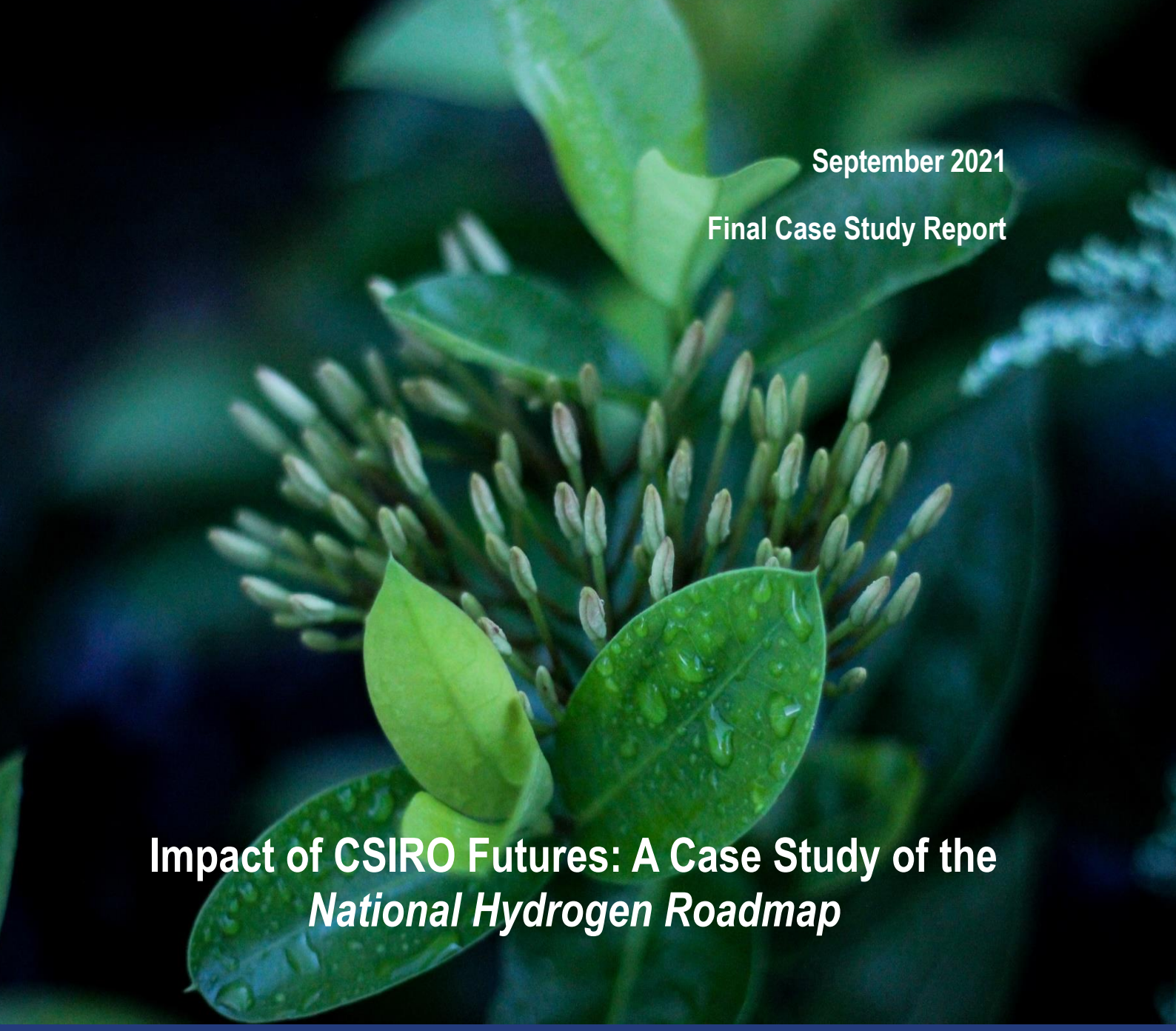

September 2021

Final Case Study Report

Impact of CSIRO Futures: A Case Study of the *National Hydrogen Roadmap*

Prepared for

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Executive Summary

CSIRO Futures is the strategic and economic advisory arm of CSIRO, Australia's national science agency.[1] Futures brings together science, technology, and economics to identify emerging opportunities and develop strategies that achieve them. Leveraging both their own expertise and the broader network and capabilities within CSIRO, the team provides strategic advisory services to public and private customers.

This case study of CSIRO Futures' work focuses on the *National Hydrogen Roadmap*. CSIRO Futures and collaborators from CSIRO's energy research team sensed the potential for hydrogen to be a near-term economic driver for Australia, noting market shifts and technological advances in hydrogen's favour. The *Roadmap* became a catalysing document that accelerated the pace of policies, investments, and actions in Australia following its publication. Hydrogen industry experts interviewed for this work noted its domestic significance for the National Hydrogen Strategy and associated investment programs as well as for the hydrogen strategies for other countries which leveraged the *Roadmap's* framework and ideas.

As reviewed in this report, the case of the *National Hydrogen Roadmap* exemplifies the role CSIRO Futures plays in strategic planning, especially in efforts related to broad-based market action. In this context, Futures generated economic and social value by

- recognising the need and opportunity for a market-focused roadmap;
- establishing a neutral, precompetitive forum for the exchange of ideas and information;
- convening diverse stakeholders from industry, government, and academia;
- producing higher quality, more timely information than otherwise would have been possible;
- avoiding duplication of effort by stakeholders who may have acted individually or in smaller groups;
- reducing asymmetries in information between market participants;
- accelerating public- and private-sector initiatives and policies to address the market opportunity during a window of opportunity; and
- catalysing action and investment and increasing the probability of success.

We conclude that through industry roadmaps CSIRO Futures generates impact for Australia by addressing information asymmetries, reducing the likelihood of duplicative and unproductive activity by industry actors, decreasing the overall level of uncertainty in an emerging industry, and thereby accelerating the pace of investment and economic activity.

[1] For more information about CSIRO Futures, please visit https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/CSIRO-futures.

1. Introduction

CSIRO Futures is the strategic and economic advisory arm of CSIRO, Australia's national science agency.[2] Futures brings together science, technology, and economics to identify emerging opportunities and develop strategies that achieve them. Leveraging both their own expertise and the broader network and capabilities within CSIRO, the team provides advisory services to public and private customers.

This report presents a case study of the Futures team, with a particular emphasis on assessing Futures' value generation for the Australian public. CSIRO has a long-standing commitment to evaluation. It uses case studies of its activities to assess value creation, account for investment of public funds, guide its strategy, and contribute to the evidence base about how CSIRO generates value.[3]

The focus of the CSIRO Futures case study is on the *National Hydrogen Roadmap.*[4] Published in 2018, the *National Hydrogen Roadmap* articulated the broader economic opportunity that hydrogen technology could provide for Australia. It reviewed key trends, market drivers, and technologies and developed a blueprint to help Australia cultivate competitive advantage and generate economic, social, and environmental value for the nation.

In contrast to most roadmaps, which typically focus on research and development (R&D) and technology priorities, the *National Hydrogen Roadmap* was largely technology agnostic. Its focus was on demand drivers and markets. When it was released to the public, it offered a fresh take on the hydrogen market opportunity that resonated with stakeholders in both the public and private sectors. Ultimately, the *Roadmap* served not only as a foundation for subsequent Australian strategies and policies, but also as a reference point for hydrogen strategies around the world.

As reviewed in this report, the case of the *National Hydrogen Roadmap* exemplifies the role CSIRO Futures plays in strategic planning, especially in efforts related to broad-based market action. In this context, Futures generated economic and social value by

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[2] For more information about CSIRO Futures, please visit https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/CSIRO-futures.
[3] CSIRO (2020). *Impact Evaluation Guide.* CSIRO, Australia.
[4] Bruce S, Temminghoff M, Hayward J, Schmidt E, Munnings C, Palfreyman D, Hartley P (2018). *National Hydrogen Roadmap*. CSIRO, Australia.

- reducing asymmetries in information between market participants;
- accelerating public- and private-sector initiatives and policies to address the market opportunity during a window of opportunity; and
- catalysing action and investment and increasing the probability of success.

1.1 Australia's Hydrogen Opportunity

Energy production, storage, transport, and consumption are undergoing a transformation towards renewables in an effort to reduce carbon emissions, address climate change, increase energy security, and stimulate economic growth. However, this market transformation faces challenges in multiple areas, from transportation and storage to identification of the right renewable fuel mix for different industries and transportation modes.

Hydrogen fuel produced from renewable sources, referred to as green hydrogen, offers a source of energy that is clean, flexible, storable, and safe.[5] Hydrogen has the potential to meet a gap in the market between low-cost renewable production (e.g., wind, solar) and final demand from industries that currently rely on fossil fuels, such as long-haul transportation and heavy industry.

Green hydrogen presents an opportunity to position Australia as an exporter of renewable energy. Reliable sunshine and prevailing winds across a large landmass mean that the country has abundant potential for wind and solar energy production. There is also favourable proximity to Asian markets, which exhibit high energy demand. As global markets shift away from fossil fuels and towards renewable and low-carbon energy sources, hydrogen is an opportunity for Australia to remain an energy exporter.[6]

However, hydrogen is not yet cost-competitive and faces market and technological barriers to widespread adoption. Multiple R&D strategies and hydrogen initiatives had been launched in Australia in earlier years, but these had varying degrees of success. Most were focused on narrow technical areas or organisation-specific market opportunities. In 2018, the Futures team, along with CSIRO's energy team, believed that the time was right for broader action that focused on the market opportunity and demand drivers.

1.2 The Value of Roadmaps

Roadmaps, whether for a technology or an industry, are strategies and guidance designed to stimulate collective action, accelerate solutions, and address common barriers and market needs. They can be particularly important for industries characterised by shortening product life cycles, rapidly changing consumer demand, and a shifting policy landscape. In essence, they provide a resource from which companies

[5] Department of Industry, Science, Energy, and Resources (2019). *Australia's National Hydrogen Strategy*. COAG Energy Council, Australia.
[6] Australia's current export portfolio includes coal, oil, and natural gas.

and industries coalesce around shared objectives and move forward with greater confidence.[7]

Roadmaps are precompetitive, meaning that they address common issues and priorities while being agnostic to specific companies, products, or technical solutions. Examples of common technology issues include standards, requirements for generic technology platforms, and analyses of commercial drivers and trends. For an emerging industry with diverse actors, roadmaps serve to coordinate critical investment activities across entities, reducing the risk of allocating funding and resources to redundant activities and underinvesting in others.[8]

In particular, industry roadmaps serve to catalyse collective action, including:

- advocating for policy solutions and programs;
- convening relevant actors and forming relationships between industry, academia, government, research organizations, and others;
- providing transparent and trustworthy data on markets and a mechanism to forecast;
- lowering barriers to information and transaction costs related to them; and
- addressing redundancy and accelerating technology development.

In an emerging technology ecosystem, roadmaps are especially valuable when they address issues where the prospect of near-term return on investment is low and action by a single entity is insufficient to make an impact on the market. An example is the high-definition LCD industry in Korea. Coordinated action was necessary to bring specific technologies together from different actors to create a product segment that was more competitive than what was available on the market.[9] Industry roadmaps are successful when they spur action by interconnected partners to address a technology or market need.

1.3 About CSIRO and CSIRO Futures

CSIRO is Australia's national science agency. With more than 5,000 staff across 55 sites in Australia, CSIRO has broad reach in R&D, laboratories and facilities, intellectual property and commercialisation, and services.

CSIRO Futures is a consultancy and strategic advisory service within CSIRO, focused on the intersection of science, technology, and economics. Futures' reports and strategies help private-sector companies and public agencies understand long-term opportunities and risks and develop strategies to address them using science and technology.

[7] Lee S, Kang S, Park Y, & Park Y (2007). Technology roadmapping for R&D planning: The case of the Korean parts and materials industry. *Technovation*, 27(8), 433-445.
[8] Garcia, ML, & Bray, OH (1997). *Fundamentals of technology roadmapping* (No. SAND-97-0665). Sandia National Labs.
[9] Lee S, Kang S, Park Y, & Park Y (2007). Technology roadmapping for R&D planning: The case of the Korean parts and materials industry. *Technovation*, 27(8), 433-445.

The team advises CSIRO executives, ASX-listed companies, multinational firms, and government agencies. Key service areas include:

- **Industry strategy:** Thought leadership or strategy development to enable growth in an existing or emerging industry by identifying key opportunities and their commercial, social, regulatory, and R&D enablers;
- **Economic analysis**: Economic analysis to inform growth and technology investments by considering market opportunity size, economic impact, and techno-economic cost analysis; and
- **Technology scans**: Technology strategy and analysis to address key business and innovation challenges by assessing technology options and risks, technology and commercial readiness, capability, and technology and research hurdles.

In addition to its leadership in hydrogen, Futures' recent areas of work include COVID-19 recovery and resilience, biosecurity, medical technologies, and food and agribusiness.[10]

1.4 Purpose of This Report

This report is an impact assessment of CSIRO Futures. It uses the example of the development of the *National Hydrogen Roadmap* to characterise how Futures generates value. Although this impact assessment is focused on CSIRO Futures, it acknowledges the important scientific leadership role of CSIRO's Energy business in the development of the *National Hydrogen Roadmap*.

CSIRO conducts regular impact evaluations to provide evidence of the effects of its activities on the economy, environment, and society. Impact evaluations serve multiple objectives for various stakeholders, notably for government accountability, leadership, research, strategy, and the Australian public. CSIRO's framework for impact evaluation, updated in 2020, includes guidelines on mixed methods, impact relative to a baseline, capture of the various benefits of R&D, and clarification of how CSIRO's activities benefit public and private stakeholders.

This case study was prepared for CSIRO by the Centre for Applied Economics and Strategy at RTI International, an independent non-profit research institute dedicated to improving the human condition. Combining scientific rigor and technical proficiency, we deliver reliable data, thorough analysis, innovative methods, novel technologies, and sustainable programs that help customers inform public policy and ground practice in evidence.

1.5 Analysis Approach and Report Organisation

This report was prepared between January and June 2021. Our team conducted a desk review of documents, strategies, and the peer-reviewed literature relevant to the hydrogen industry and technology roadmaps. We also interviewed 11 stakeholder representatives from the public and private sectors. Interviews explored questions about Australia's opportunity in hydrogen, the process of developing the *Roadmap*, the

[10] More information about CSIRO Futures is available at https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures.

availability of the *Roadmap* and value of CSIRO Futures leadership, and its impacts and influence. The full list of interview questions can be found in Appendix A.

The remainder of this report is organised as follows:

- Section 2 describes the genesis of the *National Hydrogen Roadmap* and the process of preparing it.
- Section 3 assesses the impact of the *Roadmap* and stakeholder perspectives on the value of CSIRO Futures.
- Section 4 places the technology *Roadmap* in the broader context of CSIRO Futures' services portfolio and offers concluding remarks.

2. Creating the *National Hydrogen Roadmap*

The *National Hydrogen Roadmap* was the product of a broad initiative led by CSIRO Futures and CSIRO Energy to assess and describe Australia's hydrogen market opportunity and to characterise the actions and activities necessary to cultivate competitive advantage. Working with CSIRO Energy, the Futures team assembled stakeholders from the federal and state governments, companies in the hydrogen supply chain, academia, and independent organisations. The goal was to provide a national resource about the state of the hydrogen market, key demand drivers and market imperatives, and the actions needed.

Stakeholder representatives interviewed for this analysis noted that the release of the *National Hydrogen Roadmap* in late 2018 marked an inflection point for hydrogen. This section reviews the *Roadmap*'s development and its impacts and influence.

2.1 Precursors to the Roadmap

CSIRO recognised a need for a national industry roadmap for hydrogen in 2017. Australia had various hydrogen strategies and roadmaps in the two decades prior, including a commonly cited 2008 strategy,[11] but the hydrogen industry did not generate traction. Australia's experience was not uncommon. Globally, national efforts to invest in hydrogen infrastructure fluctuated and initiatives were not sustained. Hydrogen was far from cost competitive, and the amount of energy needed to produce hydrogen with fossil fuels, referred to as brown or grey hydrogen, made it inefficient.

In the 2010s, renewable energy production from wind and solar grew rapidly both in Australia and around the world. Improvements in energy technologies, more efficient manufacturing processes, and economies of scale supported by favourable public policies and incentives meant that renewable energy technologies became cost-competitive relative to fossil fuels.

Australia's 2017 *Low Emissions Technology Roadmap* (*LETR*),[12] also led by CSIRO Futures, put forward the technology options at Australia's disposal to meet its emissions goals under the 2015 Paris Agreement and provided new economic opportunities for national industry. Following its publication, stakeholders within and beyond CSIRO noted that the *LETR* offered evidence for hydrogen as a low-emissions fuel that could soon be cost-competitive. Further detail was needed to understand the market potential.

CSIRO Futures and hydrogen experts in CSIRO Energy believed that the market was at an inflection point in 2017. The technologies related to production, storage, and utilisation of hydrogen were at a level of maturity where it was possible to envision a

[11] Department of Resources, Energy, and Tourism (2008). Hydrogen Technology Roadmap: Enhancing Australia's Economic Prosperity.
[12] Campey T, Bruce S, Yankos T, Hayward J., Graham P, Reedman L, Brinsmead T, Deverell J (2017) Low Emissions Technology Roadmap. CSIRO, Australia. Report No. EP167885.

green hydrogen industry. Furthermore, renewable energy, zero-emission mobility, and decarbonisation had broad market support domestically and internationally.

At the same time, Australian states were taking the initiative to develop their own hydrogen strategies. For example, South Australia launched a Hydrogen Roadmap in 2017, followed by $42 million in dedicated investment in 2018.[13] Victoria entered a consortium with the Australian and Japanese governments in 2018 to invest in hydrogen infrastructure, and ARENA was beginning to fund hydrogen projects.[14] These developments suggested the potential for a national, coordinated effort.

2.2 Development of the *Roadmap*

CSIRO Futures convened stakeholders from industry, academia, and government in October 2017 to test the hypothesis that hydrogen could be a broad-based market opportunity for Australia. The evidence from the *LETR*, various state government investments, and CSIRO research showed the need for a guiding document for the next steps for hydrogen. Futures viewed the *Roadmap* as a tool to support the scale-up of new industries using emerging science and technology, with a broad understanding of the market potential and priorities.

Futures proposed a market-oriented roadmap that would be sponsored by a mix of stakeholders, guided by a steering committee, and supported by working groups. To avoid a perception of "pay-to-play," sponsorship was not a requirement to sit on the steering committee or working groups. The proposition was attractive to energy companies, state governments, oil and gas companies, and industrials, many of whom had representatives on the steering committee. The steering committee provided overall leadership and direction; working-group coordination, elicitation, analysis, and writing was led by Futures' staff.

The *Roadmap* was oriented towards the market potential of hydrogen, developing an understanding of assumptions and cost drivers required for hydrogen to be competitive for different applications in the market. It also provided guidance for hydrogen production, storage and transport, and applications, including hydrogen use in transport, industrial feedstocks, electrical grids, heating, synthetic fuels, and export.

Input was received from over 50 companies, universities, government agencies, and international collaborators from North America, Europe, and Asia (Table 1). It included analysis of Australia's competitive position in the market, policies and technologies, and results from economic models based on various assumptions of production, storage, and utilisation.

[13] Government of South Australia (2017) A Hydrogen Roadmap for South Australia. http://www.renewablessa.sa.gov.au/content/uploads/2019/09/hydrogen-roadmap-11-sept-2017.pdf
[14] The state of Victoria Department of Environment, Land, Water and Planning (2021). Victorian Renewable Hydrogen Industry Development Plan.

Table 2.1 Stakeholders Contributing to the National Hydrogen Roadmap

Australian Gas Infrastructure Group (AGIG)	Engie	Monash University
Air Liquide	EVO Energy	Moreland Council
Australian Pipeline and Gas Association (APGA)	Fraunhofer Society	New Energy and industrial Technology Development Organisation (NEDO)
Australian Petroleum Production and Exploration Association (APPEA)	Fuel Cell and Hydrogen Energy Association	NOW: National Organisation for Hydrogen and Fuel Cell Technology
ATCO	GE Power	Renewable Hydrogen Pty Ltd
BHP	Global CCS Institute	Renewable Hydrogen Fuel Cell Collaborative
BOC Group	Griffith University	RMIT
Bollard	H2H Energy	Shell
California Fuel Cell Partnership	Heraeus	Siemens
Caltex	Hydrogenics	Southern Oil
CarbonNet	Hydrogenious Technologies	Thyssenkrupp
Caterpillar	Hyundai	Toyota
Curtin University	International partnership for Hydrogen and Fuel Cells in the Economy	Transit Systems
Department of Defence: Science and Technology (DST)	ITM Power	U.S. Department of Energy
E4Tech	Jemena	University of Hawaii
Energy Australia	JPower	University of Melbourne
Energy Networks	Linde	University of New South Wales
Energy Pipelines CRC	Ludwig-Bölkow-Systemtechnik	University of Queensland
		Yara

Source: National Hydrogen Roadmap.

2.3 Roadmap Publication and Impacts

The *Roadmap* was published in August 2018 alongside two other major reports, *Hydrogen for Australia's Future*[15] and ARENA's hydrogen report focused on exports.[16] While each of the three reports served a different audience, their findings complemented one another and reached the following similar conclusions:

- Australia was in a prime position to lead as an exporter of renewable energy through hydrogen.

[15] Commonwealth of Australia (2018). Hydrogen for Australia's Future: A Briefing for the COAG Energy Council, Australia. https://www.chiefscientist.gov.au/sites/default/files/HydrogenCOAGWhitePaper_WEB.pdf
[16] ACIL Allen Consulting (2018). Opportunities for Australia from Hydrogen Exports. Australian Renewable Energy Agency: ARENA. https://arena.gov.au/assets/2018/08/opportunities-for-australia-from-hydrogen-exports.pdf

- Hydrogen could fill a missing piece in the market for decarbonisation and zero-emission fuels, notably in storage, transport, and applications in heavy industry and long-haul transportation.
- Although green hydrogen was not yet cost-competitive in the market, technologies were more mature and pointed towards a shorter time horizon for cost-competitiveness.
- To become a market leader in hydrogen fuels, Australia needed a coordinated effort between research, commercialisation, infrastructure, policy, financing, and all points along the value chain for production, storage, and applications of hydrogen.

Between August and October 2018, hydrogen quickly entered the national conversation on a larger scale and affected domestic strategies and investments over the 2 years that followed the publication of the *Roadmap* and the other documents.

2.3.1 Domestic Strategies

Federal and state actors released detailed strategies that built, at least in part, on the *Roadmap*, or if not the document, then the national dialogue that the *Roadmap* had progressed. The Council of Australian Governments' Energy Council released *Australia's National Hydrogen Strategy* in 2019, the product of the work led by Dr. Alan Finkel, then Australia's chief scientist.[17] The strategy focused on hydrogen hubs, creating clusters around the country to drive demand and economies of scale. The strategy laid out detailed priorities and economic forecasts for the potential impact on jobs and output. It also described how states and locales across Australia could benefit from strengthening the green hydrogen economy. The strategy estimated over 8,000 jobs supported and $11 billion in annual economic output from hydrogen by 2050.

Around the same time, CSIRO Futures released additional reports, including Hydrogen Research, Development, and Demonstration: Priorities and Opportunities for Australia in 2019 and Opportunities for Hydrogen in Commercial Aviation in partnership with Boeing in 2020.[18]

The Department of Industry, Science, Energy, and Resources, in its first Low Emissions Technology Statement – 2020, placed hydrogen as a top priority in low emissions technologies, with a focus on clean hydrogen under $2 per kilogram, an analysis built on modelling from the National Hydrogen Roadmap.[19] The statement focused on technology and R&D priorities to achieve that goal.

[17] Department of Industry, Science, Energy, and Resources (2019). Australia's National Hydrogen Strategy. COAG Energy Council, Australia. https://www.industry.gov.au/data-and-publications/australias-national-hydrogen-strategy

[18] Bruce S, Temminghoff M, Hayward J, Palfreyman D, Munnings C, Burke N, Creasey S (2020) Opportunities for hydrogen in aviation. CSIRO. https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/CSIRO-futures/Futures-reports/hydrogen-commercial-aviation

[19] Australian Government Department of Industry, Science, Energy and Resources (2020). First Low Emissions Technology Statement—2020. https://www.industry.gov.au/sites/default/files/September%202020/document/first-low-emissions-technology-statement-2020.pdf

Additionally, state governments across Australia developed their own strategies to attract investment. Western Australia (with the support of CSIRO Futures), Tasmania, Queensland, and Victoria released hydrogen strategies in 2019. New South Wales released its Net Zero Plan in 2020 with hydrogen as one component.[20]

2.3.2 Investments

Since its publication, public investments in green hydrogen increased, and hydrogen rose to the top of national priorities for investment in decarbonisation and infrastructure. For example,

- At the launch of the Hydrogen Strategy in 2019, the Australian Government allotted over $500 million to hydrogen projects.
- The Australian Government's 2019 investment package in clean energy technologies totalled over $1.9 billion, including $1.6 billion in new funding for ARENA and additional funding for Future Fuels programs and new Hydrogen Hubs.
- In 2020, the Australian Clean Energy Finance Corporation allocated $300 million in funding to green hydrogen projects. Additionally, development began on the $300 million Bundaberg Hydrogen Hub in Queensland.
- In 2021, renewable energy was listed for the first time on Infrastructure Australia's priority list, including projects for clean hydrogen fuels.[21]

2.3.3 Global Strategies

Global interest in hydrogen fuels accelerated between 2019 and 2021, with many national and regional strategies following a similar structure and market focus as first presented in CSIRO Futures' *National Hydrogen Roadmap*. These strategies included those for New Zealand, South Korea, Japan, France, Portugal, Germany, the European Union (EU), Chile, Canada, and other national and subnational agencies around the world, as seen in Figure 2.1.

Australia's work is directly referenced in seven of the international strategies and roadmaps (Canada, EU, Japan, Netherlands, New Zealand, Norway, South Korea). In these strategies, there is a common recognition that hydrogen fuels play a critical role in decarbonisation that cannot currently be met by today's renewable production, transportation, and storage technologies. Applications covered in those reports also include heavy industry, long-haul transportation, commercial aviation, and other forms of energy storage and transportation where batteries are insufficient.

[20] NSW Government: Department of Planning, Industry, and Environment (2020). Net Zero Plan Stage 1: 2020-2030. https://www.environment.nsw.gov.au/topics/climate-change/net-zero-plan
[21] Karp, Pl (25 Feb 2021). Renewable energy listed for first time as one of Australia's top infrastructure priorities. *The Guardian*. https://www.theguardian.com/business/2021/feb/26/renewable-energy-listed-for-first-time-as-one-of-australias-top-infrastructure-priorities

Figure 2.1 Timeline of Select Hydrogen Roadmaps, Strategies, and Investments

3. CSIRO Futures' Added Value

This section reviews the ways in which CSIRO Futures adds value. Whereas the preceding section described the significance of the *National Hydrogen Roadmap* overall, this section focuses specifically on the value add and impact delivered by CSIRO Futures as a strategic advisory group.

3.1 CSIRO Futures Recognised—and Acted During—a Window of Opportunity

CSIRO Futures recognised the need for a national roadmap and acted within a window of opportunity where hydrogen's cost-competitiveness was on the horizon but there was no clear global leader. Working with CSIRO Energy, the team proposed the project concept, secured funding and support, recruited participants, and acted to close the asymmetries of information that existed between market actors.

Stakeholders point to the period between August and October 2018 as an inflection point for hydrogen in Australia. Following the *Roadmap's* publication, research, policies, and investments in hydrogen accelerated quickly. A national hydrogen strategy followed in 2019 and thereafter the Low Emissions Technology Statement and national investments. The acceleration of the pace of strategies and statements in support of the hydrogen industry is evidence that the *Roadmap* helped invigorate.

3.2 The *National Hydrogen Roadmap* Had a Market Focus, Not a Technology Focus

Whereas most roadmaps focus on technologies and R&D strategy, the *National Hydrogen Roadmap* focused on markets. This focus made the document more digestible and relevant for more actors across the value chain. Futures' strategy expertise, talent for expert elicitation, and ability to facilitate complex discussions with a variety of stakeholders were cited by participants as integral to the roadmapping process.

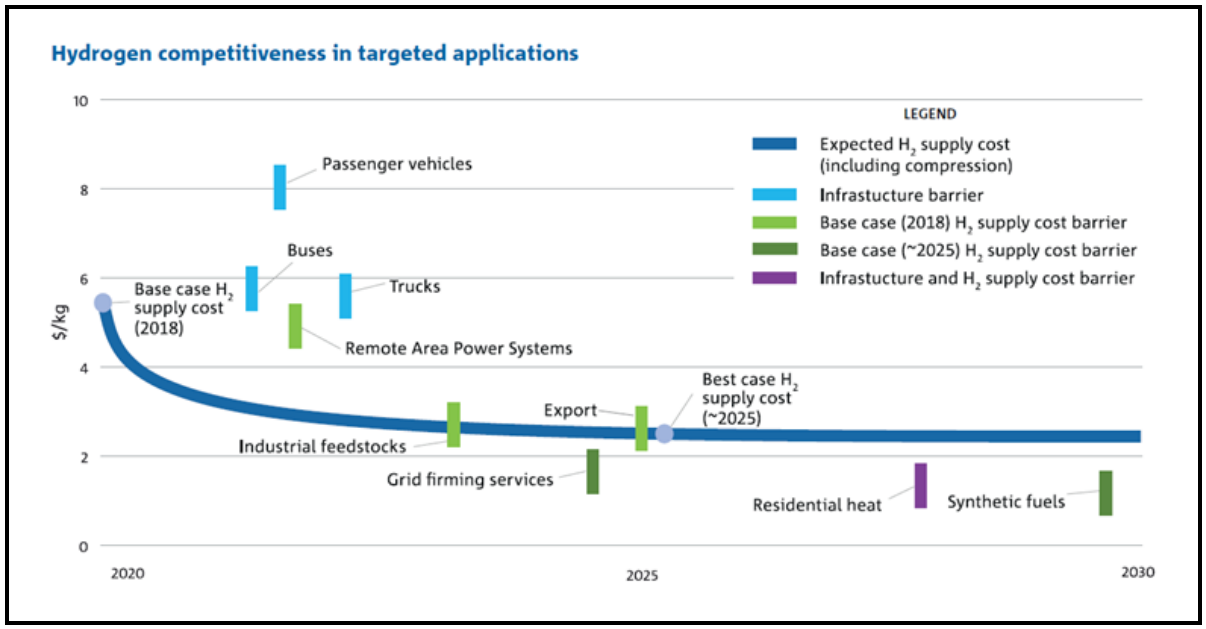
Participants valued a roadmap that spoke to all market actors while maintaining the integrity expected of a rigorous scientific process. Interviewees noted that prior research, including the 2017 *LETR*, was prepared for a technical audience but was difficult for others without scientific backgrounds to act on or understand. The team avoided this issue with the *National Hydrogen Roadmap* by intentionally combining the scientific and technical expertise of CSIRO's Energy Business Unit with the strategic and economic capabilities of CSIRO Futures. This ensured that scientific and technical content was described and presented in a way that was approachable for a broad audience.

3.3 The *Roadmap* Was a High-Quality Resource Available to All

The *Roadmap* is a high-quality, insightful document available to all at no cost. In many ways, the *Roadmap* has characteristics of a public good: it is more valuable because it is available to everyone and all were encouraged to leverage it.

Interviewees noted that the cost-competitiveness chart produced by the Futures and CSIRO's energy economics team (see Figure 3.1) appeared in nearly every conference presentation related to hydrogen in Australia and in many presentations by non-Australian organisations about hydrogen markets.

Figure 3.1 Hydrogen Cost-Competitiveness Forecast



Source: National Hydrogen Roadmap.

3.4 CSIRO Futures Convened Stakeholders in a Neutral Forum

That the Futures team was able to convene a wide variety of stakeholders, secure their buy-in, and encourage them to share their insights underscored how CSIRO consistently ranks among the most trusted entities in Australia and often plays the role of an honest broker. Interviewees unanimously agreed that the *Roadmap* was more credible (and therefore reliable) because it came from CSIRO rather than from an industry organisation, government organisation, or university. CSIRO's brand and reputation signalled objectivity and expertise.

3.5 CSIRO Futures Facilitated the Creation and Expansion of More Robust Social Networks in the Hydrogen Industry

The *Roadmap* was not the first effort to articulate the hydrogen industry in Australia, but it characterised the energy ecosystem in a way that had not been done before. As the *Roadmap* points out, the scalability of the hydrogen industry requires growth in a coordinated manner with national leadership to connect the value chain.

As an example of a less successful effort, interviewees noted that multiple actors had tried in the past to build a strategy for geothermal energy in Australia. Those efforts were disjointed, and stakeholders were unable to coalesce around a common plan. Ultimately, the industry failed to take off on a large scale. Transformation of a large and

complex energy ecosystem requires a coordinated effort with strong networks between actors.

Interviewees agreed that CSIRO Futures' leadership was valuable because it coordinated previously disconnected efforts across the academic, private, and public sectors. The team established a steering committee and working groups that were representative of government and industry, intentionally not limiting participation to only those who had supported the *Roadmap* financially. This work helped facilitate trust, and interviewees noted that social networks are more expansive and robust following the roadmapping exercise.

3.6 CSIRO Futures Accelerated Market Development and Lowered the Likelihood of Unproductive or Duplicative Activity

CSIRO Futures helped the hydrogen industry coalesce around a shared national vision and accelerated the momentum behind the hydrogen fuels in Australia. In the absence of the *Roadmap*, interviewees thought it was likely that individual actors or stakeholder groups would have embarked on roadmapping exercises, but also thought that there was a high probability of duplicative efforts. It is also possible that investment decisions or action plans would have been made and implemented that could have been less effective. From a market perspective, the analysis and consensus building led by Futures were efficient and reduced the likelihood of unproductive or duplicative activities. It is not possible to quantify the avoided economic losses, but they are likely substantial given the hydrogen industry's large capital requirements.

4. Summary Remarks

The example of the *National Hydrogen Roadmap* offers insight into how CSIRO Futures, a strategic advisory group embedded in a science agency, adds value. In particular, we noted that by working with CSIRO researchers the Futures team:

- recognised the market opportunity and assembled a broad call to action planning;
- convened and facilitated effective dialogue across a variety of stakeholders;
- led the development of a common, high-quality resource for the industry;
- reduced information asymmetries between market actors;
- avoided duplication effort and reduced the probability of unproductive investments;
- accelerated hydrogen initiatives; and
- catalysed action and increased the probability of success.

4.1 Next Steps for the Hydrogen Industry in Australia

The *National Hydrogen Roadmap* had the impact expected: it galvanised support, brought stakeholders together on the same page, spurred collective action across the industry, and accelerated momentum.

Hydrogen quickly moved to the top of government priorities for investment following the publication of the *Roadmap*. In 2020, Clean Hydrogen was central to the Low Emissions Technology Statement and in 2021 was at the top of Infrastructure Australia's priority list for the first time.

From 2018 to the start of 2021, public-sector actors at the state and federal levels in Australia committed nearly $1.2 billion to green hydrogen projects. By the end of 2020, CSIRO identified 20 hydrogen demonstration projects across the country.[22]

The Australian Government also committed over $1.4 billion to ARENA over the next 10 years as part of the Low Emissions Technology Statement. This funding will provide grants, loans, and equity funding for R&D, supply chain development, large-scale projects, future fuels, hydrogen export hubs, and carbon capture and storage.

Because of the rapid growth, stakeholders are calling on CSIRO Futures and its partners to revise and update the *Roadmap* in 2021 based on technology development, market opportunities, investments, and government policies. The hydrogen economy is accelerating quickly, and over a dozen countries have released hydrogen strategies, investments, and roadmaps. Stakeholders emphasized that new data and insights are needed as the market continues to evolve.

[22] Australia's Hydrogen Industry: Opportunities and Progress. Australian Hydrogen Showcase at First Annual Asia-Pacific Hydrogen Summit. Delivered by Patrick Hartley, 24-26 November 2020.

4.2 CSIRO Hydrogen Industry Mission

In May 2021, CSIRO announced the launch of the CSIRO Hydrogen Industry Mission. CSIRO and its partners plan more than 100 projects valued at more than $68 million to develop new technologies, drive down the cost of hydrogen fuel production, and position Australia for global leadership in the industry. A large portion of the Mission's strategy is underpinned by the *National Hydrogen Roadmap* and subsequent hydrogen projects.

Partners include the following:

- Department of Industry, Science, Energy and Resources;
- ARENA;
- Fortescue Metals Group;
- Swinburne University;
- Government of Victoria;
- Future Fuels CRC;
- National Energy Resources Australia;
- Australian Hydrogen Council;
- Toyota; and
- Hyundai.

Under the scope of the mission, CSIRO and its partners will establish a hydrogen knowledge centre, conduct feasibility and strategy studies, fund collaborative demonstration projects, and enable science and technology to further industry scale-up.

4.3 Other Areas of Focus for CSIRO Futures

The example reviewed in this case study was the *National Hydrogen Roadmap*, but the team has prepared other industry and technology roadmaps. These include roadmaps in the areas of food and agribusiness, materials, quantum technology, advanced manufacturing, health, and medical technology. In 2019, Futures released the Australian National Outlook, a forward-looking vision for 2060 that addresses broad issues related to economic growth, climate change, demographics, and Australia's role in the world more broadly. Futures is laying out a roadmap for Australia's recovery from the COVID-19 pandemic and economic crisis.

Futures is differentiated in part because they bridge management consultancies and technology-development organisations. At this nexus, they have the service capability of the former and the knowledge and depth of the latter. For example, Futures continues to advise on hydrogen; see, for example, its 2019 report on hydrogen fuels in commercial aviation (sponsored by Boeing) and the Western Australia Renewable Energy Strategy. Additional customers include Woodside, Origin, and APA.

Providing services to government, internal CSIRO, and private-sector customers ensures that the team is attuned to different stakeholder perspectives, as well as how different

technology and industry development pathways could generate economic, social, and environmental value.

4.4 Concluding Remarks

CSIRO Futures generates impact for Australia by addressing information asymmetries, reducing the likelihood of duplicative and unproductive activity by industry actors, decreasing the overall level of uncertainty in an emerging industry, and thereby accelerating the pace of investment and economic activity. A cost-benefit analysis was beyond the resources afforded this case study, however based on the strength of evidence offered by interviewees, it is clear that the *Roadmap* was a socially-productive achievement.

Appendix A.
Interview Guide

Case Study of CSIRO Futures' National Hydrogen Roadmap Project
Interview Guide

On behalf of CSIRO, RTI International, an independent non-profit research institute, is conducting a case study to analyse the impacts of CSIRO's 2018 National Hydrogen Roadmap Project. Case studies are an important accountability approach for assessing the value that CSIRO generates for the Australian people.

Our goal is to understand the impact and value of the development of the National Hydrogen Roadmap, and how it is serving as a tool to guide the growth of the national hydrogen industry. We are interviewing stakeholders across the public, private, and research sectors to capture information on:

- Australia's hydrogen economy and global competitive position,
- The process of developing the roadmap,
- Actions and outcomes of adoption of the roadmap,
- And the value of the roadmap as a guiding document for the hydrogen industry.

Our final deliverable will be a public case study report. Any comments you share with us will be held in confidence and presented in summary form with those from other respondents, unless otherwise approved by you.[23] RTI's team includes Michael Hogan and Alan O'Connor. Questions about this case study can also be directed to CSIRO's Brooke Edwards.

Background and Context

- What do you perceive to be Australia's (or your state's or industry's) opportunity in the hydrogen industry and what are the primary obstacles? What are Australia's comparative advantages in the global market?
- How did you learn about the national hydrogen roadmap? Please characterise your thoughts about the need for a resource such as this.
- What ongoing efforts related to Hydrogen in Australia before the creation of the roadmap?

Roadmap Development

- Did your organisation contribute to the roadmap's development? If so, how, and was any value gained as a consequence (e.g., networking, convening)?
- In your view, would the roadmap have been *more/as/less* useful had it not been led by CSIRO?

Availability of the Roadmap

- Consider the following: Would a national roadmap have emerged had CSIRO not been engaged? If so, how might the roadmap have differed? For example, in terms of
  - depth or quality of information,

[23] No personally identifiable information (PII) or sensitive business information will be shared. You can learn more about RTI's standards of ethics and human research protection here (https://www.rti.org/ethics-and-human-research-protection).

  - scope and scale of stakeholder input,
  - timing of the availability of this resource,
  - public-private consensus,
  - other dimensions?
- Thinking specifically about your organisation, did the roadmap
  - provide insights that otherwise would have been more difficult or costly to generate?
  - provide a platform or framework for further investigation of the hydrogen market opportunity?
  - provide an information resource that your organisation may otherwise have replicated (at least to some degree)?
  - facilitate conversations and decision-making among executives?
- Without the roadmap, how would your organisation's trajectory have been different (e.g., investments, programs, and resources)

Impacts and Influence of the Roadmap

- Consider the trajectory of collective action (e.g., public-private, industry) as well as the actions of individual stakeholders (e.g., governments, businesses) over the past 3 years. From your vantage point, what impacts or influences have you observed that are traceable, at least in part, to the national hydrogen roadmap?

  For example, events, policies, or industry shifts that might not have occurred without the roadmap or that were strongly influenced?
- What are we not asking about that you think is important for us to know?

Thank you for your time.

RTI International is an independent, nonprofit research institute dedicated to improving the human condition. Customers rely on us to answer questions that demand an objective and multidisciplinary approach—one that integrates expertise across the social and laboratory sciences, engineering, and international development. We believe in the promise of science, and we are inspired every day to deliver on that promise for the good of people, communities, and businesses around the world.

For more information, visit www.rti.org.