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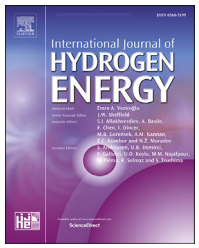

Skilling the green hydrogen economy: A case study from Australia

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HIGHLIGHTS

- Cross-sector collaboration is needed to support education and training on hydrogen energy.
- Insufficient training is available to support skill development in hydrogen energy.
- Training on electrolysers, fuel cells, hydrogen storage and refuelling stations is most needed.

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ABSTRACT

This paper explores the skills landscape of the emerging green hydrogen industry in Australia drawing on data collected from a study that gathered insights on training gaps from a range of hydrogen industry participants. A total of 41 industry participants completed a survey and 14 of those survey respondents participated in industry consultations. The findings revealed widespread perceptions of training and skilling as being very important to the industry, but under-provisioned across the sector. Data were analysed to consider the problem of skilling the green hydrogen industry and the barriers and enablers as perceived by industry stakeholders. In this paper we argue that urgent cross-sector attention needs to be paid to hydrogen industry training and skill development systems in Australia if the promise of green hydrogen as a clean energy source is to be realised.

Introduction

Countries around the world are seeking to reduce carbon emissions in order to address the risks posed by climate change and meet their commitments to the Paris Agreement ratified by 196 parties in 2015. Accordingly, there has been a resurgence of interest in directing resources and research in the use of hydrogen as a zero-emissions energy carrier, evident by an increasing number of countries adopting a hydrogen strategy [1–3]. The importance of the role of hydrogen energy is evident in a recent Bloomberg New Energy Finance [4] report that found that if the world is to keep global warming to below 1.5° Celsius, renewable hydrogen will be needed to meet between 7% and 24% of the global energy needs by 2050. Likewise, the International Energy Agency's (IEA) Global Hydrogen Review 2021 [5] declares "hydrogen will be needed for an energy system with net zero emissions" (p. 5) and the IEA expects 10% of total energy consumption will be

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met by hydrogen by 2050 with its value being particularly important for hard to abate sectors.

All countries transitioning to a hydrogen economy[1] will face a key challenge of providing adequate training and upskilling to support hydrogen energy roll out. In Australia, the breadth and depth of training required across the industry has yet to be thoroughly scoped. This article draws on data from a recent study undertaken by Swinburne University of Technology through the Victorian Hydrogen Hub that investigated views of key participants in the emerging Hydrogen sector in Australia using both survey and interview methods [6]. The research aimed to identify specific training and skills requirements by engaging with a broad selection of industries, such as transportation, mining, infrastructure and agriculture. Below, we outline the methods of the study and profile the participants, before presenting the quantitative analysis of the survey data. The broad findings are extended with qualitative analysis of the interview data. We discuss the insights the study provides into the challenges of skilling the hydrogen economy and consider implications for policy and the energy sector in Australia.

International context

While there has been interest in growing the hydrogen economy for decades, only recently has research focused on workforce requirements to support growing demand in the Australian context. In this section, we review literature exploring the development of hydrogen related education and training and how the sector is currently situated to meet current and future workforce demand.

In looking to the future of the Australian hydrogen sector, some insights can be drawn from the development of the sector in the northern hemisphere. Reijalt (2010) over a decade ago, estimated that 50,000 technicians and 40,000 educated sales staff would be needed to meet the workforce needs of the hydrogen sector in Europe, and projected up to 200,000 people would require additional education [7]. In 2019 [8], in the United States projected 42 new occupations would be created and modelled the potential skills and incomes associated with them. His work suggested that "jobs will be created across a new continuum of employment, skills, responsibilities, and earnings … many of these jobs do not currently exist … Further, many of these new jobs require different skills and education than current jobs" (p. 3). High hopes lay in the job opportunities created through the hydrogen industry alongside anxieties of how training and education could ensure an available workforce.

In Europe, understanding and planning for hydrogen education and training began in the early 2000s. In 2003 the European Technology Platform for Hydrogen and Fuel Cells (HFP) undertook a comprehensive mapping exercise of the current and future education and training needs across school, academia, industry and Government sectors [9]. Immediate education and training needs appropriate to each of the sectors were identified [7]. In his exploration of this work, advocated that an "intense and coordinated" approach would be required to ensure a ready-workforce for the growth and maintenance of hydrogen systems. Since then, a number of the recommended education and training initiatives have been implemented in Europe, though a comprehensive evaluation of effectiveness or level of coordination across countries is yet to be undertaken.

Globally, education and training needs have revolved around hydrogen safety. In 2005 [10], advanced thinking in this space with their recommendations of modules to support training in hydrogen safety. This work was foundational to the establishment of programs undertaken by the International Association for Hydrogen Safety (IAHS), founded by prominent Universities, laboratories and businesses from across Europe, whose mission is "to facilitate the international coordination, development and dissemination of hydrogen safety knowledge by being the focal point for hydrogen safety research, education and training" [11]. Dahoe and Molkov (2007) described key barriers to Europe's advancement of hydrogen education including: language barriers that cause fragmentation; enclosed education systems due to national borders; and a lack of harmonisation between educational programmes [12]. The creation of HySafe - the internationally recognised network and focal point for all hydrogen safety related issues - was in part a response to the fragmentation of the delivery of hydrogen safety education across Europe [13]. More recently, Tretsiakova-McNally et al. (2017) developed an innovative method of training first-responders, including virtual reality and scenario-based andragogy [14]. Advantages of virtual reality methods were noted including, distance learning capabilities and capacity to adapt scenes and contexts quickly to suit training requirements.

The challenges to ensuring a hydrogen-ready workforce are similar to those experienced in the renewable energy sector more broadly. In 2018, Lucas et al. found that a mismatch between education system offerings and industry demand, alongside the suitability of curricula were common issues globally in the renewable energy sector [15]. Kandpal and Broman (2014) in their review paper, identified that the unavailability of appropriately trained and qualified personnel is commonly reported as a key reason for the poor dissemination of renewable energy technologies [16]. While education and training is recognised as needed across the global hydrogen ecosystem, Nowotny (2014, p. 4156) notes "an urgent need to develop education programs for training the technical staff able to work at the front line of the development of the technologies on sustainable energy systems (SESs) [17]." To date, the integration of hydrogen education has been ad hoc and research is most abundant in exploring integration and effectiveness of learning about hydrogen in engineering qualifications [18–21]. Learnings from the renewable energy sector suggest that advancing education and training alongside technological and capital developments should be a priority.

The development of a workforce to support a hydrogen economy depends upon education and training availability. In

[1] In this paper we make reference to both the hydrogen economy and the green hydrogen economy more specifically. When we refer to education and training it relates to the hydrogen economy more broadly because when it comes to education, the knowledge and skills required for many aspects of the hydrogen economy will be the same, regardless of the mode of production (i.e., electrolysis, steam reformation). Therefore, the term hydrogen economy is generally employed, except when discussing green hydrogen in particular.

the United States and Europe, documentation of the education and training journey is available and showcases how coordination within and between education sectors is considered integral to success [7–9]. Emphasis has largely centred on engineering qualifications across regions, though recognition of a diversity of workforce opportunities is noted. Finally, when reviewing workforce needs, safety has continued to dominate concerns and educational programme development. However, to date, research on the education and training needs in support of a hydrogen sector tend to be based upon desktop modelling of projected workforce needs, or in reviewing currently available education and training materials. The perspectives of people already working in the industry are missing from the research literature; a gap that this study goes some way to addressing.

Australian context

In Australia, 113 hydrogen projects are registered on the national hydrogen project register at the time of writing, though a total of eight projects are currently operating and six are classified as in advanced development, signifying having reached Final Investment Decision [22]. The slow speed at which hydrogen projects are reaching operational stage has been cause for concern for some industry commentators [23,24].

Historically, the Australian Government's interest in hydrogen first appeared in 2003 with the commissioning of a National Hydrogen Study for the Department of Industry, Tourism and Resources [25]. The report recommended education as a specific subgroup of a National Hydrogen Working Group. Since this time, in communications about advancing the hydrogen economy, economic opportunity and job creation have been prominent promises put forward by Government and industry alike [26,27,28].

Australia adopted a national hydrogen strategy in November 2019, agreed to by state, federal, and territory governments with a vision for a clean, innovative, safe, and competitive hydrogen industry that would help Australia transition to a sustainable, affordable, and low-emissions future [26].

The National Hydrogen Strategy claimed, "the industry could provide about 7600 jobs in 2050 with targeted global deployment – more if global markets develop faster". Jobs would likely include engineers, technicians, gas fitters, plumbers and builders and other associated trades and services [26]. The Strategy makes reference to the need for collaboration between Government, industry and the education sector to adequately prepare an Australian hydrogen-ready workforce.

Though, projections on employment impacts in Australia from research institutions and workforce agencies have tended to report numbers non-specific to the hydrogen sector, instead reporting job creation opportunities related to decarbonisation, emphasising domestic energy supply [29], medium-term time horizons and overall job figures [30]. New research led by universities in Australia has sought to extend understandings of employment impacts of the hydrogen sector. The Net-Zero Australia project is one such initiative, led by the University of Queensland and the University of Melbourne, using the modelling method developed by Princeton University for the Net-Zero America study. Preliminary findings from the Net-Zero Australia project [31] indicate that over the coming decades, an increase in higher skilled occupations will be needed to support the renewable energy sector, inclusive of hydrogen technologies.

In 2022, the Department of Employment and Workplace Relations commissioned a study by Pricewaterhouse Coopers (PwC) to inform the development of hydrogen education and training in Australia [32]. PwC indicated that advancing the hydrogen sector will likely involve 46 existing job roles "that will be augmented to undertake hydrogen activities … [I]t is not expected that many job roles will require significant upskilling or retraining in order to engage in the hydrogen economy." After reviewing the literature, it is apparent that the changes required to education and training in Australia for the hydrogen sector remains largely based on projections, with little research based on live project experience.

Additionally, there are currently limited understandings of how employment and training will be impacted by national and global demands for hydrogen. By reaching out to Australian industry, the study intends to develop a clearer view of those industries and organisations that are likely to be impacted, and therefore gain a clearer view of the existing gaps in education, training and upskilling. Knowing the gaps in education, training and upskilling is important for informing the development of policies and strategies for the hydrogen industry workforce, and for developing accredited courses that will meet these industry needs. Next, we introduce the research questions underpinning the present study and outline the methods employed.

Methods

The research questions this paper addresses are.

1. What are industry stakeholders' perceptions of the current and future education and training needs of the green hydrogen sector?
2. What are the barriers and enablers to meeting the education and training needs of the green hydrogen sector?

This research was part of a larger research study mentioned above [6]. This research project followed a concurrent mixed-methods design [33]. Ethics approval for the project was received from Swinburne University of Technology (20226050-9553).

This project sought to address the knowledge gap relating to vocational training and upskilling, by working with industries across a number of different sectors, such as transportation, mining, infrastructure and agriculture, to identify their current and future training and upskilling needs through the lens of a hydrogen economy. The methods included a survey delivered online, followed by industry consultations with a smaller number of survey participants to further explore the survey findings.

The participant sample was generated from transportation, mining, infrastructure and agriculture industry contacts (as outlined below) as well as TAFE/Skills Services Organisations

(SSOs) contacts. Contacts were sought through: (1) meetings/discussions with peak industry bodies, industry professionals and TAFE/SSOs participating in hydrogen energy forums; (2) introductions from key stakeholders within the VH2 project team; and (3) introductions from partner organisations and industry professionals with a stake in the emerging hydrogen energy economy. Participants were recruited primarily from organisations operating in industry sectors including: transport and logistics (e.g. freight, aviation, car and truck distributors), infrastructure (including gas pipelines), gas storage and processing, manufacturing (including steel and glass), smelting companies and cement-making. Insync Surveys Pty Ltd were engaged as an external organisation to assist with participant recruitment and data collection.

Survey

The survey included quantitative and qualitative response items to capture data relating to participants' views on the education and training landscape of the emerging hydrogen energy sector as well as demographic information such as details of participants' role and sector of employment and the state in which they were located. The quantitative items used a five-point likert scale. Specifically, the responses aimed to identify from participants, their perceptions of present and future business training needs; if/how business would be impacted by the hydrogen economy; and the potential barriers to training/upskilling of the existing and future workforce. Open-ended qualitative items on the survey provided the opportunity for participants to share their views on the training and education required in the hydrogen sector in the next 5 years. The survey took approximately 15 min to complete, and 41 responses were collected.

Industry consultations

Respondents indicated upon completion of the survey if they would be willing to participate in further consultation. Fourteen respondents agreed and consultations were conducted online via Microsoft Teams during the period October 2021 to December 2021. Each consultation involved a meeting between members of the research team and the invited industry participants which lasted between 20 and 60 min. A member of the research team [Author 4] typed field notes during the meeting and the notes were analysed for emerging themes and additional information to extend upon the insights generated from the survey.

Data analysis

In employing mixed methods [33], we draw on both quantitative and qualitative data to provide deeper understanding. Descriptive statistics were used for the quantitative data to analyse participants' responses to statements in the survey. As the research questions did not involve measuring differences between independent variables, statistical tests (i.e., *t*-test or ANOVA) were not employed. Open-ended questions from the survey and the field notes from the consultations were entered into NVIVO data management software and thematically analysed by the researchers around key themes which were generated inductively from the data. Selected quotes from data themes are included to illustrate stakeholders' perspectives. The findings presented below are organised around the following key themes: needs and availability of education and training for the hydrogen industry; and barriers and enablers to effectively developing the skills needed for the hydrogen sector.

Findings

The study investigated current skilling and training capacities to fulfil the potential of a hydrogen economy in Australia. Key findings of the study included a recognition among participants that advancement of hydrogen will impact their work; that education and training is required to support the industry's success; and that currently, a lack of hydrogen technologies expertise, alongside uncertainties of fast-evolving technologies, creates challenges for education and training development.

When participants were asked to what extent hydrogen would impact the industries they worked in over the next five years, 87% indicated that it would have an important impact. Similarly, almost 90% perceived that significant levels of hydrogen training and education will be necessary for their industry over that same period. Participants identified the following job roles as being the most impacted by the hydrogen industry: gas fitters, plumbers, drivers and mechanics [6].

Need for education and training: perspectives from industry

Participants were asked to indicate the gaps that they perceive exist in current education and training programs, with the results shown in Fig. 1. Overall, technical knowledge, transport infrastructure and hazard reduction were identified as the major training gaps. Differences were evident based on participants' industry context, for example, participants from the transport industry tended to identify gaps in transport infrastructure.

The survey asked participants to nominate the education and training topics where there were gaps in training provision. The results shown in Fig. 2 revealed that more than 70% of participants indicated that education and training about electrolysers, fuel cells, hydrogen storage and refuelling stations was needed. Education topics relating to the policy and market context of hydrogen technologies were identified as the least needed across the sector.

To understand the perceived need for hydrogen related training and education, the survey asked participants: "In the next 5 years, what percentage of industry employees will require hydrogen related training and education?". Results for this question were ambiguous, with almost a third of participants indicating that over 80% of industry employees would require hydrogen related training and education, and almost half of participants indicating less than 20% of employees would require it (Fig. 3).

Likewise, the open-ended responses to survey questions reflected this difference in views about the extent of education and training required in the industry. Some participants indicated training was 'essential', as the following comments reveal:

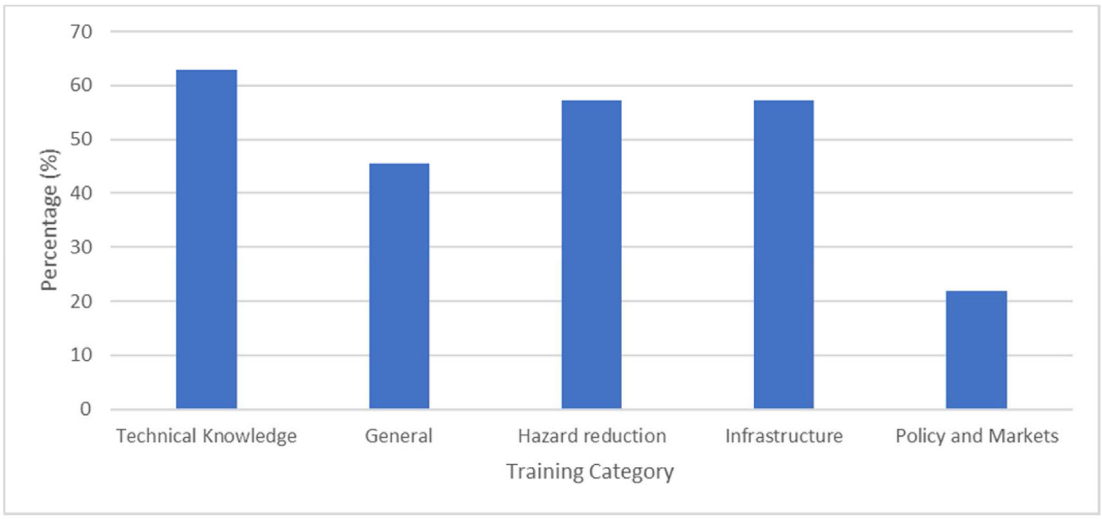

Fig. 1 – Education and training needs (thematic) for the Hydrogen industry.

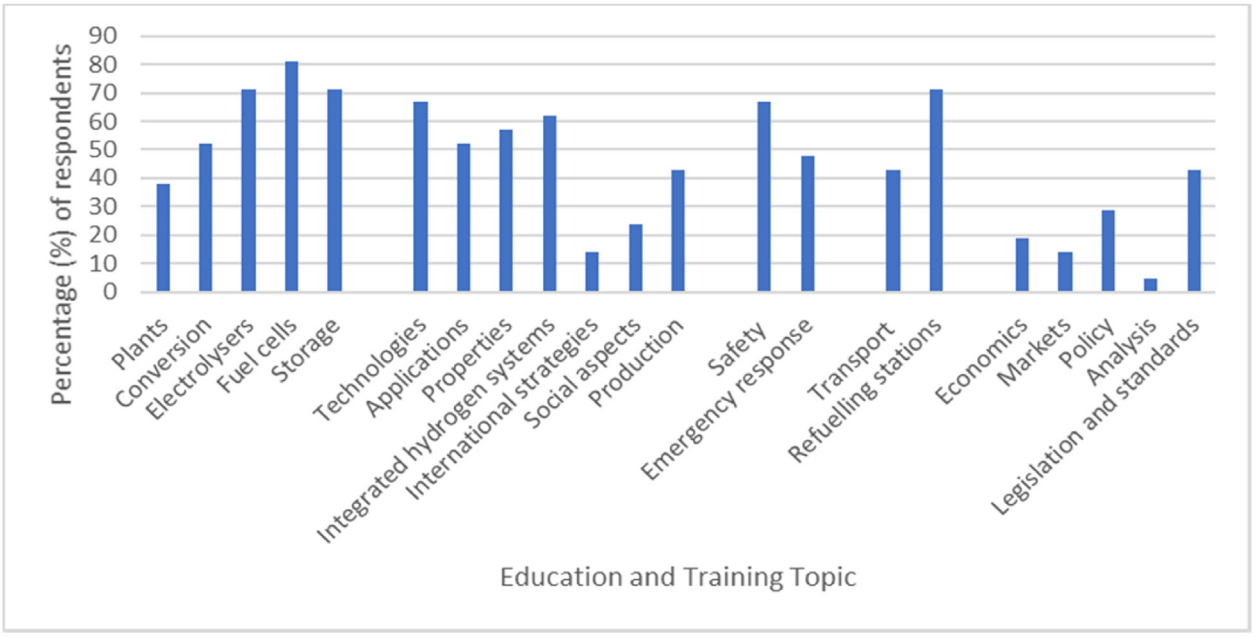

Fig. 2 – Specific education and training needs for the Hydrogen industry.

Hydrogen can be a very dangerous gas to work with and hence appropriate training is essential. (Industry consultant, survey comment)

CERT IV UEE (electrotechnology) skills are required urgently. These skills can be utilised by Gasfitters, plumbers, electricians and others working with fuel cells electrolysers and storage. Presently the development of vocational education and training (VET) skills for hydrogen work has been put on hold by the Commonwealth (Australian) Government. When the Commonwealth has completed its assessment of skills requirements in 2022, UEE skills development should be a priority. (Service technician, survey comment)

By contrast, the following comment played down the need for retraining for hydrogen in the current phase of the industry's development:

> *For gas infrastructure, I do not think the introduction of hydrogen will require major retraining, the fundamentals of managing a pressurised, explosive gas will not change. There will be many specialised and niche education requirements to ensure the physical properties of hydrogen are understood across all aspects of the industry. (Gas industry officer, survey comment)*

While this participant did not think there was a need for 'major retraining', nevertheless they envisaged there would

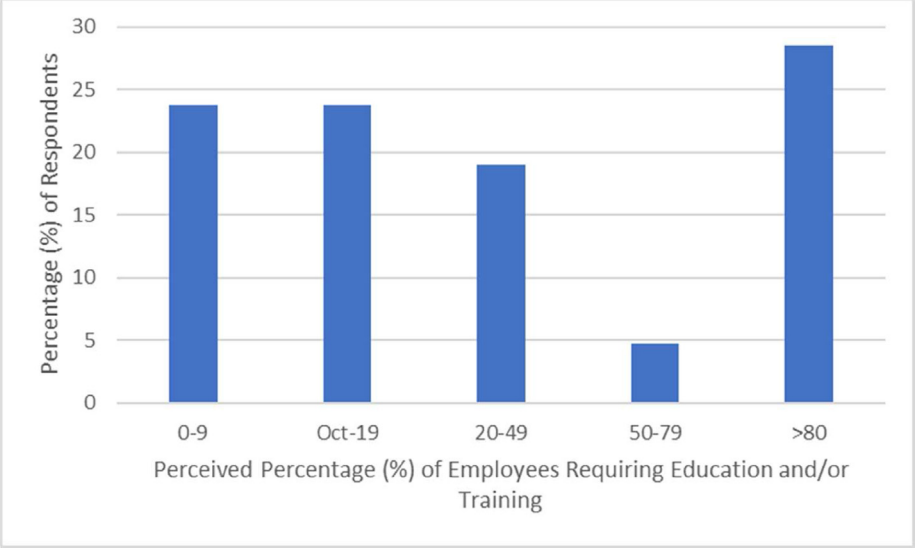

Fig. 3 – Perceived education and training needs.

be need for 'specialised and niche education' relating to hydrogen, which raises the notion of there potentially being education and training needs *of differing scales* required in the sector. Another participant pointed to the uncertainties within the sector that hamper making reliable predictions of education and training needs.

> *There are significant technical and operational uncertainties over the form of future hydrogen industries, which makes it very difficult to predict with any precision the exact skills that will be required. It is very important that the education sector liaise closely with industry bodies and key technology providers (including [de-identified] association members) in the development of future training courses. (Transport association officer, survey comment)*

Results relating to the question of the proportion of industry employees that would require hydrogen related training and education varied widely which suggests there is an ambiguity or an 'unknowingness' in the industry about future education needs. The survey comments presented above offer insight into how questions of scale of training requirements and uncertainties within the hydrogen sector are just some of the areas that create ambiguity within the industry.

Availability of training and training provision

The survey sought to collect data on the knowledge participants had of currently available hydrogen education and training. Over 70% of participants suggested that a lack of training was the biggest barrier to integrating hydrogen training into workers' existing knowledge. Results revealed that 47% of participants noted that while training and education does exist, it does not currently meet industry needs. Of the 41 respondents, only two suggested that training was offered in their company.

When availability of training was discussed during the industry consultations, participants suggested that there were challenges to developing and accessing hydrogen skills and training due to the ownership of information. One gas industry officer noted that "much knowledge lies with the [hydrogen equipment] manufacturer – they are doing most of the training now". Participants suggested that the protection of intellectual property was one of the reasons that manufacturers provided training: "Hydrogen businesses are relying on manufacturers for training - problem of IP" *(Industry workforce provider)*. Another participant noted that "manufacturers like [de-identified] and [de-identified] have their own training" *(Industry researcher)*. Findings highlighted that much knowledge is held and controlled by hydrogen equipment manufacturers, which may have both positive and negative implications for the development of the education and training landscape.

Barriers to education and training: Expertise and delivery

The findings revealed a number of barriers to education and training. Three quarters of participants indicated that there was a lack of available training and similarly, of hydrogen industry knowledge. The single largest barrier reported by industry participants was a lack of hydrogen expertise as identified in this comment.

> *Hydrogen and many new emerging technologies lack trainer and industry expertise. At a minimum, I believe the trainer should have industry experience and some expertise. (Jobs training provider, survey comment)*

Time, funding and a lack of training facilities were other factors hampering progress in training as identified by the following respondents.

> *A lack of funding and time for people to develop training resources are also major hurdles at the current time. (Industry executive, survey comment)*

Lack of Hydrogen facilities to provide training. (Training manager, survey comment)

Comments from industry participants suggest further investment is needed in both human and physical infrastructure to support growing education and training demands.

Barriers to education and training: leadership and policy

In addition to tangible and on-the-ground barriers, a lack of leadership was noted as a barrier to advancing education and training in the sector. An area of widespread agreement was the need for coordination within the sector around training and education. Participant comments suggested that training now would be integral to success within the sector over the short and medium term future.

I think the hydrogen training requirement will be much greater in 5+ years but it is really important to get it right in the next five years so we are ready. (Gas industry Officer, survey comment)

A coordinated and agreed approach to training and education in the H2 sector is critical … Training should be industry endorsed and accredited by an industry body or a Service Skills Organisation/State Training Board. (Training manager, survey comment)

A detailed skills gap matrix should be developed with a clear understanding as to planned roll out of hydrogen across Australia. (Jobs training provider, survey comment)

Presently the development of VET skills for hydrogen work has been put on hold by the Commonwealth Government. (Gas industry technician, survey comment)

The above comments signal the importance participants place on undertaking strategic skills planning now for the future expansion of the hydrogen economy and the need for co-ordinated and systematic planning of education and training. Findings suggest that industry stakeholders are reliant upon governments to take a leadership role in planning for the provision of education and training, though they also expect industry to be heavily involved in determining how this landscape evolves.

The policy and legislative context are important to advancing the hydrogen sector and specifically the education and training landscape. Field notes from the industry consultations revealed that there are many changes occurring in hydrogen policies and legislation that impact upon the education and training needs of the sector.

[De-identified] has succeeded in getting the case for endorsement for Hydrogen [education] units approved because of urgency for the gas industry. The Case for change for gas units to include reference to renewables has been submitted. Hoping to get these through too to avoid the time of change next year when AISC (Australian industry and skills committee) introduces changes to the training package and election changes if any.[2] *(Industry specialist)*

Consultation participants noted the uneven rate of change at different governmental levels:

States are moving quicker than national in legislation changes (Industry specialist)

Australian Industry and Skills Committee (established by Coalition of Australian Governments) is waiting on the [de-identified consultant's] National Skills Training Analysis before approving training changes. (Industry executive)

The changes at national and state level of policies and legislation referred to by participants in the consultations, appear to have created an environment of uncertainty that leaves industry participants waiting for changes to be resolved before moving forward with education and training.

Discussion

The landscape of education and training for the Australian hydrogen economy encompasses a complex array of stakeholders. The study found that industry stakeholders reflected an awareness of the need for more education and training to support a hydrogen economy and articulated areas in need of development. Industry stakeholders, and their engagement in the hydrogen sector is an enabler that can (and should) be utilised in advancing fit-for-purpose and responsive education and training. By working together to develop common understandings and common approaches for addressing hydrogen related education, an education and training framework based on the inputs and expertise of others could be advanced (Jordan, 2006). However, in describing the training landscape, stakeholders expressed some concern over the availability of experts to design and deliver necessary training, along with complexities surrounding intellectual property and how this influences the delivery of training. In addition, questions were raised by participants relating to the speed at which leadership and policy were emerging in support of educating and training a workforce for the sector.

Developing a well coordinated education and skills landscape for the hydrogen industry is essential to maximising the potential of the sector [7]. This will require ongoing mapping of skills requirements and appropriate planning to match demand and supply of skills, education and training. The results of this study showed there is at present, a perception that the hydrogen education and training space lacks leadership. Arguably, Government-delivered education is slow to respond to innovations and shifts within the energy sector [34]; meanwhile, the hydrogen industry is changing and growing rapidly with increasing private and Government investment. The Hydrogen Skills Roadmap report highlighted that of all the existing national training packages, only one was identified to have successfully revised its curriculum to introduce hydrogen-specific units of competency [6 p. 23].

[2] The Australian Federal election was held in May 2022. Participants indicated an awareness at the time of data collection, that a change of Government could influence how education and training would be supported.

There is a danger that the current structure of vocational and higher degree education and training for the hydrogen industry will be insufficient to meet growing workforce demands [34], especially if there is a lack of coordination among education institutions in the development of courses and learning materials. To realise the economic potential of the hydrogen economy for Australia, strategic and coordinated planning around workforce needs is necessary [26]. This study suggests that currently, little confidence exists within industry that this is occurring.

Working with hydrogen necessitates high quality training across the supply chain - from production through to off-take and consumption - to ensure safety and effective risk management. The complex landscape of accreditation within the VET sector and in higher degree institutions has led to a reliance on short courses (including micro-credentialing) for filling training needs, since these bypass accreditation roadblocks [6 p. 52]. In addition, there may be a need for reshaping the way that skilling and training occurs in the hydrogen industry in Australia, in order to prevent bureaucracy from holding it back from delivering on its potential. Jobs required in a hydrogen economy will entail new combinations of skills, drawing together for example, the knowledge and skills of gas plumbers and electricians [6]. In what follows, we focus on two particularly influential parts of that landscape: 'top-down' qualification/accreditation processes and 'bottom up' direct participation in training by equipment manufacturers.

'Top down' processes too slow for rapid emergence of green hydrogen sector

Industry training in Australia has traditionally been delivered through what can be described as a 'top down' approach, whereby skills training is centralised and delivered through TAFE or other Registered Training Organisations in which accreditation/qualifications are managed through government defined standards frameworks. Observations from the industry consultations about how the skills landscape is developing, revealed that the qualification/accreditation pipeline and processes operated by the traditional government providers of industry skilling (ie. TAFE), are not keeping pace with the rapidly scaling demands of the sector. Among all Australian national endorsed training packages at TAFE institutions, only the Gas Industry Training Package (UEG) was revised to include units of competency relevant to the emerging hydrogen economy[3] [35]. The 'top down' approach to education and training led by governments, provides a sequential and standardised approach to training, access, availability, and costs. Importantly, information about education and training within the sector is publicly available and is, therefore, less subject to market forces. Over the long term, the delivery of education and training through registered training organisations protects workers transitioning into the hydrogen economy (and the economy more generally) from exclusivity of skilling and a marketised training landscape.

Yet, because the centralised system is not keeping pace with the fast-moving green hydrogen industry, there is a 'bottom up' manoeuvring being pursued by industry to fill the gaps. Consequently, in the interim, the training and education void is being filled by short courses and the emergence of 'micro-credentialing' offered by a variety of organisations to address skills gaps. Benefits of this include flexibility and a degree of resilience [36]; however, there are also risks of such a fragmented landscape, as the next section discusses.

Resilience and the dangers of designing skilling and education from the 'bottom up'

Survey participants and industry consultations identified that considerable skilling and training was conducted by equipment manufacturers dominant within the sector. Participants acknowledged that this enabled needed training, and reflected on the difficulties of training occurring any other way due to intellectual property complexities. A consideration with this kind of 'bottom up' approach is the potential for the market to determine who gets skilled and who doesn't, through cost, access and availability [36]. In this sense, manufacturing companies filling the void of training need, are doing so in such a way that they can hold on to the intellectual property. While this may be necessary to ensure commercially sensitive information is protected, there is the risk that workforce strategies for the sector experience distortions brought about by companies seeking to maintain monopoly power, due to manufacturers either inadvertently or deliberately exerting control over the training landscape.

Questions might be asked about what may be the benefits and constraints of a potential 'industry capture' of training in the green hydrogen sector. Manufacturers having an outsized influence on training and who can access it can have unintended consequences for the sector as a whole. Manufacturers, particularly those with intellectual property rights (IPR), can limit access to training and can set their own prices to access training. This can make training expensive, exclusive and less accessible. Further, there is little transparency or accountability about the quality of such training. Nevertheless, this issue is one that has been experienced and addressed in other industry sectors previously with particular intellectual property rights and manufacturers holding the strings to the workforce and the training [37]. This may provide some insight that will be useful for the hydrogen sector.

Of further consideration is the possibility that a fragmented and piecemeal training landscape emerges because the training is aligned with particular manufacturers, rather than broader skill development that is transferable across technologies and equipment. This potentially limits opportunities for there to be more comprehensive, systematic and distributed skilling and training of the workforce for the sector as a whole. While there is a risk that the manufacturing market will determine who gets skills/access to training - which could limit establishing an equitable and well developed workforce and jeopardise sector resilience - this 'bottom up' approach is filling a short-term need in the sector and

[3] With the assistance of Technical Advisory Committees, the Gas Industry Reference Committee created six new Units of Competency, three new Skill Sets, and revised 13 units. The new Units of Competency and Skill Sets were developed particularly for hydrogen gas, and the existing units were updated to include hydrogen contextualisation as well as other gases. The updated Training Package addresses the skill requirements of gas technicians who work with hydrogen.

enabling the advancement of the emerging hydrogen economy.

Conclusion

There is an urgent need for carbon abatement solutions at scale and the green hydrogen industry is 'a lifebuoy of hope' [38]. Skilling and education play a central role in ensuring the development of an adaptable and resilient hydrogen economy in Australia. This study identified industry stakeholders' recognition of the importance of workforce development and their desire to work alongside those in the education and training sector to find appropriate and fit-for-purpose solutions. However, findings revealed that those in the industry perceive insufficient training opportunities currently with limited expertise available to support the hydrogen sector in its current phase of growth, or to facilitate the (re)skilling of the workforce required to realise the promise of the green hydrogen economy. As identified through this study, there is a risk that Australia will miss its moment of implementing green hydrogen energy at scale because of a lack of skills and expertise.

This study has contributed toward understanding how industry stakeholders perceive education and training and its role in supporting an emerging hydrogen economy. More research is needed to improve understanding of the education and training needs of the hydrogen sector in Australia and the enabling structures that can support delivery. Research in this area will help build the human-infrastructure needed for the emerging green hydrogen sector to realise its forecast potential as a major contributor to decarbonisation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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