



Australia's National  
Science Agency

# Hydrogen Research, Development and Demonstration

Priorities and opportunities for Australia

## **EXECUTIVE SUMMARY**

December 2019



# Acknowledgement

CSIRO acknowledges the Traditional Owners of the lands that we live and work on across Australia and pay their respect to Elders past, present and emerging. CSIRO recognises that Aboriginal and Torres Strait Islander peoples have made and will continue to make extraordinary contributions to all aspects of Australian life including culture, economy and science.

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# Chief Executive Foreword

Australia's economic prosperity and energy security will depend on us solving national challenges to follow the global market trend towards zero emissions energy. Australia is blessed with vast energy resources, many of them renewable, but some of our biggest trading partners are not so fortunate and are grappling with how to transition from a reliance on imports to lower-emissions alternatives. This is where science can unlock a seemingly impossible challenge, because hydrogen energy could both fill the gap in our export dollars and help the world navigate this energy market transition.

Australia can become a renewable energy superpower through the production and export of hydrogen, but it isn't easy to invent a new industry around an existing one. The past 18 months have seen unprecedented support for hydrogen, and with good reason. It has a role to play across transport, power, and industrial sectors, and is experiencing increasing domestic and international demand – especially when made from renewable energy. But hydrogen requires a fundamental paradigm shift – and we know that paradigm shifts are often the undoing of new technology. This is where science, as the great former Australian Prime Minister Billy Hughes said, “can lend a most powerful aid.”

This report builds on the concepts introduced in our National Hydrogen Roadmap to identify five key hydrogen industry breakthroughs where research, development and demonstration (RD&D) can develop the Australian and global hydrogen industry. By focusing on these unfair advantages for Australia, we can bring together industry, government, and research organisations to de-risk technologies and catalyse industrial demonstration of critical elements, linking Australian activities with international projects.

Our goal is to fast-track the deployment of emerging hydrogen technologies, providing a means for industry to undertake the technical work required to help them transition to a new energy future.

National leadership is critical to connect key players and capabilities across the value chain, and as Australia's national science agency, CSIRO is partnering with key stakeholders like the Australian and Victorian governments, Origin, Woodside, BHP, and the Australian Renewable Energy Agency (ARENA) to frame this dialogue and develop a path for hydrogen in Australia through this report, as well as in a range of specific projects with partners like Toyota, Hyundai and Fortescue.

Science has already broken one of our major roadblocks by enabling seamless conversion between gaseous hydrogen and liquid ammonia using our patented hydrogen cracker. This simplifies storage and transport and leverages existing liquid fuel infrastructure. We've also invested in other key breakthroughs of the future through our Hydrogen Energy Systems Future Science Platform (FSP), de-risking new hydrogen technologies and supporting development of new energy markets including in chemicals and transportation sectors.

CSIRO has been forming collaborative networks around national missions for over a century and is now rallying partners to do the same for hydrogen. We can focus RD&D and bring together industry, government, and other research organisations in an initiative that will facilitate the development of industrial-scale, export-focused hydrogen value chains for Australia. This work will de-risk technologies and catalyse industrial demonstration of critical elements, and link Australian activities with international projects. It will fast-track the deployment of emerging hydrogen technologies developed by CSIRO and its partners.

We believe that building this new industry will focus all our energy on building a better future rather than arguing about the past – that's the power of national missions. Together, we can build a robust and innovative domestic and export hydrogen industry to power a brighter energy future for Australia.

**Dr Larry Marshall**  
Chief Executive  
CSIRO

# Executive Summary

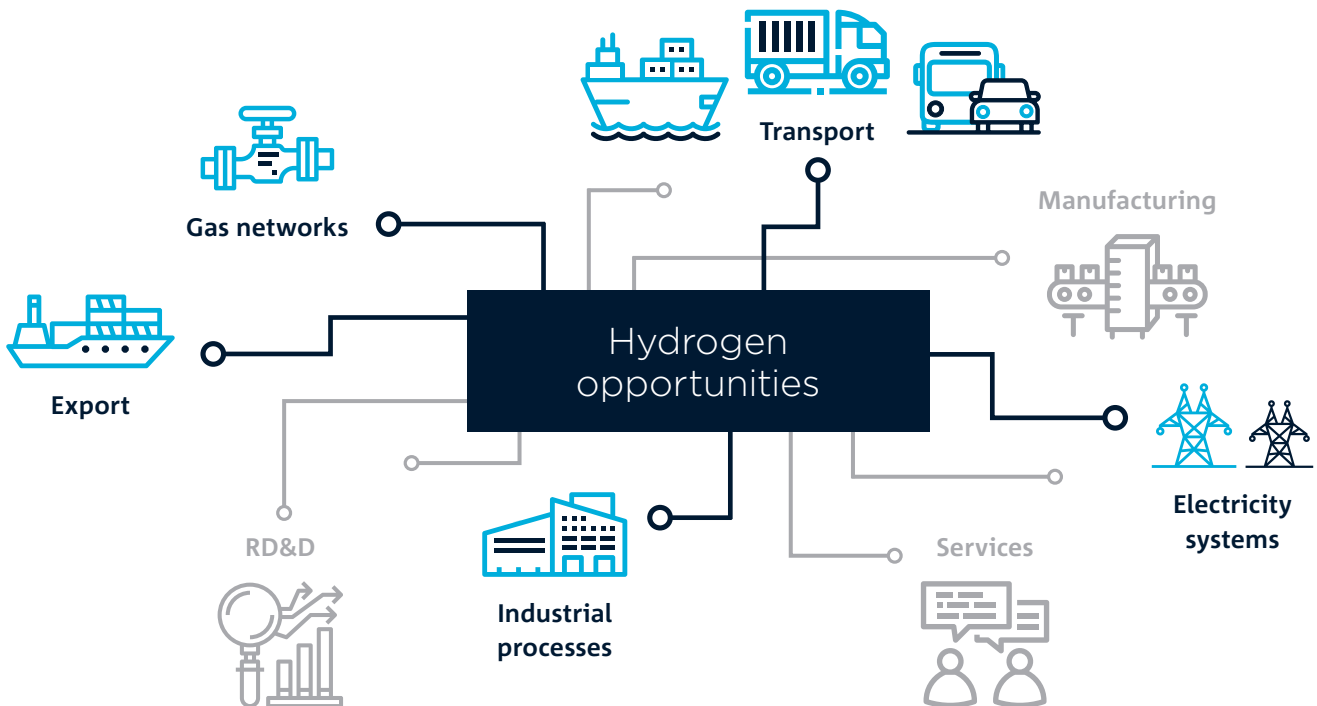
In 2018, CSIRO released the *National Hydrogen Roadmap*,<sup>1</sup> which articulated the opportunity for Australia to build an economically sustainable domestic and export hydrogen industry which could deliver both economic benefits for Australia and support global decarbonisation efforts. In addition to highlighting the importance of market activation through improvements in costs and scale, the Roadmap identified the significant role of research, development and demonstration (RD&D) in enabling hydrogen industry development.

Building on the *Roadmap*, this report investigates Australia's hydrogen RD&D opportunities in greater detail.

It was developed in parallel with *Australia's National Hydrogen Strategy* and will support implementation of the Strategy.<sup>2</sup>

This report, informed through consultation, explores the supporting role of RD&D across five active hydrogen industry opportunity areas: the export of hydrogen, and the integration of hydrogen into gas networks, transport systems, electricity systems and industrial processes (see Figure 1). It provides comprehensive analysis of current Australian RD&D capabilities as well as analysis of opportunities for RD&D to support industry development now and into the future.

Figure 1: Hydrogen industry opportunities



1 Bruce, S., Temminghoff, M., Hayward, J., Schmidt, E., Munnings, C., Palfreyman, D., Hartley, P. (2018). *National Hydrogen Roadmap*, CSIRO.

2 Commonwealth of Australia (2019) *Australia's National Hydrogen Strategy*. [Online] Available from: <https://www.industry.gov.au/sites/default/files/2019-11/australias-national-hydrogen-strategy.pdf>, Accessed: 25/11/2019

# Research, Development and Demonstration (RD&D)

has an important role to play in enabling the continued development of Australia's hydrogen industry.

## A collaborative approach

This report is informed by:



Interviews with representatives from **35** industry and government organisations



**80+** interviews with researchers from 23 institutions across Australia



Broad literature review

For each of the opportunity areas, RD&D can deliver both incremental and breakthrough technological outcomes; and support industry development through non-technical or cross-cutting RD&D (see Figure 2).

If coordinated and aligned to a broader strategy, RD&D can support national and international collaboration and knowledge sharing. It can lead to new hydrogen industry opportunities beyond those explored. Further, it can help to grow technology, manufacturing and service businesses that provide highly competitive solutions to the hydrogen industry and are differentiated using science, technology and innovation.

Figure 2: The role of hydrogen RD&D



- Reducing capital and operating expenses by delivering incremental improvements in mature technologies.
- Delivering new technologies which offer step-change benefits to hydrogen value chains.
- De-risking critical enabling technologies through demonstration and scale-up.



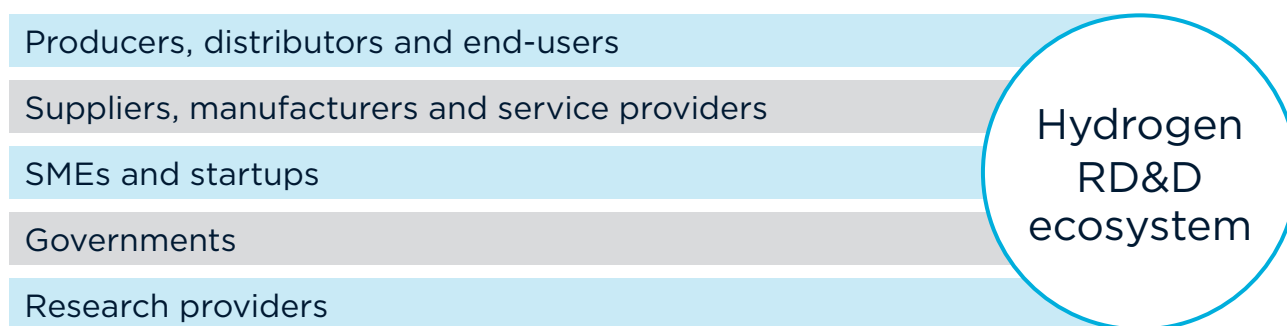
- Understanding and minimising the environmental impacts of a large-scale hydrogen industry.
- Helping to ensure and demonstrate safety; and inform community awareness of the safe production, storage, transport and use of hydrogen.
- Aiding and accelerating decision making through modelling to reduce project uncertainties and complexities; provide insight to optimise systems and integration; narrow technology selection; and demonstrate and determine project value and returns.
- Supporting and informing policy and regulations to support policy, regulators and lawmakers during scale-up and the long-term development of the hydrogen industry.

# Australia has a strong RD&D ecosystem that can be leveraged to address challenges across the hydrogen industry value chain and support economic development in Australia.

Australia’s hydrogen RD&D ecosystem encompasses activities which range from fundamental research through to pilot and demonstration project delivery. It comprises researchers, technologists, engineers, policy makers, manufacturers and end-users (see Figure 3).

Australia has a strong foundation of hydrogen RD&D skills and infrastructure across this ecosystem that can support market activation and improve the long-term sustainability of the domestic and international hydrogen industry.

Figure 3: Hydrogen RD&D ecosystem



## 23 Australian institutions are active in hydrogen research

Through the course of developing this report, 23 Australian research institutions with active hydrogen projects were identified and interviewed. These institutions are spread across the country and are working across the value chain.

### National

CSIRO  
Future Fuels CRC  
Blue Economy CRC

### QLD

Griffith University  
Queensland University of Technology  
University of Queensland

### WA

Curtin University  
University of Western Australia

### SA

Flinders University  
University of Adelaide

### ACT

Australian National University

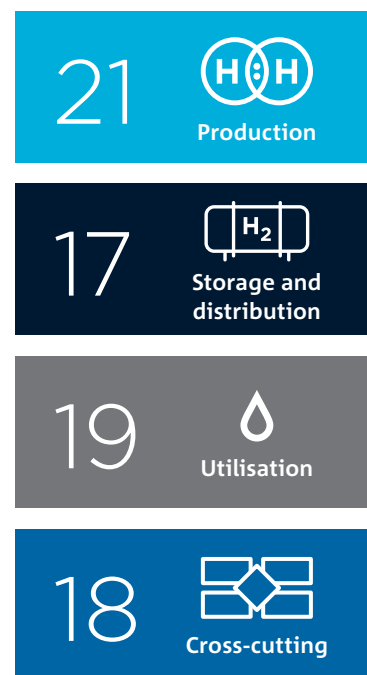
### NSW

Macquarie University  
University of New South Wales  
University of Newcastle  
University of Sydney  
University of Technology Sydney  
Western Sydney University

### VIC

Deakin University  
Monash University  
RMIT University  
Swinburne University  
University of Melbourne  
Victoria University

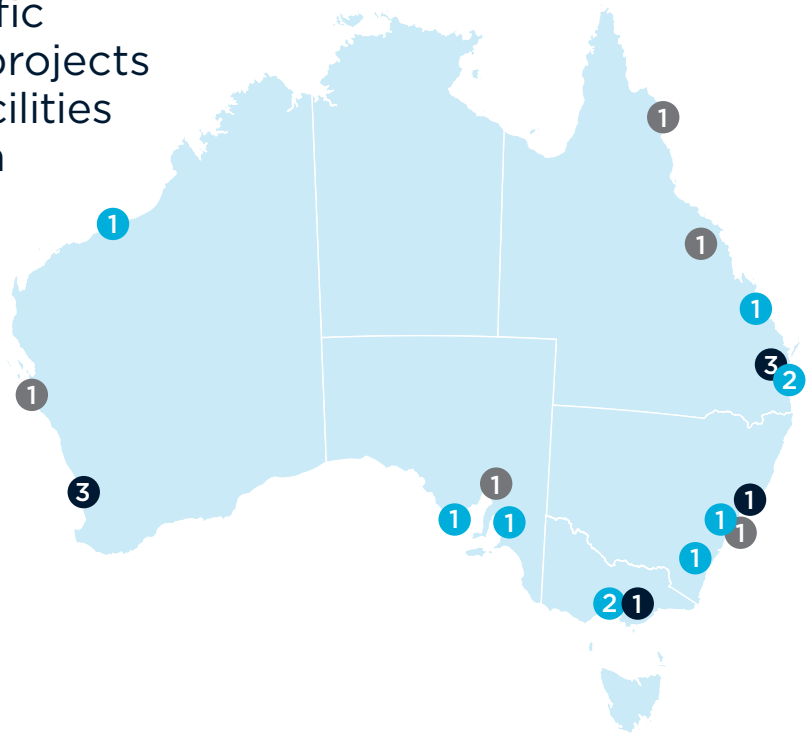
Number of institutions engaged in RD&D across the value chain\*



\* Based on snapshot of currently active projects only

# 23 Hydrogen-specific demonstration projects and research facilities around Australia

- Completed
- In progress
- Proposed



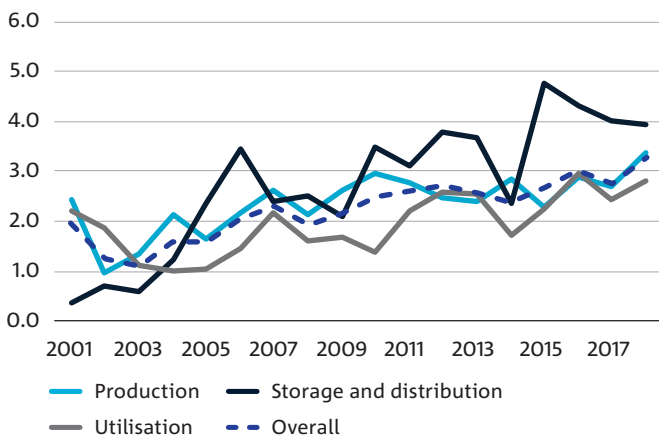
## Publications and patents

Australia is a leading country with respect to global publications in the area of hydrogen research.

This is demonstrated by strong performance in publications output, citation impact and international publication collaboration (see Figure 4).

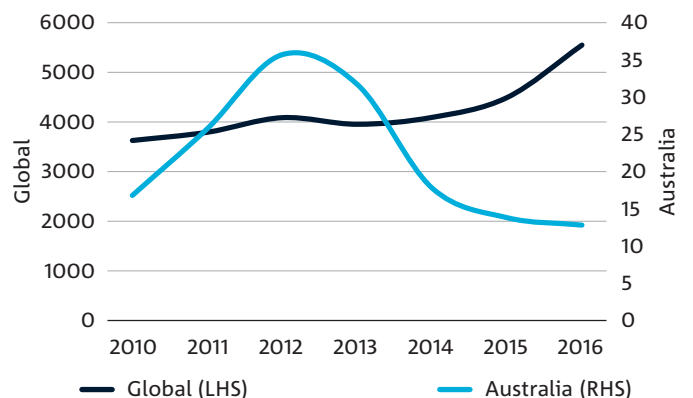
However, despite a strength in publications, there is scope for improvement (see Figure 5). While not the only indicator of innovation performance, data suggests a weakness in converting research insights into patents and commercial opportunities. This innovation performance challenge is not unique to hydrogen and mirrors challenges in Australia's national innovation performance.

**Figure 4: Australian hydrogen publication output as percentage of the world (%)**



Data was drawn from the Web of Science (WoS) from Clarivate and InCites by Clarivate Analytics.

**Figure 5: Global and Australian hydrogen patent family filing trend, number of publications**



# Global hydrogen industry developments will address many market activation challenges; however, RD&D is required to overcome current barriers and help stimulate demand.

The realisation of hydrogen opportunities at scale requires ongoing investments amongst various stakeholder groups (e.g. industry, government and research). Whilst many market activation challenges will be addressed through global hydrogen industry developments, there remains the potential to accelerate this through RD&D.

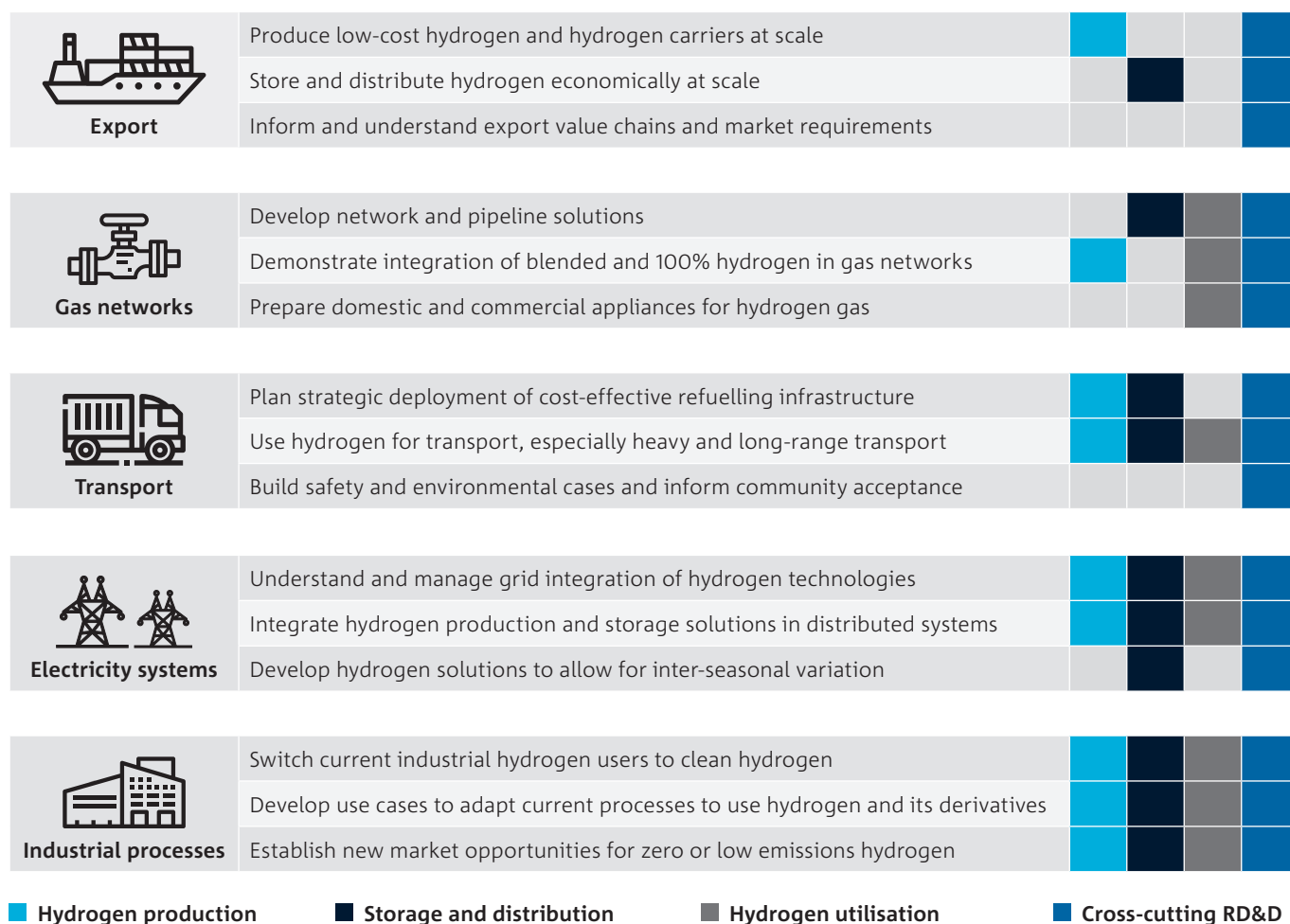
To understand where the Australian hydrogen RD&D ecosystem could assist, this report identifies three short-to medium-term market activation challenges for each opportunity area (see Figure 6). Each of these challenges highlights the importance of coordinated RD&D effort across the value chain and in cross-cutting fields.

Importantly, solving the challenges identified can have a multiplier effect that boosts demand for hydrogen and

encourages further hydrogen supply cost reductions through improvements in efficiency and economies of scale. Hydrogen use in industrial processes provides a strong example of this in action given the breadth of industries that already use hydrogen as a feedstock, the number that could use hydrogen and the volume of hydrogen required by these industries to support ongoing operations.

While not exhaustive, the challenges selected aim to support decision making and greater collaboration between industry and the research community. This collaboration will be essential given that the market activation challenges, and their associated RD&D opportunities, are interrelated and will change over time as the industry grows and diversifies, and as competitive pressures increase.

Figure 6: Opportunities and RD&D-related challenges





## Diverse industry challenges and solutions require diverse RD&D capability.

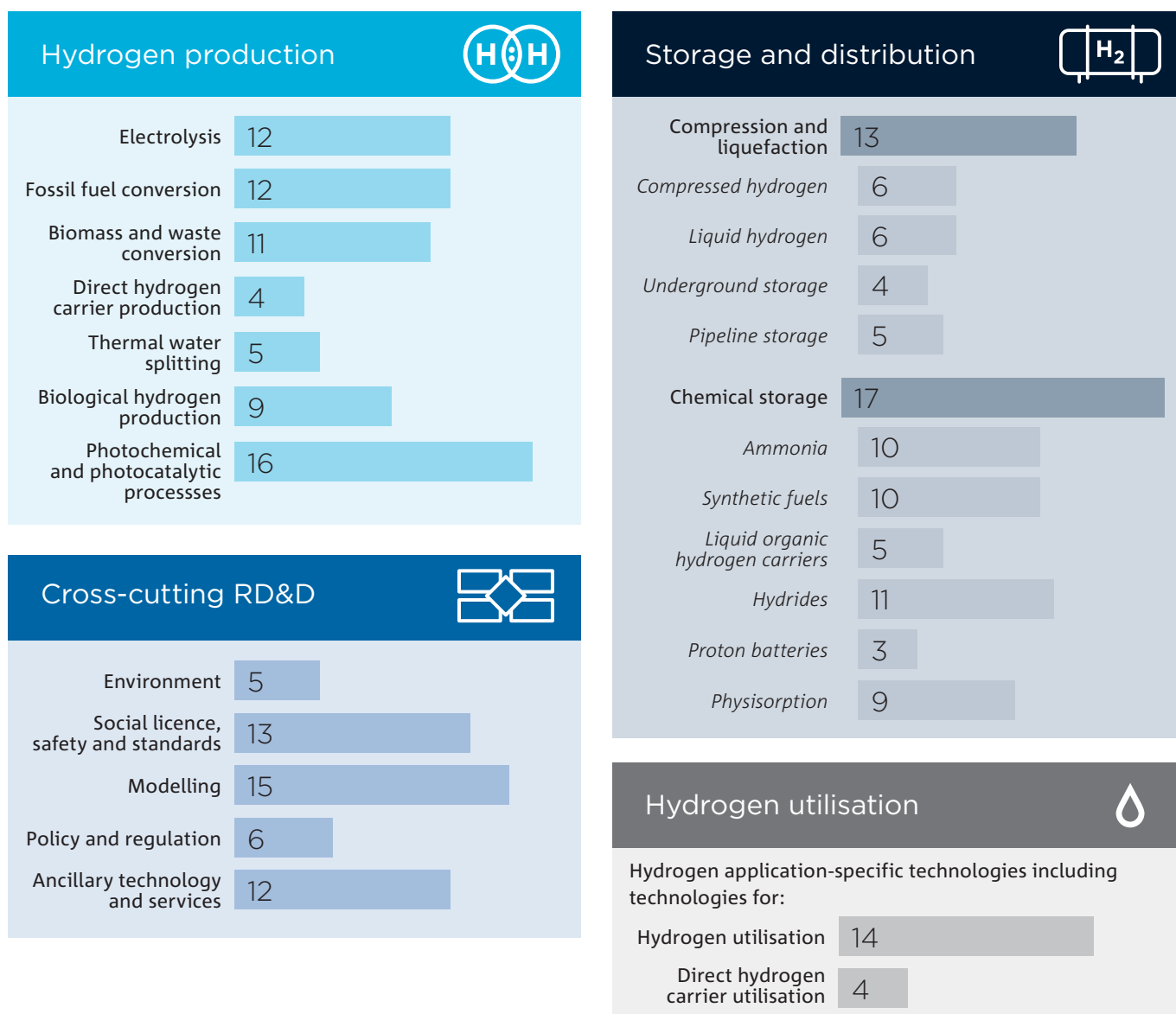
The complexity and diversity of hydrogen industry challenges and possible pathways requires a diverse range of RD&D capability to match. This includes deep technical expertise in hydrogen-related technologies, complemented by expertise in cross-cutting RD&D fields. Understanding current active hydrogen projects can be used to indicate existing capability that could be leveraged and readily transferred into new RD&D areas (see Figure 7).

Australia's diverse RD&D capability should be developed and strategically leveraged to collaboratively respond to global and domestic industry opportunities.

Together, this diversity will help foster near-term and breakthrough technologies and create new knowledge that helps the global industry develop.

This report (along with the technical appendix) presents detailed analysis of technologies and research areas from across the value chain to explore the breadth of diversity required and allow stakeholders in industry, research and government to make informed choices. Over time, Australia's RD&D capability can be further refined or focused as the industry matures and investment in specific opportunities increases.

Figure 7: Snapshot of current hydrogen RD&D project activity, by category and number of active Australian institutions






## RD&D to deliver cost and efficiency improvements will be a critical success factor.

Achieving low-cost production of hydrogen at scale will be a critical factor for determining the growth and success of the hydrogen industry. This analysis identified a broad range of cost and efficiency opportunities across the value chain which are achievable through RD&D (see Figure 8). From a cost perspective, there are specific

opportunities to reduce capital and operating costs through new materials, system designs and improvements in integration between technologies. While inherently linked to cost, efficiency is particularly important for making the most out of the resources available.

Figure 8: Example cost and efficiency opportunities for RD&D

Hydrogen production 	Storage and distribution 	Hydrogen utilisation 
<ul style="list-style-type: none"> <li>• <b>Reactor or stack improvements</b> through new materials and designs for greater durability, lower cost, operation at desirable conditions, etc.</li> <li>• <b>Integration and key process improvements</b> to power sources, production stacks and storage systems.</li> <li>• <b>Balance of plant reductions</b> through actions such as operating condition optimisation, heat source integration, complementary technology co-location, etc.</li> </ul>	<ul style="list-style-type: none"> <li>• <b>Storage materials and system designs</b> to improve hydrogen storage capacity, costs, material life and round-trip energy efficiency; and enhance applicability to specific use-cases.</li> <li>• <b>Synthesis methods</b> to optimise reactor materials, conditions and efficiency at lower costs where hydrogen carriers are used.</li> <li>• <b>Compression methods</b> to improve hydrogen compression costs and efficiency.</li> </ul>	<ul style="list-style-type: none"> <li>• <b>Stack improvements</b> through development of new materials and designs for electrolytes, catalysts, gas diffusion media and cell hardware.</li> <li>• <b>Balance of plant improvements</b> to reduce costs and increase durability of components including humidifiers, compressors and fuel processors.</li> <li>• <b>Turbine durability and function improvements</b> with development of heat resistant materials, management of combustion profiles and emissions reductions.</li> </ul>

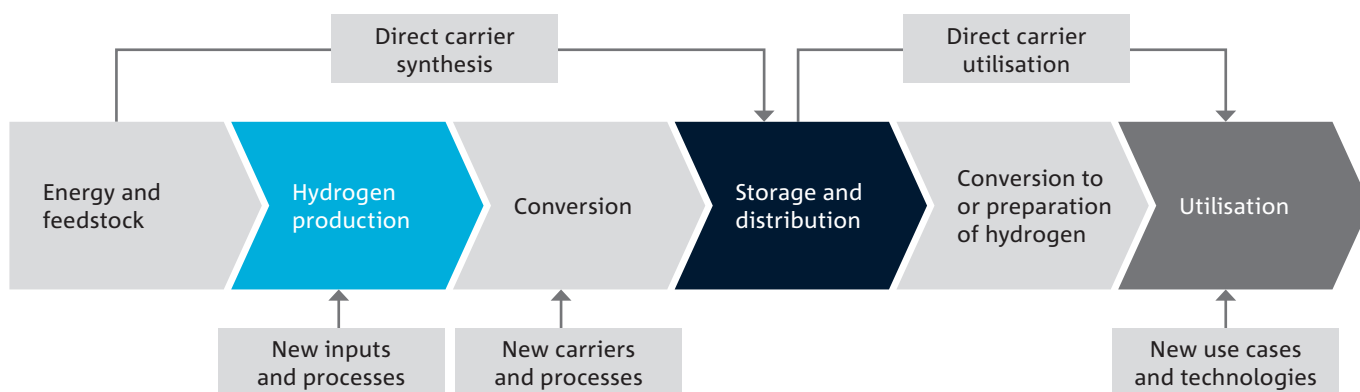
## RD&D in breakthrough technology areas, including in hydrogen utilisation, can lead to step-change cost reductions or process improvements across the value chain.

Identifying and developing breakthrough technologies can offer step-change benefits across the hydrogen value chain. This could include eliminating the need to process a given feedstock for hydrogen production, for example by using low quality or waste water inputs without pretreatment. Breakthrough technologies could also allow the use of alternative feedstocks such as biomass or waste streams; or value chain transformation for example through direct use of carriers (see Figure 9). While difficult to predict the timeline of

such developments, RD&D on new hydrogen generation or storage technologies could lead to breakthroughs that change cost structures or eliminate process steps.

A key opportunity is in the development of new hydrogen utilisation technologies, particularly in large scale industrial settings. Such technologies will serve to boost demand and help encourage cost reductions in hydrogen production, storage and distribution. It will also increase the development of ancillary technologies and services that are required to support the industry.

Figure 9: Example breakthrough opportunity areas

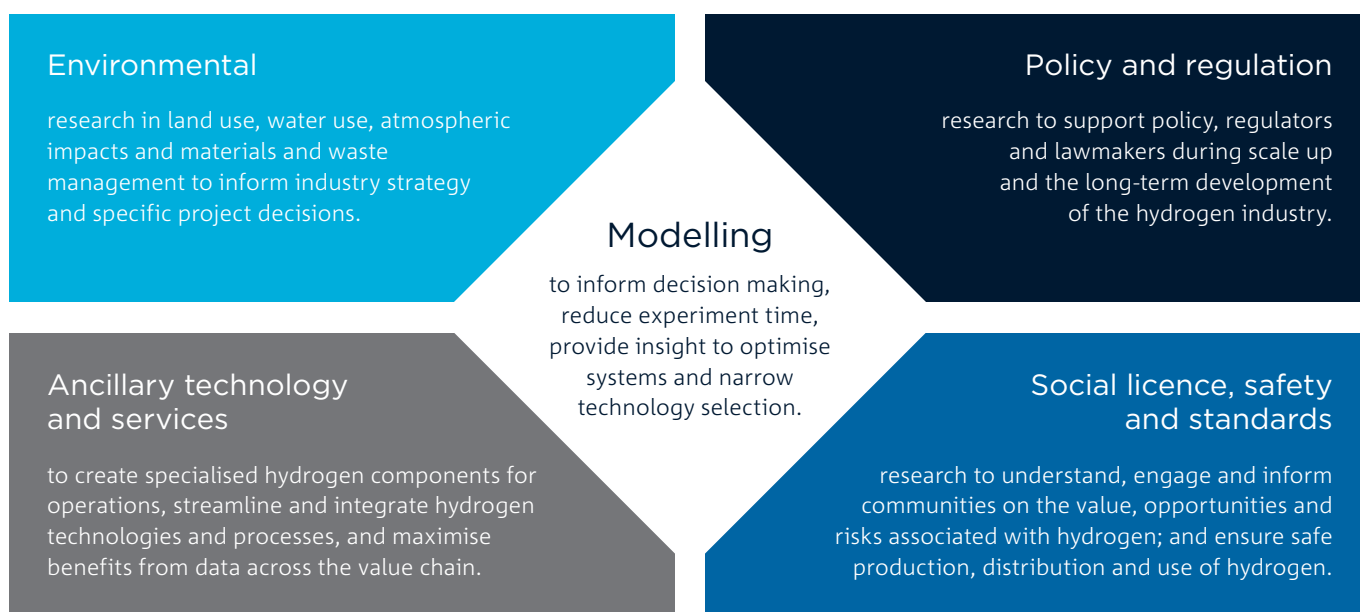


## **Integrated decision-making** support through research in cross-cutting areas can de-risk project development and deliver industry outcomes.

The development of the hydrogen industry will be strengthened by information and decision-making support through five cross-cutting RD&D fields (see Figure 10). While each of the five fields are often viewed independently, they are interrelated and can be integrated to achieve greater industry and economy-wide outcomes. For example, an integrated response to sector coupling can

be enhanced through the combination of research efforts in land use and land rights, community engagement and modelling; and supported through the development of ancillary technologies that monitor and measure outcomes. Such an integrated approach could lead to more efficient industry development, drive new opportunities and help to understand dividends for the entire economy.

**Figure 10: Cross-cutting RD&D fields**



# Mobilising the RD&D community to address hydrogen industry development challenges requires coordinated actions from across the research community, industry and government.

For the Australian RD&D community to maximise impact and innovation performance, coordinated actions must be taken. While there is no silver bullet for enhancing Hydrogen RD&D outcomes in Australia, based on interviews and analysis this report has identified four interrelated actions with specific activities. This includes ongoing development and optimisation of an Australian hydrogen RD&D strategy, encouraging greater RD&D activity in scale-up efforts, promoting RD&D connections and contributions to international hydrogen RD&D efforts, and addressing hydrogen industry-research sector collaboration challenges.

These actions are not unique to hydrogen RD&D and in many cases apply to Australia's national innovation system. Therefore, any effort to enhance Australia's hydrogen RD&D outcomes can also be leveraged to support improvements in Australian innovation and RD&D more broadly.

## RD&D strategy:

Establish and monitor ongoing RD&D priorities for Australia as part of a national hydrogen industry strategy. Activities should focus on encouraging hydrogen RD&D collaboration, identifying ongoing RD&D opportunities and reporting on progress. This monitoring should be linked to other monitoring of hydrogen industry development as identified by *Australia's National Hydrogen Strategy*.

As both the domestic and global hydrogen industry grow, it is anticipated that Australia's RD&D opportunities and priorities will evolve over time. Keeping track of these evolving RD&D opportunities and priorities will require a coordinated and ongoing strategic review and response which should be closely aligned to broader national monitoring of industry development. This will be key to realising the economic gains available from the hydrogen industry and maximising the value of Australia's RD&D contribution to it. The insights from this report provide the foundations for a hydrogen RD&D strategy and the identification of Australian RD&D priorities. However, there is a need for further work to occur which could include:

- Identifying and supporting a prioritised and balanced portfolio of hydrogen RD&D opportunities that considers both industry-driven and fundamental RD&D.
- Providing support for projects to have early access to modelling and techno-economic analysis to help projects identify specific cost targets or industry outcomes that RD&D should aim to achieve.
- Establishing knowledge sharing mechanisms to accelerate industry innovation and enable industry-RD&D collaboration.
- Establishing RD&D key performance indicators that support hydrogen innovation.

### Industry scale-up:

Enable industry growth through hydrogen hubs that support scale-up and establish pathways for greater RD&D engagement and technology development.

There is a global need for commercial-scale investments which demonstrate the viability and cost-competitiveness of hydrogen industry pathways. Supporting this scale-up will require concerted and collaborative action from industry, government and communities, with RD&D acting as a critical enabler. To address this need, *Australia's National Hydrogen Strategy* highlighted the value of hydrogen hubs as key to support hydrogen industry growth. Hubs are areas where hydrogen demand is aggregated. Demand could come from existing industrial users, hydrogen exports, transport applications, or injection into gas networks.

For the RD&D ecosystem, the establishment of relevant hubs would help bring together industry stakeholders and support engagement, provide clearer direction on demonstration and scale-up requirements, and help maintain focussed effort and a long-term perspective. Activities to support the hydrogen hubs and align industry and RD&D expertise could include:

- Providing incentives for industry, technology providers and researchers to collaborate and de-risk technologies within hubs and demonstrators.
- Promoting early collaboration and engagement activities between researchers and engineers through RD&D scoping studies to validate opportunities ahead of conducting a hydrogen project within or outside of a hub or demonstrator.
- Supporting hydrogen RD&D projects with small and medium-sized enterprises and start-ups to help develop novel hydrogen value chain technologies, processes and services that could be utilised or sold domestically and in international markets.
- Supporting and streamlining access to new and existing hydrogen research facilities.

### International collaboration:

Establish joint programs with international governments and industry to facilitate RD&D connections and contributions to international hydrogen RD&D efforts, with a focus on supporting timely global and domestic hydrogen industry development.

International hydrogen RD&D collaboration is an opportunity for Australia. It can help to avoid unnecessary duplication of effort across collective global industry opportunities and challenges. It offers a more effective way to accelerate hydrogen technology development and adoption by leveraging existing capability, infrastructure and talent; pooling capital; and sharing risks and rewards. Finally, it can support international relationship building, using science (and science networks) as a vehicle for international diplomacy and strengthening Australia's bilateral relationships. Findings from researcher interviews and analysis highlighted that international RD&D collaborations in hydrogen is currently often driven by chance and not connected to a broader national or industry strategy. Key activities to support the establishment of joint programs could include:

- Enabling translation of international experience by supporting participation in international hydrogen collaboration platforms.
- Analysing drivers and strategic goals by country to identify gaps and help determine where Australian RD&D capability could play a leadership role and be best suited to support an existing international project.
- Establishing an international hydrogen RD&D partnership scheme and bilateral agreements.
- Providing international project engagement and execution support services.

### **Culture and capability:**

Build collaborative hydrogen industry-research sector interactions through engagement programs and activities which unite industry and RD&D communities in identifying and addressing key industry challenges.

There are many individual researchers and institutions working in hydrogen that are already highly engaged with industry. However, it is not consistently occurring across the Australian hydrogen RD&D community. Based on interviews and analysis, many of the industry and research collaboration issues stem from differences in RD&D attitudes, drivers and objectives across innovation stakeholders. While there is no simple solution to improve collaboration outcomes for all Australian RD&D, addressing this challenge in the hydrogen industry is achievable given the nascent state of the industry and hydrogen RD&D. While new hydrogen-specific programs could be created, there are many well-established mechanisms that could be leveraged to improve business and research collaboration. Key activities to help build collaborative hydrogen industry-research sector interactions could include:

- Launching industry placement or secondment programs for researchers.
- Running targeted hydrogen incubator or accelerator programs to encourage innovation.
- Enabling and recognising the value of Australian and international in-kind RD&D industry contributions to support concept validation, identify requirements for upscaling and generate early buy-in.
- Continuing to grow a comprehensive hydrogen stakeholder network by supporting hydrogen-specific conferences and events.

International momentum towards the development of a clean hydrogen industry is building, with industry development quickly approaching an inflection point and beginning a period of rapid growth.

Australia's hydrogen opportunities, and the RD&D priorities to support them, will continue to evolve based on changes in national priorities, progress in global and domestic hydrogen projects, and other developments in Australia's hydrogen industry and RD&D capabilities.

Beyond supporting the National Hydrogen Strategy, this report aims to spark a broader national discussion between industry, government and the research community about the role of RD&D and how it can be best leveraged now and into the future.

The scale of Australia's hydrogen opportunity is too large to be left to chance. While the nation has a well-positioned hydrogen RD&D community, successfully leveraging this to build a domestic industry and support market activation requires collaboration. Strategic, coordinated action is critical in realising the opportunities available through RD&D to facilitate the growth of Australia's emerging hydrogen industry.

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