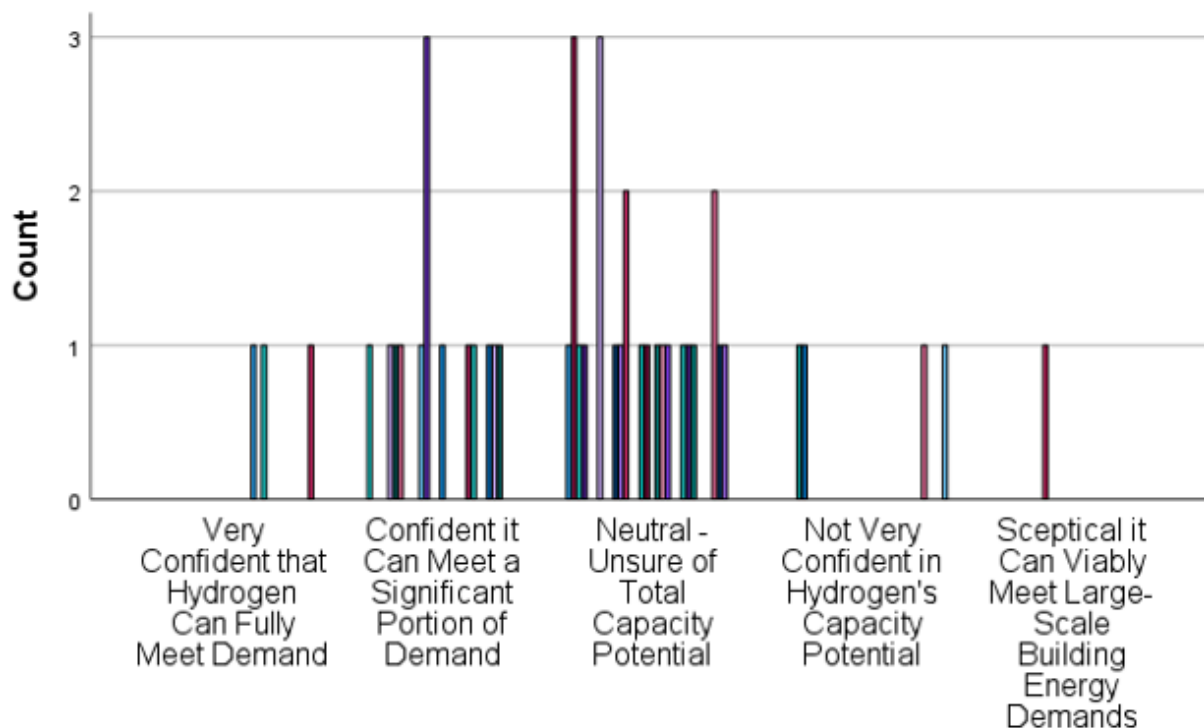


Diagram 20: Relationship between Familiarity with Advanced Hydrogen Technologies and Confidence in Addressing New Zealand's Energy Needs

Interestingly, outliers were observed among respondents holding decision-making positions such as CEOs and general managers, who expressed negativity across all responses. It is interesting to note that one of the two CEOs based in New Zealand who participated in the survey expressed negativity across all questions, while the other CEO located in Australia demonstrated positivity regarding green hydrogen potential and familiarity with hydrogen technologies. This highlights the importance of further research to understand the factors influencing their perspectives and whether they align with the broader sentiments observed in the survey.

In conclusion, while correlational relationships do not imply direct causation, the analysis underscores the positive association between familiarity with hydrogen technologies and favourable perceptions of their feasibility, potential benefits, and the importance of government support. This suggests that increasing understanding and exposure to hydrogen technologies may contribute to more positive attitudes and support for their adoption and development in New Zealand's energy landscape. Overall, these statistically significant positive correlations reinforce the finding that those ascribing greater promise and potential to hydrogen technologies across a range of dimensions tend to be more familiar with the technologies and more supportive of government investment, promotion efforts and decarbonisation of the built environment via green hydrogen technologies. While correlational relationships do not necessarily imply direct causation, the analysis indicates strong positive associations between familiarity, confidence, and perceived importance related to hydrogen systems integration. This suggests that increasing understanding and exposure is linked to more favourable perceptions of feasibility, potential benefits, and needed policy support.

7.2 Confidence Intervals

Confidence intervals (CIs) are statistical tools used to estimate the range within which a population parameter, such as a mean or proportion, is likely to fall. They provide a level of uncertainty associated with sample estimates and help in gauging the precision of the estimate. A common confidence level is 95%, indicating that if we were to repeat the sampling process multiple times, the

true parameter would fall within the calculated interval about 95% of the time (Cohen, 1988; Rothman et. al., 2008).

The data table includes 95% confidence intervals (CI) for each correlation coefficient calculated. A 95% CI provides a range of values that has a 95% probability of containing the true population correlation value. Wider CIs indicate more uncertainty around the estimate, while narrower CIs reflect more precision (Cumming & Finch, 2005).

Correlations					
Variable	Variable2	Statistic			
		Correlation	Count	Lower C.I.	Upper C.I.
13. Are you aware of hydrogen technologies and their potential benefits in addressing energy affordability and economic growth in New Zealand?	12. Transitioning to new energy models like green and low carbon hydrogen has the potential to meet building energy demands while reducing environmental impacts. How confident are you that hydrogen technologies can provide sufficient capacity to displace fossil fuels?	0.529	180	0.415	0.627
13. Are you aware of hydrogen technologies and their potential benefits in addressing energy affordability and economic growth in New Zealand?	19. Are you familiar with advanced hydrogen technologies and their potential as a new energy vector in New Zealand?	0.558	180	0.448	0.651
13. Are you aware of hydrogen technologies and their potential benefits in addressing energy affordability and economic growth in New Zealand?	22. How confident are you in the potential of advanced hydrogen technologies to address New Zealand's energy needs?	0.594	180	0.49	0.681
19. Are you familiar with advanced hydrogen technologies and their potential as a new energy vector in New Zealand?	22. How confident are you in the potential of advanced hydrogen technologies to address New Zealand's energy needs?	0.541	180	0.428	0.637
25. The government may invest in green hydrogen projects to provide communities with secure, affordable and sustainable energy. How important do you think government support and investment is for realising this vision?	24. How important is it for the government to actively promote and support the development of advanced hydrogen technologies in New Zealand?	0.667	180	0.578	0.741

Table 89: Correlation coefficients measuring the statistical relationships between several key survey variables related to perceptions of hydrogen technology's potential.

All CIs reported are reasonably narrow, suggesting these sample correlations are fairly stable estimates of true underlying correlations in the population of interest. For instance, the 95% CI for

the correlation between familiarity (Q19) and capacity confidence (Q12) ranges from 0.415 to 0.627. This conveys that we can be 95% confident the true population correlation lies between these values. The lack of CIs encompassing 0 lends greater credibility that genuine positive linear relationships exist between the variable pairs. Zero represents no correlation. If CIs spanned zero, it would mean the possibility of no actual correlation cannot be ruled out given the sample size and spread (Cumming & Finch, 2005).

The uniformly high lower bound CIs reinforce that statistically significant medium-strength positive correlations exist between the variables analysed. This aligns with the interpreted findings suggesting substantive connections between familiarity, confidence, awareness, and perceived importance related to hydrogen systems integration.

7.3 The Posterior Distribution

The Posterior Distribution, a fundamental component of Bayesian statistics, represents the updated probability distribution of parameters after considering both the observed data and prior information. In Bayesian analysis, it is derived through Bayes' theorem, incorporating prior beliefs about parameters and updating them based on observed evidence (Kruschke, 2015). The posterior distributions for the pairwise correlations between the questions provide information about the strength and direction of the relationships between different aspects of hydrogen technologies and their implementation in New Zealand built environment. The mode and mean values for each posterior distribution indicate the most likely correlation between each pair of questions, while the variance and 95% credible interval provide information about the uncertainty surrounding these estimates. Overall, the posterior distributions suggest that there are strong positive correlations between questions related to the potential benefits of hydrogen technologies and their importance for energy affordability, economic growth, and job creation. For example, a strong positive correlation is observed between questions Q13 and Q24, indicating that those who are aware of the potential benefits of hydrogen technologies are more likely to consider government support and investment as important for realizing this vision.

Similarly, strong positive correlations are observed between questions Q18 and Q22, as well as between questions Q18 and Q24, indicating that those who believe that hydrogen technologies have the potential to provide sufficient capacity to displace traditional energy sources and create job growth opportunities are also more confident in the potential of advanced hydrogen technologies to address New Zealand's energy needs and consider government support and investment as important.

- Adoption of international or specific hydrogen safety standards (Q4): The posterior distribution for Q4 reveals that the correlations with other questions are centred around zero, with relatively wide credible intervals spanning both positive and negative values. The correlation coefficients for Q4 with other questions are relatively low, suggesting that the decision to adopt international or specific safety standards is not strongly associated with factors such as public awareness, confidence in hydrogen technologies, or government support. This suggests a lack of strong evidence for or against the association between the adoption of safety standards and factors such as public awareness, confidence in hydrogen technologies, or government support. A moderate positive correlation is also observed between questions Q4 and Q6, indicating that those who believe that New Zealand should adopt international hydrogen safety standards are more likely to consider public awareness and education regarding hydrogen safety as important for the successful implementation of hydrogen technologies.
- Public awareness and education regarding hydrogen safety (Q6): The posterior distribution for Q6 shows weak to moderate positive correlations with questions related to confidence in

hydrogen technologies (Q12, Q22), awareness of benefits (Q13), and government support (Q24, Q25). The credible intervals, while including zero, have a higher density in the positive region. This aligns with the literature, which highlights the crucial role of public awareness and education in fostering acceptance and successful implementation of technologies (Huijts et al., 2012).

- Confidence in hydrogen technologies to meet energy demands (Q12): The posterior distribution for Q12 exhibits strong positive correlations with questions concerning awareness of benefits (Q13), economic opportunities and job creation (Q18), confidence in addressing energy needs (Q22), and government support (Q24, Q25). The credible intervals are entirely in the positive region, indicating robust evidence for these associations. This finding is consistent with the literature on public acceptance and willingness to support new energy technologies (Huijts et al., 2012).
- Awareness of benefits for energy affordability and economic growth (Q13): The posterior distribution for Q13 shows moderate to strong positive correlations with questions related to economic opportunities and job creation (Q18), familiarity with advanced hydrogen technologies (Q19), confidence in addressing energy needs (Q22), and government support (Q24, Q25). The credible intervals are predominantly in the positive region, suggesting strong evidence for these associations. This highlights the importance of raising awareness about the potential benefits of hydrogen technologies in fostering public acceptance and support (Huijts et al., 2012).
- Economic opportunities and job creation (Q18): The posterior distribution for Q18 exhibits moderate to strong positive correlations with questions concerning confidence in hydrogen technologies (Q12, Q22), awareness of benefits (Q13), and government support (Q24, Q25). The credible intervals are entirely in the positive region, providing robust evidence for these associations.
- Familiarity with advanced hydrogen technologies (Q19): The posterior distribution for Q19 shows moderate positive correlations with questions related to confidence in addressing energy needs (Q22) and government support (Q24). While the credible intervals include zero, they have a higher density in the positive region, suggesting some evidence for these associations. This is consistent with the literature, which suggests that increased familiarity with advanced hydrogen technologies may contribute to greater confidence in their potential and support for their development (Huijts et al., 2012).
- Confidence in addressing energy needs with hydrogen technologies (Q22): Q22 exhibits strong positive correlations with questions concerning confidence in hydrogen technologies (Q12), awareness of benefits (Q13), economic opportunities and job creation (Q18), and government support (Q24, Q25). This reinforces the interconnected nature of these factors in shaping public confidence and support for hydrogen technologies, as discussed in the literature (Huijts et al., 2012).
- Importance of government promotion and support (Q24): Q24 shows strong positive correlations with questions related to confidence in hydrogen technologies (Q12), awareness of benefits (Q13), economic opportunities and job creation (Q18), and confidence in addressing energy needs (Q22). This highlights the crucial role of government support and promotion in fostering public acceptance and successful implementation of hydrogen technologies, as emphasized in the literature.
- Importance of government investment in green hydrogen projects (Q25): Q25 exhibits moderate to strong positive correlations with questions concerning confidence in hydrogen technologies (Q12), awareness of benefits (Q13), economic opportunities and job creation (Q18), and confidence in addressing energy needs (Q22).

In summary, the data analysis reveals interconnections among public awareness, confidence in hydrogen technologies, perceived benefits, economic opportunities, and government support. These findings align with the existing literature on the successful implementation of new energy technologies, highlighting the importance of a holistic approach encompassing public education, regulatory frameworks, economic incentives, and government support. The data provided shows the posterior distributions for the pairwise correlations between several questions related to hydrogen technologies and their implementation in New Zealand. These posterior distributions provide information about the strength and direction of the relationships between different aspects of hydrogen technologies, such as safety standards, public awareness and education, capacity to displace traditional energy sources, potential benefits, and government support.

7.4 Bayes Factor Inference on Pearson Correlations

Bayes Factors quantify the evidence provided by data in favour of one hypothesis over another within Bayesian hypothesis testing. They involve comparing the likelihood of the observed data under different hypotheses, providing a means to assess the strength of evidence for or against a particular hypothesis (Dienes, 2014).

The Pearson Correlation Coefficient measures the strength and direction of a linear relationship between two variables. It ranges from -1 to 1, where -1 indicates a perfect negative linear relationship, 1 denotes a perfect positive linear relationship, and 0 implies no linear relationship. Its calculation involves the covariance of the variables divided by the product of their standard deviations (Hauke & Kossowski, 2011).

The Pearson correlation coefficients provide information about the strength and direction of the relationships between different aspects of hydrogen technologies, while the Bayes factors provide information about the relative evidence for the null hypothesis (no correlation) versus the alternative hypothesis (non-zero correlation).

The Bayes Factor (BF) provides an indication of the evidence for one hypothesis over another based on the data. In this case, it assesses the evidence for a non-zero correlation versus no correlation (the null hypothesis). The Bayes factor is calculated as the ratio of the probabilities of the data under the two competing hypotheses:

$$BF = P(\text{Data} | H1) / P(\text{Data} | H0)$$

Where H1 is the alternative hypothesis of a non-zero correlation, and H0 is the null hypothesis of no correlation. A larger Bayes factor indicates greater evidence in favour of H1 over H0.

Bayes factors between 1-3 are considered weak or anecdotal evidence, 3-10 moderate evidence, 10-30 strong evidence, and >100 very strong evidence for the alternative hypothesis (Jeffreys, 1961; Lee & Wagenmakers, 2013). The Bayes factors quantify the relative evidence from the data for or against correlations between the various aspects of hydrogen technology perspectives. Used alongside effect sizes like Pearson coefficients, they provide a more comprehensive basis for statistical inference (Wagenmakers et al., 2018).

The Pearson correlation coefficient (r) measures the strength and direction of the linear relationship between two continuous variables. It ranges from -1 to 1.

- Values close to 1 indicate a strong positive correlation
- Values close to -1 indicate a strong negative correlation
- Values near 0 indicate little to no correlation

Some key Pearson correlations in the survey data include:

- $r = 0.529$ between Q12 and Q13, indicating a moderately strong positive correlation between confidence in hydrogen's potential and awareness of benefits.
- $r = 0.541$ between Q19 and Q22, indicating a strong positive correlation between familiarity with hydrogen technologies and confidence in their potential to address energy needs.
- $r = 0.108$ between Q18 and Q22, indicating a weak correlation between perceptions of economic impact and confidence in hydrogen's potential.

Guidelines for interpreting the strength of Pearson coefficients (Evans, 1996):

- .00-.19 “very weak”
- .20-.39 “weak”
- .40-.59 “moderate”
- .60-.79 “strong”
- .80-1.0 “very strong”

The Pearson coefficients quantify the strength and direction of the linear relationships between the survey variables, providing an intuitive metric to complement the Bayesian inference. Used together, they provide a robust statistical analysis.

- Based on the Pearson correlation coefficients, there are several moderate to strong correlations between different aspects of hydrogen technologies and their implementation in New Zealand. For example, the Pearson correlation coefficient between questions Q12 and Q13 is 0.529, indicating a moderate positive correlation between confidence in the potential of hydrogen technologies to provide sufficient capacity to displace traditional energy sources and awareness of hydrogen technologies and their potential benefits.
- Similarly, the Pearson correlation coefficient between questions Q13 and Q18 is 0.341, indicating a moderate positive correlation between awareness of hydrogen technologies and their potential benefits and the potential impact of hydrogen sector job creation and growth opportunities for the NZ economy.
- The Pearson correlation coefficient between questions Q18 and Q19 is also 0.255, indicating a moderate positive correlation between the potential impact of hydrogen sector job creation and growth opportunities for the NZ economy and familiarity with advanced hydrogen technologies and their potential as a new energy vector in New Zealand.
- The Pearson correlation coefficient between questions Q19 and Q22 is 0.541, indicating a strong positive correlation between familiarity with advanced hydrogen technologies and their potential as a new energy vector in New Zealand and confidence in their potential to address New Zealand's energy needs.
- The Pearson correlation coefficient between questions Q22 and Q24 is 0.538, indicating a strong positive correlation between confidence in the potential of advanced hydrogen technologies to address New Zealand's energy needs and the importance of government support and investment in their development.

One notable finding from the data is the positive correlation between familiarity with advanced hydrogen technologies and confidence in their potential to address New Zealand's energy needs (Pearson Correlation coefficient = 0.541, Bayes Factor = 0.003). This suggests that as people become more familiar with advanced hydrogen technologies, they tend to have greater confidence in their ability to address New Zealand's energy needs.

The study's findings are further elucidated through a series of diagrams and bar charts, which illustrate the interplay between participants' familiarity with green hydrogen technologies and their confidence in the potential of these technologies to meet energy demands within the built environment.

The first set of visuals depicts a positive correlation between participants who reported being “very familiar” with the technology and their expressed levels of confidence. Specifically, those who indicated a high degree of familiarity exhibited a correspondingly high level of confidence, with a significant proportion expressing that they were “very confident” or “somewhat confident” in the technology’s ability to meet energy demands. This observation aligns with the notion that an in-depth understanding of a technology’s intricacies and applications can foster a greater sense of confidence in its potential and viability.

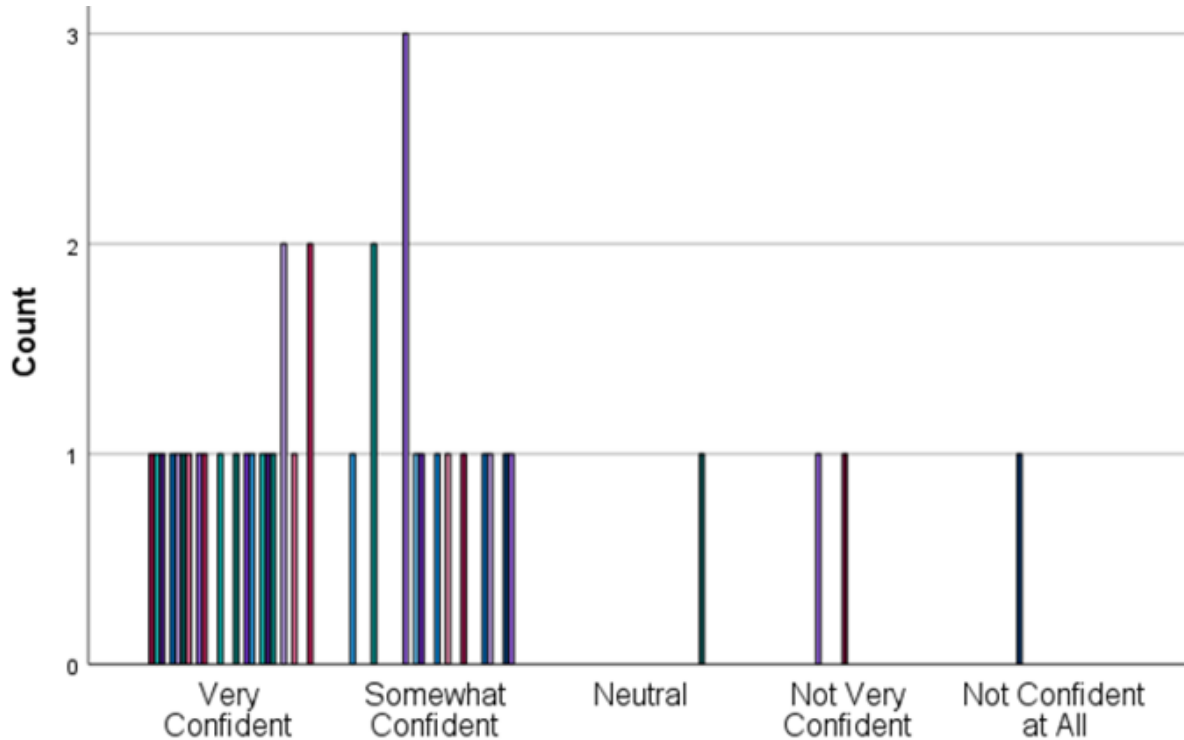
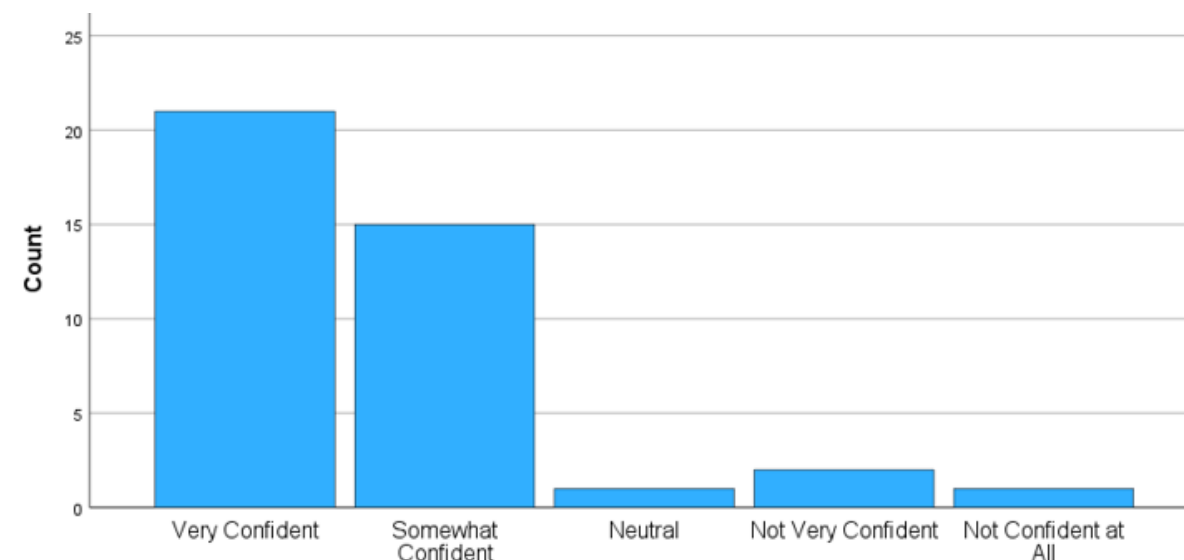


Diagram 21: Familiarity vs. Confidence in Meeting Energy Demand (Very Familiar)



Bar Chart 9: Distribution of Confidence Levels Among Very Familiar Participants

In contrast, the second set of visuals illustrates a more varied distribution of confidence levels among participants who reported being “somewhat familiar” with green hydrogen technologies. While a notable contingent expressed “somewhat confident” or “neutral” sentiments, there was a discernible presence of individuals who remained “not very confident” or “not confident at all”. This finding suggests that a partial understanding or familiarity with the technology may not be sufficient to instil

unwavering confidence in its capabilities, potentially highlighting the need for more comprehensive knowledge dissemination and awareness-raising efforts.

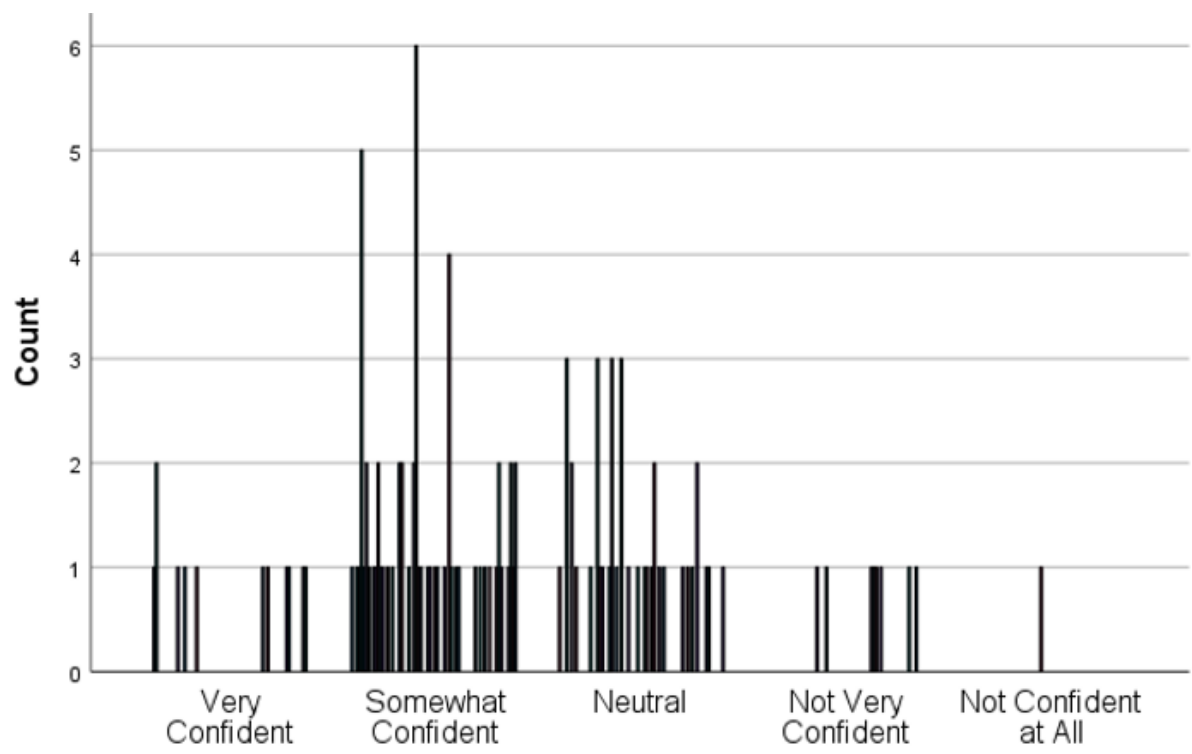
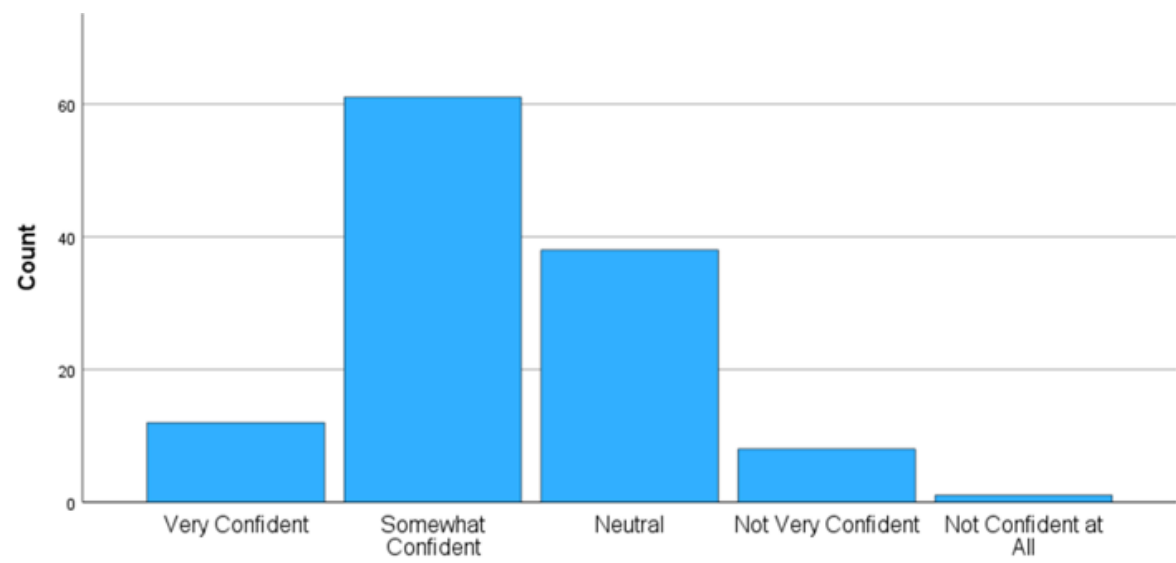


Diagram 22: Familiarity vs. Confidence in Meeting Energy Demand (Somewhat Familiar)



Bar Chart 10: Distribution of Confidence Levels Among Somewhat Familiar Participants

The third set of visuals presents a concerning trend, wherein participants who self-reported as “not very familiar” with green hydrogen technologies exhibited a marked lack of confidence in the technology’s potential to meet energy demands. A significant proportion of this cohort expressed sentiments ranging from “not confident at all” to “neutral”, with only a marginal presence of those expressing any degree of confidence. This observation underscores the critical importance of addressing knowledge gaps and fostering a deeper understanding of the technology among

stakeholders, as a lack of familiarity appears to breed scepticism and uncertainty.

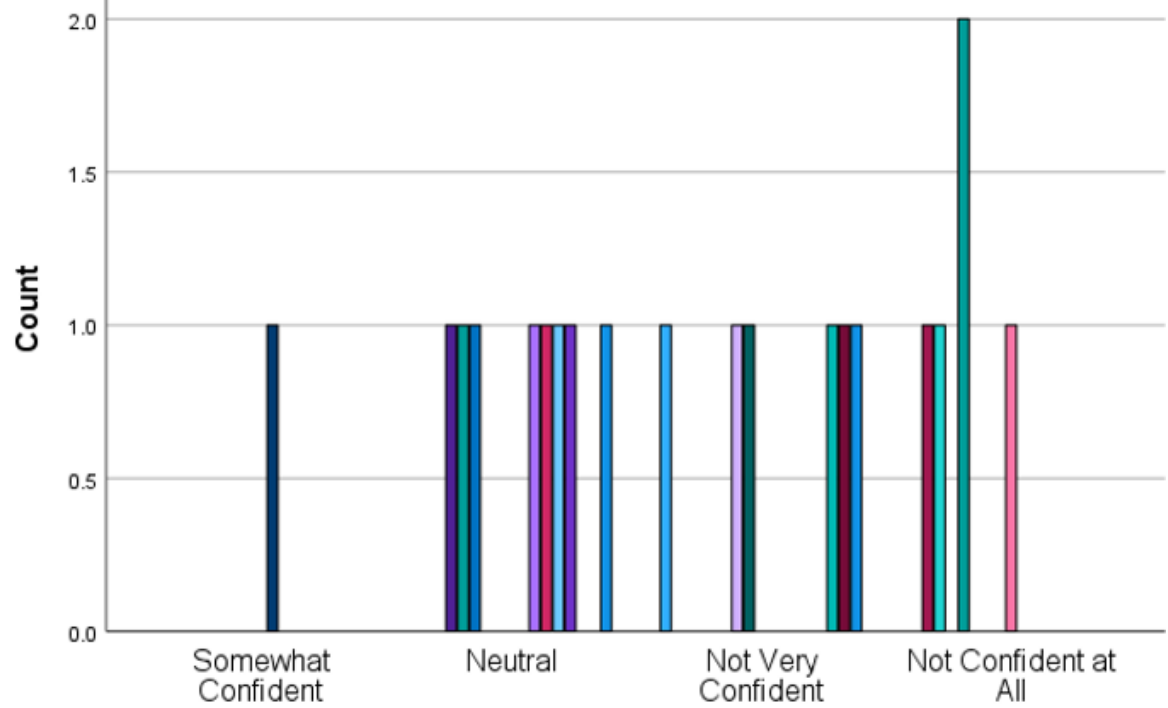
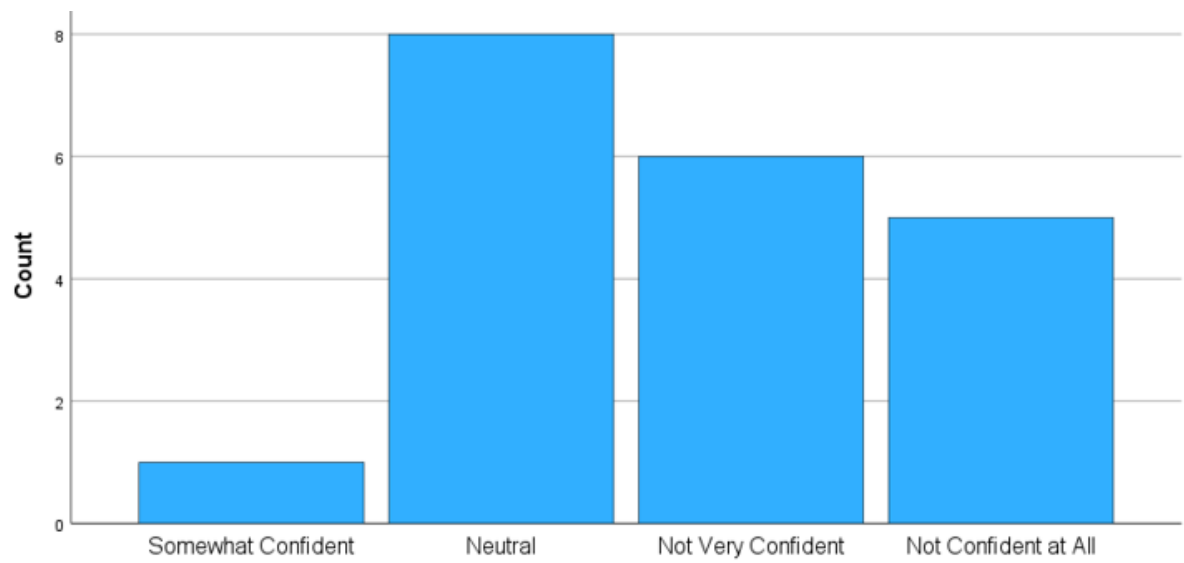


Diagram 23: Familiarity vs. Confidence in Meeting Energy Demand (Not Very Familiar)



Bar Chart 11: Distribution of Confidence Levels Among Not Very Familiar Participants

These visual representations offer valuable insights into the intricate relationship between familiarity and confidence, illuminating the potential challenges and opportunities that may arise in the pursuit of widespread adoption of green hydrogen technologies in the built environment. While a high degree of familiarity appears to cultivate confidence, a lack of familiarity can breed doubt and resistance, highlighting the need for targeted educational and awareness-raising initiatives.

The study revealed the presence of outliers who expressed significant scepticism and resistance towards the implementation of green hydrogen technologies within the built environment. These individuals, holding influential positions as chief executive officers, policymakers, and general managers, represent key stakeholders whose perspectives and decision-making capabilities have the potential to impede or accelerate the adoption of such decarbonization strategies.

This finding underscores the critical need for further investigation and a nuanced understanding of the concerns and rationales underpinning their opposition. Future research endeavours should prioritize exploring the root causes of their reservations, which may emanate from a myriad of factors, including perceived risks, economic considerations, regulatory challenges, or a lack of familiarity with the intricacies of the technology. By gaining insights into the drivers of their opposition, subsequent studies can develop targeted strategies to address these concerns and facilitate a more constructive dialogue, ultimately mitigating potential barriers to adoption.

Conversely, the research findings also indicated that participants who possessed a higher degree of familiarity with green hydrogen technologies expressed a greater level of confidence in their potential to meet the energy demands within the built environment. This observation underscores the pivotal role of education, awareness, and knowledge dissemination in overcoming barriers to the adoption of such technologies. Future research efforts should focus on developing effective communication and engagement strategies to bridge the knowledge gap and foster a better understanding of the benefits, feasibility, and practical applications of green hydrogen technologies among decision-makers and key stakeholders.

Additionally, future studies should delve into the specific concerns raised by the identified outliers, such as potential risks, economic viability, regulatory hurdles, or technical challenges. By addressing these concerns through rigorous research and data-driven analysis, valuable insights can be generated to inform decision-making processes and facilitate the development of policies and frameworks that support the adoption of green hydrogen technologies in the built environment.

Furthermore, comparative case studies or pilot projects that demonstrate the successful implementation of green hydrogen technologies in real-world scenarios could prove instrumental in building credibility and showcasing the practical viability of these solutions. Such initiatives could potentially alleviate concerns and scepticism among resistant stakeholders by providing tangible evidence of the technology's effectiveness and feasibility, thereby fostering a more conducive environment for adoption.

Ultimately, a multidisciplinary approach involving collaboration between researchers, industry professionals, policymakers, and other relevant stakeholders is imperative to address the challenges posed by outliers and promote the widespread adoption of green hydrogen technologies in the built environment. By fostering open dialogue, addressing concerns, and leveraging empirical evidence, future research endeavours can play a pivotal role in overcoming barriers and facilitating the transition towards a more sustainable and decarbonized built environment.

In conclusion, the positive correlations suggest that those who believe that hydrogen technologies have the potential to provide sufficient capacity to displace traditional energy sources, are aware of their potential benefits, and are familiar with advanced hydrogen technologies and their potential as a new energy vector in New Zealand, are also more confident in their potential to address New Zealand's energy needs. Furthermore, the positive correlations between familiarity with advanced hydrogen technologies and their potential, and the importance of government support and investment in their development, suggest that those who believe that the government should actively promote and support the development of advanced hydrogen technologies in New Zealand are also more confident in their potential.

7.5 One-Sample Test

A one-sample test is a statistical method used to determine if the mean of a single sample is significantly different from a known or hypothesized population mean. This test is particularly useful

when dealing with a single group or sample, and the objective is to assess whether the sample mean deviates from a specified population parameter (Gosset, 1908).

Cohen's d is a measure of effect size used in statistical analysis to quantify the difference between two groups. It is particularly employed in the context of comparing means and expresses the size of the difference in standard deviation units. A larger Cohen's d indicates a more substantial effect (Cohen, 1988).

Hedges' correction is a modification of Cohen's d and is employed to account for potential biases, especially in small sample sizes. The correction involves adjusting the estimated effect size to provide a more accurate reflection of the population effect size. Hedges' correction helps mitigate the impact of small sample bias and provides a more reliable estimation of the true effect size (Hedges, 1981).

One-Sample Effect Sizes					
		Standard Deviation	Point Estimate	95% Confidence Interval	
				Lower	Upper
4. Should New Zealand adopt international hydrogen safety standards or develop its own specific standards?	Cohen's d	0.962	2.362	2.076	2.646
	Hedges' correction	0.966	2.352	2.067	2.635
6. How important do you think public awareness and education regarding hydrogen safety are in the successful implementation of hydrogen technologies in New Zealand?	Cohen's d	0.839	2.132	1.867	2.396
	Hedges' correction	0.842	2.123	1.859	2.386
12. Transitioning to new energy models like green and low carbon hydrogen has the potential to meet building energy demands while reducing environmental impacts. How confident are you that hydrogen technologies can provide sufficient capacity to displace	Cohen's d	1.005	2.515	2.215	2.812
	Hedges' correction	1.009	2.504	2.206	2.8
13. Are you aware of hydrogen technologies and their potential benefits in addressing energy affordability and economic growth in New Zealand?	Cohen's d	0.409	2.959	2.619	3.298
	Hedges' correction	0.411	2.947	2.608	3.284
18. Development of a robust regulatory framework with a risk-based approach for hydrogen could enable new economic opportunities and jobs growth. In your view, how impactful would hydrogen	Cohen's d	0.901	2.295	2.015	2.572
	Hedges' correction	0.904	2.285	2.006	2.562

sector job creation and growth opportunities be for the NZ economy					
19. Are you familiar with advanced hydrogen technologies and their potential as a new energy vector in New Zealand?	Cohen's d	0.568	3.325	2.95	3.698
	Hedges' correction	0.571	3.311	2.938	3.682
22. How confident are you in the potential of advanced hydrogen technologies to address New Zealand's energy needs?	Cohen's d	1.009	2.352	2.067	2.635
	Hedges' correction	1.013	2.342	2.059	2.624
24. How important is it for the government to actively promote and support the development of advanced hydrogen technologies in New Zealand?	Cohen's d	1.03	1.941	1.692	2.189
	Hedges' correction	1.035	1.933	1.685	2.179
25. The government may invest in green hydrogen projects to provide communities with secure, affordable and sustainable energy. How important do you think government support and investment is for realising this vision?	Cohen's d	1.056	1.936	1.687	2.183
	Hedges' correction	1.061	1.928	1.68	2.174
a The denominator used in estimating the effect sizes.					
Cohen's d uses the sample standard deviation.					
Hedges' correction uses the sample standard deviation, plus a correction factor.					

Table 90: One-Sample Effect Sizes Comparison Table

The provided data presents the one-sample effect sizes (Cohen's d and Hedges' correction) and associated 95% confidence intervals for several survey questions related to hydrogen technologies in New Zealand. Effect sizes are measures of the practical significance or magnitude of an observed effect, independent of sample size (Sullivan & Feinn, 2012).

- Adoption of International or Specific Hydrogen Safety Standards (Q4): The effect size (Cohen's d = 0.962, Hedges' correction = 0.966) and the associated confidence intervals suggest a large and statistically significant positive effect. This indicates that the respondents tend to favour the adoption of international hydrogen safety standards over developing specific standards for New Zealand.
- Importance of Public Awareness and Education (Q6): The effect size (Cohen's d = 0.839, Hedges' correction = 0.842) and the confidence intervals indicate a large and statistically significant positive effect. This suggests that respondents perceive public awareness and education as highly important for the successful implementation of hydrogen technologies in New Zealand.

- Confidence in Hydrogen Technologies for Meeting Energy Demands (Q12): The effect size (Cohen's $d = 1.005$, Hedges' correction = 1.009) and the confidence intervals suggest a large and statistically significant positive effect. This implies that respondents are generally confident in the potential of hydrogen technologies to provide sufficient capacity to meet building energy demands while reducing environmental impacts.
- Awareness of Benefits for Energy Affordability and Economic Growth (Q13): The effect size (Cohen's $d = 0.409$, Hedges' correction = 0.411) and the associated confidence intervals indicate a small to moderate positive effect. This suggests that respondents have a moderate level of awareness regarding the potential benefits of hydrogen technologies in addressing energy affordability and economic growth in New Zealand.
- Impact of Hydrogen Sector Job Creation and Growth Opportunities (Q18): The effect size (Cohen's $d = 0.901$, Hedges' correction = 0.904) and the confidence intervals indicate a large positive effect. This suggests that respondents perceive the development of a robust regulatory framework for hydrogen as having a significant impact on enabling new economic opportunities and job creation in the hydrogen sector, which could benefit the New Zealand economy.
- Familiarity with Advanced Hydrogen Technologies (Q19): The effect size (Cohen's $d = 0.568$, Hedges' correction = 0.571) and the confidence intervals suggest a moderate positive effect. This implies that respondents have a moderate level of familiarity with advanced hydrogen technologies and their potential as a new energy vector in New Zealand.
- Confidence in Advanced Hydrogen Technologies for Addressing Energy Needs (Q22): The effect size (Cohen's $d = 1.009$, Hedges' correction = 1.013) and the confidence intervals indicate a large and statistically significant positive effect. This suggests that respondents are generally confident in the potential of advanced hydrogen technologies to address New Zealand's energy needs.
- Importance of Government Promotion and Support (Q24): The effect size (Cohen's $d = 1.03$, Hedges' correction = 1.035) and the confidence intervals suggest a large and statistically significant positive effect. This implies that respondents perceive government promotion and support for the development of advanced hydrogen technologies as highly important in New Zealand.
- Importance of Government Investment in Green Hydrogen Projects (Q25): The effect size (Cohen's $d = 1.056$, Hedges' correction = 1.061) and the confidence intervals indicate a large and statistically significant positive effect. This suggests that respondents perceive government support and investment in green hydrogen projects as highly important for realizing the vision of secure, affordable, and sustainable energy for communities in New Zealand.

It is important to note that the effect sizes and confidence intervals provide an estimate of the practical significance or magnitude of the observed effects, but do not directly address the statistical significance or the probability of observing such effects by chance (Sullivan & Feinn, 2012). Additionally, the interpretation of effect sizes should be done in conjunction with other statistical analyses and within the context of the research question and theoretical framework (Baguley, 2009).

In summary, the analysis of effect sizes reveals that respondents generally have positive perceptions and attitudes towards the adoption of hydrogen technologies in New Zealand, with varying levels of confidence, awareness, and perceived importance regarding different aspects such as safety standards, public education, economic opportunities, and government support. These findings align with the literature on the potential benefits and challenges associated with the implementation of emerging energy technologies (Staffell et al., 2019).

7.6 Discussion

The data suggests that there is a strong interest in the use of hydrogen technologies in New Zealand, particularly in the areas of decarbonization and economic growth. Respondents generally agreed that safety requirements such as ventilation and leak detection systems, storage and handling guidelines, comprehensive fire safety and emergency response measures, and personnel training and certification are crucial for the introduction of hydrogen technologies in New Zealand built environment. They also identified the need for clear regulatory frameworks and standards to ensure safe adoption of hydrogen technologies.

The majority of respondents also believed that organizations such as the Ministry of Business, Innovation and Employment (MBIE), Energy Safety, WorkSafe New Zealand, the Environmental Protection Authority (EPA), and Standards New Zealand should play a significant role in setting and enforcing hydrogen safety standards. In terms of safety, respondents emphasized the importance of adequate ventilation and leak detection systems, proper hydrogen storage and handling guidelines, comprehensive fire safety and emergency response measures, strict training and certification requirements for personnel, and adherence to international safety standards. They also identified the need for clear regulatory frameworks and standards to ensure safe adoption of hydrogen technologies.

In terms of specific design requirements, respondents generally agreed that secure hydrogen storage facilities, automated hydrogen leak and shutdown valves, and adequate ventilation and exhaust systems are important for safe installation of hydrogen systems in residential and commercial buildings. Respondents also indicated that hydrogen technologies can contribute to the decarbonizing of the built environment through the use of hydrogen as a clean energy source for heating buildings, hydrogen-powered fuel cells for electricity in buildings, hydrogen-based combined heat and power systems, and hydrogen as an energy storage solution for renewable energy. The majority of respondents also agreed that the most impactful aspect of using hydrogen technologies in decarbonizing the built environment is reducing carbon emissions.

When it comes to measuring the impact of hydrogen technologies on decarbonization, respondents generally agreed that reduction in carbon emissions (measured in CO₂ equivalents), increased renewable energy utilization ratio, and reduction in natural gas/fossil fuel consumption are effective metrics. However, some respondents also pointed out challenges in measuring the impact of hydrogen technologies due to lack of standardized measurement metrics, difficulty in data collection and analysis, variability in regional infrastructure and energy mix, and technological advancements outpacing measurement approaches.

Regarding the contribution of hydrogen technologies to the decarbonizing of the built environment, respondents agreed that hydrogen can be used as a clean energy source for heating buildings instead of natural gas, hydrogen-powered fuel cells for electricity in buildings, hydrogen-based combined heat and power systems, and hydrogen as an energy storage solution for renewable energy.

Regarding factors that hinder public acceptance of hydrogen technologies, respondents generally indicated that lack of awareness and education, perception about high costs, safety concerns and lack of information, and uncertainty about hydrogen's effectiveness and reliability are significant challenges. To increase public awareness about hydrogen technologies, respondents generally recommended public education campaigns and workshops, showcasing successful case studies and demonstrations, involvement of schools and educational institutions, media campaigns and informational advertisements, and engaging hydrogen industry experts for public talks.

In terms of the role of the government in accelerating the acceptance of hydrogen technologies, respondents generally recommended providing financial incentives for hydrogen adoption,

establishing clear regulatory frameworks and standards, funding research and development in hydrogen technologies, and collaborating with industry to promote hydrogen use. Respondents also perceived the main benefits of investing in advanced hydrogen technologies as reducing carbon emissions and environmental impact, potential for energy independence and security, economic growth and job creation in the hydrogen sector, facilitating transition to renewable energy sources, and enhancing energy storage and grid stability.

In terms of adoption, respondents identified several factors that could increase their confidence in the safe use of hydrogen technologies, including comprehensive safety regulations and building codes, rigorous personnel training requirements, public awareness campaigns about hydrogen risks, government oversight and industry standards enforcement, and independent safety testing and certification regimes.

Based on the data analysis, it is evident that there exists a strong positive correlation between the recognition of potential benefits associated with hydrogen technologies and the perceived importance of factors such as energy affordability, economic growth, and job creation. This observation underscores the notion that a comprehensive understanding and appreciation of the multifaceted advantages offered by these technologies can foster a more favourable outlook towards their adoption and implementation.

However, it is noteworthy that the study also identified a cohort of key decision-makers, such as chief executive officers, policymakers, and general managers, who exhibited lower levels of confidence and familiarity with hydrogen technologies. This finding presents a significant challenge, as these influential stakeholders possess the decision-making authority and power to either catalyse or impede the widespread adoption of these technologies within the built environment.

To address this critical juncture, a multifaceted approach is imperative, encompassing both strategic and analytical considerations. Firstly, it is crucial to recognize that the lack of confidence and familiarity among key decision-makers may stem from a myriad of factors, including perceived risks, economic considerations, regulatory uncertainties, or a lack of exposure to the technological intricacies and practical applications of hydrogen solutions.

Consequently, future research endeavours should prioritize the development of targeted awareness and education campaigns tailored specifically for these decision-makers. These initiatives should aim to bridge the knowledge gap by providing comprehensive insights into the technological advancements, economic viability, and regulatory frameworks surrounding hydrogen technologies. By fostering a deeper understanding of the potential benefits and addressing potential concerns, these efforts can play a pivotal role in cultivating confidence and support among key stakeholders.

Furthermore, it is imperative to leverage the findings of this study to establish a strategic dialogue between researchers, industry experts, and decision-makers. Through this collaborative approach, concerns and reservations can be addressed in a transparent and constructive manner, allowing for the exchange of knowledge, insights, and perspectives from various stakeholders. By fostering an environment of open communication and mutual understanding, potential barriers to adoption can be identified and addressed proactively, paving the way for informed decision-making and policy formulation.

Additionally, the implementation of pilot projects or case studies demonstrating the successful integration of hydrogen technologies within the built environment could prove invaluable. These real-world examples can serve as tangible evidence of the technology's viability, effectiveness, and economic feasibility, potentially alleviating concerns and scepticism among decision-makers. By showcasing the practical applications and measurable outcomes of these technologies, these initiatives can contribute to building confidence and garnering support from key stakeholders.

Ultimately, the path towards widespread adoption of hydrogen technologies in the built environment necessitates a collaborative and multidisciplinary approach, encompassing strategic awareness campaigns, open dialogue, and the dissemination of empirical evidence. By addressing the concerns and fostering a deeper understanding among key decision-makers, future research can play a pivotal role in bridging the gap between the recognition of potential benefits and the implementation of these technologies, ultimately driving the transition towards a more sustainable and decarbonized built environment.

Overall, the data suggests that there is a strong interest in the use of hydrogen technologies in New Zealand, particularly in the areas of decarbonization and economic growth. However, there are also significant challenges to overcome, including lack of awareness and education, perception about high costs, safety concerns and lack of information, and uncertainty about hydrogen's effectiveness and reliability. The government has a key role to play in accelerating the acceptance of hydrogen technologies through providing financial incentives, establishing clear regulatory frameworks and standards, funding research and development, and collaborating with industry. The adoption of hydrogen technologies in New Zealand has the potential to contribute to the decarbonizing of the built environment and support the transition to a low-carbon economy. However, ensuring the safe adoption and effective integration of these technologies will require a coordinated effort from government, industry, and the public to address safety, design, regulation, and public acceptance concerns.

Chapter 8 - Synthesis of Findings

This chapter provides a comprehensive synthesis of the key findings from the research, structured around the four primary research objectives. It systematically addresses how the global review of hydrogen projects, analysis of techno-economic performance, framework development for New Zealand, and policy recommendations for government have been validated through expert interviews, surveys, and literature reviews.

The chapter is divided into four main sections, each aligned with a specific research objective:

Section 1 - Safety Requirements: This section synthesizes findings related to Objective 1, which aimed to conduct a global review of hydrogen projects to identify safety standards, challenges, and opportunities. It discusses safety protocols, codes, and regulations derived from state-of-the-art hydrogen projects, validated through expert interviews and surveys, to build public acceptance of hydrogen technologies.

Section 2 - Decarbonisation Potential: Aligned with Objective 2, this section analyses the decarbonization potential of hydrogen technologies in the built environment. It reviews the techno-economic performance of hydrogen systems and their capacity to displace fossil fuels, presenting data-driven insights on how hydrogen can maximize energy outcomes and provide measurable economic benefits.

Section 3 - Public Awareness and Education: This section relates to Objective 3 and focuses on public awareness and education. It explores the social and environmental dimensions of introducing hydrogen technologies, emphasizing the need for public engagement and education to ensure alignment with New Zealand's security objectives and public well-being.

Section 4 - Government Investment: The final section, connected to Objective 4, outlines recommendations for government investment and policy formulation. It details the safety regulations, codes, and standards necessary to establish a regulatory framework for hydrogen technologies, supporting their secure integration and long-term viability in New Zealand's energy landscape.

Each section integrates qualitative insights from expert interviews and surveys, supplemented by the literature review, to validate the research hypotheses and objectives. The findings offer a holistic understanding of hydrogen's role in New Zealand's future energy systems and provide clear recommendations for safe, sustainable implementation. The chapter concludes with additional insights gained from participant feedback, further refining the practical implications of the research.

8.1 Section 1 – Safety Requirements

The survey findings provide valuable insights into the critical safety requirements, standards, and regulations necessary for the successful introduction of hydrogen technologies in New Zealand. The data highlights the multifaceted nature of the challenge, underscoring the need for a comprehensive and nuanced approach to address safety concerns across various stakeholder domains.

In this section, critical themes related to hydrogen safety requirements for the built environment are examined based on insights provided by participants. These insights highlight key considerations such as standards and regulations, zoning and classification, clear indication and marking, fire suppression and safety measures, public acceptance and education, compliance and training, global safe use history, pilot programs and demonstrations, as well as regulatory alignment and cost-effective processes. Each of these themes will be explored in detail to provide a comprehensive

understanding of the factors influencing the safe implementation of hydrogen technologies in New Zealand.

- **Standards and Regulations:** Participants highlighted the necessity of aligning with international safety standards, such as those seen in the adoption of LPG standards (NZS 5435:2012). The call for the adoption of existing standards, including AS/NZS IEC 60079 series for Ex II C equipment, demonstrates a consensus on leveraging established frameworks to ensure safety. Robust governance frameworks, including comprehensive regulations, codes, standards aligned with global best practice were consistently emphasized. 76.1% highlighted regulations and building codes as crucial for confidence.
- **Zoning and Classification:** The importance of zoning and classification based on hydrogen release risks, akin to the ATEX European regulation, was underscored. This reflects a meticulous approach towards delineating safe zones and implementing design measures in accordance with recognized risk categories.
- **Clear Indication and Marking:** Clear marking and signage on hydrogen equipment were advocated as essential for identification. This emphasis aligns with the broader safety narrative, promoting visual cues to enhance situational awareness and mitigate potential risks.
- **Fire Suppression and Safety Measures:** Recommendations for fire suppression systems compatible with hydrogen, placement criteria, and adherence to the Ex II C classification illuminate a thorough consideration of safety measures. These proposals aim to mitigate fire risks and enhance overall system safety. Prudent system design and installation provisions, especially for leak prevention, ventilation, certified components, and emergency shutdowns. These areas were prioritized in selecting essential design requirements.
- **Public Acceptance and Education:** Public acceptance and understanding were deemed crucial, with suggestions to democratize the positive environmental impact of hydrogen technologies. This reflects an awareness of the importance of public perception and the role of education in fostering confidence. Public education and awareness campaigns to foster understanding of hydrogen risks and benefits. 62.2% selected this factor for building confidence and open-ended comments reinforced its importance.
- **Compliance and Training:** Addressing compliance issues, particularly in the context of New Zealand's cultural nuances around industry regulations, emerged as a significant concern. The emphasis on training for installers, technicians, and building managers highlights a recognition of the human element in ensuring safety. Stringent training, competency requirements and personnel certification for those working with hydrogen. 71.1% identified this in multiple choice questions, and it was reiterated in open-ended responses. Official oversight and qualified independent validation through government regulators, standards bodies, and third-party testing/certification to oversee industry and confirm safety.
- **Global Safe Use History:** Drawing confidence from the safe use history of hydrogen technologies in other parts of the world underscores a comparative approach, leveraging global experiences to inform New Zealand's safety framework.
- **Pilot Programs and Demonstrations:** Suggestions for piloting or applied technology demonstrations within New Zealand serve as a pragmatic approach to showcase the real-world safety and feasibility of hydrogen technologies, potentially contributing to public and stakeholder confidence. Learning from successful international cases while ensuring local nuance. Global knowledge exchange along with NZ-specific demonstration emerged as advisable.
- **Regulatory Alignment and Cost-Effective Processes:** The call for alignment with Australian standards in the development of regulations and the emphasis on cost-effective compliance processes indicates a pragmatic and collaborative approach, recognizing the importance of international alignment and economic feasibility.

In conclusion, the survey findings provide a comprehensive understanding of the critical safety requirements, standards, and regulations that must be addressed for the successful introduction of hydrogen technologies in New Zealand. The data highlights the importance of a multifaceted approach, encompassing robust governance frameworks, meticulous zoning and classification, visual identification, fire suppression measures, public education, compliance considerations, global benchmarks, and pragmatic pilot initiatives. This synthesis of insights coalesces into a solid foundation for developing safety standards and regulations conducive to the responsible and sustainable integration of hydrogen technologies across diverse stakeholder domains in New Zealand.

8.2 Question 1 - Data Validation Experts' Interviews and Survey

- Both the survey and expert interviews emphasized the importance of proper ventilation and leak detection systems to monitor and control potential hydrogen leaks and accumulation. This was highlighted as a crucial safety measure.
- Strict hydrogen storage and handling guidelines were recognized as very important by both data sources. Adhering to stringent protocols and regulations for the safe storage and usage of hydrogen was a common theme.
- Comprehensive fire safety and emergency response plans were deemed important by survey respondents and experts to mitigate risks associated with hydrogen's flammability.
- Rigorous training and certification requirements for personnel working with hydrogen technologies was a shared priority between the surveys and interviews to ensure competence.
- Adopting relevant international safety standards where applicable was referenced by the survey and experts to leverage established best practices. However, some experts also noted the potential need for localized codes.
- Public awareness and education initiatives were identified in both datasets as key to building understanding and acceptance of hydrogen by addressing perceptions and managing risks.
- Regular system maintenance and personnel training were emphasized to continuously ensure safe operations over the long-term.
- Addressing potential hydrogen leakages, especially in enclosed spaces, was underscored as requiring careful ventilation strategies and sensor monitoring.

Overall, there is strong alignment between the safety priorities highlighted through the survey responses and expert interviews. Both sources emphasize prudent leak management, qualified staffing, robust emergency protocols, code compliance and public engagement as essential factors. This consensus validates the key findings on core safety requirements needing consideration.

8.3 Research Question 1, Objective 1 and Hypothesis 1

The survey evidence strongly supports the hypothesis that prudent management of safety concerns will enable public acceptance of new hydrogen-based energy vectors. Respondents clearly identified specific technical and perceptual factors that can mitigate apprehension.

On the critical issue of particular safety requirements, respondents emphasized adherence to rigorously developed standards modelled on proven frameworks like Europe's ATEX directive. Precise zoning and spatial classifications based on quantitative risk levels were advised, along with strict adherence to the highest equipment ratings such as Ex II C. Visually identifiable demarcations and comprehensive signage also help instil situational awareness. Fire suppression compatibility and leak detection figured prominently, alongside fail-safe measures like emergency shutdowns.

Additionally, public education was widely noted as key to demystifying hydrogen properties. Demonstration projects can likewise exhibit real-world safety. Together these initiatives help calibrate risk perceptions. Ongoing training and licensing ensures human competency factors do not

introduce undue hazards. Taken comprehensively, these principles align with global best practices as implemented in leading hydrogen economies like Germany, Japan and California.

In summary, the survey data furnishes a substantive profile of targeted safety provisions spanning technical risk reduction, perceptual enhancements, and knowledge development. These insights successfully fulfil the core research objective of elucidating the particular standards and opportunities that can enable public acceptance, informed by global precedents. The hypothesis that acceptance hinges on apt safety controls has been thoroughly validated. Ongoing research can continue refining the optimal mechanisms identified here to responsibly integrate clean hydrogen into sustainable energy systems. But the current evidence provides confidence in the feasibility of safe adoption through prudent, multi-tiered safety strategies.

8.5 Section 2 – Decarbonisation Potential

The survey findings in Section 2 provide valuable insights into the potential contribution of hydrogen technologies to the decarbonization of the built environment and the methodologies that can be employed to quantify and assess this impact. The data highlights the multifaceted nature of the challenge and the diverse perspectives held by stakeholders across various occupations.

- One of the key themes that emerged from the survey is the recognition of hydrogen technologies as a viable means for displacing fossil fuels and enabling the integration of renewable energy sources in the built environment. The majority of respondents (63.9%) identified the use of hydrogen for heating instead of natural gas as a significant contribution to decarbonization. This aligns with the broader objective of reducing reliance on carbon-intensive fossil fuels, which was selected by 67.2% of respondents as one of the most impactful aspects of using hydrogen technologies.
- Furthermore, the survey data revealed a strong consensus on the potential of hydrogen combined heat and power systems (60.6%) and the role of hydrogen as a renewable energy storage medium (65%). These findings underscore the perceived value of hydrogen technologies in facilitating the integration of intermittent renewable energy sources and enhancing energy system resilience through load shifting and energy storage capabilities.
- The survey responses also highlighted the potential of hydrogen technologies in decarbonizing heavy industry and transportation sectors. Respondents recognized the contribution of hydrogen in enabling high-temperature heating processes for industries such as steel and cement production (19%), as well as powering heavy transportation modes like shipping and trucks (13%). These insights align with the broader recognition of hydrogen's versatility in addressing hard-to-abate sectors and applications.
- However, the survey data also revealed some scepticism and divergent perspectives regarding the viability of hydrogen technologies in certain applications within the built environment. Some respondents (6%) questioned the appropriateness of residential hydrogen applications, citing concerns about efficiency challenges and the availability of alternative solutions such as electrification. This divergence of opinions underscores the need for a nuanced approach that considers specific use cases and weighs the economic and technical feasibility of different decarbonization pathways.
- The survey data also provided valuable insights into the methodologies for measuring the impact of hydrogen technologies on decarbonization effectively. The respondents overwhelmingly favoured direct metrics such as tracking CO₂ emission reductions (71.7%) and reductions in natural gas and fossil fuel consumption (65%). These findings align with the overarching emphasis on displacing carbon-intensive processes and reducing reliance on fossil fuels as the primary drivers for adopting hydrogen technologies.

- While direct emission and fuel consumption reductions were prioritized, respondents also recognized the importance of considering indirect impacts, such as efficiency improvements (39.4%), increased renewable energy share (46.1%), and comparative analysis against conventional systems (42.8%). These perspectives highlight the need for a holistic approach that accounts for the systemic effects of hydrogen technologies on energy systems and the broader built environment.
- Moreover, the survey responses highlighted several challenges in measuring the impact of hydrogen technologies on decarbonization effectively. The lack of standardized measurement methodologies (65.6%) emerged as the most significant obstacle, underscoring the need for collaborative efforts to establish internationally accepted standards and protocols. Difficulties in data collection and analysis (58.9%) and variability in regional infrastructure and energy mixes (51.1%) were also identified as significant challenges, emphasizing the importance of robust data acquisition and localized impact assessments.
- The open-ended responses provided further insights into potential challenges, such as accounting for energy losses throughout the hydrogen value chain, addressing cultural resistance to change, verifying the source of hydrogen (fossil fuel-derived or renewable), and mitigating the influence of misinformation campaigns and biases. These qualitative insights highlight the multifaceted nature of the challenge and the need for a comprehensive approach that addresses technical, social, and regulatory aspects.
- Regarding the confidence levels in hydrogen technologies' ability to displace fossil fuels for building energy demands, the survey revealed a range of perspectives influenced by respondents' occupations and familiarity with the technology. On average, respondents indicated a moderate level of confidence (mean score of 2.53 out of 5), suggesting a general belief in hydrogen's potential to meet at least a significant portion of building energy demands.

However, the survey data also revealed variations in confidence levels across different occupations. Respondents directly involved in hydrogen projects, technologies, and infrastructure, such as advisors, developers, and engineers working with hydrogen and power systems, expressed higher levels of confidence. This is likely due to their deep understanding of the technology's potential and feasibility.

In contrast, respondents in occupations, such as CEOs, Policy Makers and General Managers, exhibited lower levels of confidence. This divergence in perspectives aligns with expectations, as those more familiar with the nuanced challenges and advancements in hydrogen technologies are better positioned to appreciate its viability, while those less exposed may adopt a more cautious or sceptical stance until mainstream adoption is achieved. The variation in confidence levels highlights the importance of bridging knowledge gaps and providing comprehensive education and demonstration projects to enhance stakeholder confidence in the potential of hydrogen technologies.

In conclusion, the survey findings in Section 2 provide a comprehensive understanding of the potential contributions of hydrogen technologies to the decarbonization of the built environment, the methodologies for measuring this impact, and the challenges and confidence levels associated with their implementation. The data underscores the need for a multifaceted approach that addresses technical, regulatory, social, and economic aspects to facilitate the responsible integration of hydrogen technologies in the built environment.

While recognizing the potential of hydrogen in displacing fossil fuels, enabling renewable energy integration, and decarbonizing hard-to-abate sectors, the survey also highlights the importance of nuanced considerations based on specific use cases and local contexts. Addressing challenges such as standardized measurement methodologies, data availability, and regional variability will be crucial for accurately quantifying the impact of hydrogen technologies on decarbonization.

Furthermore, the divergence in confidence levels across occupations highlights the need for knowledge dissemination, demonstration projects, and stakeholder engagement to bridge gaps and foster a shared understanding of hydrogen's potential and limitations. By addressing these challenges and leveraging the insights gained from the survey, policymakers, industry stakeholders, and research institutions can collectively pave the way for the responsible and sustainable integration of hydrogen technologies in the built environment, contributing to the broader goal of decarbonization and energy system resilience.

8.6 Question 2 - Data Validation: Experts' Interviews and Survey

- Both the survey and interviews identified displacing natural gas heating as a key avenue, aligning on this pathway.
- Combined heat and power (CHP) systems and renewable energy storage were also highlighted by both datasets as impactful applications. The interviews further specified uses like residential/commercial heating and high-temperature industrial processes.
- Interview participants similarly discussed hydrogen enabling remote/off-grid renewable integration and diversifying the energy system. These themes were also present in the open-ended survey responses.
- Concerns around efficiency versus electrification alternatives were noted in both the interviews and additional survey comments. There was concurrence on this potential issue warranting ongoing evaluation.
- Production methods and ensuring hydrogen is renewable-derived emerged as important considerations across the interview and survey responses. Both emphasized the importance of this factor.
- For impact quantification, directly measuring emissions and fossil fuel reductions was prioritized by the survey data and referenced by several interviews. This shows alignment between the two sources.
- Challenges in quantification were acknowledged in interviews and as survey response options/open-ended comments, with issues like data availability and standardization converging.

In summary, there is clear validation between the priority pathways, applications, issues and metrics for quantification identified in the interview versus survey responses. The two datasets reinforce each other and do not appear to contradict on any major points.

8.7 Research Question 2, Objective 2 and Hypothesis 2

The survey evidence lends measured support to the hypothesis that hydrogen deployment can effectively decarbonize the built environment while meeting energy demands. Respondents highlighted pathways like displacing natural gas for heating, combined heat and power, enabling renewable integration, and electrification. Quantifiable metrics were proposed to track progress.

Specifically, directly substituting conventional fossil fuel applications was viewed as the most intuitive decarbonization measure, especially natural gas for thermal loads. Complementing intermittent renewables through storage and peak balancing also scored highly, underscoring hydrogen's role in optimizing clean power systems. Some questioned efficiency comparability with electrification, warranting ongoing assessment.

To quantify impacts, monitoring carbon emission reductions scored very high, reflecting a focus on net contributions to climate goals. Tracking displacement of natural gas consumption also rated

highly. Some noted efficiency metrics, though secondary to displacing outright emissions. Comparative assessments against conventional systems can further validate benefits.

Overall, the data conveys a measured outlook that hydrogen can significantly contribute to decarbonization across various built environment applications. This aligns with demonstrations underway in Europe and Asia. Continued deployment and scaled-up pilot projects will help substantiate technical and economic viability. The environmental optimization objectives highlighted by respondents successfully fulfil the research goal of elucidating impact quantification.

While not overly effusive, the generally affirmative perspectives indicate cautious potential. As acknowledged by participants, realization depends on strategic policy, public awareness, and responsible development. But the foundations underscored here provide a constructive framework to guide evidence-based advancement. With prudent strategies guided by sustainability principles, hydrogen presents a promising pathway for deep decarbonization of the built environment.

8.8 Section 3 – Public Awareness and Education

The survey results underscore the significance of public awareness and education as a critical factor in accelerating the acceptance of hydrogen technologies.

- A substantial majority of respondents (78.9%) demonstrated awareness of hydrogen technologies and their potential benefits in addressing energy affordability and economic growth in New Zealand. However, the remaining 21.1% of respondents indicated a lack of awareness, highlighting the need for continued education and engagement initiatives to disseminate understanding more broadly. This finding aligns with the existing literature, which emphasizes the importance of public awareness and education in facilitating the adoption of emerging technologies (Rao and Kishore, 2010; Sovacool et al., 2015). As a relatively new domain, the level of unfamiliarity among some respondents is not unexpected, but it underscores the necessity for targeted campaigns and outreach efforts to increase public knowledge and acceptance.
- Respondents identified showcasing successful case studies and demonstrations (68.9%), public education campaigns and workshops (54.4%), as well as involving schools and educational institutions (55.6%) as effective strategies for increasing public awareness. These approaches resonate with the recommendations of previous studies, which have highlighted the efficacy of hands-on experiences, community-based initiatives, and incorporating hydrogen education into school curricula in fostering a deeper understanding and acceptance of new technologies (Karlstrøm and Ryghaug, 2014; Foley and Olabi, 2017).
- Economic Opportunities and Fuel Poverty Alleviation: The survey findings indicate a cautious optimism regarding the potential of hydrogen technologies to contribute to economic growth and alleviate fuel poverty in New Zealand. The most commonly cited aspects of hydrogen technologies that can aid in this endeavour were diversification of energy sources leading to economic resilience (65.6%), job creation and economic opportunities in the hydrogen sector (60%), and the affordability of hydrogen as an energy source (58.3%). These perspectives align with the existing literature, which recognizes the potential of hydrogen technologies to stimulate job creation, foster economic growth, and enhance energy security through diversification (Hydrogen Council, 2020; IRENA, 2023). The diversification of energy sources is particularly relevant in the context of New Zealand's efforts to transition towards a more sustainable and resilient energy system, reducing reliance on any single source and safeguarding against potential shocks. The affordability of hydrogen as an energy source received a lower percentage of responses (58.3%), suggesting that cost reductions may need to come from further technological development and economies of scale for hydrogen to

become truly affordable. This finding is consistent with the existing literature, which acknowledges that the current costs of hydrogen production and distribution remain a barrier to widespread adoption, and that continued research and development efforts are crucial to driving cost reductions (Hydrogen Council, 2020; IRENA, 2023).

- **Regulatory Framework and Economic Opportunities:** The survey results indicate a notable degree of support for the establishment of a clear and supportive regulatory framework as a means to accelerate the acceptance of hydrogen technologies in New Zealand. Over 70% of respondents agreed that a regulatory framework is important to provide long-term certainty for industry planning and investment, reflecting the need for a stable and predictable policy environment to foster the growth of the hydrogen sector. This finding aligns with the existing literature, which emphasizes the pivotal role of government policies and regulations in shaping the development and deployment of new technologies (Böhm et al., 2020). By providing a clear and consistent regulatory framework, governments can create an enabling environment that reduces investment risks, promotes innovation, and facilitates the scaling up of hydrogen technologies.

Furthermore, the survey results suggest that respondents view the development of a robust regulatory framework with a risk-based approach as having a positive economic impact for New Zealand through job creation and growth opportunities. Over three-quarters of respondents saw at least some degree of impact, with 26.1% expecting highly significant impacts. This finding is consistent with the existing literature, which suggests that the development of clean energy technologies, including hydrogen, can serve as a catalyst for job creation and economic growth, particularly in the areas of production, storage, distribution, and end-use (Vona et al., 2018; IRENA, 2022).

However, the diversity of sentiments among respondents, with 17.2% remaining neutral, underscores the need for further assessment of concrete impacts and the development of robust scenario modelling to elucidate likely outcomes under different policy and investment conditions. Additionally, research on labour markets and skills development can help ensure that the workforce is adequately prepared to meet the anticipated demands of the growing hydrogen sector (IRENA, 2022).

- **Barriers to Public Acceptance:** The survey also shed light on the factors that respondents perceive as hindrances to the public acceptance of hydrogen technologies in New Zealand. The lack of awareness and education (66.7%) emerged as the most significant barrier, followed by safety concerns and lack of information (60%), perception about high costs (52.8%), and uncertainty about effectiveness and reliability (56.7%). These findings align with the existing literature, which has identified similar barriers to the public acceptance of emerging technologies, including low awareness, safety concerns, cost perceptions, and uncertainties regarding performance and reliability (Huijts et al., 2012; Sovacool et al., 2015). Addressing these barriers will require a multifaceted approach, involving targeted education campaigns, demonstration projects, transparent communication of risks and benefits, and policy incentives to address cost concerns.
- **The Role of Government:** The survey results highlight the crucial role that the government is expected to play in accelerating the acceptance of hydrogen technologies in New Zealand. Respondents emphasized the importance of establishing a clear and supportive regulatory framework, providing financial incentives, funding research and development, and collaborating with industry for promotions and awareness initiatives. These findings resonate with the existing literature, which recognizes the government's pivotal role in supporting the development and deployment of new technologies through a combination of regulatory measures, financial incentives, research and development funding, and public-private partnerships (Bozeman, 2000; Foxon and Pearson, 2008; Sooriyaarachchi et al., 2015).

Some respondents cautioned against open-ended subsidies and favoured a technology-neutral approach that allows market forces to determine the most cost-effective low-carbon technologies. This perspective aligns with the principles of economic efficiency and the notion that government support should be directed towards creating an enabling environment for innovation and competition, rather than picking winners (Sawin and Martinot, 2010).

Overall, the survey findings suggest that a balanced approach, involving strategic regulatory reform, targeted financial incentives, and collaboration with industry stakeholders, can facilitate the responsible scaling up of hydrogen technologies in New Zealand while adhering to principles of sustainability and economic efficiency.

8.9 Question 3 - Data Validation: Experts' Interviews and Survey

The interview responses provided by the experts generally align with and reinforce the perspectives gathered from the survey responses discussed in the document. Summarising the alignment:

- Both sources emphasized public education campaigns, showcasing successful case studies, and addressing safety misconceptions to increase awareness and acceptance.
- Interview responses corroborated the need to communicate hydrogen technologies' benefits for sustainability, energy security, and economic growth to foster public acceptance, matching survey findings.
- Survey and interviews underscored government support through subsidies, incentives, tax rebates, and supportive regulations to reduce costs and encourage adoption.
- Survey analysis aligned with interviews stressing public-private partnerships' importance for promotions and awareness initiatives.
- Decentralized on-site hydrogen production's potential for energy independence and self-sufficiency, highlighted in the survey, echoed in interviews discussing off-grid hydrogen-powered communities and decentralized systems' benefits.
- While perspectives varied based on context and scale, both sources addressed the large-scale versus small-scale electrolyser cost-effectiveness debate.
- Clear and supportive regulatory frameworks' need, identified in the survey, resonated with interviews emphasizing stable regulatory environments and standards for instilling investor and developer confidence.
- Considering local resources and needs' importance, indicated in the survey, aligned with interviews discussing specific context relevance and adaptive solutions.

Overall, the expert interviews closely reinforced and provided real-world examples validating the key survey insights, strengthening the analysis and recommendations for accelerating public acceptance and realizing hydrogen technologies' economic potential in New Zealand.

8.10 Research Question 3, Objective 3 and Hypothesis 3

The survey results lend overall support to Hypothesis 3 that implementing a new risk-based regulatory framework can open up economic opportunities and improve New Zealand's economy as hydrogen adoption advances.

Specifically, 49.4% of respondents in Question 15 did not view current regulations as a major obstacle, while 57% in Question 16 expressed confidence or neutrality that risks could be appropriately managed under revised frameworks. This indicates openness to regulatory evolution, rather than negativity.

As highlighted through open-ended feedback, factors like public acceptance, infrastructure availability, and technology costs were viewed as more pressing than regulations alone. This implies strategic regulatory reform could facilitate increased hydrogen deployment rather than impede it.

While acknowledging uncertainty in realization, especially regarding upfront costs and acceptance challenges, respondents' perspective tentatively affirmed hydrogen's role if supported strategically. Continued education, policy momentum and responsible development will thus be crucial to guide evidence-based growth, with sustainable principles central. Hydrogen may offer NZ a viable pathway to reducing fuel poverty and stimulating economic activity through clean energy if these foundations are strengthened prudently over the long term.

Specifically, realising cost savings from hydrogen as an energy source received the strongest endorsement, suggesting affordability is key to alleviating fuel poverty. Creating sustainable jobs and industries in the hydrogen sector also scored highly, indicating economic growth potential. Complementing renewable energy with energy storage and export opportunities further underscored hydrogen's role in optimizing clean energy systems and trade.

To quantify impacts, monitoring job creation and economic contributions scored as top indicators, reflecting priorities around fuel poverty alleviation and gross domestic product (GDP) impacts. Tracking hydrogen production and infrastructure rollout additionally rated highly. Some caveats around reliability and effectiveness comparisons with alternatives were raised, highlighting the need for ongoing assessments. With apt standardization as pioneered in leading hydrogen economies, new employment and business openings are likely to arise as the sector scales, improving productivity and GDP.

Therefore, the survey findings provide measured yet affirmative evidence that regulatory modernization can enable economic growth, fulfilling Hypothesis 3. This also answers Research Question 3 regarding accelerating public acceptance to alleviate fuel poverty and drive growth. Regulations viewed as safe and agile can aid adoption. Finally, Objective 3 set out to develop guidance for introducing new energy systems. The openness to evolutions in regulation indicates a framework with appropriate safety protocols and industry input could achieve this. In summary, the survey furnished useful insights on the opportunities around regulatory reform to responsibly scale hydrogen in a socially and economically productive manner. This helps validate Hypothesis 3 and address the associated research question and objective.

8.11 Section 4 – Government Investment

The survey results reveal a multifaceted perspective on the factors that may influence the New Zealand government's decision to accelerate investment in green hydrogen technologies for the built environment. A key finding is the primacy of demonstrating economic viability and cost-effectiveness, selected by 72.2% of respondents in Question 21. This aligns with literature emphasizing policymakers' need to justify strategic priorities through rigorous cost-benefit analyses and value-for-money assessments (Brown et al., 2019). Quantifying hydrogen's competitiveness against alternatives is crucial.

However, respondents identified several pathways through which hydrogen could create economic opportunity beyond just deployment costs. 66.7% cited enabling renewable energy transitions and 63.9% highlighted energy security benefits in Question 20. These reflect hydrogen's potential for domestic production, energy storage revenue streams, and diversifying imports (IRENA, 2022). Early-mover advantages in emerging global markets were another recognized factor (52.8%). This suggests a holistic economic case considering system-level impacts and strategic positioning could

bolster investment rationales. Simply achieving cost-parity with incumbent options may understate hydrogen's dynamic advantages as an integrated energy solution.

Nonetheless, 59.4% supported collaborating with industry experts in Question (Q23), underscoring the need for robust techno-economic validation and co-development of business models. Coupling demonstrations (66.1% support) with regulatory standards (65.6%) can provide this systematic evidence. International partnerships (57.8%) could further accelerate learning.

The survey illuminated additional nuances around determining public investment timelines. While 45% saw technological research as important (Q21), 60% prioritized existing commercial readiness signals like pilot projects and clear regulatory frameworks before scaling deployment (Q23). Managing risk through evidence-based staging appears prudent.

Importantly, the results showed public familiarity and confidence are developing foundations rather than prohibitive barriers. Reasonably high average familiarity (M=1.89 on 3-point scale in Q19), modest confidence in addressing needs (18.3% "Very", 42.8% "Somewhat" in Q22), and 76.1% support for active government promotion (Q24) all suggest openness to responsibly realizing hydrogen opportunities despite lingering uncertainty.

Deeper analysis uncovered occupational divides where focused capability building could enhance holistic policy preparedness. For example, technical specialists like engineers exhibited consistently high hydrogen familiarity contrasting with more variable understanding across non-technical roles like policymakers despite their policy influence.

This is substantiated through the clear prioritization of cost-effectiveness (72.2% in Q21) and recognition of hydrogen's advantages in enabling renewable integration (66.7%), enhancing energy security (63.9%), and unlocking economic growth opportunities (43.9%) per Question 20.

Addressing Research Question 4 on factors influencing acceleration of new energy vectors, the findings illuminate a pragmatic outlook emphasizing technological maturity, commercial viability signals, and progressive regulatory preparedness - balanced against economic, environmental and energy resilience payoffs.

Finally, Objective 4's aim to recommend policies supporting regulatory framework development aligns with respondents' emphasis on pilot demonstrations (66.1%), standards and codes (65.6%), strategic research and development (R&D) funding (63.3%), and public-private co-development (59.4%) based on Question 23 feedback.

Collectively, the survey insights validate hydrogen's potential as a secure, affordable and sustainable energy solution. However, realizing this role requires comprehensive, sequenced policies focused on:

- Validating techno-economic competitiveness through targeted applications and use cases
- Collaboratively establishing codes, standards and approval processes with industry
- Funding research and development while incentivizing private co-investment in pilot demonstrations
- Developing occupational capabilities and bridging knowledge gaps
- Capitalizing on international partnership opportunities

By pursuing this evidence-based, multi-stakeholder approach, the New Zealand government can gain confidence to invest in green hydrogen as a strategic component of future-proofing the built environment's energy systems. Though challenges remain, these findings provide an instructive foundation for responsibly unlocking hydrogen's potential as a cornerstone of secure, affordable and sustainable energy transitions.

8.12 Question 4 - Data Validation: Experts' Interviews and Survey

The survey and interviews provided insightful perspectives on factors influencing government acceleration of hydrogen technologies.

- Both sources highlighted economic viability/cost-effectiveness and international cooperation/agreements as prominent influencers. The survey also prioritized demonstrations and research progress.
- Both highlighted the importance of quantifying economic benefits like job creation and tax revenues. The survey showed this as the top response, aligning with interviews emphasizing tangible advantages.
- Emphasis on energy security, independence and climate targets also featured prominently. Interviews echoed these aspects, underscoring hydrogen's role in diversifying energy sources.
- Interviews provided diverse individual viewpoints and suggested additional considerations like tailored regulations, standards adoption approaches, and dynamics of influencing pressure.
- Areas of alignment included strategic funding, international learning, demonstrated use cases, and cost reductions bolstering confidence over time.
- Some differing perspectives emerged regarding regulatory needs and levels of influence from various stakeholder opinions.
- While perspectives differed on issues like direct subsidies and centralized/distributed models, consensus supported establishing enabling environments through strategic policymaking.
- Survey and interview findings demonstrated consistent and correlated emphasis on core drivers like economic benefits, energy security, and local proof points for gaining government confidence in hydrogen investments.

Together, the results validate recommendations to foster hydrogen leadership by strategically demonstrating benefits, establishing policy stability and facilitating technology maturation through targeted initiatives.

8.13 Research Question 4, Objective 4 and Hypothesis 4

The survey findings provide strong affirmative evidence supporting Hypothesis 4 - that the New Zealand government may invest in green hydrogen technologies to deliver secure, affordable and sustainable energy.

Specific data points validating this hypothesis include:

- 72% of respondents in Question 21 citing cost-effectiveness as the top factor likely to influence government investment decisions, underscoring the importance of demonstrating hydrogen's economic sustainability.
- 66.7% in Question 20 and 63.9% identifying renewable energy transition and energy security as key benefits, highlighting hydrogen's role in ensuring stable affordable supply.
- 18.3% 'Very Confident' and 42.8% 'Somewhat Confident' in Question 22 regarding hydrogen's potential to address needs, indicating positive perceptions of capacity.

Additionally, the research aimed to identify factors influencing government acceleration of new energy vectors (Research Question 4). The data revealed economic viability, renewable integration, and security as primary drivers.

A series of medium positive Pearson correlation coefficients were calculated between the survey variables of awareness, familiarity, capacity confidence, and government support importance regarding hydrogen technology integration.

For example, the correlation between familiarity (Q19) and capacity confidence (Q12) was $r = +0.529$ ($p < 0.01$), indicating a statistically significant moderate positive relationship. Respondents more familiar with hydrogen technologies exhibited greater confidence in the capacity to displace fossil fuels (Field, 2018).

Additionally, awareness of economic benefits (Q13) correlated positively with capacity confidence (Q12) at $r = +0.558$ ($p < 0.01$). Those perceiving higher capacity also tend to be more conscious of affordability and growth opportunities.

Furthermore, awareness (Q13) correlated with energy needs confidence (Q22) at $r = +0.594$ ($p < 0.01$), linking greater consciousness of potential benefits to higher confidence in meeting overall requirements.

These correlations align with Hypothesis 4 that awareness of benefits may influence government investment confidence in green hydrogen for energy security and sustainability. The data shows familiarity and recognized opportunities associate with positive perspectives on capacity and viability.

By demonstrating affirmative technical and economic potential, governments can gain confidence in strategic promotion per Objective 4. Continued engagement highlighting benefits as in Research Question 4 is implied.

Finally, Objective 4 sought recommended policies for supporting regulatory frameworks. Strong support in Question 23 for demonstration projects, funding incentives, and partnerships implies targeted government measures can enable investment confidence.

Overall, the statistically significant positive correlations indicate consistent associations between familiarity, awareness and confidence related to hydrogen systems. This provides an evidentiary basis to guide policy and strategy for enabling government confidence in accelerating sustainable hydrogen transitions. The survey furnished robust, multi-dimensional insights into how prudent policymaking can unlock green hydrogen's advantages for secure and affordable decarbonization of the built environment. The findings comprehensively validate Hypothesis 4 while addressing the associated research question and objective.

8.14 Validation and Additional Insights from Participant Feedback

In order to corroborate the findings gleaned from the interviews and survey, the participants involved in the interviews were subsequently engaged to validate the derived conclusions and solicit any supplementary insights they may offer. This step was crucial in ensuring the accuracy and comprehensiveness of the findings, as participant validation is a well-established technique for improving the credibility and trustworthiness of qualitative research (Creswell, 2014).

One of the participants (KQ) responded with the following insights:

“Hydrogen has potential to decarbonize the built environment through fuel cells and blending with the natural gas grid, but direct electrification may be more attractive for heating due to efficiency losses”.

This participant highlighted an important consideration regarding the trade-offs between hydrogen-based solutions and direct electrification for building heating applications. While hydrogen-powered fuel cells can contribute to decarbonization, the participant noted that direct electrification may be

more efficient in certain scenarios, alluding to the importance of considering system-level efficiency when evaluating alternative technologies.

KQ further elaborated:

“One should also consider that there are high-temperature fuel cells that run on hydrogen-rich feedstocks, such as natural gas, methane, landfill gas, etc. In addition to electricity, these fuel cells produce heat, which has been shown to efficiently provide hot water. So depending on the situation and available resources, there are other options one could consider”.

This additional perspective broadens the scope of hydrogen-based solutions, introducing the concept of high-temperature fuel cells that can utilize a wider range of hydrogen-rich feedstocks. Importantly, the participant highlighted the potential for these fuel cells to generate both electricity and useful heat, which could enhance their overall efficiency and viability in certain applications, particularly for hot water production.

SGJA concurs with the researcher’s findings, affirming that they comprehensively encapsulate the broad facets of green hydrogen as a decarbonization tool for the built environment. SGJA does not have additional insights to contribute nor does he express disagreement with the researcher’s insights.

In a further effort to validate the research findings, the study engaged another participant, RH, who provided additional insights and perspectives on the regulatory considerations surrounding the adoption of hydrogen technologies. After acknowledging the researcher’s initial conclusions, RH expressed concern that the cost of compliance could potentially *“smother the baby hydrogen business before it takes its first steps”*.

RH emphasized that hydrogen does not inherently introduce fundamentally new hazards and argued that the industry should leverage existing regulations wherever possible. As an example, RH suggested that *“gas fitters who are qualified to work on natural gas or LPG have all the essential skills - all they might need is a ‘hydrogen endorsement’ just to cover of 5% of extra information about the unique properties of hydrogen”*. This perspective highlights the potential for building upon established regulatory frameworks and training programs, rather than developing entirely new systems, as a means of facilitating a more cost-effective transition to hydrogen.

Furthermore, RH noted that the storage of hazardous goods should be updated to address energy density rather than simply volume, as *“hydrogen is such a low density gas that is gets restricted at very low levels (compared to LPG)”*. This observation underscores the need for regulatory frameworks that are tailored to the specific properties of hydrogen, rather than relying on outdated approaches designed for other energy carriers.

Acknowledging the rationale behind the proposed regulatory measures, RH expressed empathy for the cultural context of risk aversion, stating, *“I do understand where all the regulatory ideas come from and I do sympathise that in a culture where risk aversion is almost at panic levels there is a reluctance to permit minimum levels and costs”*. However, RH cautioned that *“Hydrogen safety investment should be intelligently assessed against scale, because all strategies that are ‘safe at all costs’ are too expensive to be practical”*. This perspective underscores the need to balance safety considerations with the practical realities of cost and feasibility, particularly in the early stages of hydrogen market development.

RH acknowledged that the researcher’s recommendations may be appropriate in an idealized world without resource constraints, but noted that *“it is just not our (New Zealand) world at present”*. This statement suggests that RH views the researcher’s proposals through a lens of practical realism, recognizing the unique challenges and resource limitations faced by the New Zealand context.

The feedback provided by RH serves to validate and further contextualize the research findings, highlighting the importance of addressing regulatory barriers in a manner that supports the nascent hydrogen industry's growth and sustainability, while also ensuring appropriate safety measures are in place. The overall tone and sentiment expressed by RH, can be characterized as primarily positive, albeit with some caveats. RH seems to be generally supportive of the research findings and recommendations, but emphasizes the need to balance regulatory requirements with the practical realities of cost and feasibility, particularly in the early stages of hydrogen market development.

Chapter 9 Conclusions and Recommendations

This chapter synthesizes the key findings from the research and presents targeted recommendations for advancing hydrogen technologies in New Zealand. It is structured around four critical areas: Health and Safety (H&S), Decarbonization, Public Acceptance, and Government Investment. Each section addresses the specific challenges and opportunities identified throughout the study, offering actionable strategies to ensure the successful integration of hydrogen systems into New Zealand’s energy landscape. The chapter concludes with general recommendations that provide a comprehensive roadmap for stakeholders moving forward.

9.1 Recommendations for Health and Safety in the Built Environment for Hydrogen Applications

As New Zealand explores hydrogen technologies for energy transition, establishing a comprehensive safety framework is essential. This section outlines key recommendations for ensuring hydrogen safety, focusing on the adaptation of international standards, risk mitigation strategies, public education, and regulatory alignment. These recommendations are designed to support the safe and effective integration of hydrogen technologies into New Zealand’s energy infrastructure while addressing both public and industry concerns.

New Zealand can benefit significantly from adopting and adapting existing international safety standards, such as the ISO hydrogen safety standards and the European Union’s ATEX directive. These proven frameworks provide a robust starting point for regulating hydrogen infrastructure, while offering flexibility to be tailored to local conditions and needs.

Recommendation	Description
Adopt International Standards	New Zealand should adapt existing international hydrogen safety standards, such as ISO standards and the EU’s ATEX directive, to leverage proven frameworks while customizing for local needs.
Implement Precise Zoning	Precise zoning, classification, and spatial separation of hydrogen infrastructure should be based on quantitative risk assessments, ensuring safe distances from inhabited areas and ignition sources.
Mandate Comprehensive Signage	Comprehensive signage and clear demarcations on hydrogen installations should be required to promote situational awareness. This includes warning signs, colour coding, and symbolic labels for safety reinforcement.
Adopt Rigorous Equipment Standards	Equipment standards equivalent to the highest global benchmarks (e.g., Ex II C ratings) should be adopted to ensure component integrity. Mandatory fail-safe emergency shutdown protocols are essential.
Incorporate Fire Suppression Systems	Fire suppression systems compatible with hydrogen’s chemical properties should be installed in all facilities and transport modes. Leak detection sensors linked to automated shutdown valves should also be implemented.
Fund Public Education Campaigns	Public education campaigns and demonstration projects should be funded to enhance familiarity with hydrogen properties, use cases, and safety measures, calibrating public risk perceptions through knowledge.

Institute Licensing and Training	Licensing, training, and certification requirements for hydrogen professionals should be established to ensure competencies in safely handling hydrogen systems.
Ensure Third-Party Validation	Independent third-party validation and testing regimes should oversee compliance with codes and standards, boosting user confidence through safety certifications.
Coordinate Regulatory Approach	A coordinated regulatory approach among government agencies, industry groups, and standards bodies should govern hydrogen safety, aligning policies for consistent governance.

Table 91: Recommendations for Health and Safety in the Built Environment for Hydrogen Applications

In ensuring the safe integration of hydrogen technologies into New Zealand’s energy landscape, a key strategy involves adopting and adapting existing international standards. Standards such as the ISO hydrogen safety standards and the European Union’s ATEX directive offer a robust foundation. These frameworks are already tested and proven internationally but need to be customized for New Zealand’s unique conditions, including its seismic activity, climatic variables, and regulatory context. By blending these global best practices with localized adjustments, New Zealand can build a solid regulatory foundation tailored to its infrastructure.

Spatial separation and zoning are critical aspects of hydrogen safety. Based on quantitative risk assessments, hydrogen storage facilities, refuelling stations, and other key infrastructure components must be strategically positioned at safe distances from inhabited areas and potential ignition sources. This not only ensures compliance with safety standards but also mitigates risks to the public and environment. Implementing precise zoning and classification criteria for hydrogen infrastructure is essential to maintain operational safety across the built environment.

Another vital aspect of safety is the clear identification and labelling of hydrogen installations. Comprehensive signage and visual identifiers should be mandated to promote situational awareness. Colour coding, symbolic labels, and warning signs need to be present on all hydrogen installation components to ensure easy identification of risks and safety precautions. These safety measures are crucial in emergency situations and also play a role in day-to-day operations, where clear communication of hazards is necessary.

Adopting rigorous equipment standards is equally important. Equipment used in hydrogen systems should adhere to global benchmarks such as Ex II C ratings, which ensure the highest level of component integrity and reliability in gas environments. Fail-safe protocols must be in place, requiring the implementation of automatic emergency shutdown systems, further securing the safety of hydrogen infrastructure. These fail-safes provide an additional layer of protection, especially in high-risk scenarios.

Fire suppression systems, customized to hydrogen’s specific chemical properties, must also be incorporated into all facilities handling hydrogen, including transportation modes. The integration of leak detection sensors connected to automatic shutdown valves provides an indispensable safeguard against potential failures. These technologies work in tandem to prevent and mitigate risks associated with hydrogen leaks, which could lead to fires or explosions if not managed swiftly.

Building public confidence and understanding of hydrogen’s potential is another critical component of safety. Public education campaigns and demonstration projects should be prioritized and funded to educate communities on hydrogen’s properties, use cases, and inherent safety measures. These initiatives serve to calibrate public risk perception, which is vital for the widespread acceptance of

hydrogen technologies. Empowering the public with knowledge and addressing safety concerns upfront will enhance trust and foster public acceptance.

To ensure proper handling of hydrogen technologies, it is necessary to establish stringent licensing, training, and certification requirements for professionals in the field. This validates the technical competencies of individuals working with hydrogen systems, ensuring that personnel handling these installations possess the requisite knowledge and skills. Such qualifications are crucial in maintaining high safety standards across the sector.

Finally, independent third-party testing and validation regimes should be introduced to confirm compliance with safety codes and standards. This layer of oversight guarantees that hydrogen systems are operating safely and according to established regulations. Certifications provided by external bodies offer another layer of assurance, fostering greater user confidence and trust in hydrogen as a safe and reliable energy solution.

A coordinated regulatory approach, involving collaboration between government agencies, industry groups, and standards bodies, is essential for consistent governance of hydrogen safety. Aligning policies across these groups ensures cohesive regulation and enforcement, establishing a clear, unified framework for hydrogen safety management in New Zealand.

9.2 Recommendations for Decarbonization Through Hydrogen Adoption in the Built Environment

In the context of decarbonizing New Zealand’s built environment, hydrogen technologies offer significant potential. This section provides key recommendations for maximizing the decarbonization impact of hydrogen through robust measurement frameworks, data-driven approaches, and strategic deployment. These recommendations emphasize the importance of aligning with international standards, fostering collaboration, and ensuring continuous evaluation to advance hydrogen’s role as a sustainable energy solution. By following these guidelines, New Zealand can effectively harness hydrogen to contribute to its carbon reduction targets.

Recommendation	Description
Establish standardized measurement methodologies	Align measurement methodologies and reporting protocols internationally to quantify emissions reductions from hydrogen adoption for consistent tracking and comparisons.
Implement robust monitoring and data gathering	Gather comprehensive datasets on hydrogen’s production sources, storage, distribution, and end-uses to understand usage patterns and model impacts accurately.
Develop customized baseline models	Create region-specific baseline models and impact accounting practices that consider local infrastructure, energy mix, and building stock.
Utilize direct emissions measurements	Use direct emissions measurements and fossil fuel displacement rates as key indicators of progress in decarbonization, alongside efficiency gains.
Conduct periodic comparative assessments	Perform lifecycle analysis to compare hydrogen systems with conventional options to validate relative advantages.

Promote data transparency and access	Strengthen research and analytics by improving data transparency and access, addressing data gaps to refine evaluations over time.
Increase demonstration deployments	Expand pilot projects across various built environments and geographies to validate real-world applications of hydrogen at scale.
Review measurement frameworks regularly	Regularly update measurement frameworks to adapt to technological advancements, ensuring indicators remain current and relevant.
Foster collaboration between stakeholders	Collaborate among industry practitioners, policymakers, and research institutions to align on robust quantification methodologies.
Develop hydrogen-specific modules	Integrate hydrogen modules within broader sustainability rating schemes and certification systems for buildings to enable holistic benchmarking.
Leverage computation tools like digital twins	Use digital twins to model hydrogen infrastructure interactions within built environments and quantify resultant emissions profiles.
Incorporate both direct and indirect impacts	Assess both direct and indirect decarbonization impacts, including renewable integration and grid stability enabled by hydrogen storage.
Account for full lifecycle emissions	Evaluate full lifecycle emissions across production, storage, distribution, and usage to provide a comprehensive impact assessment.
Envision fuel cells as enablers	Highlight the role of fuel cells in enabling self-sufficient buildings and resilient community energy hubs, emphasizing the need for localized demonstration projects.
Continued advancements needed	Acknowledge the need for ongoing improvements in efficiency, storage solutions, and cost reduction to enhance the economic viability of hydrogen as a decarbonization solution.
Explore niche applications	Investigate hydrogen technologies for unique applications in off-grid and remote settings, emphasizing their potential for decarbonization in these areas.

Table 92: Recommendations for Decarbonization Through Hydrogen Adoption in the Built Environment

Hydrogen has significant potential to aid decarbonization across various sectors of the built environment, but its success depends on the development and implementation of robust measurement methodologies and frameworks to quantify its impact. Standardizing these methods, aligning them with international protocols, and ensuring comprehensive data gathering will be essential to consistently track emissions reductions and assess hydrogen's true contributions to New Zealand's net-zero goals.

Establishing standardized, internationally aligned measurement methodologies and reporting protocols is crucial for tracking emissions reductions from hydrogen adoption. Implementing robust monitoring systems across hydrogen's production, storage, distribution, and end-use processes will

enable stakeholders to collect accurate data on usage patterns and model their environmental impacts. This approach, complemented by customized baseline models that reflect regional infrastructure, energy mixes, and building stock, allows for context-sensitive decarbonization assessments.

Direct emissions measurements and fossil fuel displacement rates should serve as primary indicators of progress, alongside efficiency improvements. Periodic lifecycle analysis comparing hydrogen systems to conventional alternatives ensures that hydrogen's relative advantages are validated over time. Data transparency will also play a key role, enabling broader research and refining impact evaluations by addressing data gaps.

Demonstration deployments and pilot projects across different geographies and building types are vital to validate hydrogen's potential at scale. As technologies evolve, regular reviews of measurement frameworks will help keep indicators current and reflective of technological advancements. Strategic collaborations between industry experts, policymakers, and researchers are needed to align on robust quantification methods, ensuring accurate assessments of hydrogen's contribution to decarbonization.

Hydrogen's potential to integrate within broader sustainability certification systems is also significant. Developing hydrogen-specific modules within sustainability rating schemes and leveraging computational tools like digital twins can help model complex hydrogen infrastructure interactions. Moreover, it is essential to incorporate both direct and indirect decarbonization impacts, such as renewable energy integration and grid stability enabled by hydrogen storage.

Finally, fuel cells present an opportunity for self-sufficient buildings and resilient community energy hubs. However, to make hydrogen truly viable as a decarbonization tool, advancements in efficiency, storage solutions, and cost reduction will be essential. Continued innovation and localized demonstration projects will help confirm hydrogen's potential to deliver meaningful emissions reductions in New Zealand's built environment.

9.3 Recommendations for Enhancing Public Acceptance of Hydrogen Technology

For hydrogen technologies to gain traction in New Zealand, fostering public acceptance is critical. This section presents targeted recommendations to enhance understanding, address misconceptions, and build trust within the community. By implementing comprehensive educational initiatives, funding demonstration projects, and establishing supportive policies, New Zealand can effectively cultivate a favourable environment for hydrogen adoption. These strategies not only aim to inform the public but also to engage them in meaningful dialogue and collaboration, ensuring that the transition to hydrogen aligns with societal values and expectations.

Recommendation	Description
Implement educational campaigns	Launch widespread campaigns to increase public familiarity with hydrogen through media, events, schools, and transparent communication, building foundational literacy and addressing misconceptions.
Fund demonstration projects	Support pilot projects showcasing real-world feasibility and safety of hydrogen applications in the built environment, helping to demystify the technology.

Provide policy incentives	Offer capital subsidies, tax credits, and preferential electricity rates to enhance cost competitiveness with conventional fuels, catalysing adoption during market establishment.
Highlight verified sustainability benefits	Communicate the sustainability benefits of hydrogen, such as emissions reductions, through rigorous impact quantification that aligns with public values.
Develop training programs and certifications	Create training programs and certifications to cultivate necessary expertise, maximizing local economic opportunities in hydrogen production, storage, and distribution.
Undertake scenario modelling and skills gap analysis	Perform scenario modelling and skills gap analysis to identify workforce needs and tailor educational initiatives, optimizing human capital development.
Emphasize hydrogen's complementary role	Highlight hydrogen's role in supporting renewable energy, energy storage, and grid stability, using integrated systems thinking to motivate adoption.
Collaborate with industry	Work with industry stakeholders to identify key challenges and advocate for pragmatic regulatory changes that address barriers to hydrogen adoption, fostering balanced innovation.
Consider guarantees of origin	Explore mechanisms like guarantees of origin to substantiate renewable sourcing claims, enhancing credibility and user reassurance.
Develop hydrogen-specific modules	Integrate hydrogen-specific criteria into broader building sustainability rating systems to improve visibility and mainstream adoption.
Leverage virtual modelling	Use virtual modelling tools to simulate hydrogen infrastructure interactions within built environments, aiding comprehension and visualization of the technology.
Promote international alignment and knowledge exchange	Encourage international collaboration and knowledge exchange to benefit from shared lessons on adoption success factors, preventing redundancy in efforts.
Maintain technology neutrality	Allow hydrogen to demonstrate its advantages without excessive subsidization, ensuring market viability drives efficiency and innovation.
Undertake community-based engagement	Engage with communities in co-developing transition pathways for hydrogen adoption, fostering local ownership and understanding of the technology.

Table 93: Recommendations for Enhancing Public Acceptance of Hydrogen Technology

For hydrogen technologies to gain traction in New Zealand, fostering public acceptance is critical. This section presents targeted recommendations to enhance understanding, address misconceptions, and build trust within the community.

First, it is essential to implement widespread educational and awareness campaigns to increase public familiarity with hydrogen. Utilizing various channels, including media, events, and schools, can build foundational literacy and address misconceptions. Transparent communication is vital to gaining public acceptance and support for hydrogen technologies.

Additionally, funding demonstration projects and pilot programs across diverse applications of hydrogen in the built environment can showcase real-world feasibility and safety. By allowing the public to see hydrogen in action, these initiatives help demystify the technology and foster trust.

Providing policy incentives, such as capital subsidies, tax credits, and preferential electricity rates, can further enhance the cost competitiveness of hydrogen compared to conventional fuels during the initial market establishment phase. These incentives can catalyse adoption and encourage investment in hydrogen technologies.

Highlighting verified sustainability benefits, particularly emissions reductions, is also crucial. Rigorous impact quantification and clear communication of these benefits can reinforce public alignment with values of environmental stewardship and sustainability.

Moreover, developing training programs and certifications for the hydrogen workforce will foster required expertise and maximize local economic opportunities in areas such as production, storage, and distribution. Undertaking scenario modelling and skills gap analysis can clarify workforce needs and tailor educational initiatives accordingly, optimizing human capital development.

It is also important to emphasize hydrogen's role in complementing renewable energy sources, enhancing energy storage, and contributing to grid stability. An integrated systems approach will provide motivation for the community to support hydrogen as part of a broader energy solution.

Collaboration with industry stakeholders can help identify key challenges and pragmatic regulatory changes needed to address barriers to adoption. A balanced approach that allows for innovation while ensuring safety is crucial for the growth of hydrogen technologies.

Establishing mechanisms like guarantees of origin will substantiate renewable sourcing claims and reassure end users, enhancing credibility and acceptance. Additionally, developing hydrogen-specific modules within broader building sustainability rating systems can improve visibility and integration of hydrogen into existing frameworks.

To further facilitate public acceptance, leveraging virtual modelling to simulate hydrogen infrastructure interactions within built environments can assist in visualization and comprehension. Promoting international alignment and knowledge exchange will also allow New Zealand to benefit from shared lessons on adoption success factors, preventing redundancy in efforts.

Finally, maintaining technology neutrality and allowing hydrogen to demonstrate its advantages without excessive subsidization will foster a competitive market environment. Community-based engagement and co-development of transition pathways will ensure that the voices and needs of the public are heard and integrated into the hydrogen adoption process.

9.4 Recommendations for Government Investment in Hydrogen Viability

To effectively foster the growth of hydrogen technologies in New Zealand, strategic government investment is essential. This section presents a series of recommendations aimed at maximizing the impact of public funding and support.

Recommendation	Description
Demonstrate cost-competitiveness	Conduct well-designed pilot projects to showcase the economic viability of hydrogen. Successful demonstrations can attract private sector investment; co-funding across applications is advised.
Develop regulatory frameworks	Establish clear regulations and standards for integrating hydrogen into building codes, zoning, and infrastructure planning, reducing risk and providing certainty for long-term investments.
Offer R&D grants and incentives	Provide targeted research and development grants and tax credits to subsidize initial innovation costs, helping to drive down technology costs over time without indefinite subsidies.
Collaborate with industry experts	Work closely with industry experts and institutions to co-create strategic technology roadmaps tailored to local conditions and resources, leveraging insights from solution developers.
Engage internationally	Participate in knowledge exchange, standards development, and explore export opportunities to capitalize on global hydrogen growth. Collaboration among international stakeholders is essential.
Communicate benefits clearly	Increase public awareness and social acceptance of hydrogen by effectively communicating its benefits, addressing current limited hydrogen literacy through outreach initiatives.
Take a balanced portfolio approach	Utilize a mix of demonstrations, incentives, partnerships, and promotions to address various transition hurdles, recognizing that no single measure dominates.
Remain technology-neutral	Explore all options for affordable decarbonization while considering hydrogen for specific applications where it proves competitive.
Act promptly	Take advantage of maturing technologies and readiness; industry is ready for investment with clear frameworks, and delays could result in losing first-mover advantages.
Aim for consistent approaches	Ensure predictable policies that provide certainty to investors, avoiding excessive regulatory changes that deter commitment, while maintaining a long-term transition perspective.
Leverage technical expertise	Utilize the technical expertise of participants who have transitioned into advisory roles to guide government policymaking and strategic planning, highlighting the importance of government support.

Table 94: Recommendations for Government Investment in Hydrogen Viability

First and foremost, demonstrating the cost-competitiveness of hydrogen is crucial. Well-designed pilot projects can provide data showcasing the economic viability of hydrogen, which remains the top priority for stakeholders. Successful demonstrations have the potential to catalyse private sector investment, making co-funding pilots across various built environment applications advisable.

Furthermore, developing clear regulatory frameworks and standards for integrating hydrogen into building codes, zoning, and infrastructure planning is vital. This approach reduces risks and provides certainty for long-term investments, while streamlining approval processes can accelerate deployment and encourage quicker adoption of hydrogen solutions.

To stimulate innovation, targeted Research and Development (R&D) grants and incentives, such as tax credits, should be offered to subsidize initial innovation costs. These financial supports can help drive down technology costs as systems mature over time, with the aim of making hydrogen cost-competitive without relying on indefinite subsidies.

Collaboration with industry experts and research institutions is also important for co-creating strategic technology roadmaps tailored to local conditions and resources. Leveraging on-the-ground insights from those developing solutions will ensure that strategies are realistic and effective.

Engaging internationally through knowledge exchange, standards development, and exploring export opportunities will allow New Zealand to capitalize on the global growth of hydrogen. Collaboration and knowledge-sharing among international stakeholders are essential for developing common frameworks and sharing technological advancements, enabling increased government investment in hydrogen solutions.

Additionally, clear communication of the benefits of hydrogen is necessary to increase public awareness and social acceptance. Currently, hydrogen literacy appears limited; therefore, outreach efforts are needed to build broader support and understanding of hydrogen technologies.

A balanced portfolio approach should be adopted, utilizing demonstrations, incentives, partnerships, and promotional efforts together. No single measure should dominate; instead, a mix of strategies will address different transition hurdles effectively.

Maintaining technology neutrality is essential, allowing exploration of all options for affordable decarbonization. Hydrogen should be considered for targeted applications where it demonstrates clear competitiveness.

Prompt action is necessary to take advantage of maturing technologies and readiness within the industry. With clear frameworks in place, the industry is poised for investment; any delays risk losing the first-mover advantage in hydrogen adoption.

Lastly, it is vital to aim for consistent and predictable approaches that provide policy certainty to investors. Excessive regulatory changes can deter commitment, so a long-term transition perspective is essential for sustainable growth. The insights and expertise of participants who have transitioned into advisory roles underscore the importance of government investment and support in guiding effective policymaking and strategic planning.

9.5 General Recommendations for Advancing Hydrogen Technology Adoption and Integration

Based on the findings of this study, a series of comprehensive recommendations are proposed to facilitate the successful adoption and integration of hydrogen technologies. These recommendations aim to address regulatory, educational, financial, and collaborative aspects, ensuring a holistic approach to promoting hydrogen as a viable energy solution. The following sections outline these recommendations in detail, emphasizing the need for a coordinated effort among stakeholders to overcome barriers and harness the benefits of hydrogen technologies.

Recommendation	Description
Establish Regulatory Frameworks	Develop clear regulations and standards for safe hydrogen technology adoption, including ventilation and leak detection, proper storage, fire safety measures, and personnel training, adhering to international standards.

Public Education Campaigns	Conduct campaigns and workshops to increase public awareness of hydrogen technologies, showcasing case studies and engaging industry experts for talks to clarify benefits and risks.
Financial Incentives	Provide funding for research and development, and collaborate with industry to promote hydrogen adoption and its integration into the energy landscape.
Impact Measurement	Measure hydrogen technologies' impact on decarbonization using indicators like carbon emissions reduction, renewable energy utilization ratios, and energy efficiency improvements.
Standardized Metrics Development	Address measurement challenges by creating standardized metrics, improving data collection and analysis, and enhancing regional infrastructure and energy mixes.
Address Fuel Poverty	Consider hydrogen's role in alleviating fuel poverty and promoting economic growth, exploring ways to leverage its benefits for broader social and economic goals.
Enhance Educational Initiatives	Strengthen initiatives to increase stakeholder familiarity with hydrogen technologies.
Communicate Economic and Environmental Benefits	Emphasize the economic and environmental advantages of hydrogen technologies in outreach strategies.
Industry and Academia Collaboration	Foster partnerships between industry and academia to address stakeholder concerns, especially scepticism about hydrogen technologies.
Monitor Stakeholder Attitudes	Continuously assess and monitor stakeholder attitudes to tailor communication strategies and address evolving concerns.

Table 95: General Recommendations for Advancing Hydrogen Technology Adoption and Integration

To ensure the safe adoption of hydrogen technologies, it is crucial to establish clear regulatory frameworks and standards. These frameworks should include guidelines for adequate ventilation and leak detection systems, proper hydrogen storage and handling, comprehensive fire safety and emergency response measures, and strict training and certification requirements for personnel. Adherence to international safety standards will further enhance safety and reliability in hydrogen applications.

Increasing public awareness and understanding of hydrogen technologies is another critical area of focus. Public education campaigns and workshops, along with the showcasing of successful case studies and demonstrations, can significantly enhance knowledge and acceptance. Engaging hydrogen industry experts for public talks will also help demystify hydrogen and provide clarity on its potential benefits and risks.

Financial incentives play a pivotal role in promoting the adoption of hydrogen technologies. Providing funding for research and development, along with collaborative efforts with industry, can facilitate the integration of hydrogen into the energy landscape. By creating a supportive financial

environment, stakeholders can drive innovation and accelerate the transition toward hydrogen solutions.

Effectively measuring the impact of hydrogen technologies on decarbonization requires a multifaceted approach. Utilizing a combination of indicators, such as reductions in carbon emissions, increased renewable energy utilization ratios, and improvements in energy efficiency metrics, will provide a comprehensive understanding of hydrogen's contributions. Additionally, addressing challenges in measuring these impacts necessitates the development of standardized metrics, improved data collection methods, and enhancements to regional infrastructure and energy mixes.

It is essential to consider both the benefits and challenges of hydrogen technologies in addressing fuel poverty and promoting economic growth. By exploring ways to leverage these advantages, stakeholders can align hydrogen initiatives with broader social and economic objectives, ensuring a holistic impact on communities.

Strengthening educational initiatives is vital for enhancing familiarity among stakeholders with hydrogen technologies. Communication strategies should emphasize the economic and environmental benefits of hydrogen, fostering a positive narrative around its adoption. Furthermore, fostering collaborations between industry and academia will help address specific concerns raised by stakeholders, particularly those expressing scepticism about hydrogen technologies.

Lastly, ongoing monitoring and assessment of stakeholder attitudes will be crucial for tailoring communication strategies and addressing evolving concerns. By staying attuned to public sentiment, stakeholders can adapt their approaches and foster a more supportive environment for hydrogen technologies.

9.6 Enhanced Summary of Research Goals and Objectives

The primary aim of this research was to explore the potential of green hydrogen technologies to decarbonize the built environment in New Zealand. Specifically, it sought to analyse the economic, technical, environmental, and safety parameters of hydrogen, as well as develop a regulatory framework to facilitate its introduction into the residential and commercial sectors. This research has successfully met these objectives by identifying key hydrogen safety standards and challenges, analysing the techno-economic performance of hydrogen technologies to optimize energy outcomes for buildings, proposing a framework for the safe and sustainable integration of hydrogen systems in the built environment, and recommending hydrogen policies that address both immediate safety concerns and long-term decarbonization goals for New Zealand.

Through this comprehensive approach, the study has established a foundational understanding of how green hydrogen can play a critical role in achieving sustainability targets, while also ensuring safety and economic viability in the deployment of these technologies.

9.7 Aligning Research with the UN Sustainable Development Goals

This research aligns with several United Nations Sustainable Development Goals (SDGs), specifically Goals 7, 8, 9, and 11 through 13.

Beginning with Goal 7 - Affordable and Clean Energy, this study directly addresses the critical challenge of providing clean and affordable energy solutions. The findings indicate that scaling up hydrogen technologies could position green hydrogen as a cost-effective energy carrier, potentially eradicating energy poverty while fostering sustainable practices.

In relation to Goal 8 - Decent Work and Economic Growth, the research highlights an often-overlooked aspect of the green energy transition: job creation. The shift toward hydrogen

technologies not only yields environmental benefits but also generates numerous employment opportunities within this emerging sector, thus aligning economic growth with environmental stewardship.

Regarding Goal 9 - Industry, Innovation, and Infrastructure, the study provides robust evidence supporting the development of resilient green hydrogen infrastructure, with a particular emphasis on its integration within the built environment. This research transcends theoretical frameworks by presenting tangible, implementable solutions that advance innovation while ensuring practicality.

The findings also robustly support Goal 11 - Sustainable Cities and Communities. The study develops practical guidelines for incorporating hydrogen technologies into urban planning, offering tools for retrofitting existing buildings and designing new hydrogen-powered infrastructure. Additionally, the study proposes solutions for remote and off-grid locations by establishing community hubs.

With respect to Goal 12 - Responsible Consumption and Production, the research emphasizes the full lifecycle of hydrogen technologies. Given that green hydrogen production is carbon-neutral and that these technologies can be recycled, the study provides a framework for genuinely sustainable practices. It also underscores the necessity of CO₂ tracking during both production and disposal - crucial details often overlooked in the pursuit of true sustainability.

Finally, this study aligns with Goal 13 - Climate Action by positioning green hydrogen as a pivotal component in achieving net-zero carbon targets, particularly within New Zealand's built environment. It offers actionable recommendations for scaling up hydrogen infrastructure, thereby grounding ambitious climate goals in practical reality.

What distinguishes this research is its holistic approach; it does not focus solely on technical aspects but also considers the broader implications of implementing hydrogen technologies. The study addressed the real-world challenges and opportunities associated with the transition to sustainable energy.

9.7.1 Critical Review of the Research Methodology Used

The research methodology employed in this study offers a robust framework for exploring the complex issues surrounding green hydrogen technologies. The use of a multimethod design, integrating both qualitative and quantitative approaches, stands out as one of its key strengths. This combination enriched the analysis by providing a comprehensive exploration of the topic, capturing diverse perspectives, and allowing for a more nuanced understanding of participants' experiences and perceptions. This multimethod design also enhanced the credibility of the findings, ensuring they are well-supported by multiple forms of evidence.

The research design was further strengthened by a thorough literature review and a systematic approach to data collection, both of which laid a strong foundation for inquiry. This structure supported the reliability of the findings and ensured the study's replicability for future researchers. The inclusion of a diverse range of participants through semi-structured interviews improved the depth of the qualitative data collected. The diversity of perspectives captured through these interviews reflected the complexities of the field, offering insights into varying levels of understanding and scepticism surrounding green hydrogen technologies.

Moreover, the study's commitment to ethical considerations was commendable. Informed consent and participant confidentiality were emphasized, fostering a sense of trust and ensuring the honesty and integrity of the data collected. The iterative feedback loop employed in the research process added further strength, allowing the researchers to continuously refine their approach in response to emerging findings. This adaptability highlighted a responsiveness to the dynamic nature of the research topic and contributed to the overall rigor of the study.

The quantitative analysis following the survey was a key element in the research, offering measurable insights into stakeholders' perceptions of green hydrogen technologies. Descriptive statistics provided a clear overview of the participants' demographic characteristics, levels of knowledge, and attitudes toward hydrogen technologies. This quantitative step was essential in identifying general trends in participants' opinions and behaviours.

In addition, the use of inferential statistics, such as correlation analyses, allowed the study to explore relationships between variables - such as the connection between familiarity with green hydrogen and support for its adoption. This helped identify key factors influencing stakeholder attitudes, offering deeper insights into the mechanisms driving support or scepticism.

A critical component of a mixed-methods approach is the validation and integration of qualitative and quantitative data. In this study, triangulation was employed to validate findings from both data types, enhancing the overall credibility of the research. The qualitative data provided context-rich insights into stakeholder motivations and concerns, while the quantitative data quantified these perspectives, making them more generalizable.

The study benefited from a clear framework that integrated both qualitative and quantitative data. For instance, testing the qualitative themes from interviews against the quantitative survey responses provided deeper insights into how various perceptions aligned with measurable trends. This cross-validation enhanced the coherence of the findings, demonstrating how qualitative and quantitative insights worked together to offer a comprehensive understanding of stakeholder attitudes.

In conclusion, the research methodology employed in this study demonstrated several strengths, including a well-structured multimethod design, a systematic data collection process, ethical rigor, and a commitment to iterative refinement. These features provided a solid foundation for the research and enhanced the credibility and reliability of the findings. By focusing on these strengths, future research can build on this study to generate even more valuable insights into green hydrogen technologies. This will enhance understanding of stakeholder attitudes and contribute to the successful adoption and implementation of these technologies in the built environment.

9.7.2 Theoretical Contribution (Achieved)

This study makes significant contributions to the existing body of knowledge on decarbonizing the built environment through green hydrogen by mapping out the specific safety, decarbonization, public acceptance, and investment needs that are critical for integrating hydrogen into New Zealand's energy infrastructure. It highlights the importance of international standards, rigorous safety protocols, and public outreach, thereby offering a foundation for practical policy-making and future studies.

One of the key contributions is addressing a critical gap in the literature regarding the application of hydrogen technologies within the built environment, an area that has been understudied compared to sectors like transportation and industry. The research developed interdisciplinary models that integrate engineering, environmental policy, economics, and safety regulations, providing a comprehensive understanding of the challenges and opportunities for green hydrogen deployment in buildings.

Additionally, the study offers theoretical insights into the role of green hydrogen in supporting renewable energy integration, with implications for the broader global transition to low-carbon energy systems. It enhances academic understanding by contributing significantly to the discourse on decarbonization through green hydrogen technologies, presenting robust theoretical frameworks that deepen our understanding of the pathways, challenges, and opportunities involved in integrating hydrogen technologies into the built environment.

Furthermore, the research successfully created interdisciplinary frameworks that combine insights from engineering, environmental science, policy, economics, and social sciences. These frameworks provide a holistic understanding of how green hydrogen technologies interact with decarbonization strategies, thus expanding their potential applications. Finally, the study identified critical gaps in existing policy frameworks and provided strategic recommendations aimed at promoting the widespread adoption of hydrogen technologies in New Zealand's built environment. These policy suggestions serve as a foundation for shaping future regulations and standards.

9.7.3 Practical Applications (Achieved)

The findings of this research hold direct relevance for policymakers, engineers, and industry professionals.

The proposed regulatory framework and safety standards for hydrogen systems in buildings serve as a crucial guide for the safe and effective deployment of these technologies, influencing both current practices and future industry protocols. By identifying the economic and technical challenges associated with the widespread adoption of green hydrogen in the built environment, the research addresses key barriers, offering solutions for retrofitting older buildings and designing new structures that incorporate integrated hydrogen technologies.

Policymakers can leverage these findings to shape national strategies, ensuring public access to reliable and affordable energy while advancing New Zealand's climate goals. Meanwhile, industry leaders can utilize the techno-economic insights to develop robust business cases for hydrogen projects and facilitate the scaling up of necessary infrastructure.

Additionally, the research provides detailed best practices for the deployment of hydrogen technologies, including insights into technological advancements and system integration strategies essential for effective scaling. Stakeholders benefit from actionable insights regarding the economic viability, technical feasibility, and environmental advantages of hydrogen technologies, enabling them to make informed decisions related to investment, infrastructure, and policy interventions.

Moreover, by identifying commercial opportunities and supporting the development of innovative business models, the research stimulates investment and entrepreneurship within the hydrogen sector, offering recommendations for financial incentives to promote growth in this emerging market. It also develops practical guidelines for urban planners, architects, and developers to seamlessly integrate green hydrogen technologies into urban infrastructure, thereby supporting New Zealand's sustainability objectives through low-carbon, energy-efficient development.

Lastly, the study highlights the significant environmental and public health benefits associated with adopting green hydrogen technologies, including notable reductions in greenhouse gas emissions and air pollutants, which contribute to efforts aimed at mitigating climate change and improving air quality.

9.7.4 Wider Implications

The implications of this research extend far beyond mere technical advancements, presenting significant environmental, social, and economic effects. Transitioning to green hydrogen holds the potential to drastically reduce New Zealand's carbon footprint, particularly in sectors with traditionally high emissions, such as building construction and operations. Furthermore, the research underscores the promising opportunities for job creation within the hydrogen sector, encompassing roles in production, installation, and maintenance. This shift not only contributes to the development of a greener economy but also addresses energy poverty by providing cleaner and more affordable energy solutions for communities.

On a global scale, the findings can inform decarbonization efforts in other countries, showcasing the feasibility of hydrogen technology as a vital component of sustainable urban development. By doing so, the research contributes to the international discourse on achieving net-zero carbon emissions, highlighting the transformative potential of hydrogen in creating a more sustainable future.

9.7.5 General Findings

The findings of this research highlight several critical areas for advancing hydrogen infrastructure in New Zealand. First and foremost, safety is paramount; adopting international standards such as ISO and ATEX will enhance safety measures across hydrogen infrastructure. This includes implementing precise zoning regulations and comprehensive signage to ensure public awareness. Additionally, establishing rigorous equipment standards, fire suppression systems, and public education campaigns, along with certification requirements for hydrogen professionals, is essential to foster a safe operational environment.

In terms of decarbonization, the research underscores the importance of consistent measurement methodologies, robust monitoring, and life-cycle analysis to effectively track hydrogen's impact on emissions reductions. By increasing pilot projects and fostering collaboration among stakeholders, New Zealand can refine its decarbonization efforts and ensure meaningful progress toward climate goals.

Public acceptance of hydrogen technologies is another crucial factor identified in the findings. Educational campaigns, coupled with real-world pilot demonstrations and financial incentives, will be essential in boosting public understanding and acceptance of hydrogen's benefits, helping to dispel any misconceptions.

Lastly, government investment plays a pivotal role in establishing hydrogen's economic viability. The research emphasizes the need for co-funded pilot projects, the development of clear regulatory frameworks, and strategic international collaboration to encourage private investment in hydrogen technologies.

9.7.6 Overall Conclusion

In conclusion, the findings of this research highlight that hydrogen technology presents substantial opportunities for decarbonization and energy sustainability in New Zealand. However, the successful implementation of hydrogen systems relies on several key factors. First, adopting international safety standards is essential to ensure the secure deployment of hydrogen infrastructure. Additionally, fostering public awareness and understanding of hydrogen's benefits will be crucial in overcoming acceptance barriers. Finally, strong collaboration between government entities and industry stakeholders is vital to create a supportive regulatory environment and promote investment. By effectively addressing these safety, regulatory, and public acceptance challenges, hydrogen technologies can significantly contribute to New Zealand's energy transition and climate goals.

9.7.7 Recommendations for Further Research

Based on the findings of this research, several areas warrant further investigation to enhance the understanding and implementation of hydrogen technologies:

- **Scaling Up Pilot Projects:** Future studies should focus on the implementation and evaluation of large-scale hydrogen demonstration projects in residential and commercial settings. These projects will provide tangible evidence of effectiveness and help alleviate scepticism.

- **Public Acceptance Studies:** Investigating public perceptions of hydrogen technologies is crucial, particularly regarding safety and cost implications. Long-term tracking of public perception changes following educational initiatives can inform future outreach strategies.
- **Understanding Outlier Perspectives:** Conduct qualitative studies to explore the concerns and motivations of stakeholders, particularly outliers who express scepticism toward green hydrogen technologies. Gaining insights into their perspectives is essential for developing effective engagement and communication strategies.
- **Educational Initiatives:** Develop targeted education and awareness programs aimed at decision-makers to bridge the knowledge gap regarding the benefits and applications of green hydrogen technologies.
- **Policy Development:** Collaborate with policymakers to address regulatory and economic challenges hindering adoption. Research should inform the creation of supportive policies that facilitate the integration of green hydrogen in the built environment.
- **Socio-Economic Impact Investigations:** Explore the socio-economic impacts of hydrogen adoption, particularly in remote or off-grid areas, to understand its potential for enhancing energy accessibility and contributing to local economies.
- **Emissions Reduction Data Collection:** Expand data collection efforts to assess hydrogen's emissions reduction potential across various infrastructure types, facilitating a more robust understanding of its environmental benefits.
- **Collaborative Framework Studies:** Investigate partnerships among academia, government, and industry to identify strategies for overcoming barriers to hydrogen adoption and refining regulatory frameworks for effective implementation.

By prioritizing these areas, future research can significantly contribute to the successful integration of hydrogen technologies in New Zealand's built environment.

Appendixes

1. Appendix 1 – Participants Information Sheet



Participant Information Sheet

Date Information Sheet Produced:

14/04/2023

Project Title

Decarbonizing the Built Environment via Hydrogen Technologies

An Invitation

My name is Olga Lozova. I am a construction project manager with an architectural background and a researcher. Currently, I work for the Government organization and conduct my PhD research in the Built Environment and Engineering at Auckland University of Technology. My goal is to explore the ways in which hydrogen technologies can be used to decarbonize the built environment. My study aims to discuss a transition from the traditional energy source to a green hydrogen fuel that is secure, energy efficient, affordable, environmentally friendly, and sustainable, while reducing the impact of carbon on the built environment during the transition period. Specifically, in order to achieve this goal, my research will be aimed at gathering professional data from the industry specialists, policymakers, and researchers who work on similar topics and problems locally as well as internationally.

What is the purpose of this research?

The purpose of this research is to investigate and develop a regulatory framework for the introduction of green hydrogen technologies into commercial and residential sectors as a new long-term strategic opportunity through the analysis of economic, technical and environmental parameters of electrolyser and hydrogen fuel cell technologies in order to tackle the challenges nations facing in urban life while preserving environment, ecology, culture and heritage.

The findings of this research will be used for academic publications and presentations.

How was I identified and why am I being invited to participate in this research?

Due to your involvement in hydrogen projects, your decarbonisation vision, and your commitment to protecting the environment, you are being invited to participate in this study.

This Information Sheet may have been passed along to you by a colleague from your professional networks as they thought it may be of interest to you.

How do I agree to participate in this research?

In order to confirm your agreement to participate in this study, you will be required to fill out a consent form and return it to me via email.

What will happen in this research?

This stage of the research will involve online interviews.

What are the discomforts and risks?

No discomforts and risks are anticipated during the interviews. The interaction will take place online, once you consent to it, no discomforts or risks are foreseen considering the nature of interaction which will be conducted for the purpose of obtaining professional information and opinions.

There is no compulsion to participate in this event. If you wish to withdraw your participation at any time after agreeing to participate, you may do this at any point in time.

How will these discomforts and risks be alleviated?

Due to the fact that the interviews will be held online, at a time that is most convenient for the participants, and only professional questions will be asked during the interview, there is no expectation of any discomfort or risk for the participants during the interview as a result, the risk of discomfort is minimal. Nevertheless, if the participants will face discomfort, they can stop the interview at any time.

What are the benefits?

The participants will benefit professionally from contributing to the global decarbonization goals by sharing their knowledge, expertise, professional opinions and visions with the academic communities as well as by contributing to economic, social, environmental, ecological and technological benefits to the wider communities.

How will my privacy be protected?

At all stages of data collection, the researcher will be cautious to ensure that your interests are protected. You will not be asked to share any sensitive information; you are free to choose what information you want to share with the researcher. As part of the data collection process, no personal information will be collected from you or recorded as part of the data collection process. No individual information will be required for this study. It is intended that only professional data collected will be aggregated for the purpose of drawing research conclusions.

The researcher will not disclose your name to anyone, including other participants. The consent form signed off by you will be stored for the mandated period separately from other research components to prevent your privacy.

What are the costs of participating in this research?

There is no monetary cost of participating in this research; however, the participants' time will be required as follows: an estimated interview time will last approximately one hour and 20-25 minutes for the survey; additional time may be required for the further clarification.

What opportunity do I have to consider this invitation?

Participation in this research is entirely voluntary. To familiarise you with the research, a project brief is attached with this document. You will have a period of two weeks from the day the Information Sheet is handed over to you for considering and confirming your participation.

Will I receive feedback on the results of this research?

Yes, you will be provided with a summary of the research results. You will be asked to provide your feedback on the interviews and the interview questions.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Professor John E. Tookey, john.tookey@aut.ac.nz, +(649) 921 9999 ext 9512

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTC, ethics@aut.ac.nz, (+649) 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Olga Lozova
Email: olgalo80@yahoo.com
Mobile: +(64)223447978

Project Supervisor Contact Details:

Professor John Tookey
Email: john.tookey@aut.ac.nz
Phone: +(649) 921 9999 ext 9512

2. Appendix 2 - Project Brief for Participants

Project Brief for Participants

This study aims to discuss a transition from the traditional energy source to a green hydrogen fuel that is secure, energy efficient, affordable, environmentally friendly, and sustainable, while reducing the impact of carbon on the built environment during the transition period.

Decarbonization and zero net greenhouse gas emissions are the main global goals that are targeted to be reached by 2050 and are becoming a high strategic priority worldwide. To achieve these targets, scientists on the global scale are working on the solution as to how to commercialize green hydrogen and make it a safe energy vector.

Currently, only 4% of all hydrogen types come from renewable energy resources. Many countries with their abundant renewable energy and prerequisites for production of green hydrogen, set up a goal to reach 100% renewable electricity by 2035 and a transition to a clean, green and carbon-neutral economy by 2050. It seems possible to meet the Governments' current plan considering that the green hydrogen is produced by splitting water via electrolysis into two elements - hydrogen and oxygen - using the electricity which comes from renewable energy resources such as wind, solar, geothermal and tidal energy.

Since the cost of production and storage of renewable sources of energy becomes economically competitive, there is a high possibility for introduction of green hydrogen energy in the built environment based on the development of technologies to allow electrical load flexibility.

Considering strategically that the power demand will continue to grow and the expectations to high quality power has already been set up, decentralisation of large power stations will be required to avoid overloading of the limited electricity capacity and ability to provide automotive energy supply to new infrastructures even in remote areas and off-grid thus protecting environment and providing sustainability.

As an energy-dependant civilization, the world's energy consumption has great importance for socio-economic and political aspects. With the world population's continuous growth, the electricity and energy demand have increased respectively. Being heavily dependent on energy, the world population has been producing greenhouse gases with an average carbon footprint of 7 tonnes of CO₂ per capita per year.

To create a more sustainable future, the United Nations agreed to urgently limit global warming to 1.5 degrees Celsius, reduce greenhouse gas emissions by 45% by 2030, reaching net zero emission by 2050 and provide "access to affordable, reliable, sustainable and modern energy for all" as it has been declared in the seventh of the seventeen Sustainable Development Goals of the UN Environment Programme.

If the growing population will continue to rely on fossil fuels to meet the energy demand, it will continue increase the temperature on the Earth. However, if fossil fuels will be replaced by green hydrogen, the overall trend will be reversed and the temperature will be stabilised. One of the possible solutions to meet energy demand is to introduce hydrogen energy via hydrogen fuel cells for static and mobile applications.

Decarbonisation is a long-term goal aiming at creating a carbon free era, where hydrogen strategy plays the main role. The future prospect for hydrogen is to be integrated into a global economy and become the main energy vector in industrial, manufacturing, transportation and buildings sectors. Thus, the main focus of this research is to discuss the transition from the traditional energy to green hydrogen energy while decarbonizing the built environment. Transition must happen exponentially to get ahead of the climate problem we are facing.

3. Appendix 3 – Consent Form



Consent Form

For use when interviews are involved.

Project title: **Decarbonizing the Built Environment via Hydrogen Technologies**

Project Supervisor: **Professor John Tookey**

Researcher: **Olga Lozova**

- ☐ I have read and understood the information provided about this research project in the Information Sheet dated 14/04/2023.
- ☐ I have had an opportunity to ask questions and to have them answered.
- ☐ I understand that notes will be taken during the interviews and that they will also be recorded and transcribed.
- ☐ I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.
- ☐ I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.
- ☐ I agree to take part in this research.
- ☐ I wish to receive a summary of the research findings (please tick one): Yes ☐ No ☐
- ☐ I agree to be contacted for later stages of the research: Yes ☐ No ☐
- ☐ I agree the data collected to be held for future research use: Yes ☐ No ☐

Participant's signature:

.....

Participant's name:

.....

Participant's Contact Details (if appropriate):

.....

Date:

Approved by the Auckland University of Technology Ethics Committee on 14.02.2023
AUTEC Reference number 23/17

Note: The Participant should retain a copy of this form.

4. Appendix 4 - Survey Questions

Demographic Information

1. What is your occupation?

- Provide your response:

Section 1 - Hydrogen Safety Requirements

Research Question Number 1 - What specific hydrogen safety requirements/standards and regulations need to be addressed to introduce hydrogen technologies to all New Zealand stakeholders?

2. What specific safety requirements do you believe are crucial for the introduction of hydrogen technologies in New Zealand? (select all that apply)

- Adequate Ventilation and Leak Detection Systems
- Proper Hydrogen Storage and Handling Guidelines
- Comprehensive Fire Safety and Emergency Response Measures
- Strict Training and Certification Requirements for Personnel
- Adherence to International Safety Standards
- Other (please describe your alternative)

3. Which organizations or authorities should play a significant role in setting and enforcing hydrogen safety standards in New Zealand? (select all that apply)

- Ministry of Business, Innovation and Employment (MBIE)
- Energy Safety, WorkSafe New Zealand
- Environmental Protection Authority (EPA)
- Standards New Zealand
- Industry Associations (Specify): _____
- Other (please describe your alternative) _____

4. Should New Zealand adopt international hydrogen safety standards or develop its own specific standards?

- Adopt International Standards
- Develop New Zealand-Specific Standards
- A Combination of Both – international and local standards
- Unsure / No Opinion

5. In your opinion, what specific design requirements should be in place to ensure safe installation of hydrogen systems in residential and commercial buildings? (select all that apply)

- Secure Hydrogen Storage Facilities

- Automated hydrogen leak and shutdown valves
- Use of Fire-Resistant Building Materials
- Adequate Ventilation and Exhaust Systems
- Emergency Hydrogen Release Systems
- Other (please describe your alternative) _____

6. How important do you think public awareness and education regarding hydrogen safety are in the successful implementation of hydrogen technologies in New Zealand?

- Extremely Important
- Very Important
- Moderately Important
- Slightly Important
- Not Important

7. New energy vectors like hydrogen may gain wider public acceptance if hydrogen safety concerns are adequately addressed. What factors would increase your confidence in the safe use of hydrogen technologies? (select all that apply)

- Comprehensive Safety Regulations And Building Codes
- Rigorous Personnel Training Requirements
- Public Awareness Campaigns About Hydrogen Risks
- Government Oversight and Industry Standards Enforcement
- Demonstration of Safe Hydrogen Use in Other Jurisdictions
- Independent Safety Testing and Certification Regimes
- Other (please describe your alternative) _____

Section 2 - Decarbonization Potential

Research question number 2 - How can hydrogen technologies contribute to decarbonizing of the built environment and how can this be measured?

8. In your opinion, how can hydrogen technologies contribute to the decarbonizing of the built environment? (select all that apply)

- Hydrogen as a Clean Energy Source for Heating Buildings Instead of Natural Gas
- Hydrogen-Powered Fuel Cells for Electricity in Buildings
- Hydrogen-Based Combined Heat and Power Systems
- Hydrogen as an Energy Storage Solution for Renewable Energy
- Other (please describe your alternative) _____

9. Which aspect do you consider the most impactful in decarbonizing the built environment using hydrogen technologies? (select all that apply)

- Reducing Carbon Emissions

- Enhancing Energy Efficiency
- Enabling Widespread Adoption of Renewable Energy
- Reducing Reliance on Fossil Fuels
- Other (please describe your alternative) _____

10. How do you think the impact of hydrogen technologies on decarbonization can be measured effectively? (select all that apply)

- Reduction in Carbon Emissions (measured in CO2 equivalents)
- Increased Renewable Energy Utilization Ratio
- Reduction in Natural Gas/Fossil Fuel Consumption
- Energy Efficiency Improvement Metrics
- Comparative Analysis with Conventional Systems
- Other (please describe your alternative) _____

11. In your opinion, what challenges do you foresee in measuring the impact of hydrogen technologies on decarbonization effectively? (select all that apply)

- Lack of Standardized Measurement Metrics
- Difficulty in Data Collection and Analysis
- Variability in Regional Infrastructure and Energy Mix
- Technological Advancements Outpacing Measurement Approaches
- Other (please describe your alternative) _____

12. Transitioning to new energy models like hydrogen has the potential to meet building energy demands while reducing environmental impacts. How confident are you that hydrogen technologies can provide sufficient capacity to displace current fossil fuel use in residential and commercial buildings?

- Very Confident That Hydrogen Can Fully Meet Demand
- Confident It Can Meet a Significant Portion of Demand
- Neutral - Unsure of Total Capacity Potential
- Not Very Confident in Hydrogen's Capacity Potential
- Sceptical it Can Viably Meet Large-Scale Building Energy Demands

Section 3 - Public Acceptance

Research Question Number 3 - How to accelerate the hydrogen technologies acceptance by the public to bring the New Zealanders out of fuel poverty and to achieve the economic growth goals?

13. Are you aware of hydrogen technologies and their potential benefits in addressing energy affordability and economic growth in New Zealand?

- Yes
- No

14. What aspects of hydrogen technologies, in your opinion, can help in alleviating fuel poverty and promoting economic growth? (select all that apply)

- Affordability of Hydrogen as an Energy Source
- Job Creation and Economic Opportunities in the Hydrogen Sector
- Diversification of Energy Sources Leading to Economic Resilience
- Supporting Local Industry and Businesses, and Supply Chain
- Other (please describe your alternative) _____

15. What factors, if any, do you believe hinder the public acceptance of hydrogen technologies in New Zealand? (select all that apply)

- Lack of Awareness and Education
- Perception about High Costs of Hydrogen Technologies
- Safety Concerns and Lack of Information
- Uncertainty About Hydrogen's Effectiveness and Reliability
- Lack of Government Incentives and Policy Support
- Other (please describe your alternative) _____

16. How do you think public awareness about hydrogen technologies can be increased? (select all that apply)

- Public Education Campaigns and Workshops
- Showcasing Successful Case Studies and Demonstrations
- Involvement of Schools and Educational Institutions
- Media Campaigns and Informational Advertisements
- Engaging Hydrogen Industry Experts for Public Talks
- Other (please describe your alternative) _____

17. In your opinion, what role should the government play in accelerating the acceptance of hydrogen technologies in New Zealand? (select all that apply)

- Providing Financial Incentives for Hydrogen Adoption
- Establishing Clear Regulatory Framework and Standards
- Funding Research and Development in Hydrogen Technologies
- Collaborating with Industry to Promote Hydrogen Use
- Other (please describe your alternative) _____

18. Development of a robust regulatory framework with a risk-based approach for hydrogen could enable new economic opportunities and jobs growth. In your view, how

impactful would hydrogen sector job creation and growth opportunities be for the NZ economy?

- Highly impactful - significant new opportunities
- Moderately impactful - some new opportunities
- Neutral - limited net economic impact
- Low positive impact expected
- No impact or negative impacts expected

Section 4 - Government Investment

Research Question Number 4 - What factors may influence the Government's decision to accelerate development of new energy vectors and how to provide the Government with a confidence to invest to advanced hydrogen technologies?

19. Are you familiar with advanced hydrogen technologies and their potential as a new energy vector in New Zealand?

- Very familiar
- Somewhat familiar
- Not very familiar

20. What do you perceive as the main benefits of investing in advanced hydrogen technologies for New Zealand's energy landscape? (select all that apply)

- Reduction in Carbon Emissions and Environmental Impact
- Potential for Energy Independence and Security
- Economic Growth and Job Creation in the Hydrogen Sector
- Facilitating Transition to Renewable Energy Sources
- Enhancing Energy Storage and Grid Stability
- Other (please describe your alternative) _____

21. What factors, in your opinion, may influence the government's decision to invest in advanced hydrogen technologies? (select all that apply)

- Scientific Research and Technological Advancements
- Economic Viability and Cost-Effectiveness
- International Trends and Agreements on Hydrogen Adoption
- Pressure from Environmental Groups and Public Opinion
- National Energy Security Concerns
- Other (please describe your alternative) _____

22. How confident are you in the potential of advanced hydrogen technologies to address New Zealand's energy needs?

- Very Confident
- Somewhat Confident
- Neutral
- Not Very Confident
- Not Confident at All

23. What actions or measures, if any, do you believe the government should take to gain confidence in investing in advanced hydrogen technologies? (select all that apply)

- Collaborating with Hydrogen Industry Experts and Institutions
- Conducting Pilot Projects and Demonstrations
- Offering Grants and Funding for Research and Development
- Establishing Regulatory Frameworks and Standards
- Engaging in International Collaborations and Knowledge Sharing
- Other (please describe your alternative) _____

24. How important is it for the government to actively promote and support the development of advanced hydrogen technologies in New Zealand?

- Very Important
- Important
- Neutral
- Not Very Important
- Not Important at All

25. The government may invest in green hydrogen projects to provide communities with secure, affordable and sustainable energy. How important do you think government support and investment is for realizing this vision?

- Extremely important - essential government role
- Very important - significant government support needed
- Moderately important - some government support useful
- Slightly important - limited government role needed
- Not important - can proceed without government

Appendix 2 – The participants’ invitation to participate in the survey

“Dear Participant,

I hope this email finds you in good health and high spirits. My name is Olga, a PhD researcher at Auckland University of Technology (AUT). I am writing to invite you to participate in a significant research study aimed at paving the way towards a more sustainable future by decarbonizing the built environment through the implementation of green hydrogen technologies.

Purpose of the Study: The objective of this study is to gain valuable insights and perspectives from individuals like yourself regarding the potential of green hydrogen technologies in decarbonizing our built environment. I believe your input will be instrumental in shaping the strategies and policies needed to transition towards a cleaner and more sustainable future.

Survey Details:

- **Topic:** Decarbonizing the Built Environment via Green Hydrogen Technologies
- **Duration:** Approximately 15 minutes
- **Follow this link to the Survey:**
[Take the Survey](#)

Or copy and paste the URL below into your internet browser:

https://qfreeaccountssjc1.az1.qualtrics.com/jfe/form/SV_6teFfYghNMQcfXM?Q_DL=WTIHcLr3oLM4o2a_6teFfYghNMQcfXM_CGC_RDIOoHWLqMCcSI7&Q_CHL=email

Your participation in this survey is entirely voluntary, and all your responses will be kept anonymous and confidential. The survey seeks to gather your opinions, knowledge, and suggestions regarding the adoption and integration of green hydrogen technologies within the built environment.

By participating in this survey, you contribute to the advancement of knowledge in this crucial field and help in shaping a greener future for all. I genuinely appreciate your time and thoughtful responses.

Please click on the provided survey link to begin. If you have any questions or need further clarification, feel free to reach out to me at 0223447978 or via email: olga.lozova@autuni.ac.nz.

Thank you for considering this invitation, and I look forward to your valuable contribution to this research endeavour.

Best regards,

Olga PhD Researcher Auckland University of Technology (AUT)”

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