EXPLORING THE AUSTRALIAN PUBLIC'S RESPONSE TO HYDROGEN

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ABSTRACT

Over the past three years there has been a rapid increase in discussions across the different levels of Australia's governments about the role that hydrogen might play in helping the world transition to a low carbon future. While those working in the energy industry are aware of the opportunities and challenges that lay ahead, the general public is less engaged. However, we know from the introduction of previous technologies that public attitudes towards technologies, including whether they view them to be safe, can severely impact overall acceptance. Understanding how the public perceives hydrogen, both for domestic and export use and the potential benefits it brings to Australia is critical for the industry to progress. In this paper we present the initial findings of a national survey of the Australian public conducted in March 2021, which builds on the results of a previous survey conducted in 2018. The 2021 respondents were drawn from all Australian states and territories (n=3,020), and quotas were used to ensure adequate representation of age groups and gender. Overall, the respondents have favorable views about using hydrogen for energy in Australia, with caveats about production-related environmental impacts and issues such as safety. While there has been a slight increase in support for hydrogen as a possible solution for energy and environmental challenges since the 2018 survey, the effect size is very small. This suggests that while hydrogen discussions have increased at a policy level, little has been done to improve public understanding of hydrogen in the last 3 years. Evidence-based public communication strategies will be needed as the Australian hydrogen industry continues to develop and gain more widespread media attention.

attitudes, safety, export, domestic use, economy

1.0 INTRODUCTION

In response to growing concerns about climate change, action to decarbonise Australia's energy sources through the introduction of future fuels such as hydrogen is underway [1]. However, successful implementation of new low-carbon energy technologies requires public acceptance, or at a minimum, tolerance of the technology [2]. For any new technology to be accepted in society, particular requirements relative to the technology and the context in which it will be used, need to be met to address stakeholders' perceived concerns and benefits associated with the technology [3].

This is also true for the transition to low-carbon fuels. In particular, strategies to inform and educate the public are necessary for their ongoing deployment [4]. Yet, simply providing educational campaigns about the emerging hydrogen economy will not be enough to ensure a social license to operate. It is important to be aware that earlier research has established that information alone does not change people's behaviours or acceptance of technologies across many environmental domains [5, 6], including hydrogen [7, 8]. Communities can display a 'value-action gap' [8], whereby they express concern for environmental issues such as climate change but do little to change their energy behaviours or technology adoption practices to support a transition to low-carbon energy.

While low-carbon energy solutions such as hydrogen are still under development, public attitudes towards hydrogen are also yet to be fully formed [8]. This provides an opportunity to ensure communication and education strategies take an evidence-based approach that starts with an understanding of current public perceptions and concerns about using hydrogen. Social surveys are one

tool that can help provide such information. These essential insights will help to inform the pathway for a social license for hydrogen in Australia.

There has been a growing body of literature about the importance of achieving a social license for mining and energy projects. For example, [9] demonstrated that in addition to minimising impacts on social infrastructure, contact quality and procedural fairness, were important for increasing trust in a project and leading to increased social license. They further tested this model and found that confidence in environmental governance structures that reduced the chance for any negative impacts were critical for gaining a social license to operate and ultimate acceptance of the project [10]. This was further enhanced when benefits associated with the project emerged around employment and local community development.

To investigate the likelihood for hydrogen to be accepted and achieve a social license to operate, we present results from a recent survey of the Australian public. Our questions aimed to identify individual attitudes towards, and perceptions of, hydrogen as a future energy source for both domestic purposes and international export. This study builds upon a 2018 national survey [11] to shed further light on the level of public support for the emergent hydrogen economy in Australia, and potential barriers to the development of the industry in the future.

2.0 METHODS

The overarching themes of the survey included: (i) initial knowledge and awareness of hydrogen, (ii) overall support for hydrogen (measured three times during the survey), (iii) perceptions of hydrogen use and production, (iv) export and future energy considerations, (v) domestic use, (vi) communication message effects, (vii) attitudes towards hydrogen, (viii) trust in organisations, and (ix) respondent characteristics related to their climate change beliefs, environmental identity, innovation adoption, household energy use, and demographics. To reduce the survey duration, the respondents were randomly allocated into one of two groups to complete either section on export and future energy considerations (n = 1,513) or domestic use (n = 1,507). All respondents answered the remaining sections. Due to space limitations, we report only key sections or questions in this paper.

The current (2021) national survey was developed using many of the same questions deployed in the 2018 survey. Minor changes were made to some questions (for clarity), and the response scale was extended to 7 points (previously 5 points in 2018) in questions that used rating scales. New questions were introduced to measure attitudes [12], awareness of recent hydrogen policy and industry developments (new statements written by the research team), environmental identity [13], climate change concern [14], and agreement with potential future energy sources (adapted from Jeanneret, Muriuki and Ashworth [15]). The survey questions were reviewed by the research team and revised for further clarity.

After measuring the initial perceptions of, knowledge about, and support for hydrogen (sections i and ii), respondents were provided with multimedia content to inform them about hydrogen. This included a video about renewable 'green' hydrogen and export opportunities for Australia (produced by the Australian Renewable Energy Agency (ARENA); https://youtu.be/fFGT2z82tOM), followed by an image and text explaining hydrogen production using both renewable and fossil fuel sources and carbon capture and storage. For respondents who were in the 'domestic use' stream of questions, images and text were provided to explain what hydrogen could be used for in domestic purposes, how the transition to hydrogen might proceed, and examples of international trials and projects.

Survey respondents were recruited through a market research company. The survey was open for approximately 3 weeks from 29th January to 20th February 2021. The sample was selected using non-probabilistic quotas for age, gender, and state of residence. The data were checked for fraudulent or inconsistent responses, and any irregularities were removed and replaced. In total, 3,020 fully completed surveys were received. The dataset was checked and cleaned prior to the analysis.

2.1 Sample characteristics

The sample approximated the spread of residents across Australian states and major territories and was almost equally distributed between males and females (Table 1). The average age of respondents was 47.8 years (SD = 17.4 years).

The respondents differed from the Australian population in several ways. First, people with higher education are overrepresented in the survey. Compared to the national population recorded by the Australian Bureau of Statistics, of which 26.7% have a Bachelor or Postgraduate degree, respondents in the survey were more likely to be highly educated (40.0% had completed a Bachelor or Postgraduate degree). Respondents in the survey were more likely to have been born in Australia (74.0%) than the Australian population (66.7%). The respondents also slightly underrepresented the Australian population in the 18-34 years age group (33.4% compared to 29.8% in the survey population), and overrepresented older people in both the 35-54 years age group (32.8% vs 34.0% in the survey) and the 55+ years age group (33.8% vs 36.3% in the survey).

Table 1. Respondent characteristics.

Characteristic	**Frequency (*n*)**	**Percent (%)**
State		
NSW	947	31.4
VIC	755	25.0
QLD	594	19.7
SA	254	8.4
WA	310	10.3
TAS	71	2.4
NT	32	1.1
ACT	57	1.9
Gender		
Male	1463	48.4
Female	1543	51.1
Other	14	.4
Age Group		
18 – 34 years	899	29.8
35 – 54 years	1026	34.0
55+ years	1095	36.3
Education completed		
Year 10 or below	289	9.6
Year 11 or equivalent	79	2.6
Year 12 or equivalent	436	14.4
Trade certificate or Apprenticeship	147	4.9
Certificate I or II	78	2.6
Certificate III or IV	348	11.5
Advanced Diploma / Diploma	387	12.8
Bachelor or Honours degree	833	27.6
Postgraduate degree (e.g. Masters, PhD)	406	13.4
Other	17	.6

3.0 RESULTS

3.1 First thoughts about hydrogen

The first question in the survey asked respondents "When you hear the word hydrogen what are the first things that come to mind?". A content analysis of the responses revealed that for many people (~46%), hydrogen conjures up thoughts of chemistry or chemicals (or chemical states; Table 2). Around one in five respondents mentioned power or energy, and a similar proportion mentioned water. Less than 10% mentioned hydrogen bombs, while 6% referred to the properties of hydrogen (such as it being flammable, explosive, and/or lighter than air). Only 5% indicated they did not know or have any thoughts about it when they hear the word hydrogen.

Table 2. What people think of when they hear the word hydrogen.

Category	Example responses	n	% of respondents
Chemical/chemistry/ element/state	*a chemical; atom and elements; first element on the periodic table; science; chemistry class in school*	1373	45.5%
Energy/power/fuel(s)	*a fuel; a source of energy; alternative power source*	660	21.9%
Water	*water; part of water; emits water*	627	20.8%
Bomb/nuclear weapon	*bomb; nuclear weapon; Hiroshima*	281	9.3%
Hydrogen properties	*flammable gas; lighter than air; explosive*	180	6.0%
Nothing/none/don't know	*don't know; I am not sure; I have no idea*	152	5.0%
Air/atmosphere	*fresh air; part of the air we breathe; a compound in our atmosphere*	102	3.4%
Balloons	*balloons; gas used to blow up balloons; hot air balloons*	63	2.1%
Hindenburg/ blimp/ airships/dirigibles/zeppelin	*Hindenburg disaster; blimp; used in early airships; has been used to fly dirigibles; Zeppelin blimps exploding*	56	1.9%
Other uses	*rocket fuel; used to remove sulfur from fuels; used in industry; used for a variety of purposes; cleaning*	44	1.5%
Other	*a lot of wind farms; essential for all life; air pollution; innovation; ammonia production; contamination; cost; fracking*	355	11.8%

3.2 Knowledge of hydrogen

To better understand objective knowledge, five questions about hydrogen properties were asked (e.g. whether hydrogen is heavier than air at room temperature, is available naturally in its pure form, has a smell, is flammable in air, and can be stored as a liquid), of which less than 6% of respondents answered all 5 questions correctly. This was slightly less than the 2018 survey, in which 7% of respondents answered all 5 questions correctly.

In addition, respondents were asked to rate their knowledge about 6 different aspects of hydrogen production and uses, for which the majority indicated they know very little about or had not heard of it at all (Table 3). This follows a similar pattern to the results from the 2018 survey, where approximately 60% of respondents had at least heard of, or know about, using hydrogen fuel cells in vehicles. Likewise, approximately two thirds of the samples in both surveys had never heard about using hydrogen fuel cells in homes. For the remaining statements, there was only a very small decrease in the percentage of 2021 respondents who indicated they had never heard about the topic.

Table 3. Self-reported knowledge about hydrogen.

	I have never heard of it		**I have heard of it**		**I know about it and could describe it to a friend**	
	n	**%**	***n***	**%**	***n***	**%**
The use of hydrogen fuel cells in vehicles	1167	38.6	1604	53.1	249	8.2
Burning hydrogen as a replacement for natural gas	1430	47.4	1360	45.0	230	7.6
Hydrogen as an energy storage medium for electricity	1598	52.9	1210	40.1	212	7.0
How hydrogen is produced	1612	53.4	1133	37.5	275	9.1
Hydrogen refuelling stations	1669	55.3	1165	38.6	186	6.2
The use of hydrogen fuel cells in homes	1944	64.4	926	30.7	150	5.0

3.3 Support for hydrogen

During the survey, the respondents were asked "how do you feel about hydrogen as a possible solution for energy and environmental challenges?" at two points in the questionnaire: the first (time 1) was near the start of the survey, and the second (time 2) was at the end of the questions related to hydrogen (but before further questions about climate change, environmental beliefs, and demographic information; Figure 1). This allowed us to investigate whether there was any change in the level of support as the respondents completed the survey questions and learned more about the potential role of hydrogen in Australia's energy future.

The average response increased slightly from 5.31 (measured on a 7-point scale, where 1 = very unsupportive, and 7 = very supportive; SD = 1.25) at time 1, to 5.85 (SD = 1.14) at time 2. We compared the level of support between the two information groups (export stream and domestic stream). However, while there was no difference between their level of support at the beginning of the survey, the export stream respondents were slightly more supportive of hydrogen ($M = 5.90$, $SD = 1.15$) later in the survey (at time 2) than the domestic stream respondents ($M = 5.80$, $SD = 1.14$, $t(3018)=2.43$, $p=.015$). Although this result is, technically, statistically significant, the Conhen's d effect size ($d = .088$) indicates the difference is very small.

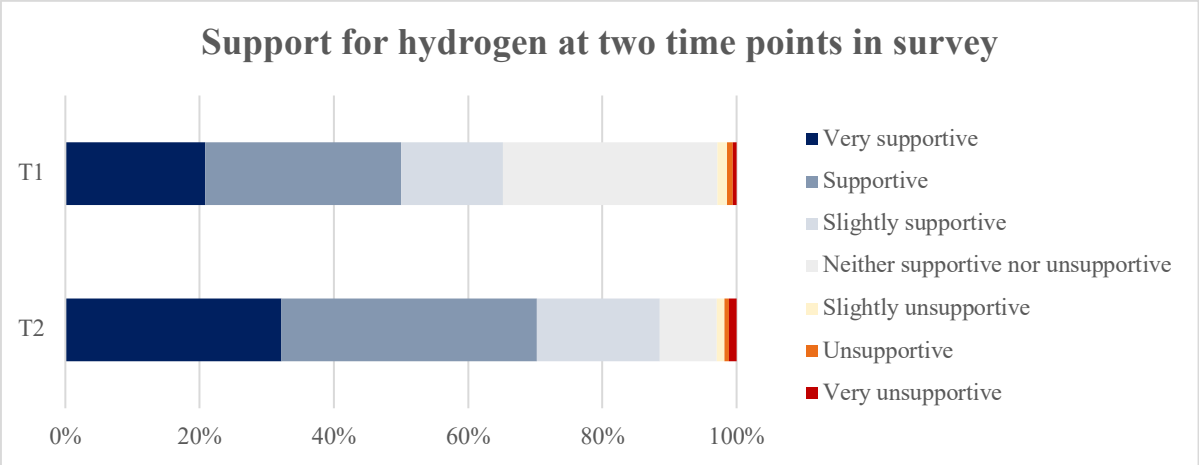

Figure 1. Changes in support for as a possible solution for energy and environmental challenges between T1 and T2.

The level of support for hydrogen (at time 1) was compared to the 2018 survey (Figure 2), which asked the same question at the start of the survey. There was a small but statistically significant increase in the level of support for hydrogen from 2018 ($M = 4.99$, $SD = 1.20$) to 2021 ($M = 5.31$, $SD = 1.25$), $t(5803)=10.20$, $p < .01$, Cohen's $d = 0.26$.

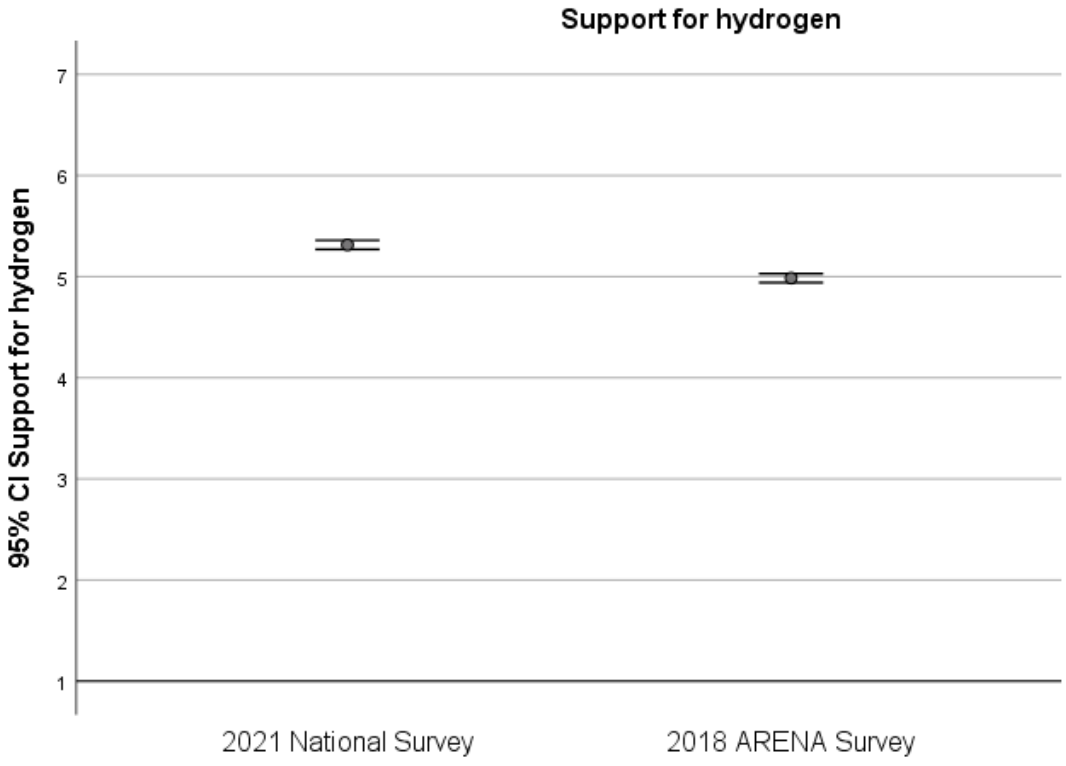

Figure 2. Change in level of support for hydrogen as a possible solution for energy and environmental challenges (2018 – 2021).

3.4 Safety concerns

As mentioned earlier, part of the questionnaire was split into two sections to reduce the duration. The first section asked respondents about export and future energy considerations (n = 1,513) while the second section asked the remaining respondents about domestic uses of hydrogen (n = 1,507). Within each of these sections, sets of statements included issues of hydrogen safety.

Export considerations

The question posed to respondents was "If Australia was to start exporting hydrogen how important are the following considerations to you?" Safety in both the way hydrogen is transported and within the production process was rated the highest importance of all the factors listed (Table 4). In addition, local and national benefits, including job opportunities, and a range of economic and environmental benefits, were also deemed very important by respondents. "Minimising the overall use of water in hydrogen production" was rated the least important, although not unimportant.

Table 4. Importance of export considerations.

	Mean[a]	**SD**
Ensuring safety in the way hydrogen is transported	4.46	.74
Ensuring safety of the production process	4.44	.77
Creating new job opportunities	4.31	.82
Increasing economic benefits to Australia	4.27	.84
Minimising the environmental impacts of the production and transport process	4.27	.85
Supporting the development of a local manufacturing industry	4.23	.81
Ensuring availability of a domestic hydrogen supply	4.23	.85
Contributing to the world's emissions reductions	4.19	.94
Creating regional opportunities through the production of hydrogen	4.13	.88
Ensuring Australia is an early mover in the export market	4.10	.92
Retaining the rights of intellectual property for hydrogen production	4.03	.99
Minimising the overall use of water in hydrogen production	3.80	1.04

[a]Measured on a 5-point scale where 1 = not at all important, 5 = extremely important; n = 1,513.

Importance of factors related to domestic use of hydrogen

Respondents in the 'domestic use' stream of questions were asked: "How important are the following factors in determining your willingness to use hydrogen in your home?" As with the 'export considerations' results, safety was also rated as the most important factor that may influence people's willingness to use hydrogen in their homes (Table 5).

Table 5. Importance of factors related to domestic use of hydrogen.

	Mean[a]	SD
Safety	4.50	.83
Reliability of energy supply	4.27	.87
Health benefits (no carbon monoxide emissions)	4.21	.94
The cost of hydrogen to fuel your home	4.18	.91
Odour for detecting leaks	4.08	1.01
The cost to modify appliances	4.02	.96
No greenhouse gas emissions	3.98	1.05
Proven demonstration projects	3.94	.98
The level of inconvenience to change over from current systems and appliances	3.64	1.08
Being able to choose between gas or electricity for cooking	3.56	1.17
Flame colour/visibility	3.42	1.24

[a]Measured on a 5-point scale where 1 = not at all important, 5 = extremely important; n = 1,507.

The prioritization of safety concerns was also expressed in the 2018 survey in which respondents rated safety as being the most important issue for both export and domestic use.

3.5 Attitudes toward hydrogen

A series of statements about the perceived utility (instrumental attitude) and perceived experience (experiential attitude) of using hydrogen for energy in Australia were administered to further investigate individual attitudes toward hydrogen. The results showed a moderately positive composite instrumental attitude score of M = +2.07, SD = 1.03 (on a bipolar scale that ranged from -3 to +3; Table 6) meaning that, overall, respondents believe that using hydrogen will be beneficial. However, the composite experiential attitude score was lower but still positive (M = +1.46, SD = 1.12), suggesting that respondents remain somewhat optimistic about the opportunities hydrogen offers.

Table 6. Attitudes towards hydrogen.

Overall, do you think using hydrogen for energy in Australia would be:	**Mean[a]**	**SD**
Instrumental attitude		
Very useful - Very useless	2.10	1.08
Very beneficial - Very harmful	2.08	1.09
Very worthwhile - Very worthless	2.05	1.11
A very good thing - A very bad thing	2.03	1.12
Composite instrumental attitude score (α = .955)	2.07	1.03
Experiential attitude		
Very inspired - Very uninspired	1.56	1.28
Very proud - Very embarrassed	1.55	1.25
Very happy - Very sad	1.52	1.24
Very calm - Very angry	1.48	1.21
Very unconcerned - Very worried	1.20	1.39
Composite experiential attitude score (α = .924)	1.46	1.12

Overall attitude score		
Mean (instrumental + experiential) attitude score (α = .951)	1.73	1.02

[a]Measured on a 7-point bipolar scale, where -3 = (most negative response, e.g. very worthless), 0 = neutral, +3 = (most positive response, e.g. very worthwhile); *n* = 3,020.

3.6 Trust in organizations

Respondents were asked the extent to which they thought particular organizations and groups would act in the best interests of consumers if a hydrogen economy was developed in Australia. Research institutions (the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and universities) were ranked the most trusted of all the groups listed, followed by environmental non-government organizations. Fuel and gas companies were ranked the lowest, however the mean score for this group sat just slightly above the neutral midpoint, that is it was not negative.

Table 7. Trust in organizations to act in the best interests of consumers.

	Mean[a]	**SD**
CSIRO	5.43	1.33
Universities	5.24	1.32
Environmental Non-Government Organisations (ENGOs)	5.18	1.42
State government	4.94	1.51
Federal government	4.89	1.64
Local government	4.84	1.47
Car/appliance manufacturers	4.50	1.50
Electricity generation companies	4.35	1.65
Media	4.33	1.54
Fuel/gas supply companies	4.08	1.76

[a]Measured on a 7-point rating scale, where 1 = strongly disagree, 4 = neither agree nor disagree, 7 = strongly agree); *n* = 3,020.

4.0 DISCUSSION

The results of this research demonstrate that, similar to the 2018 survey results [11], the Australian public is positive about the possibilities offered by the developing hydrogen industry. However, this optimism is tempered by with some concerns about safety in the production, export, and use of hydrogen. As echoed in the social license literature [9, 10], ensuring no negative environmental impacts arise from the development of a hydrogen industry and its implementation was also seen to be important. Similarly, the results confirmed that as in the earlier social license studies, individuals were generally positive towards hydrogen because it was seen to present opportunities for economic and regional benefits, including jobs.

Despite the overall sample being more educated than the Australian population, it was clear that many individuals currently do not know a lot about hydrogen (such as the way it is produced and its potential uses). As such, government agencies and industry will need to work to educate the public about the opportunities it brings. Such campaigns and other stakeholder engagement activities will need to ensure a focus on the concerns the public hold in relation to safety and explain how they are mitigating any risks associated with the development of hydrogen. Paying attention to the organizations the public are more likely to trust to be responsible for the industry's development will also help in building confidence in the industry.

Given the growing interest in hydrogen across the world including, for example, New Zealand, Japan, Korea and Germany, there is an opportunity to join forces in developing communication messages that

are consistent across the globe. While it is early days, this could help to reduce overall costs of campaigns and avoid the potential for mixed messages emerging across different countries. Since public perceptions of hydrogen are yet to be fully formed, a coordinated communication effort is especially important now that social media connects people across the world, enabling information and misinformation to spread faster than ever.

Public support for hydrogen appears to be growing, albeit slowly. The slight increase in support observed between the 2018 and 2021 surveys may be a result of the increasing media attention the industry has experienced in recent years, coupled with the recent announcements by almost every Australian state and territory about various hydrogen projects under development. Regulating the environmental impacts of the projects and ensuring their safe deployment will be extremely important for ongoing acceptance. While water use did not emerge as the highest priority for developing an export industry, participants in earlier focus groups conducted across Australia raised this as a potential concern. Given Australia is a relatively dry continent, it will still require careful communication and management of this issue.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Although the Australian public's knowledge about hydrogen is still developing, when presented with information about the opportunities an emergent hydrogen industry may bring to Australia, the general public's response remains cautiously optimistic. When presented with information about hydrogen, the public were generally supportive of it as an industry due to its export potential, employment prospects, and opportunity it presents to decarbonize global energy systems. While somewhat lower support was demonstrated for domestic use, the public were still positive towards its use and implementation across Australia overall.

However, as with other social license issues, caveats were expressed around ensuring no negative environmental impacts, that it is safe to use, as well as the importance of bringing additional benefits including jobs, growth for regional communities and broader economic benefits for Australia. Currently there is no firm revenue model for hydrogen export, and this will require additional focus by government. In addition, because of the strong need shown for safety considerations and environmental protection, there is a clear role for policy makers to ensure adequate regulatory processes are in place.

As with all new industries and technologies, there is an exciting opportunity for communication experts to create evidence-based education materials along with appropriate communication and engagement activities that help to address the gaps in people's knowledge highlighted in this research. A question remains as to whether this will be led by government or industry. However, given the global demand and interest in hydrogen there is an opportunity to join forces to ensure clear and consistent messages are delivered about hydrogen. Given that many recall the hydrogen from their early chemistry lessons, it may also be appropriate to build on school programs to raise awareness of the potential for hydrogen as a safe, low carbon source of energy.

ACKNOWLEDGEMENTS

This work was funded by the Future Fuels CRC, supported through the Australian Government's Cooperative Research Centres Program. We gratefully acknowledge the case and in-kind support from all our research, government and industry participants.

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