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The Australian public's perception of hydrogen for energy

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Contents

Tables

Figures

Executive Summary

Around the world there is growing excitement about the potential for an emerging hydrogen economy to transform many countries' energy supply. Australia, rich in renewable energy resources, is well positioned to take advantage of this opportunity, particularly in light of the interest expressed by its close trading partners, Japan and South Korea, to import hydrogen. A hydrogen supply chain requires the deployment of emerging technologies at scale, and will require public support in order to be successful.

While technical research is well underway there was a gap in understanding of the general public's views towards hydrogen. Through a mixed methods approach combining a literature review, ten focus groups (N=92) and a nationally representative online survey (N=2,785) we set out to explore the Australian public's response to the burgeoning opportunities of hydrogen for export, transport and domestic use.

The results demonstrate that the Australian public are supportive of the opportunities that are emerging from a potential hydrogen industry. Many felt that there are a number of opportunities for hydrogen projects to be developed in regional Australia, with hydrogen eventually being made available to local consumers as long as it was cost competitive with conventional technologies. However, use and the management of Australia's valuable water resources and any associated land use change were also deemed critical for community support.

Those living in regional Australia were excited about the prospects of new skills and jobs associated with this burgeoning industry. Although production from renewable sources was most preferred there was a pragmatic acceptance of the need to transition over time and in places that are heavily reliant on fossil fuel production these emergent opportunities were also welcomed.

In addition to costs, of importance were concerns about safety both to consumers and for environmental protection. These were not negotiable, but it seems the majority of the public trust that governments (federal and state) will ensure the necessary regulations and standards are in place to minimise any concerns. Because most of the public are unaware of the use of hydrogen for energy, participants in the focus groups and survey also felt the government, research institutions and industry had a responsibility to educate the public about the emergent hydrogen opportunities with new projects being an important component of this education process.

From the focus groups, existing international project examples provided further comfort to the participants that a hydrogen industry can be safely deployed and had the potential to bring greater economic benefit to Australia. This concept of demonstration and scale up was also reiterated in discussions around the use of fuel cell electric vehicles for transport. Many Australians felt that the development of a hydrogen bus fleet and long-haul trucks would pave the way for the future of hydrogen fuel cell vehicles if their price became more competitive. The development of a large-scale industry in Japan and South Korea was also recognised to help this goal.

To that end, the public was supportive of the government developing a national strategy for the development of a hydrogen industry. There were a number of question around expected timelines required for the successful development and a strategic approach to this was seen to be helpful for bringing Australians along the journey. It was felt that any strategy should include a skills assessment and capability development to identify potential opportunities across the country as well as providing funding for new projects and providing incentives to consumers and industry to help with the transition. To help smooth the transition and increase the potential for widespread ongoing communication and engagement with key stakeholders and the wider community was also felt to be an important part of the strategy to promote greater awareness of the benefits of a hydrogen economy.

Similar to the Japanese experience, it seems that a well coordinated approach across all levels of government, industry and academia will help cement Australia's position in the emergent global hydrogen

economy. At the heart of this will be the need for institutions to collaborate, as if successful, there are multiple opportunities to be had that will benefit all Australians. Key survey findings are summarised below.

Key survey findings

- When Australians first heard the word hydrogen they were most likely (81%) to respond with a neutral response (e.g. gas, energy, water), with only 13% giving negative associations (e.g. bomb, explosion, Hindenburg) and 3% positive (e.g. clean, future).
- Australians' objective knowledge of the properties and uses of hydrogen is relatively low with only 7% of survey participants answering all five knowledge questions correctly. Sixteen percent (16%) answered four correct and 22% answered only three correct.
- Males answered more of the 5 knowledge questions correct than females. Similarly, those with a Bachelor degree or higher, early adopters of technology and those born overseas had a greater knowledge of hydrogen than the general sample.
- The majority of participants (52%) were supportive of *hydrogen as a possible solution for energy and environmental challenges* with another 45% neither supportive nor unsupportive.
- Support for hydrogen varied significantly by gender with 65% of males supportive or very supportive compared to only 40% of females. Most females (58%) were neither supportive nor unsupportive versus 32% of males. Support was also strongly dependent on knowledge, that is, those who answered more of the 5 knowledge questions correctly were more supportive.
- The main benefits associated with the use of hydrogen technologies centred around the environment - reduced greenhouse gas emissions and climate change mitigation potential were key benefits. Those who believe climate change is already happening are more supportive of using renewables only ($p<0.001$) and less supportive of using fossil fuels (either as a transition $p<0.05$ or indefinitely $p<0.001$) than those who do not believe it is happening or will happen
- Safety, cost and environmental impacts, particularly concerns around pollution, emissions and water use, were the most frequently cited concerns about the production and use of hydrogen.
- The majority (77%) of the Australia public believe there will be adequate safety precautions to keep the risks under control. This appeared to stem from a trust in government to act in the best interests of society.
- The major role for government was seen to be to ensure adequate regulations and standards to enable the development of a hydrogen industry. Other important government roles included developing a long-term strategy for hydrogen, continuing to fund research and providing necessary incentives for consumers and businesses.
- In response to the question *If a hydrogen economy was to be developed in Australia, who should be responsible for disseminating information? Tick all that apply.* Government received 68%, followed by research organisations (49%) and industry (43%) which dmeonstrates each group were seen to have some role to play.
- Strongest support was for hydrogen being produced using renewable energy and electrolysis only (57%). However, some (38%) were accepting of hydrogen being produced using fossil fuels with carbon capture and storage (CCS) as an intermediate step while transitioning to renewables. Only 25% were prepared to tolerate the production using CCS indefinitely.
- South Australia had the highest support for renewable production, although the difference was not statistically significant. Queensland showed the highest support levels for transitioning using fossil fuels with CCS, which was significantly different to South Australia and Western Australia. Victorians had the

highest mean for producing hydrogen using fossil fuels with CCS indefinitely, however only 27% of the state was in favour of it. The Australian Capital Territory had the strongest opposition with 45% against using fossil fuels indefinitely.

- There were very few (5%) who opposed the export of hydrogen with most (72%) supportive. In contrast, only 38% were happy to have a hydrogen export facility built near them, with 22% opposed.
- There was support for the introduction of hydrogen fuel cell buses and long-haul trucks, and participants were also happy to be a passenger on a fuel cell bus.
- There was general acceptance of hydrogen being used for a range of domestic applications, particularly hot water heating and on-site electricity generation.
- Participants seemed unconcerned about 10% hydrogen being blended with natural gas and seemed to prefer this term slightly more than piped and injected. They were less sure about replacing natural gas with 100% hydrogen (38% support) and electrifying the gas network (30% support).

Recommendations

In addition to the development of a long term strategy for hydrogen in Australia we recommend:

- Ongoing engagement with all stakeholders around emerging hydrogen trials and new projects
- Ensuring communication materials do not assume any prior knowledge of hydrogen
- Proactively sharing safety considerations in public engagement activities and communication materials
- A coordinated approach between government, industry and academia which aims to bring the public along with the developments occurring in the hydrogen space
- Raising awareness of the benefits and opportunities presented to Australia by developing a hydrogen industry.

1. Introduction

The transition to renewable energy will require technology innovations, but it will also depend on the widespread uptake of those innovations. The sector has already seen some examples of this, where the use of technology at scale has proved transformative. Solar PV for example, first developed to power earth orbiting satellites, can now be found on the roofs of 20% of Australian homes, and generated over 9,000 GWh in 2017[1].

Another stream of innovative technology that is experiencing growing interest is the use of hydrogen as a clean fuel. Hydrogen can be produced renewably, and can be used to generate electricity, heat or in transport with no emissions. Hydrogen can also act as a storage medium for energy, and can be transported, opening the possibility of a renewables-based energy export market. Australia, with its abundance of solar and wind resources, is well placed to benefit from this future supply chain. Whilst the concept of a 'hydrogen economy' may seem futuristic, globally, the utilisation of hydrogen for energy is gaining significant attraction.

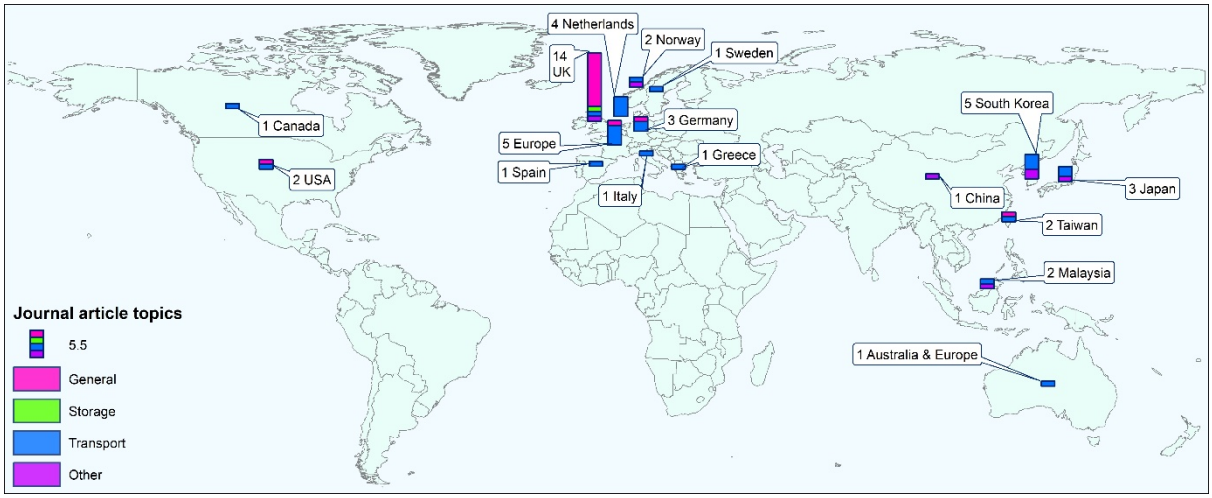
Countries such as Japan and South Korea, that are heavily dependent on imported fossil fuels to meet their energy requirements and have limited capability of producing renewables domestically, see hydrogen as the solution for decarbonising their energy system. Both countries have set aggressive targets for increasing hydrogen use, and together with commercial financing, have made significant investments into the development of their hydrogen industries. Whilst the main focus of hydrogen use in Japan and South Korea is for transport and electricity production, hydrogen can also be used to produce heat. In the United Kingdom, the "h21 Leeds City Gate[2]" project seeks to decarbonise the entire local gas supply for 660,000 people, by converting the natural gas network to 100% hydrogen.

Despite the growing technical and policy focus on hydrogen it remains an emerging technology. As with the deployment of any emerging technology, particularly those that may require public funds to support pre-commercial development, public perception and acceptance is important. Some work has been undertaken to understand the public's current attitude towards hydrogen, and what their key concerns are based on, however the focus of these studies has largely been in Europe (Figure 1) and on hydrogen in the transport sector.[3]

A number of articles studied public attitudes towards hydrogen in a broader context, across multiple applications, however, only one article focused on storage. Several papers were not specific to hydrogen at all, but considered hydrogen in the context of attitudes towards energy technologies, transport policies, or compared with battery electric vehicles (BEVs). Fuel cells were the dominant technology with most applications in transport, one for home use, and one considering multiple applications of fuel cells in the workplace. Three studies considered internal combustion engines, although two of these also examined fuel cells.

[1] Australian Energy Council, Solar Report, January 2018
[2] https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf
[3] 49 papers investigating public attitudes were found with almost half of these assessing the public's perception of hydrogen in the transport sector (n=26). Hydrogen powered buses and cars were studied equally (n=8 each), while hydrogen fuelled shipping was addressed in a single study. Several studies investigated attitudes towards refuelling stations (n=7).

Figure 1: Geographic spread of articles investigating public attitudes to hydrogen



To address the gap in knowledge of public perception of hydrogen for broader energy uses, and its relevance within Australia, this study investigated the Australian public's attitudes to hydrogen. Key themes and findings arising from the existing literature were drawn on to inform the scope of the study, and any quantitative studies were mined for measures to compare with the Australian public.

In addition to ascertaining the public's overall knowledge and understanding of hydrogen and its properties, the research focused on assessing individual responses to the emergent opportunities - export, transport and other domestic uses for energy. The main objectives were to:

- identify the current knowledge and understanding of hydrogen in the Australian public through a literature review,
- ascertain the potential barriers and enablers for the development of a hydrogen industry in Australia,
- understand how these barriers may be influenced by various demographic factors such as age, gender, location, socio-economic status and cultural background,
- test a number of hydrogen industry scenarios with the Australian general public,
- identify policy and regulatory considerations and outline the potential opportunities and challenges that may arise as a result of the public's response to the hydrogen industry scenarios, and
- make recommendations on potential ways for hydrogen projects to ameliorate challenges and build on the opportunities that emerge from this research.

The findings of this study were informed through focus groups studies, conducted in South Australia and Victoria in June, 2018 (see Appendix section A-2), and a national survey, conducted in September, 2018 (see Appendix A-3 and A-4). The results of these studies and the literature review are expanded on in this report.

2. General attitudes towards hydrogen

2.1 Most attitudes are neutral

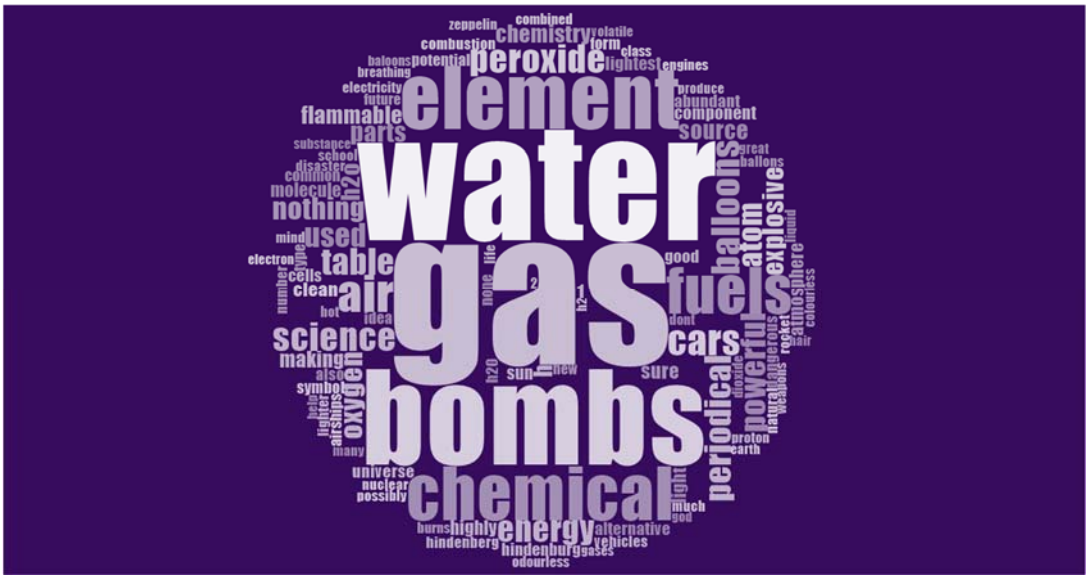
The results of the research indicate that hydrogen does not have a significant, pre-disposed negative association that needs to be overcome. Australian public attitudes appear to be generally neutral, presenting an opportunity to position hydrogen in a positive frame.

From the literature review, many studies began by asking participants for the concepts they associate with hydrogen. In the national survey, responses to the question "*When you hear the word hydrogen what are the first things that come to mind?"* are shown in Figure 2. The most frequently occurring words are depicted by their size in the word cloud with gas, water and bombs being the most common[4]. Neutral responses (e.g. gas, energy, water) were the most common (81%), while 13% were negative (e.g. bomb, explosion, Hindenburg), 3% were positive (e.g. clean, future), and 4% did not know. These responses also reflect the focus group findings where the majority of participants (75%) volunteered neutral associations, 14% negative associations, 7% were positive, and 6% responded that they did not know.

These results agree with the literature where neutral associations with the word "hydrogen" are the most common response. In an earlier study undertaken in Perth associations with hydrogen were mostly neutral (gas, peroxide, fuel, 54%), followed by 23% reporting negative associations (hydrogen bomb, 17% and Hindenburg, 2%), while 7% reported positive associations (clean, environmental) and 15% who did not know[5,6]. Neutral associations were also found in both London and Stavanger populations where the researchers were comparing knowledge and acceptance of hydrogen vehicles and refuelling stations[7], and also in Germany where the research focused on the same topics[8]. Another German study[9] reported that "specific dangers such as explosions or the H2 bomb were seldom mentioned" and only 3% cited safety concerns in a Canadian study[10]. An online survey in the Netherlands (n=406) found 28% associated the word hydrogen with bomb/dangerous/explosion, while only 1% related it to the Zeppelin[11].

[4] Gas N=492, water N=422, bomb N=386
[5] O'Garra, T. 2005. AcceptH2 Full Analysis Report: Comparative Analysis of the Impact of the Hydrogen Bus Trials on Public Awareness, Attitudes and Preferences: a Comparative Study of Four Cities.: Imperial College, London.
[6] Garrity, L. Public Perception and Economic Preferences towards the use of H2FC buses in Perth. Hydrogen and Fuel Cell Futures Conference 12th - 15th September 2004.
[7] Thesen, G. & Langhelle, O. 2008. Awareness, acceptability and attitudes towards hydrogen vehicles and filling stations: A Greater Stavanger case study and comparisons with London. *International Journal of Hydrogen Energy,* 33**,** 5859-5867.
[8] Zimmer, R. & Welke, J. 2012. Let's go green with hydrogen! The general public's perspective. *International Journal of Hydrogen Energy,* 37**,** 17502-17508
[9] Schmidt, A. & Donsback, W. 2016. Acceptance factors of hydrogen and their use by relevant stakeholders and the media. *International Journal of Hydrogen Energy,* 41**,** 4509-4520.
[10] Hickson, A., Phillips, A. & Morales, G. 2007. Public perception related to a hydrogen hybrid internal combustion engine transit bus demonstration and hydrogen fuel. *Energy Policy,* 35**,** 2249-2255.
[11] Montijn-Dorgelo, F. N. H. & Midden, C. J. H. 2008. The role of negative associations and trust in risk perception of new hydrogen systems. *Journal of Risk Research,* 11**,** 659-671.

Figure 2: First things that come to mind when you hear the word hydrogen



2.2 There is limited awareness of hydrogen

The Australian public has limited knowledge of hydrogen properties and its uses, and the survey results indicate that support for hydrogen is directly related to knowledge.

An individual's perceived or actual knowledge has been shown to influence overall acceptance of a technology[12,13,14] and this was also demonstrated in a number of hydrogen studies[15,16]. To test if this also held for the Australian population, early in the survey participants were asked five questions to test their knowledge of the properties of hydrogen (Figure 3). A little more than half of the respondents correctly answered that hydrogen can be stored as a liquid, has no smell and is flammable in air. In total 192 (7%) participants answered all five questions correctly, 447 (16%) four correct and 615 (22%) answered three correct. In total, 1022 (37%) answered less than three correctly and there were 509 (19%) who did not answer any questions correctly. The average score was 2.24 out of 5, or 45%. Males answered more of the 5 knowledge questions correct than females. Those with a Bachelor degree or higher, early adopters of new technology[17] and those born overseas had a greater knowledge than the general sample, while those who subscribed to GreenPower[18] had the highest knowledge scores. Low income earners[19] typically had lower knowledge levels. Queenslanders were most informed, although this was not statistically significant.

Following this, a set of questions investigated participants' familiarity with hydrogen production and its uses, and whether they felt they knew enough about each one to explain it to a friend. Figure 4 shows that participants felt most confident in their knowledge of the production of hydrogen[20]. Similarly, hydrogen fuel

[12] Harris, J., Hassall, M., Muriuki, G., Warnaar-Notschaele, C., McFarland, E. & Ashworth, P. 2018. The demographics of nuclear power: Comparing nuclear experts', scientists' and non-science professionals' views of risks, benefits and values. *Energy Research and Social Science*, *46* 29-39.
[13] Hobman, E.V. & Ashworth, P. 2013. Public support for energy sources and related technologies: the impact of simple information provision. *Energy Policy*, *63* 862-869.
[14] Huijts, N.M.A., Molin, E.J.E. & Steg, L. 2012. Psychological factors influencing sustainable energy technology acceptance: A review-based comprehensive framework. *Renewable and Sustainable Energy Reviews*, vol. 16, no. 1, pp. 525-31
[15] Thesen, G. & Langhelle, O. 2008. Awareness, acceptability and attitudes towards hydrogen vehicles and filling stations: A Greater Stavanger case study and comparisons with London. *International Journal of Hydrogen Energy,* 33**,** 5859-5867.
[16] Ono, K. & Tsunemi, K. 2017. Identification of public acceptance factors with risk perception scales on hydrogen fueling stations in Japan. *International Journal of Hydrogen Energy,* 42**,** 10697-10707.
[17] Based on question to test Rogers (1962) Diffusion of innovations theory
[18] N=108, 4% of the sample
[19] Low income earners < $50,000 gross household income per annum
[20] N=248, 9%

cell vehicles was the use that most participants had heard of[21]. Of the other uses (refuelling stations and various domestic uses) approximately 60% of participants had never heard of any of them. Men were more likely to say they know about it and could describe it to a friend (up to 13%) while less than 5% of females declared this. Those who "could describe it to a friend" generally had higher mean scores[22], however the number of questions they answered correct ranged between 0 and 5.

Figure 3: Objective knowledge of hydrogen properties

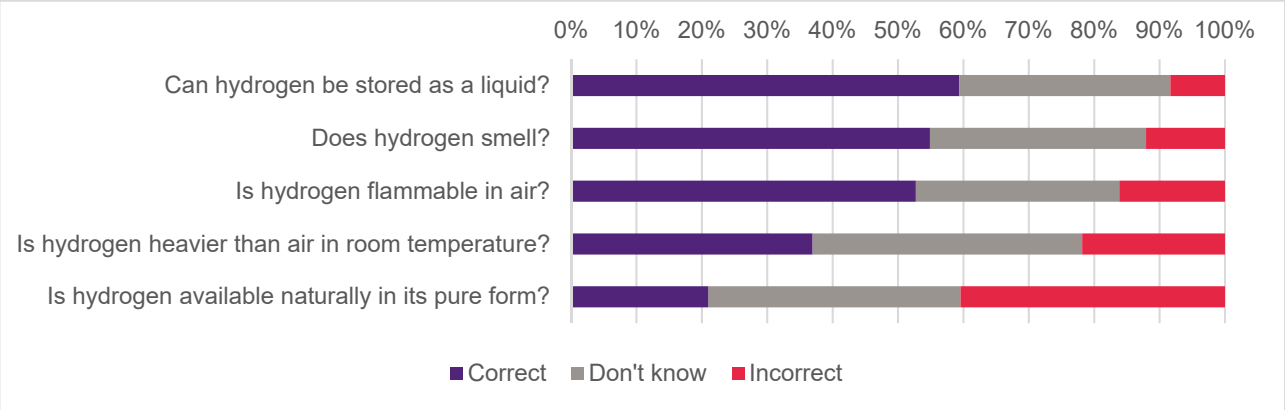
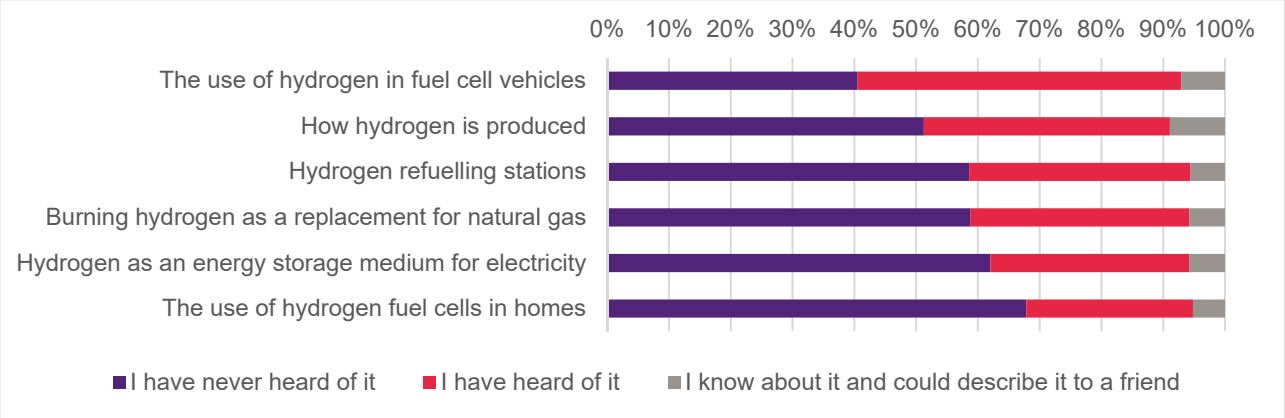


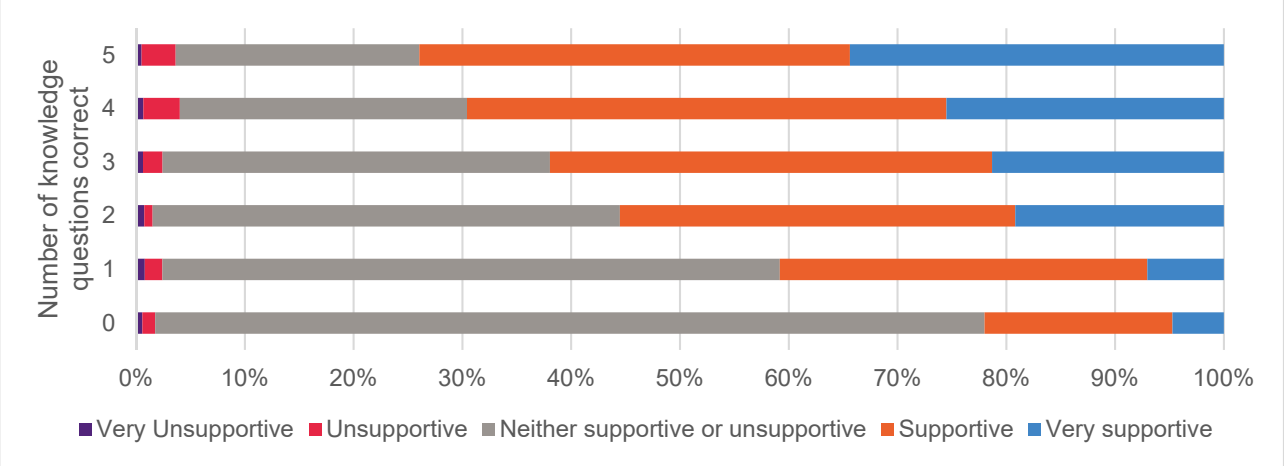
Figure 4: Knowledge of hydrogen production and its uses



Despite the limited knowledge about hydrogen, in response to the question "*Overall how do you feel about hydrogen as a possible solution for energy and environmental challenges",* the majority of participants were supportive (52%) with another 45% neither supportive nor unsupportive. This varied significantly by gender with 65% of males supportive or very supportive compared to only 40% of females. Most females (58%) were neither supportive nor unsupportive versus 32% of males. Support was also strongly dependent on knowledge, that is, those who answered more of the 5 knowledge questions correctly were more supportive, while those who knew less were neither supportive or unsupportive.

[21] N= 1460, 52%
[22] Means ranged from 2.70 to 3.28, compared to the sample average of 2.24 out of 5 questions correct.

Figure 5: Support for hydrogen as a solution to energy and environmental challenges depends on knowledge



2.3 Safety is the main concern

During the focus group discussions safety concerns emerged across all groups. Many focus group participants expressed concern about the volatility and flammable nature of the gas. While there was often someone who noted that other fuels are also flammable and explosive, participants wanted to know the relative risk to conventional fuels.

> *"How explosive it is, is a problem, that's a pretty big con" [FG10]*

> *"What's the worst case scenario if things went wrong?" [FG1]*

> *"Just looking on the aspect of it being volatile, if you actually take any of the fuels, except possibly diesel, they are all volatile to a certain extent."[FG4]*

> *"What about the risk at the plant?" [FG5]*

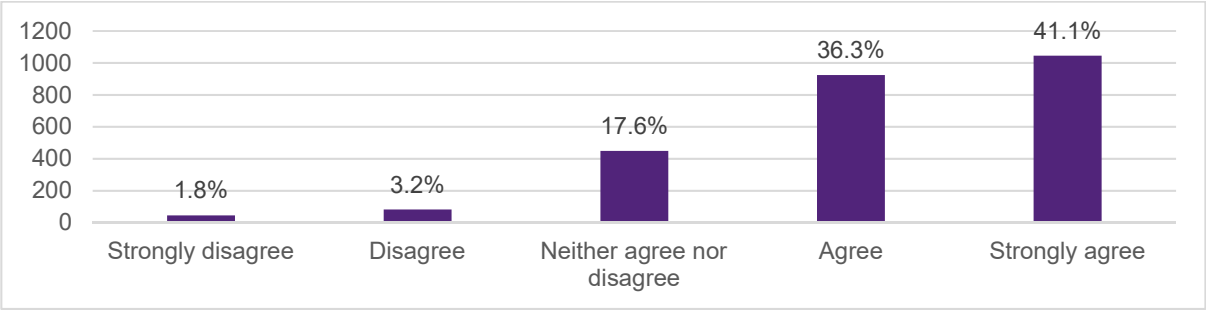
In response to the question "*What are your main concerns associated with the use of hydrogen technologies?"* safety[23] was the most frequently identified concern, with cost[24] the second most common term, which was also reflected in the focus group discussions (Figure 6). Environmental impact was the other major theme that emerged[25], particularly concerns around pollution, emissions and water use. Other less frequently mentioned included concerns around production and transport and the impact on consumers. Some people had no concerns, while others were not sure or did not know enough[26].

[23] safety (i.e. safety, danger, explosions, risk, volatility, flammable, fire, unstable, leaks) N=1517
[24] cost (i.e. cost, price, expensive) N=399
[25] environment (i.e. environment, pollution, emissions and water) N=426
[26] none N=202 and not sure N=496

Figure 6: Key concerns associated with the use of hydrogen technologies

In spite of expressed concerns about safety which occurred in focus groups and across the survey responses, the majority (77%) of the Australia public believe there will be adequate safety precautions to keep the risks under control (Figure 7). Trust in safety controls was greater for early adopters, males, older participants, those from regional areas or with more frequent power outages. However, university graduates and those who were sceptical about climate change[27] were more likely to score this question lower.

Figure 7: Trust in adequate safety precautions around the development of a hydrogen economy



2.4 Environmental benefits are important

In the national survey the main benefits associated with the use of hydrogen technologies centred around the environment (Figure 8). Reduced greenhouse gas emissions and climate change mitigation potential were key benefits. Hydrogen was considered cleaner as a renewable energy, and could help reduce fossil fuel use. Improved air quality was another benefit. People were hopeful that hydrogen may lower energy prices (electricity, gas, cars), and recognised there could be opportunities for jobs, the economy and industry. Some people were unsure of the benefits, while a small fraction thought there were none.

[27] Climate change sceptics include those who do not believe global warming is happening now or will happen, and those who do not know or are not sure

Figure 8: Key benefits associated with the use of hydrogen technologies

Environmental impacts were also identified in the national survey as one of the major concerns associated with hydrogen technologies. During the focus groups, environmental, health and visual impacts were questioned, and people wanted to know more about waste and by-product storage and disposal.

> *"I want to know more about the environmental impacts and what other offsets or derivatives are going to be left" [FG3]*

> *"What's the actual production facility going to be like? Because I know there's a lot of backlash against some renewable ones – people are like, well, I don't want a wind farm next to my house." [FG8]*

> *"…how many years do you keep using coal as a source and what does that do to the environment?" [FG3]*

> *"…I'd have some concerns about safety issues, both environmental and industrial, because it is still a highly volatile gas, and I would hate to see a spark setting off something, so I'd have concerns both about environmental production and also industrial." [FG6]*

Participants also voiced concerns over the water required to produce hydrogen, noting that Australia is the driest continent on Earth with much of the country in drought, while costly desalination plants were often sitting idle.

> *"So water might be an issue for South Australia because we have really so little water." [FG1]*

> *"South Australia is the driest state in the driest continent on Earth" [FG2]*

> *"You are saying renewables with water. Do we currently have a surplus of water in Australia? You ask people in NSW, the farmers, they are fighting over water. If they went down that path, where is that extra water going to come from?" [FG9]*

Most survey and focus group participants (79%) agreed climate change was already occurring or will happen within the next 30 years and is a direct result of human impacts. However, there were some who were sceptical about whether it is man-made, citing volcanic eruptions and other natural cycles. Some thought it

was over-hyped in the media with fear campaigns, while others felt that changing their behaviour would have little impact on a global scale.

> *"I think it is a natural oscillation that happens to the planet, and the amount of affect that we have, compared to natural events, is minimal." [FG6]*

> *"There is definitely changes in how the climate around us is working, certainly. But an overall warming, I wouldn't say I'm seeing any evidence of." [FG10]*

Half of the survey respondents agreed that the use of hydrogen contributes to climate protection, while 40% neither agreed nor disagreed. This was higher for early adopters, younger people, males, those with stronger environmental concerns, living in metro areas, highly educated, subscribed to GreenPower, employed or those born overseas.

2.5 Hydrogen needs to be cost competitive

Less than half of the survey sample would be willing to pay more for hydrogen technologies even if there were clear environmental benefits. Cost was a key issue for the focus group participants. Most discussions came back to the cost to the consumer (vehicle prices, fuel costs, appliance upgrades, electricity costs) as well as cost of production (including desalination, CCS, conversion between physical states) and storage. While many participants felt that the environment was important and were concerned about climate change they were still unwilling to transition to a hydrogen economy if it was felt that it would place unnecessary cost burdens on the Australian society. There was a perception amongst the younger focus groups that there may be generational differences in willingness to pay for environmental benefit, with older people less likely to pay more for or take up new technologies. Cultural and geographic differences were also mentioned.

> *"It's a lovely pipe dream but they need to make it affordable." [FG7]*

To investigate these concepts further, survey participants were asked "*What would you be willing to pay for the use of hydrogen technologies?"* As can be seen below the majority of participants would only be willing to pay if the costs were comparable (40%) or less (15%). However 30% would be willing to pay slightly more if it bought about clear environmental benefits and a few (6%) would pay a lot more if there were clear environmental benefits. Unsurprisingly, GreenPower subscribers were the most willing to pay for environmental benefits. Early adopters and younger people were also more willing to pay as were those with power outages or supply disturbances, or with higher education levels. Those who do not believe in climate change were the least willing to pay (Figure 10), along with low income earners, older people[28], 3rd generation Australians and women. Nine per cent (9%) would not be willing to pay for hydrogen technologies at all. South Australians were the least willing to pay, while those from NSW would pay the most.

[28] Older people = 55+

Figure 9: Willingness to pay for the use of hydrogen technologies

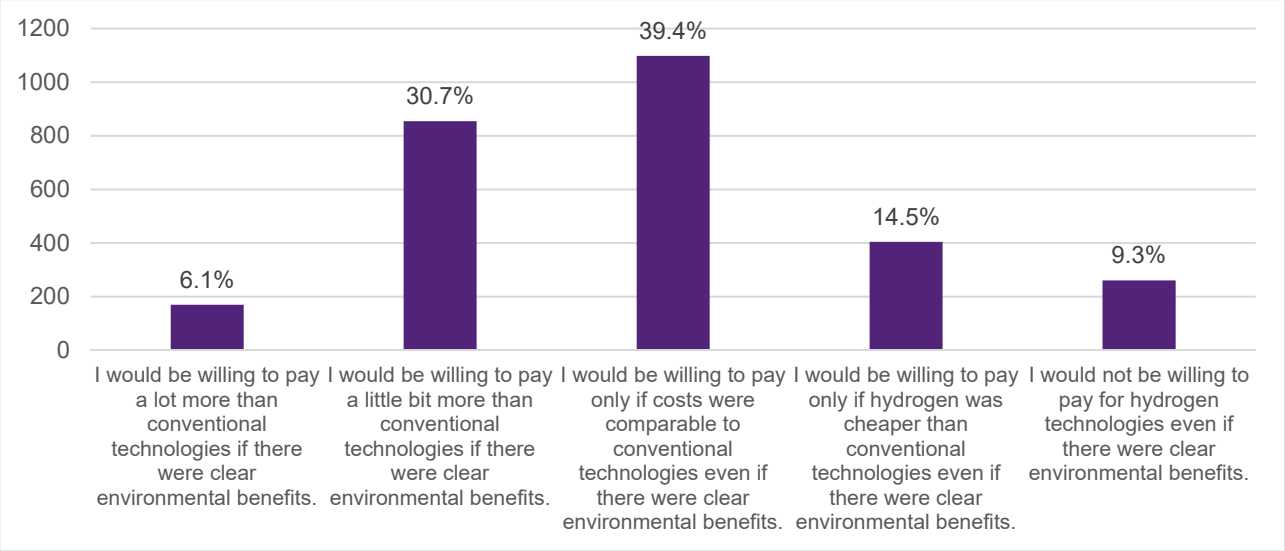


Figure 10: Global warming belief affects willingness to pay

2.6 The source of hydrogen matters

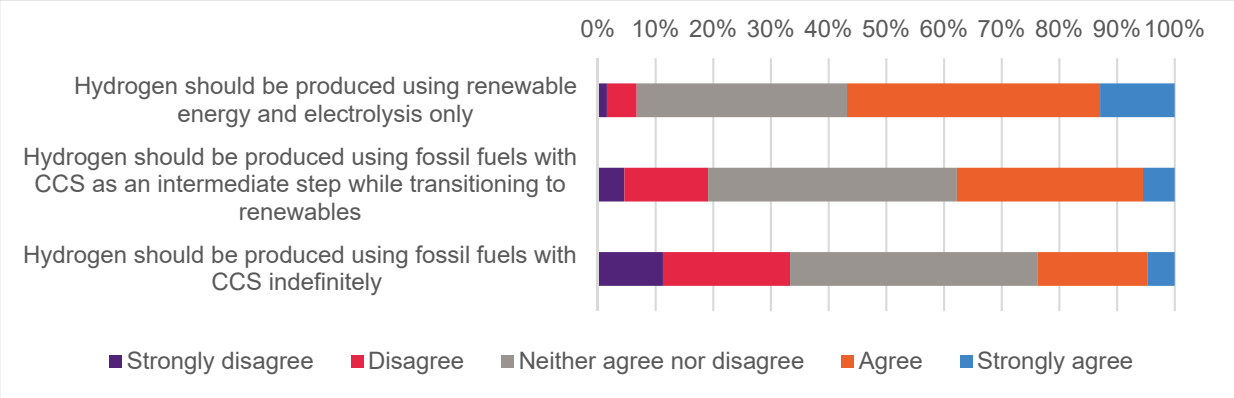
The majority of Australian survey respondents prefer hydrogen production from renewable sources, particularly those with strong environmental beliefs.

In the survey, participants were provided the same general information video[29] that was shown in the focus groups and were then provided with a short description on the ways that hydrogen can be produced. They were then asked their levels of agreement (1=strongly disagree to 5=strongly agree) with a series of statements about the different processes for producing hydrogen (Figure 11). The results show strongest support was for hydrogen being produced using renewable energy and electrolysis only (57%). However, some were accepting of hydrogen being produced using fossil fuels with carbon capture and storage (CCS)

[29] Student energy group. https://www.youtube.com/watch?v=Kv8WT3-7ZHE

as an intermediate step while transitioning to renewables (38%). Only a quarter were prepared to tolerate the production using CCS indefinitely.

Figure 11: Levels of agreement for different production processes



South Australia had the highest support for renewable production, although the difference was not statistically significant (Table 1). Queensland showed the highest support levels for transitioning using fossil fuels with CCS, which was significantly different to South Australia and Western Australia. Victorians had the highest mean for producing hydrogen using fossil fuels with CCS indefinitely, however only 27% of the state was in favour of it. The Australian Capital Territory had the strongest opposition with 45% against using fossil fuels indefinitely.

Table 1: Preferences for hydrogen production by State and Territory

Hydrogen should be produced using…	N	Renewable energy and electrolysis only	Fossil fuels with CCS as an intermediate step while transitioning to renewables	Fossil fuels with CCS indefinitely
NSW	878	3.60	3.20	2.87
Victoria	704	3.63	3.23	**2.88**
Queensland	557	3.60	**3.26**	2.85
South Australia	215	**3.66**	3.10	2.80
Western Australia	289	3.65	3.10	2.72
Tasmania	70	3.61	3.09	2.79
Northern Territory	25	3.36	2.96	2.64
ACT	47	3.60	3.19	2.60

Those with strong environmental beliefs were most in favour of renewables for hydrogen production (73%), although they were also supportive of fossil fuels with CCS as a transition method. Males and those with higher levels of education also rated renewable production higher. Young people (18 – 34) were more supportive of transitioning with fossil fuels and CCS. The results show there is a significant ($p<0.05$) difference in the means for those 55 years and older compare with the rest of the sample, where older people were slightly less supportive of using fossil fuels with CCS as a transition and indefinitely[30]. A similar result occurred when comparing the regional sample where their mean was less than the metropolitan average, which indicated they are less supportive of fossil fuels as a transition[31]. Climate change deniers were less supportive of renewables and more supportive of both transitioning and using fossil fuels with CCS indefinitely. Those suffering from frequent power outages were also more supportive of fossil fuel production. Early adopters showed higher levels of support for all methods of hydrogen production.

Exploring the source of production in the focus groups demonstrated a similar mixed response. Some participants felt very strongly that from an environmental or sustainability perspective production should only be via renewables and that continuing to use coal and other fossil fuels may simply perpetuate the non-renewable market. Others however, thought that using coal with CCS as an intermediate step to kick start the hydrogen industry in Australia may help to reduce costs and/or risks. However, a few were happy to use coal indefinitely and felt that utilising Australia's abundant coal resources, compared to the relative scale of emissions of China and other countries, made sense. However, most participants suggested that the transition from coal to renewables was inevitable. Overall cost of production and environmental impacts were also seen to be critical for the acceptance of either process. There were references to the finite nature of natural resources – in particular fossil fuels, air quality and health impacts of burning coal as reflected in the quotes below:

> *"…regardless of climate change, we should be trying to do renewables anyway." [FG3]*

> *"When you think of brown coal, you think dirty...and if they are trying to use brown coal to actually then extract things, then why would you use something that is actually dangerous to the environment, and then possibly causing more emissions and more harm to the environment?" [FG7]*

> *"The more that we invest in technologies which use non-renewables, like doing our hydrogen through the fossil fuels, we are just perpetuating the market, we are just perpetuating the companies going out there looking for more sources, looking for more coal, looking for more oil, it's feeding it as opposed to saying, ok we don't want to do it anymore, we are moving away from it, let's invest in renewables" [FG8]*

> *"If this is the way forward then that's great, and if we use coal as a means of getting there then I don't have a problem with that either." [FG1]*

> *"It is important to transition obviously from fossil fuels, but in terms of managing risk, it would make sense to do both concurrently until whatever process is appropriate and successful." [FG8]*

> *"…taking care of the environment's good, but as well as that, you can't take care of something else if you can't afford to take care of yourself." [FG10]*

Focus group participants expressed some concerns about the use of carbon capture and storage (CCS) and the risks it may present. The risks included whether CCS would indirectly raise the potential for earthquakes, or contaminate freshwater aquifers. The amount of energy required to implement CCS and the cost to do so were also of concern, alongside an expressed need to locate adequate storage locations.

However, there was a recognition that local production would bring regional benefits through increased opportunities for jobs and services. With the location of renewable resources often in remote or country areas, there were seen to be natural synergies. There was also a concern that new energy industries would

[30] FF+CCS as transition: <55 mean = 3.22; 55+ mean = 3.15 (p=0.034) FF+CCS indefinitely: <55 mean = 2.87; 55+ mean = 2.78 (p=0.015)
[31] FF+CCS as transition: Metro mean = 3.22; Regional mean = 3.14 (p=0.031) FF+CCS indefinitely: Metro mean = 2.89; Regional mean = 2.74 (p=0.000)

cause loss of jobs in existing coal and gas industries. Retraining and upskilling was therefore important to help workers transition between industries. This was particularly important to those living in Traralgon who were clearly suffering after the closure of Hazelwood Power Station.

> *"That's where renewables are, in country areas, so if you link it in with the production of hydrogen power then you get natural synergy" [FG1]*

> *"how many jobs will we lose when we move away from coal as well and how does that weigh up? [FG2]*

> *"…we've lost major stores. Target's gone, supermarkets are going. So, big things like that have affected the retail side and people can't provide for their own families. But there's been a lot of – a lot more families accessing food hampers and extensions on bills, that sort of thing." [FG10]*

Most focus group participants agreed that reducing greenhouse gas emissions was beneficial but questioned how much energy was required to produce hydrogen and what the net benefit would be. There were also discussions around embodied energy, resource use and lifespan, with comparisons to solar panels and batteries.

> *"I think it sounds interesting in that it has potential to carry energy, but it sounds like it uses up energy to get it into its pure form so then you've got to consider how much energy you use to get there in the first place." [FG2]*

> *"…how much energy do you get from hydrogen, related to how much you have to put in?" [FG10]*

> *"It sounds like a good idea, but then when you think about it, there is a lot you need to do with it, and is it going to be a better outcome than we are already doing? Less pollution, greenhouse gases?" [FG8]*

Half (50.5%) of the survey respondents believed that the use of hydrogen contributes to climate protection, while 39.9% neither agreed nor disagreed. This varied by demographic, with males, younger people, early adopters, higher educated, those subscribing to GreenPower, living in metropolitan areas, or born overseas all agreeing more strongly with this idea.

2.7 Research institutions are most trusted to act in the public's interest

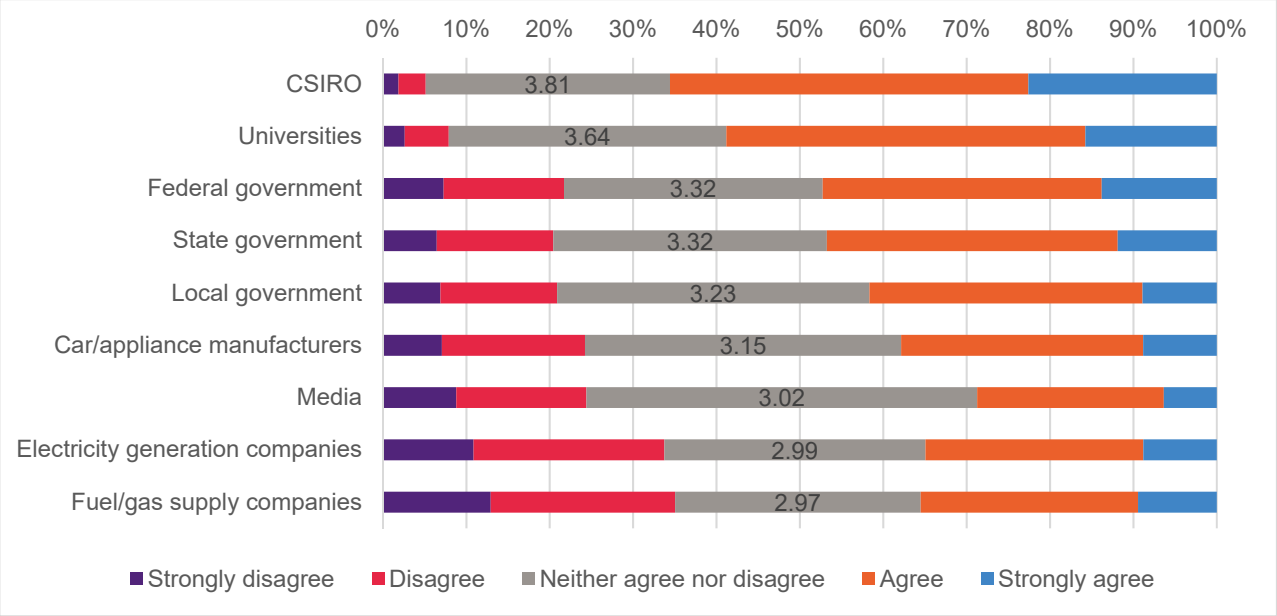
Australians feel that CSIRO and universities are the most trusted institutions to act in the best interest of the consumer, followed by all levels of government.

Gaining a social licence to operate is deemed important for a project's success. The literature suggests that a social licence to operate can be gained over time but is easily lost. Critical to earning a social licence to operate are concepts of trust, procedural and distributive fairness, governance and quality of contact with affected communities[32]. Therefore, judgements about how different stakeholders and institutions are perceived to act form an important consideration for whether a social licence to operate will be granted by communities or not.

In Australia, it appears there is less trust in the media, fuel and gas supply companies and energy generation companies to do the right thing. Based on the discussions in the focus groups this is most likely in response to the negative impressions of the rise in electricity and gas prices coupled with concerns around domestic reserves for gas.

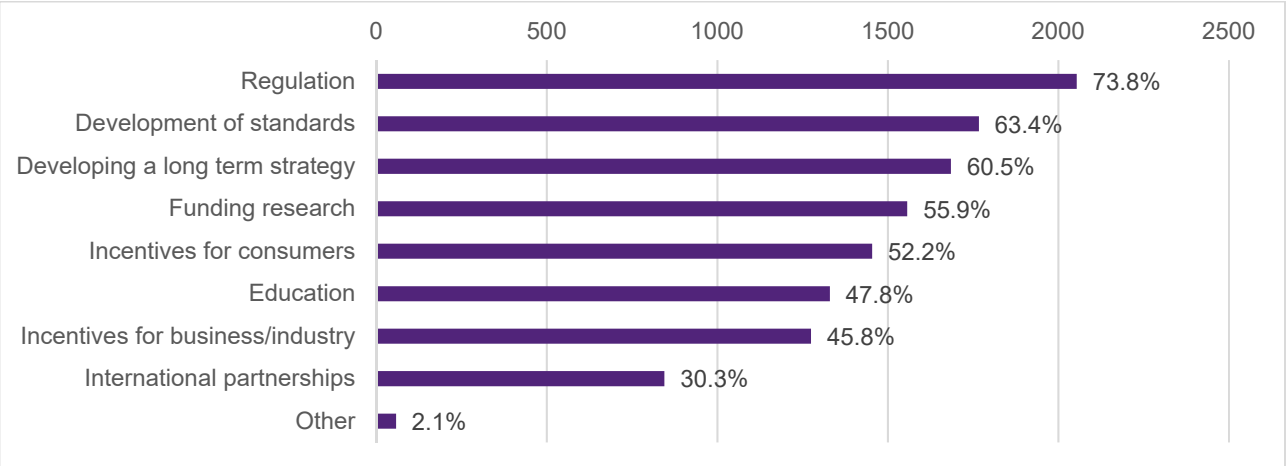
[32] Moffat, K & A. Zhang, 2014, The paths to social licence to operate: An integrative model explaining community acceptance. *Resources Policy* V39. pp 61-70.

Figure 12: Strength of agreement on who will act in the best interest of the consumer



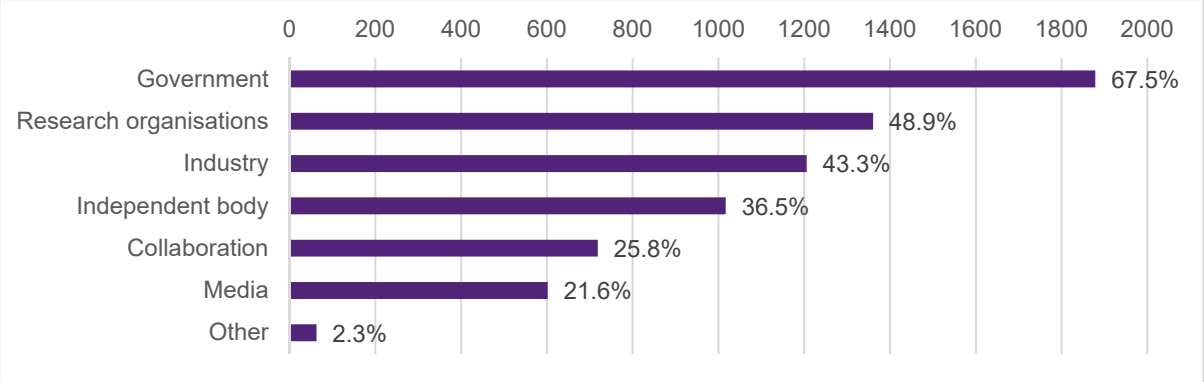
During the focus groups a number of suggestions emerged around the role for government if a hydrogen economy was developed. Further investigating these concepts in the survey, it was clear the major role for government was around ensuring adequate regulations for a hydrogen industry and the development of standards (Figure 13). These concepts echo the concerns for safety, as it is often felt that government regulations will ensure the safe operation of different industries. Other roles deemed important included developing a long-term strategy for hydrogen, continuing to fund research and providing necessary incentives for consumers and businesses.

Figure 13: The role of government in developing a hydrogen economy



Education was also seen to be a role for government. In response to the question *If a hydrogen economy was to be developed in Australia, who should be responsible for disseminating information? (Tick all that apply),* 67% of respondents felt the government and research institutions (49%) should be responsible for disseminating information (Figure 14). However, participants also recognised that industry (43%) has a role to disseminate information. At least one quarter of respondents felt it should be a collaborative approach.

Figure 14: Who should be responsible for disseminating information



3. Export of hydrogen

3.1 Support for export is strong

Export had the highest support levels of all hydrogen applications provide safety, the environment and domestic supply are guaranteed. In the focus groups there was a strong feeling that export production should not take precedence over domestic supply/reserves, with many referencing Australia's gas exports as an example and concerns about the impact on domestic energy prices. Others were concerned about exporting Australia's limited water resources through the manufacture and export of hydrogen, and the waste brine by-product if desalination was used.

> *"Like with your liquid petroleum gas and that, they are exporting more than they're giving to your domestic market, so if you're looking at exporting hydrogen, what guarantees could you make that locally, domestically, you have enough to use?" [FG10]*

> *"If we export this kind of energy using our renewable energy, so our solar and wind, could that possibly make energy more expensive for us?" [FG2]*

> *"Sounds good but I'd be concerned about water." [FG4]*

Focus group participants saw developing an export industry as an opportunity for innovation but noted how Australia has sold off innovative solutions or products, or fallen behind, in the past, so it was seen as important to keep knowledge and intellectual property local to ensure benefits for Australia. Export opportunities were also seen to be threatened by competition from other countries who may be able to make hydrogen cheaper with lower wages, cheaper energy prices, and less regulation. There were queries about scale of production, whether we could meet demand (both international and local), and how quickly production could be ramped up. Transport by ammonia raised some additional questions such as the efficiencies and cost associated with conversion here and back to the destination, and whether there would be environmental or other impacts from accidents at sea. Generally the participants recognised there would be economic benefits from exporting hydrogen and additional benefits could be gained through economies of scale bought about by a large scale export market. Maintaining strong international trade relationships with countries was also seen to be valuable.

> *"We are uniquely positioned for renewables here so why wouldn't we be producing for ourselves and for export?" [FG1]*

> *"As long as it is not a strain on our natural resources, like water or anything else, it would make great economic sense." [FG2]*

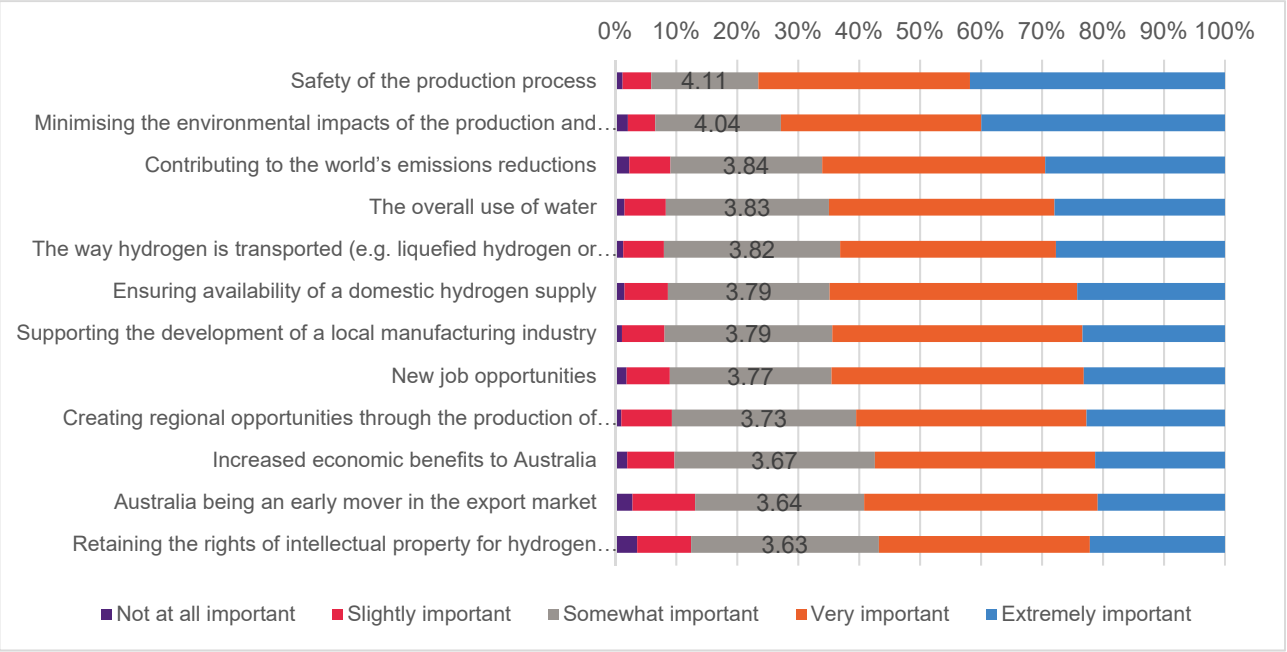
"There's always going to be a need for energy, so if we can get into that market, it's boundless what we can get out of it." [FG8]

"Certainly if we are exporting to Japan we start to get advantages of scale that makes whatever energy we use a bit cheaper for us to step into it." [FG1]

From the survey Stream C: Export participants[33] there were very few (5%) who opposed the export of hydrogen with most (72%) supportive. In contrast, only 38% were also happy to have a hydrogen export facility built near them, with 22% opposed. Early adopters, males and those with a university education were more supportive of both export and hosting a facility nearby. Those experiencing frequent power outages and younger people were more supportive of a plant being built near them. Safety and environmental impacts of the production and transport process were of highest concern (Figure 15).

These priority areas also reflected the focus group discussions with considerations about the water required for export, the opportunities such an industry might bring to regional communities and the obvious economic benefits to Australia more broadly. Women rated concerns for safety, environmental impacts and water use higher than men. Contributing to the world's emissions reductions was of higher importance for younger people, on par with their importance of safety. Environmental impacts of export were also considered to be of higher importance by those born overseas.

Figure 15: Important considerations for Australia exporting hydrogen.



[33] N=916

4. Hydrogen in the transport sector

4.1 Public transport and long haul hydrogen vehicles could help build confidence

Hydrogen fuel cells power a range of vehicles including cars, buses, trucks, forklifts and even trains. As fuel cell electric vehicles emit no carbon emissions and only produce water vapour as a by-product, they present an attractive option for countries who are experiencing high pollution from transport. For example, South Korea where air pollution from diesel exhaust is a growing problem. Associated with this, results from 1000 interviews conducted in South Korea found that householders were willing to pay additional income tax to expand hydrogen stations in the country[34]. Similarly, residents of Perugia, Italy, where air pollution has damaged historic buildings, were willing to pay extra for the introduction of hydrogen buses[35].

When discussing hydrogen transport options, Australian focus group participants felt that rolling out hydrogen fuel cell buses as a first step for fuel cell electric vehicle deployment would be a good way to increase familiarity with the technology. Deploying hydrogen public transport vehicles before personal vehicles was thought as a positive way to demonstrate the safe use of hydrogen and build confidence in the technology. At the same time it would allow any issues to be ironed out before rolling out the required infrastructure on a large scale to support more domestic use. However, while participants thought it would be a cleaner option than current public transport options and therefore more attractive, safety and cost implications were still essential for their introduction and acceptance.

> *"I think it is a good idea for public transport to start with hydrogen before even the public do. That is probably a good transition" [FG2]*

> *"I feel trucks and probably public transport is a starting point and then once that seems to be working individuals would be more likely to take it up after that" [FG8]*

> *"Convincing the general public because if a lot of people have got doubts and they might be hesitant about putting it forward or using public transport or whatever if there's that risk." [FG7]*

> *"Health-wise for the whole world would be brilliant." [FG4]*

While long haul trucks were also considered to be a good idea, safety issues were raised more often when discussing this type of transport compared to buses. Whilst one person thought their use might raise the cost of goods due to the vehicle transition costs, others thought hydrogen fuel prices might be more stable compared with fluctuations in oil and petrol prices which would be driven by the finite nature of fossil fuel reserves.

> *"Because I reckon there's more…trucks transporting now and they reckon it's going to get busier and busier. You don't want bombs travelling on the road." [FG4]*

> *"If two trucks collide, what's going to happen?" [FG5]*

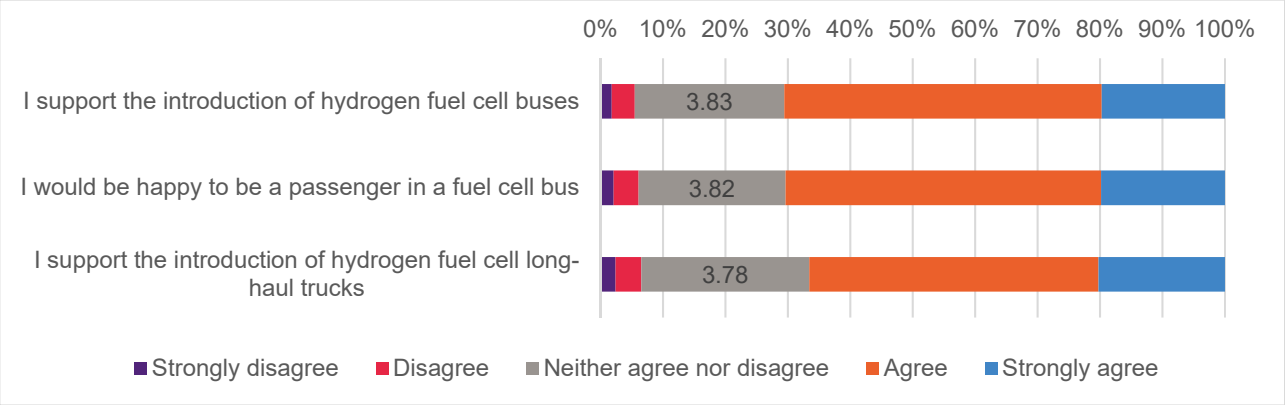
> *"It has the potential, like whenever supermarkets put their prices up on things it's because of the transport costs, or so they claim, so if you can have cheaper transport, then it might keep those food prices and other prices..." [FG1]*

Those survey participants who completed Stream A: Transport[36] expressed positive support (1=strongly disagree to 5=strongly agree) for the introduction of the use of hydrogen fuel cell buses and long-haul trucks. Equally they reported being happy to be a passenger on a fuel cell bus, similar to the results reported in the

[34] Yang, H. J., Cho, Y. & Yoo, S. H. 2017. Public willingness to pay for hydrogen stations expansion policy in Korea: Results of a contingent valuation survey. *International Journal of Hydrogen Energy,* 42**,** 10739-10746.
[35] Bigerna, S. & Polinori, P. 2015. Willingness to Pay and Public Acceptance for Hydrogen Buses: A Case Study of Perugia. *Sustainability,* 7**,** 13270-13289.
[36] N=948

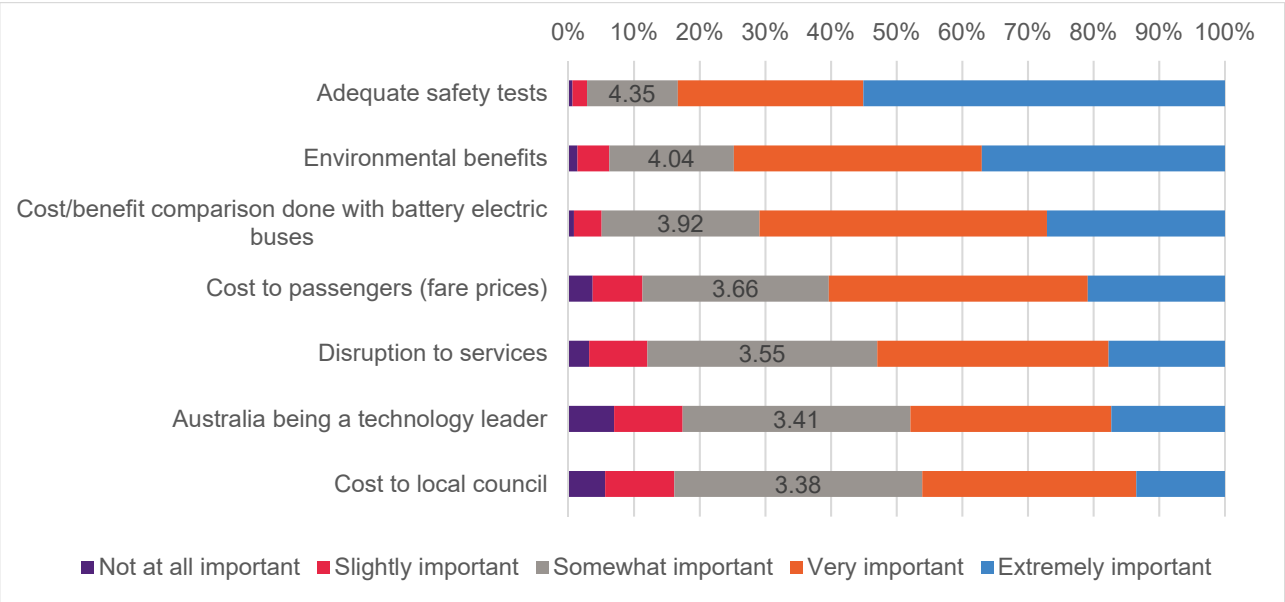
literature review (Figure 16). However, females expressed lower support for fuel cell buses and trucks than males.

Figure 16: Support for fuel cell buses and long haul trucks



Using the Likert scale, 1=not at all important to 5=extremely important, as with the focus groups, safety and environmental benefits remained paramount to Australian survey participants when considering the introduction of hydrogen fuel cell buses. Cost considerations were the third most important, including both the cost benefit comparison with battery electric vehicles and the anticipated fare costs to passengers utilising hydrogen buses. Participants felt that reliability, Australia being a technology leader and local council costs were considered less important factors for the introduction of hydrogen buses. Older people had higher concerns about safety and Australia being a technology leader but were less worried about fare prices[37]. This maybe because many may pay a lower fare as a senior, or perhaps do not use public transport very often. Fare prices were of higher importance to employed[38] respondents, those with a university degree and those born overseas. The importance of safety was lower for early adopters.

Figure 17: Factors determining support for the introduction of hydrogen fuel cell buses



[37] Cost to passengers (fare prices) <55 mean = 3.75; 55+ mean = 3.51 (p=0.001)
[38] Employed includes full and part time employment

These results agree with other studies that emerged from the literature review, including the HyFLEET:CUTE study[39] associated with the Clean Urban Transport for Europe (CUTE) project - a small trial of fuel cell-powered buses (27) in nine European cities[40]. Comparing results from interviewer led surveys conducted across 8 different cities: Amsterdam, Barcelona, Berlin, Hamburg, London, Luxembourg, Madrid and Reykjavik; with over 300 respondents in each city (N=3352). On average, 68% expressed support for replacing conventional buses with hydrogen buses, although this ranged across cities from between 52% in Amsterdam to 89% in Madrid. The majority of respondents (77%) said they would ride a hydrogen bus over a conventional one if the same conditions (ride, time, ticket price) were maintained (with a range of 73% to 90%).

Similarly, in a Canadian study documenting bus passenger experiences on board a hydrogen hybrid internal combustion engine bus, the performance was perceived as superior to a normal diesel bus in all categories (ride comfort, smoothness of acceleration, smoothness of stopping, noise level, temperature comfort)[41]. Ninety two per cent (92%) of those surveyed thought hydrogen fuel was a good idea. However, males were more strongly in favour than females (75% males thought it was a "very" good idea versus 55% of females).

The AcceptH2 study, conducted across four different cities (Berlin, London, Luxembourg and Perth), found over 90% acceptance towards fuel cell bus trials[42]. In all cities it was found that initially 56% of participants had heard of hydrogen vehicles, with Berlin residents being the most informed (72%)[43]. Surveys conducted after the trials found average support for the introduction of hydrogen powered vehicles rose from 46% to 67%. However, the Perth sample were more cautious with support growing from 30% to 51%, with a further 42% offering conditional support.

4.2 Fuel cell cars are preferred if the price is right

If the cost was the same as their current vehicle, 61% of Stream A: Transport survey respondents would be happy to buy a hydrogen fuel cell vehicle. Younger people, early adopters, those with a degree or living in metropolitan areas showed even higher levels of support.

In the focus groups questions were first focused on safety, particularly related to accidents and collisions. Concerns included leaks, ruptures, fires, and explosions. It was important for participants to know that hydrogen was no more or less safe than conventional fuels, and that extensive safety testing was conducted (e.g. bullet tests). Comparisons with conventional fuel flammability was also often raised.

> *"Bottom line, if you are in a catastrophic accident in a car, that's [hydrogen] as opposed to [petrol], what's your survivability?" [FG1]*

> *"…if you're involved in a car crash and your car catches on fire, isn't there a risk of you basically going kaboom?" [FG7]*

> *"…petrol's flammable, gas is flammable, we use that every day"[FG2]*

Several groups mentioned that people tend to have a fear of the unknown, and do not like change, but this tends to diminish with familiarity. The demonstrated uptake in other countries, as shown in the Hydrogen Mobility handout, was reassuring for most focus group participants.

> *"I look at this map and I see Japan, Germany, US and all those leading nations are obviously taking the lead and going for it and adopting the method, so I don't see why we wouldn't do it." [FG3]*

[39] Heinz, B. & Erdmann, G. 2008. Dynamic effects on the acceptance of hydrogen technologies - an international comparison. *International Journal of Hydrogen Energy,* 33**,** 3004-3008.
[40] http://www.eltis.org/discover/case-studies/testing-fuel-cell-buses-amsterdam-netherlands
[41] Hicksom, A., Phillips, A. & Morales, G. 2007. Public perception related to a hydrogen hybrid internal combustion engine transit bus demonstration and hydrogen fuel. *Energy Policy,* 35**,** 2249-2255.
[42] O'Garra, T. 2005. AcceptH2 Full Analysis Report: Comparative Analysis of the Impact of the Hydrogen Bus Trials on Public Awareness, Attitudes and Preferences: a Comparative Study of Four Cities.: Imperial College, London.
[43] O'Garra, T., Mourato, S., Garrity, L., Schmidt, P., Beerenwinkel, A., Altmann, M., Hart, D., Graesel, C. & Whitehouse, S. 2007. Is the public willing to pay for hydrogen buses? A comparative study of preferences in four cities. *Energy Policy,* 35**,** 3630-3642.

Cost was the next biggest issue. The cost to purchase a hydrogen vehicle compared to an internal combustion engine or battery electric vehicle was discussed at length. There was recognition of economies of scale and that prices will be high in the early stages, and that incentives may help to make these vehicles more affordable.

> *"Most people can't even afford electric cars yet." [FG1]*

> *"It's a lovely pipe dream but they need to make it affordable because if they're going and saying, "Hey, we've got this great new energy source and it's great for the environment, it's cheap, it's easy," but then they put out a car that's like $80,000." [FG7]*

> *"That's like everything else, when you first come out with something it's so expensive but as the years go by it gets cheaper and cheaper." [FG4]*

> *"Yeah, there would have to be sort of a government incentive and initiative to sort of upgrade your car, like a trade-in" [FG10]*

Participants also wanted to know how much it would cost to refill relative to conventional fuels, and whether it would help reduce reliance on fossil fuel reserves and potentially lead to more stable prices for fuels.

> *"…you'd want to think that if you were spending more money on the car itself that – that initial outlay would then be mitigated by the fact that each time you're filling up you're saving money" [FG8]*

> *"I think it sounds like a good thing. I think the problem will be, especially with vehicles, the price of vehicle, cost of actually purchasing at the pump. People look at cost at the end of the day." [FG1]*

> *"It all gets down to cost, and probably the convenience of it as well" [FG2]*

Performance of the vehicle (torque, efficiency, power) was important to some. Comparisons between hydrogen fuel cell vehicles and battery electric vehicles included cost, range, refuelling, embodied energy, and lifespan. A couple of people noted that battery electric vehicles were not necessarily clean, particularly while electricity for recharging was still predominantly coal-fired. A few people queried whether hydrogen vehicles would overtake battery electric vehicles. With the only tail pipe emissions being water, the elimination of greenhouse gases and reduced air pollution were definite benefits. While low noise was generally seen as a positive, some considered a silent engine to be an issue for pedestrians, particularly children.

> *"I mean the problem is the distance. I mean I just went and looked at the latest BMW electric and it's still got distance issues." [FG6]*

> *"…the longer travel range, that's very appealing" [FG2]*

> *"Certainly the charge time or fill up time sounds much better. It's not as though you can pull into a service station and charge up, not in three minutes." [FG1]*

> *"The best factor is there are no greenhouse emissions, that'd be your number one factor at the moment." [FG1]*

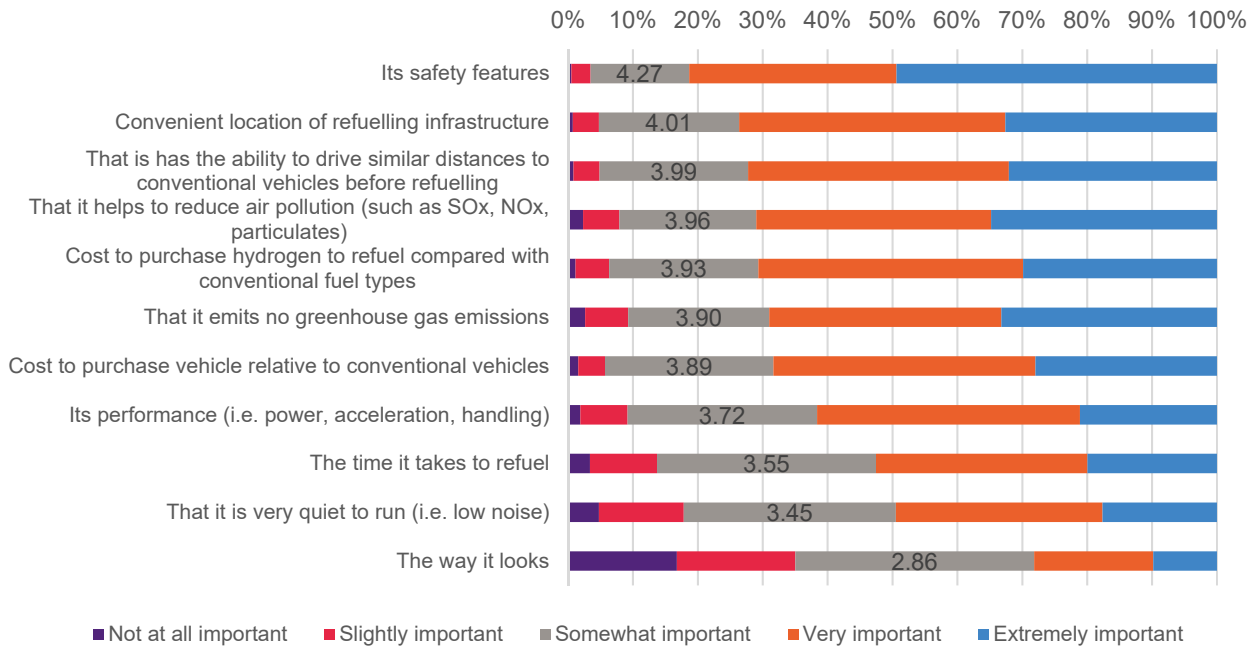
> *"It would be obviously better than some of our other sources, as an energy source, if it's only putting out water vapour." [FG9]*

Reiterating the findings from the focus group discussions, on a scale of 1=not at all important to 5=extremely important, Stream A survey participants[44] were most concerned about safety, convenience of refuelling infrastructure, range, environmental benefits and costs (Figure 18). Aesthetics and performance were deemed less important overall with the way the car looks being considered the least important, although this was ranked slightly higher by younger people and early adopters. Safety, fuel cost and registration costs were more important to older people. Women rated safety, greenhouse gas emissions and performance as

[44] N=948

more important than men. Convenient refuelling, range, air pollution, greenhouse gas emissions and power were more important in regional areas than cities.

Figure 18: Relative importance of factors determining purchase of a fuel cell vehicle

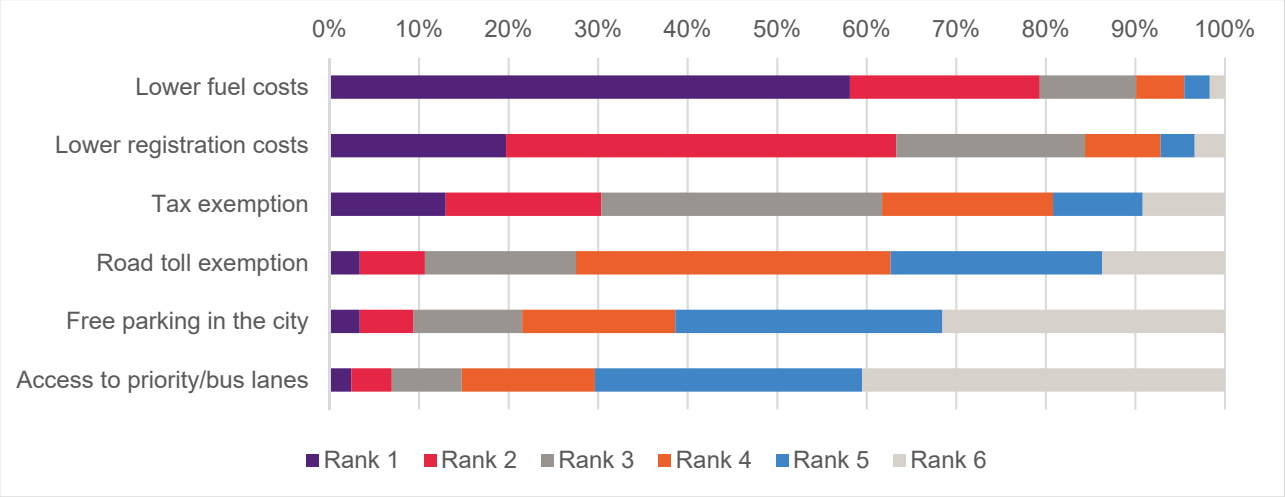


Stream A participants ranked a range of incentives that might influence their motivation to purchase a fuel cell vehicle, where 1 was most important and 6 was not at all important. Participants clearly identified the incentives that immediately impacted their hip pocket on a regular basis were most important – lower fuel costs and lower registration costs. These were followed by tax and road toll exemptions with convenience factors considered much less important (Table 2 & Figure 19). Fuel and registration costs were ranked even higher by older people and those in the regions. Younger people ranked free parking in the city more highly than the general population.

Table 2: Combined rankings of government incentives to motivate purchase of fuel cell vehicles

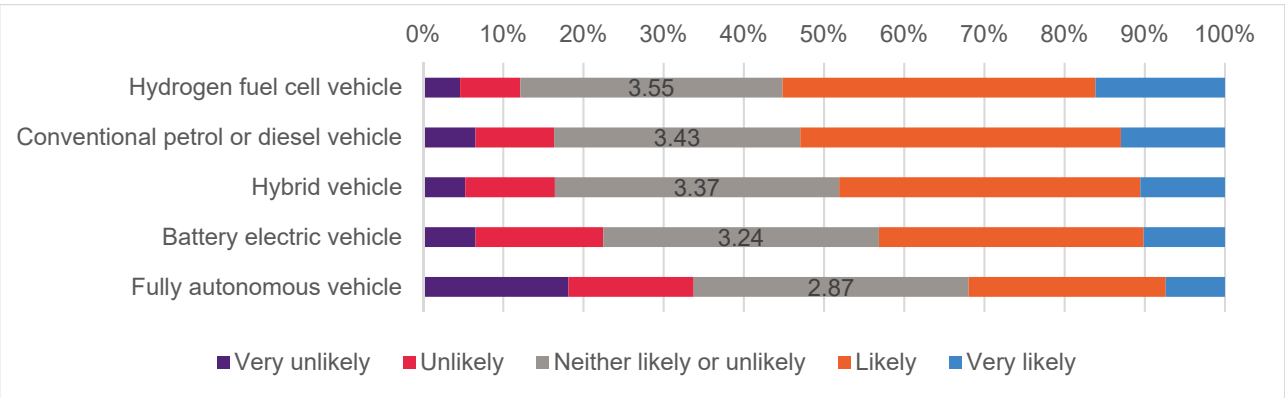
Incentive Type:	N	Min	Max	Mean	St Dev.
Lower fuel costs	948	1	6	1.79	1.177
Lower registration costs	948	1	6	2.43	1.201
Tax exemption	948	1	6	3.23	1.435
Road toll exemption	948	1	6	4.09	1.241
Free parking in the city	948	1	6	4.59	1.372
Access to priority/bus lanes	948	1	6	4.87	1.283

Figure 19: Ranking of government incentives to motivate purchase of fuel cell vehicle



When the Australian public was asked about the likelihood of purchasing different vehicles with all other features being constant, (i.e. price, features, design, and brand), Stream A survey participants rated the fuel cell vehicle over conventional petrol or diesel vehicles, followed by hybrid and battery electric vehicles (Figure 20). While there is likely to be some response bias in their answers, given the survey focused on hydrogen, the results reflect the focus group discussions with many individuals happy to transition for improved environmental outcomes. Others prefer to maintain the status quo of conventional vehicles until other vehicles became more well-known and accepted. However, the price of the vehicle compared to conventional vehicles is likely to be a deal breaker for many as seen in responses to that question in Figure 18 above. Early adopters of new technology, younger people and those with degrees were more likely to purchase all of the non-conventional vehicle types. The biggest difference was with autonomous vehicles which were least preferred. Overseas born respondents were more likely to buy a hybrid vehicle than those born in Australia. Those on low incomes were less likely to purchase any vehicle type.

Figure 20: Comparison of vehicle choices



When asked to explain the reason for their vehicle preferences, the hydrogen fuel cell vehicle was considered the most environmentally friendly option, and was the most preferred provided it was also affordable and thoroughly tested to be safe. Conventional vehicles are familiar and considered to be proven technology, with cost, convenience, safety and reliability other reasons for this choice. Hybrid vehicles were considered to be environmentally friendly, affordable, safe and proven. Battery electric vehicles were preferred for environmental reasons, cost and safety. Those in favour of autonomous vehicles see it as the way of the future, with low cost and environmental impacts coupled with improved safety and efficiency. It is also the vehicle of preference for those who cannot or do not like to drive. Others did not trust autonomous vehicles, and preferred to retain driving control.

There were a number of international studies that examined perceptions of the use of fuel cell electric vehicles for personal use and also compared them with battery electric vehicles. It appears there are mixed responses and a number of factors will influence the ultimate decision of consumers to purchase a fuel cell vehicle. For example, in a UK focus group, participants decided that technological improvements for fuel cell vehicles would overcome disadvantages such as length of time to fill up, tank size and range compared to conventional vehicles[45]. While in South Korea, performance, purchasing cost and running cost of fuel cell vehicles were significant factors influencing purchasing intentions, along with psychological motivation[46]. The authors suggest that without addressing vehicle performance, the government program "low carbon, green growth" will not be effective at stimulating customers to purchase hydrogen vehicles.

Competition with battery electric vehicles has also been identified as a major challenge facing fuel cell vehicles[47,48]. A UK study reported results from fuel cell vehicle trials at a low carbon vehicle event, which found that the fuel cell vehicles were considered superior to battery electric vehicles for range and refuelling time, however were similar to battery electric vehicles in performance, fuel economy, environmental impacts, image/looks and brand, and inferior for purchase price and running costs**Error! Bookmark not defined.**.

A Finnish study investigating the public acceptance of biofuels found that 60% of respondents thought the ideal fuel for their car would be electricity[49]. Twenty per cent (20%) nominated hydrogen and the remaining 20% supported hybrid vehicles. In contrast, Norwegians were more supportive of hydrogen, with 35% of respondents selecting hydrogen as the most environmentally friendly vehicle for them, with electric vehicles second at 21%[50]. A Spanish study identified cost and technical issues (such as availability of refuelling stations, vehicle features) as key barriers to hydrogen vehicle success[51].

4.3 Convenient refuelling is paramount

Convenience of refuelling infrastructure is considered one of the most important factors in determining whether to purchase a fuel cell vehicle, second only to safety.

By 2017, the number of global refuelling stations had risen to 270, with 2 in Australia (Hydrogen Mobility): one at the Hyundai Sydney headquarters, and a portable refuelling station for Toyota's three demonstration Mirai hydrogen cars. Hyundai and Toyota are making significant investments in laying the foundation for the introduction of FCEVs to the country, including displays and demonstrations nationwide as well as testing and tuning of vehicles to Australian conditions in preparation for the first commercial launch of an FCEV in Australia in late 2018 (the Hyundai NEXO)[52].

In the survey, Stream A participants showed strong support for the implementation of hydrogen refuelling stations and bowsers, with only slight hesitancy over them being built nearby (Figure 21). Support for refuelling stations nearby was highest for those who subscribed to GreenPower, were early adopters of technology, the younger generation, males, those with a university education and people in employment. Older people and those who were on lower incomes were less supportive of a refuelling station being built near them.

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[45] Bellaby, P., Upham, P., Flynn, R. & Ricci, M. 2016. Unfamiliar fuel: How the UK public views the infrastructure required to supply hydrogen for road transport. *International Journal of Hydrogen Energy,* 41**,** 6534-6543.

[46] Kang, M. J. & Park, H. 2011. Impact of experience on government policy toward acceptance of hydrogen fuel cell vehicles in Korea. *Energy Policy,* 39**,** 3465-3475.

[47] Hardman, S., Chandan, A., Shiu, E. & Steinberger-Wilckens, R. 2016. Consumer attitudes to fuel cell vehicles post trial in the United Kingdom. *International Journal of Hydrogen Energy,* 41**,** 6171-6179.

[48] Hanley, E. S., Deane, J. P. & Gallachoir, B. P. O. 2018. The role of hydrogen in low carbon energy futures-A review of existing perspectives. *Renewable & Sustainable Energy Reviews,* 82**,** 3027-3045.

[49] Moula, M. M. E. 2017. Public acceptance of biofuels in the transport sector in Finland. *International Journal of Sustainable Built Environment,* 6**,** 434-441.

[50] Tarigan, A. K. M., Bayer, S. B., Langhelle, O. & Thesen, G. 2012. Estimating determinants of public acceptance of hydrogen vehicles and refuelling stations in greater Stavanger. *International Journal of Hydrogen Energy,* 37**,** 6063-6073.

[51] Iribarren, D., Martin-Gamboa, M., Manzano, J. & Dufour, J. 2016. Assessing the social acceptance of hydrogen for transportation in Spain: An unintentional focus on target population for a potential hydrogen economy. *International Journal of Hydrogen Energy,* 41**,** 5203-5208.

[52] https://docs.wixstatic.com/ugd/ee7380_167e5c4ef9254c4b80da51b2599156e5.pdf

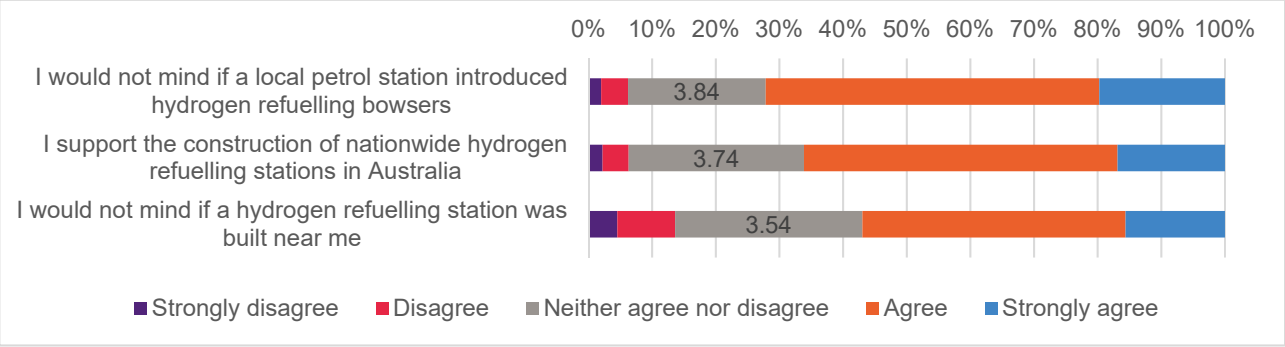
The focus groups shed more light on these preferences as convenience, including number of and proximity of refuelling stations and time to refuel, was paramount with many comparing the difficulty in finding recharge points for battery electric vehicles. Participants were also interested in the potential timeframes for rolling out hydrogen refuelling station infrastructure and whether they could be installed at existing fuel stations. The extent and cost of building an infrastructure network in Australia compared to other smaller countries implementing either battery recharge infrastructure or hydrogen refuelling stations was also raised. Some participants were interested to know how hydrogen would be stored at the refuelling station and thought that reduced potential for environment damage from spills or leaks at refuelling stations compared to petrol was a benefit.

> *"It's got to be convenient and easy as well. People will quite often…even if some things are on parity as far as cost and everything, if it's not an easy process then people don't always want to take it up." [FG8]*

> *"…with the electric cars there was a huge uproar when it came to travelling interstate and things because you couldn't recharge so they had to start putting in charge stations and then money and infrastructure and all that stuff comes into it..." [FG2]*

> *"Filling infrastructure: so possibly in areas that have got greater population density, than large parts of Australia, it would be easier to set up that sort of infrastructure, to put in all new filling infrastructure could be expensive."[FG4]*

Figure 21: Support for refuelling stations and national infrastructure



In the literature review, a lack of refuelling infrastructure and cost were identified in a UK study as barriers to adoption of fuel cell vehicles[53]. In a separate Spanish study[54] using an online survey (n=1005), a high level (71%) of awareness of hydrogen as a transport fuel was found. Forty three percent (43%) were accepting of local hydrogen refuelling stations, with a further 54% supportive if they were located away from residential areas. However, there were mixed responses in relation to the production of hydrogen, where 41% supported on site production of hydrogen at refuelling stations while 27% preferred centralised production. Fifteen percent (15%) said they would not purchase a hydrogen fuel cell vehicle until better infrastructure was available, while 63% would await mass market penetration.

Another Spanish study found that refuelling stations close to home (less than 10 minutes away) and the number of stations available (10 to 20% of conventional stations) were very important considerations in the decision to switch to alternative fuels[55]. Five and a half percent (5.5%) of drivers (older age and lower education levels) were reluctant to purchase an alternative fuel, because they lacked confidence in the alternative fuels.

[53] Hardman, S., Chandan, A., Shiu, E. & Steinberger-Wilckens, R. 2016. Consumer attitudes to fuel cell vehicles post trial in the United Kingdom. *International Journal of Hydrogen Energy,* 41**,** 6171-6179.
[54] Iribarren, D., Martin-Gamboa, M., Manzano, J. & Dufour, J. 2016. Assessing the social acceptance of hydrogen for transportation in Spain: An unintentional focus on target population for a potential hydrogen economy. *International Journal of Hydrogen Energy,* 41**,** 5203-5208.
[55] Brey, J. J., Brey, R. & Carazo, A. F. 2017. Eliciting preferences on the design of hydrogen refueling infrastructure. *International Journal of Hydrogen Energy,* 42**,** 13382-13388.

In the Stavanger “Back Yard” project - defined as those living within 1 km of an existing hydrogen refuelling station - there was no evidence of the Not In My Back Yard (NIMBY) attitude[56]. In fact those living locally were more supportive than the Greater Stavanger sample. Positive “framing” was proposed as a key factor in determining the public’s very supportive attitude. The hydrogen refuelling station had received some positive media attention as a regional success story at the scientific and environmental forefront, and it is believed this encouraged local ownership of the project and elicited high levels of support.

[56] Thesen, G. & Langhelle, O. 2008. Awareness, acceptability and attitudes towards hydrogen vehicles and filling stations: A Greater Stavanger case study and comparisons with London. *International Journal of Hydrogen Energy,* 33**,** 5859-5867.

5. Hydrogen for domestic use

5.1 Hydrogen in the home must be safe

While safety is identified in the survey as the number one priority for all hydrogen applications, this is particularly true for domestic use. Most people rate safety in the home as extremely important (Figure 23).

The focus group participants' support for domestic hydrogen grew when they saw the video excerpt of the *Leeds City Gate h21*[57] project in the UK. Safety concerns remained paramount. However, some participants recalled concerns being expressed prior to the switch to town gas in Australia, but noted that everyone quickly became accepting of it. Gas was considered to offer better control for cooking than electricity, and instant hot water was also considered a benefit. Others felt that hydrogen would not be any different to natural gas but the invisible flame was a safety concern (burns, cooking control). As well, participants felt the lack of odour could present a problem if a hydrogen appliance was accidentally left on. The high flammability was a concern and participants were interested in any associated health impacts from using hydrogen in the home.

> *"And obviously, hydrogen's quite dangerous. Is it like, as dangerous as other – like, as having gas at the moment? Or is it going to be like, more dangerous because it's more flammable and the higher percentage we get up, is it going to get more dangerous?"*

> *"Yeah, but you know, when they did that changeover, …there were all the dramas leading up to it…Well, shock horror, it's going to smell different for a start, and the flame was different and all of this jazz but within a couple of weeks, nobody was talking about it anymore." [FG1]*

Participants wanted to know more about the need for and cost of appliance upgrades and felt that any cost of upgrades would need to be subsidised by the government. Choice was also important, particularly whether individuals would be able to choose to be part of a hydrogen community if one was rolled out in their area. Similarly, the cost of fuel compared to current gas prices was an important influencer in whether to accept such a change. Overall, participants favoured demonstration projects and thought it made sense to roll hydrogen out in new developments rather than existing areas, where it may be expensive to change over. Participants wanted to know what timeframes were involved before the infrastructure and technology would be available for domestic use, and thought that any transition should be phased in over time to allow sufficient education to ease people into it.

> *"…when you're talking about you and your neighbour and you know, you decide to invest and they don't. I think that the government…would have to offer subsidies or something to encourage you to actually make those changes to your appliances..." [FG3]*

> *"It sounds great if it's a practical swap." [FG8]*

> *"If they could show me that it was no less unsafe to what we're currently using and that the emission side of it was much, much better, then I'd be able to live in a hydrogen city." [FG7]*

In the national survey Stream B: Domestic Use[58] participants predominantly reported being connected to the grid (91%) with 50% also having mains gas supply, and 20% having bottled gas (almost half of these in regional areas). Over one-fifth (23%) of the sample had installed solar rooftop PV panels and another 14% had solar hot water. Only 22% reported having an all electric home.

Figure 22 shows that Stream B participants were in general agreement (1=strongly disagree to 5=strongly agree) of hydrogen being used for a range of domestic applications, particularly hot water heating and on-site electricity generation. Those born overseas were happier to use hydrogen for space and hot water

[57] https://www.northerngasnetworks.co.uk/2016/07/12/watch-our-h21-leeds-city-gate-film/ - excerpt from 50sec – 4min 30 secs

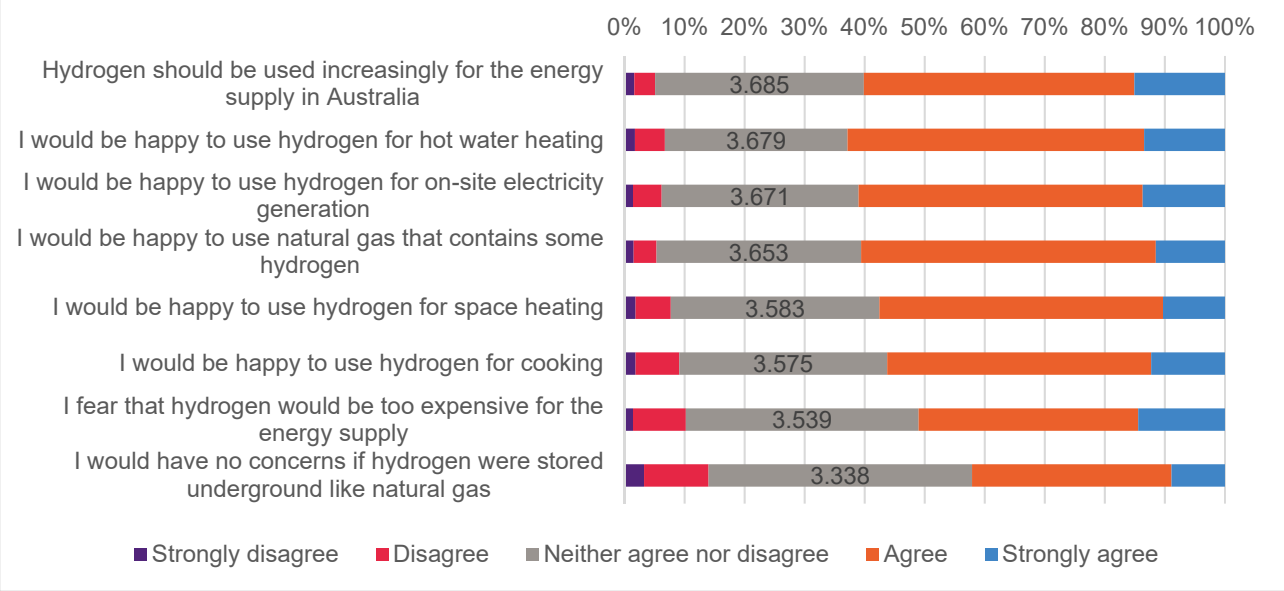
[58] N=921

heating. Highly educated people were more supportive of space heating, hot water heating and cooking. Those with frequent power disruptions or supply disturbances were happier to use hydrogen for on-site electricity generation. Early adopters and those paying for GreenPower were on average more supportive of all domestic uses, while all electric households were less supportive of hydrogen use in the home.

Participants seemed unconcerned about 10% hydrogen being blended with natural gas and seemed to prefer this term slightly more than piped and injected. They were less sure about replacing natural gas with 100% hydrogen (38% support) and electrifying the gas network (30% support). Younger and higher educated indivivduals were more supportive of electrification, while the older generation were less supportive of electrification or the use of 100% hydrogen in gas networks. Those located in metro areas or with frequent supply disturbances were more supportive of pure hydrogen, while those in all electric homes were less supportive of any hydrogen in the gas network.

In a UK focus group study[59], where levels of awareness of hydrogen technologies were low, participants expressed mostly neutral views on shifting to hydrogen. They wanted "much more detailed information about the likely benefits, costs and risks of such technologies". Demonstrable benefits for the individual such as cost and practicality were of primary concern, whereas environmental benefits were less important.

Figure 22: Agreement with potential domestic uses of hydrogen

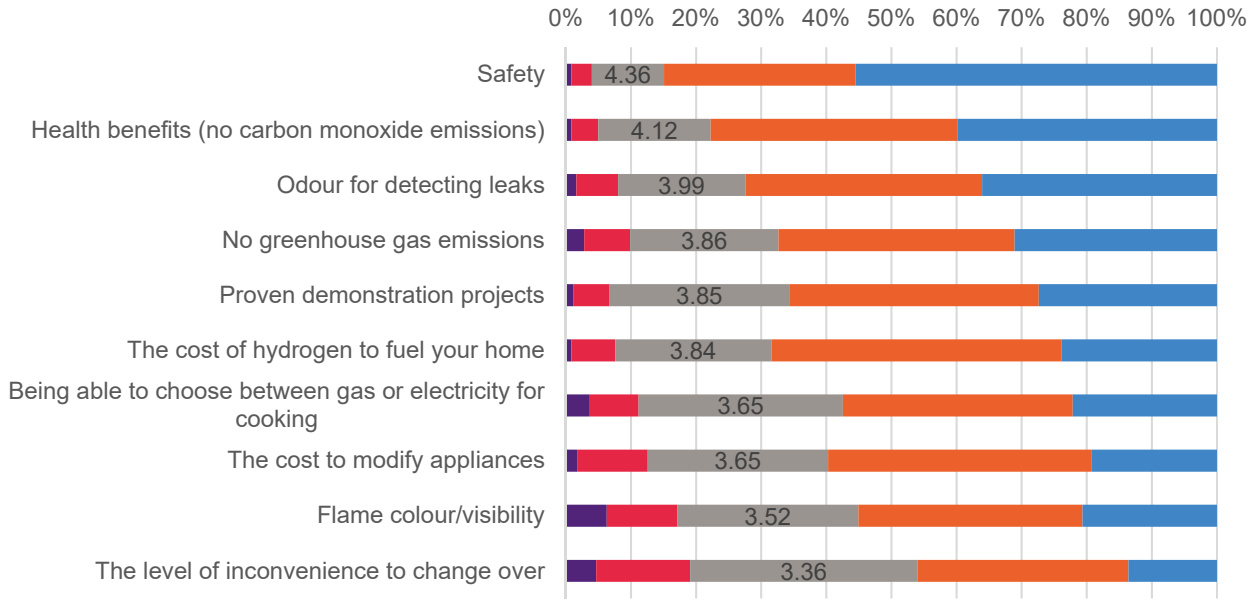


When it came to living in an all hydrogen home, for Stream B participants, safety was the most important consideration as well as health benefits, that is no chance of carbon monoxide poisoning (1=not at all important to 5=extremely important) (Figure 23). There was however some concerns about the odourless nature of hydrogen and participants deemed this an important feature. Confirming the results of the focus groups, other important features included demonstration projects to show how hydrogen homes work, the cost of supplying hydrogen to the home and to modify appliances as well as the ability to maintain choice between gas or electricity for cooking. Cost to fuel their home was more important to low income earners. Women were less supportive than men for all domestic uses, and their concerns about odour, greenhouse gas emissions and inconvenience to change were higher. Younger people rated everything of lower importance with the exception of inconvenience to change over. Those in metropolitan areas also thought inconvenience was more important than those in the regions, as did those with frequent power disruptions or in full or part time employment. Early adopters rated cost, safety and odour less important than the general

[59] Flynn, R., Bellaby, P. & Ricci, M. 2008. Environmental citizenship and public attitudes to hydrogen energy technologies. *Environmental Politics,* 17**,** 766-783.

group. Choice was important to those with frequent power outages or supply disturbances, as well as older people.

Figure 23: Determining factors to live in a hydrogen home



5.2 Storage potential of hydrogen is an advantage

The potential for hydrogen storage to improve reliability and potentially reduce costs was seen as a definite advantage in the survey and focus groups. Five percent of survey respondents reported often or almost always suffering from power outages and 7% from supply disturbances.

Australian survey participants appeared to have some concerns with hydrogen being stored underground like natural gas with only 42% support (Figure 22), but little information was presented on this option in the survey. However, the focus groups provide insights into the issue of storage as those participants saw great potential in the ability to produce hydrogen using excess renewable energy and store for later use to balance supply and demand, thereby increasing the resilience of a renewable heavy grid.

Focus group participants were suffering from high electricity prices and participants expressed concern for the elderly, sick, unemployed and other low socio-economic families who are struggling to pay bills. Those who had invested in solar panels were somewhat insulated from power prices, particularly those on high feed-in tariffs. However some complained that it was not meeting their expectations of electricity savings. Some people thought that subsidies for renewables were responsible for increases in electricity prices. Energy security and reliability was an issue for some. Adelaide residents had experienced power outages as recently as the previous week, citing bad weather and wind.

> *"we had the most unreliable power source and pay the most for our electricity." [FG3]*

> *"…they need to have a transition plan that's not going to cost us, and South Australia are a great example of expense and unreliability. I'm all for renewables, you can't argue against it, how could you? Transition properly such that you are not going to be paying the kind of pricing that we are, and the lack of reliability that we've had? If you can sort that out that's great." [FG1]*

"The smoothing stands out to me, because that's one of the main big factors in our high electricity prices is to deal with peaks and troughs, smooth it and that could potentially bring costs down." [FG1]

"…produce as much and store it until you need it is a big advantage over other power sources, batteries, etcetera." [FG10]

Replacing diesel with hydrogen generated from renewable sources in remote communities was seen as a sustainable closed loop system, particularly as the water could be reused. Others thought there was great potential for energy intensive industries to switch to hydrogen as an energy source.

Similarly, hydrogen storage was investigated in Germany through a series of interviews (n=10) combined with an online survey (n=141)[60]. Comparisons with batteries or flywheels found that hydrogen was considered the cleanest form of storage, but also the most dangerous and most threatening. Despite this, acceptance of hydrogen storage was high. There was high trust in the technology, although some scepticism related to storage near residential areas.

[60] Zaubrecher, B. S., Bexten, T., Wirsum, M. & Ziefle, M. 2016. What is stored, why, and how? Mental models, knowledge, and public acceptance of hydrogen storage. *10th International Renewable Energy Storage Conference, Ires 2016,* 99**,** 108-119.

6. Conclusions and recommendations

This research fills a gap in identifying the Australian public's knowledge and understanding of hydrogen and the emergent opportunities that are arising from export, transport and domestic use. While the majority of Australians have a limited knowledge of hydrogen properties and its uses, they mostly hold neutral associations when they hear the word.

Australians were very supportive of Australia developing an export market. They clearly recognise the economic benefits that it will provide while also continuing to build important international trade relationships with neighouring Asian countries. At the same time, they were hopeful that the development of a hydrogen industry in Australia would bring additional benefits to regional Australia through new projects and jobs. Particularly if hydrogen was produced from renewable energy which was the most preferred production method (57%). Although focus group participants cautioned that capitalising on an export market should not penalise opportunities for domestic use.

The main benefits associated with the use of hydrogen technologies centred around the environment - reduced greenhouse gas emissions and climate change mitigation potential were key benefits. However, consistently in this research safety was the number one concern in relation to the production and use of hydrogen. Other high priority concerns included associated costs and any environmental impacts. In particular, the amount of water required for hydrogen production as participants did not want to see Australia exporting our valuable water resource to other countries in the form of hydrogen.

In spite of expressed concerns, the majority of the Australia public believe there will be adequate safety precautions to keep the risks under control. This appeared to stem from a trust in government to act in the best interests of society by ensuring adequate regulations and developing standards for a hydrogen industry. Other important roles included developing a long-term strategic vision for hydrogen in Australia and continuing to fund research for its development.

Education was also seen to be a role for government and research institutions and it was felt that ensuring adequate information was disseminated early in the development of the industry would have an important influence in building overall acceptance of a hydrogen industry in Australia. The early use of hydrogen in the form of fuel cell buses and long-haul trucks was also seen as an important first step in building awareness of the opportunities and benefits that hydrogen presents. Many suggesting that once it was proven as a public transport method, domestic use and greater uptake would naturally follow both into fuel cell electric vehicles if the price was right as well as in domestic housing.

What is clear from this research is that Australians remain positively cautious about the opportunities an emergent hydrogen industry can bring to the country. There remains a number of questions in relation to the expected timelines required for the development of a successful hydrogen industry, as well as the anticipated costs relative to existing infrastructure and fuel uses. However, it appears that much can be done to promote more awareness and understanding in the broader Australian public of the benefits of a hydrogen economy. At the same time anticipating the skills that will be required to support such an emergent industry and identifying the prime locations for production will also be important next steps.

Similar to the Japanese experience, it seems that a well coordinated approach across all levels of government, industry and academia will help cement Australia's position in the emergent global hydrogen economy. At the heart of this will be the need for institutions to collaborate, as if successful, there are multiple opportunities to be had that will benefit all Australians.

In addition to the development of a long term strategy for hydrogen in Australia we recommend:

- Ongoing engagement with all stakeholders around emerging hydrogen trials and new projects
- Ensuring communication materials do not assume any prior knowledge of hydrogen

- Proactively sharing safety considerations in public engagement activities and communication materials
- A coordinated approach between government, industry and academia which aims to bring the public along with the developments occurring in the hydrogen space
- Raising awareness of the benefits and opportunities presented to Australia by developing a hydrogen industry.

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