SCIENCE AND INDUSTRY ENDOWMENT FUND

CSIRO

CSIRO's Hydrogen Generator for Refuelling Fuel-Cell Electric Vehicles (FCEV)

SIEF Impact Case Study

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FINAL

Published by:

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The SIEF support enabled the demonstration of this concept on a 5-15 kg/day H_2 pilot-production scale, operating over 1,000 hours with >80% NH_3 'cracking' efficiency and >80% H_2 extraction rate through membranes. In the world's first demonstration of fuel-cell vehicles refuelling with hydrogen derived directly from ammonia, a public demonstration of CSIRO's hydrogen generator was held on 8 August 2018, with two commercial FCEVs (Toyota Mirai and Hyundai Nexo) being refuelled with hydrogen directly sourced from ammonia.

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- Improvements to air quality through the reduction in particulate emission from ICE vehicles</td><td>- Better health and wellbeing through the use of hydrogen as a clean energy source.
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• New future renewable energy export industry based on ammonia
• Australia's research effort supporting decarbonisation of global economies (e.g. Japan, Korea, Germany).
• Establishing Australia's competitiveness in this space globally and connecting Australian researchers with industry.</td></tr>
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Major Project Partner – BOC, Toyota, Hyundai

Other Partners: Queensland Dept of Environment & Science (QLD DES)

Commercialisation: Subsequent to the completion of the SIEF project, an agreement was developed between Fortescue Metals Group Ltd (Fortescue) and CSIRO for Fortescue to provide support for the next stage of this work which is the demonstration of a pilot -scale CSIRO H_2 generator capable of producing approximately 200 kg/day of hydrogen. This is a 5-year collaboration CSIRO-Fortescue Collaboration</td></tr>
</table>

Glossary

ARENA	Australian Renewable Energy Agency
BEV	Battery electric vehicle
BOC	British oxygen company
CFD	Computational fluid dynamics
CIF	Cost, insurance and freight
CRI	Commercial Readiness Index
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CO_2	Carbon dioxide
EDP	Experimental Development Program
FCEV	Fuel-Cell Electric Vehicles
Fortescue	Fortescue Metals Group Ltd
FOB	free on rail
H_2	Hydrogen
HFCV	Hydrogen Fuel Cell Vehicle
NH_3	Ammonia
PV	Present Value
QLD DES	Queensland Dept of Environment & Science
ROI	Return on Investment ratio
SIEF	Science and Industry Endowment Fund
TRL	Technology Readiness Level
WDWL	With deadweight loss
WODWL	Without deadweight loss
Wrt	With respect to

2 Purpose of case study and audience

The purpose of this case study is to assess the prospective benefits emerging from the Hydrogen Fuel Cell Electric Vehicle (FCEV) project and highlight the role of The Science and Industry Endowment Fund (SIEF; https://sief.org.au/) in advancing this work. It is difficult to store and transport hydrogen safely and cost-effectively; a key focus of the project involves the development of a H_2 generating system based on liquid ammonia (NH_3) as the carrier technology with the capability of efficient decomposition into pure hydrogen through the application of innovative membrane technology. Achievement of this goal has potential to facilitate Australian export of hydrogen (in the form of ammonia; especially over distances of 4,000 km) to a number of countries where demand is expected to grow substantially in the medium to long term.

The report also highlights the current and potential future impacts of the technology to inform investment decision making as CSIRO continues to progress on the pathway of technology development in a coordinated manner.

With *Sustainable Energy and Resources*, and *Future Industries* being two of the 6 major challenges that CSIRO is focused on, the study highlights the potential for a spectrum of economic, environmental and social benefits arising for a range of stakeholders from this work at the macro (government at three levels/ public), meso (CSIRO and similar organizations like Fortescue, BOC, Toyota, Hyundai, Queensland Government, Dept of Environment & Science, Thomson Environmental Systems) and micro levels (researchers/ social scientists).

The analysis provides an estimate of the potential direct and indirect future impacts of the R&D. The case study will be used to benchmark progress to enable a more robust performance evaluation in future assessments.

This report can be read as a stand-alone item or alongside other CSIRO Energy/ SIEF evaluations to substantiate the impact and value of CSIRO's activities against funds and resources invested in this program. CSIRO as a service provider to the Government and Industry is highly focused on delivering value and impact through the scientific interventions that originate from research activities. The information is provided for accountability, communication, engagement, continuous improvement and future application purposes. The intended audience includes SIEF, Business Unit Review Panels, federal, state and local governments, collaborators like CSIRO, Fortescue, BOC, Toyota, Hyundai, universities and the general public.

3 Background

Growing global demand for clean hydrogen (H_2) fuel is driving interest and momentum globally with North Asia and Europe actively investigating hydrogen-based transportation and energy systems. This presents a significant opportunity for the establishment of economically sustainable domestic and export Australian renewable hydrogen industry. The nation has resources, skills base and access to vast energy resources through sun, wind, biomass, natural gas, and coal, all of which can be used as feedstock for the production of ammonia to support hydrogen industry while addressing concerns around energy security.

One of the major advantages of hydrogen in energy applications is its ability to replace liquid hydrocarbons as an energy source in transport applications. This is one of the reasons why hydrogen-powered FCEVs have attracted so much attention and why the emergence of FCEVs could become a major driver of demand for low-carbon hydrogen (for example, in Korea, Japan and China). While gas-to-power and household consumption of hydrogen are also important, use of hydrogen in transport applications is seen by many countries as a more promising source of hydrogen demand growth over the next decade; especially with decarbonisation efforts in place globally.

Using ammonia (NH_3) as a carrier, renewable hydrogen produced in Australia can be readily distributed, at large scale, to emerging markets in Japan, Korea and Europe using existing infrastructure for ammonia transport. This presents the most viable option for transporting Hydrogen to distances > 4,000 km. The gap in this supply chain is a technology that can efficiently and inexpensively convert ammonia into high-purity hydrogen at or near the point of use. Hydrogen must be at least 99.999% pure to meet fuel cell electric vehicle (FCEV) requirements.

SIEF's Role

The 2-year SIEF project (Jan 2017-2019) aimed at addressing this industry need by:

- completing the final development step of CSIRO's metal membrane technology (Figure 1), and
- incorporating this membrane technology into a 5-15 kg H_2/day[1] proof-of-concept plant for the refuelling of Australia's first hydrogen-powered FCEVs.

In this $3.4 million project, 50% of the project cost was funded from the SIEF as an 'Experimental Developmental Program' (EDP); the remainder was contributed by CSIRO. BOC provided over $100,000 of in-kind gas products and equipment as well as technical expertise

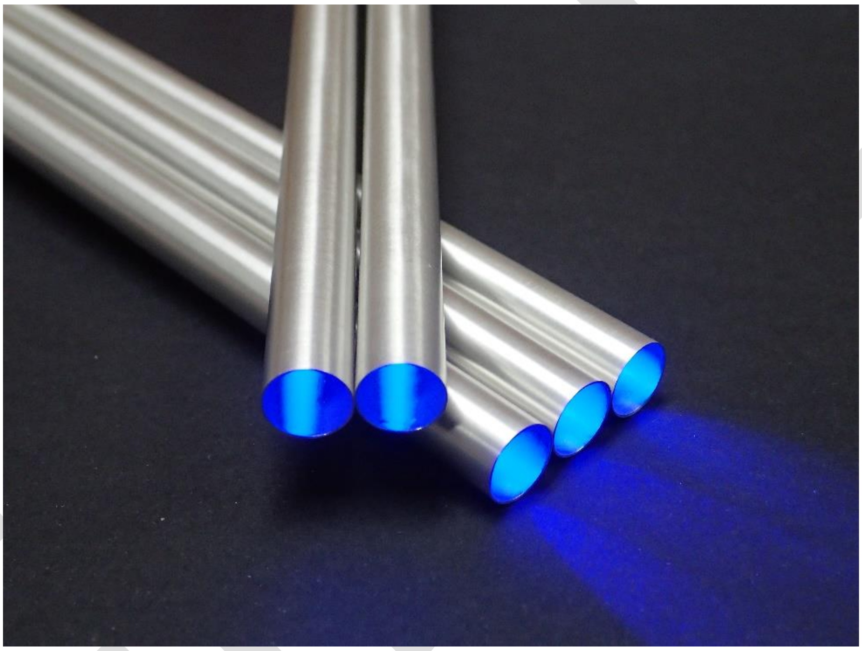

Figure 1: CSIRO's metal membrane tubes, which were scaled up to 500 mm in length, allowing a production scale of 5 kg H_2/day under the SIEF EDP project.

4 Market Analysis

Industry challenge

Hydrogen has the potential to power vehicles and industry around the world while decarbonising the environment; however, due to its low density, it is notoriously difficult to store and transport. In addition, there is a need for more robust transportation solutions as round trip distances (i.e. > 4,000 km) and demand for hydrogen increases.

The available technologies such as compression, liquefaction of hydrogen (producing liquid H_2, below -253°C) or storing in metal hydride, incur a significant energy penalty, are poorly suited to export this commodity, thereby offering a complex, inefficient and/or relatively expensive process for the intended utilisation.

[1] https://www.ammoniaenergy.org/articles/csiro-demonstrates-ammonia-to-hydrogen-fueling-system/

CSIRO’s response

CSIRO’s solution addresses the conversion of ammonia to high-purity hydrogen at, or near, the point of use. Ammonia stores almost twice as much hydrogen than liquid hydrogen and is easier to ship and distribute, opening up possibilities for a renewable energy export market—as long as it can be converted to high purity hydrogen effectively and efficiently. It provides a preferred solution for long round trip distances and higher demand for hydrogen.

The project team developed a metal membrane reactor (Figure 2), which allows hydrogen to pass while blocking all other gases. By coupling membranes with a suitable catalyst for ammonia decomposition, pure hydrogen can be extracted from ammonia efficiently. There is an opportunity for this technology to influence the design of, and to be a key component of equipment and devices in, ammonia-hydrogen distribution and refuelling systems.

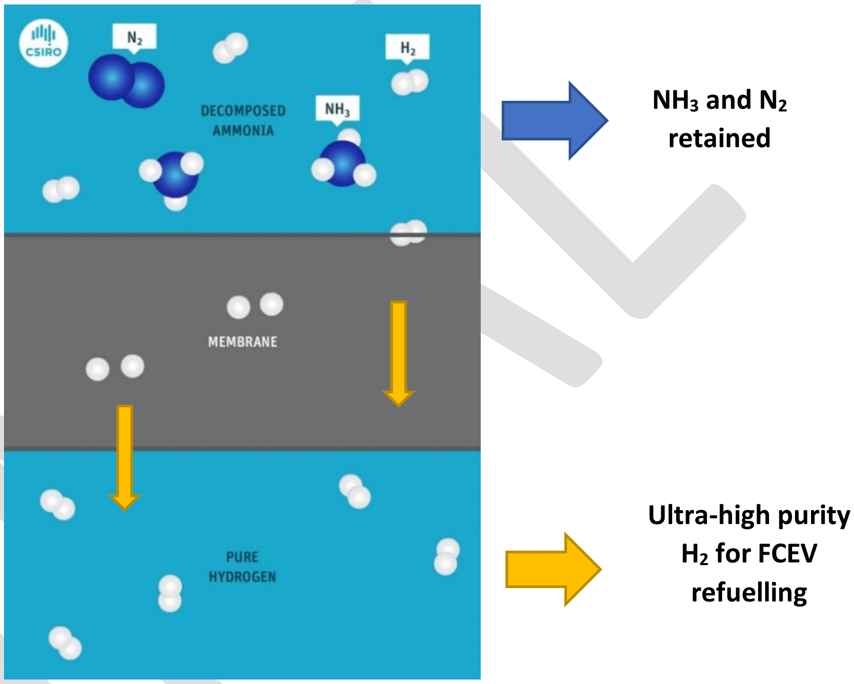

Figure 2: Schematic of CSIRO’s metal membrane technology which selectively allows H_2 to pass through, while blocking all other gases such as NH_3 and N_2.

Market Opportunity

The global market for hydrogen is expected to reach USD155 billion by 2022[2], with a number of Australia’s existing trading partners such as Japan, being resource-constrained and implementing policy commitments for hydrogen imports and use.

The industry has a renewed focus on hydrogen. This includes policy commitments from countries across Europe and Asia as well as increasing investment from multinational technology manufacturers and energy companies. The new developments are driving the focus from technology development to market activation.

Ammonia (NH_3) has long been considered a prospective H_2 storage and transport medium, exhibiting a higher volumetric H_2 density than liquid H_2, through liquid-phase storage at mild pressure. In the Australian context, the financial and technical barriers to using ammonia as a hydrogen carrier are much lower compared to other

[2] International Energy Agency Hydrogen Technology Collaboration Program 2017, Global Trends and Outlook for Hydrogen

available options (methanol, ethanol, toluene, organic chemical hydrides) due to existing infrastructure and industry to support transport/storage of NH_3 at large-scale.

There is currently a significant glut in ammonia production capacity: current capacity will soon reach 250 Mt per annum, but current production is 200 Mt per annum. Not only can the ammonia industry accommodate a shift to renewable hydrogen production, but the industry is also actively seeking an opportunity to use this excess capacity.

Key Barriers (scientific and commercial)

The primary barriers to the broader hydrogen market are the current capital cost of FCEVs and lack of infrastructure supporting their use. Both barriers can be overcome via a series of strategic investments along the value chain from both the private and public sector.

Ammonia offers an attractive mechanism for transporting hydrogen by ship. However, technical developments that support process economics associated with the conversion of hydrogen to ammonia, and reconversion back to hydrogen at the point of use need further work.

5 Impact Evaluation

Impact Pathway

INPUTS ► ACTIVITIES ► OUTPUTS ► OUTCOMES ► IMPACT

INPUTS

Market research

- Market research with Opportunity, infrastructure and capability mapping
- Missions approved project portfolio

Funding

- CSIRO Business Unit funding and in-kind support
- SIEF funding support
- Industry funding

Research Capabilities

- Background knowledge and expertise
- Experience from LNG export industry
- Access to high calibre, multidisciplinary capabilities (CSIRO and partners incl Universities)
- Access to infrastructure and resources to execute projects (e.g. on-site and off-site facilities, labs, computer resources etc)

Translational and commercialization Support

- CSIRO's strategic position and existing relationships that enables liaison with different players for uptake and adoption
- Availability of industry data to conduct trials for testing
- Advisory groups
- Regulatory support

State & Fed Govt Hydrogen Industry groups; Research Funding Agencies (e.g. ARENA); Research organization partners (Universities, PFRA's, CRC's); Large scale and SME Hydrogen Industry supporters; CSIRO staff & leadership (Energy, Manuf, CMR, O&A, L&W, Futures, Data61, InfraTech); Hydrogen FSP

ACTIVITIES

Research Activities

- Deliver **Feasibility Studies & Strategy** comprising trusted strategic & technical advice to de-risk projects in partnership with industry experts and project proponents
- Enable **Demonstration Projects** through RD&D in support of industrial technology deployment and hydrogen value chain validation
- Develop technologies (experimentation, modelling)

Translation and BD focus

- Strategic business development and external engagement for project partnerships (domestic and global)
- External steering committee governance
- Shape development and evolution of National Strategy

Engagement and Communication Activities

- Fundamental science studies in identified gap areas possible linked to FSPs
- Collaborative projects across universities and industries. International and domestic collaborations.
- Benchmarking data for monitoring and evaluation
- Development of Comms Marketing Strategy
- Writing proposals and funding grants
- Demonstration activities (participation in trade shows etc)
- Communication and relationship building
- Commercialization activities
- Engaging with key stakeholders – Government and Industry for science-based discussion and informed decision making

Training and Licencing Activities

Education and Outreach

CSIRO xBU Staff; Hydrogen FSP staff; national & international research organisations; Industry & SME partners; State & Federal governments

OUTPUTS

Feasibility studies & Strategy

Industry and Government-partnered/ funded technoeconomic study projects which de-risk hydrogen tech deployment in industrial settings

Demonstration Projects

CSIRO Involvement in industry led demonstration projects, focussing on supply and demand scaleup and export industry potential

Train retrofit (may have interest from NSW govt.)

World-class science

- Journal papers, international presentations, Final research program reports

- Awareness, Engagement and Delivery Platforms
- Databases
- Invention disclosure document
- Publications and Awards
- Industry Roadmaps
- Case Studies

Enabling Science & Technology

- IP development & commercialization agreements for CSIRO H_2 technologies
- Environmental & Social License to Operate (SLO) studies to identify hydrogen industry risks & opportunities
- Other Industry de-risking projects (e.g. consultancies)
- Fundamental science/ FSP platforms
- Industry capability building programs

New Capability

- Capability for Govt and industry to implement solutions to address food provenance within Australia
- Postdoc recruitment
- Go to market strategy and International engagement strategy

New Services

Training Programs

CSIRO xBU Staff; Hydrogen FSP staff; national & international research organisations; CSIRO Comms; Industry & SME partners; State & Federal governments, regulators

OUTCOMES

Uptake and adoption of new knowledge and developed tools and prototypes for:

- Multiple domestic and export commercial scale renewable powered hydrogen production plants in operation
- A clear and consistent safety and regulatory environment for hydrogen technology deployment across multiple sectors
- Guidelines/benchmarks for environmentally- tolerable maximum H_2 emission rates at global, national, industry scales
- Community awareness and acceptance for sustainable operation and growth of Hydrogen industry
- Decrease in competition and increase in collaboration to enhance the strength and appeal of Australia's hydrogen products.
- Diversified application with accelerated economic returns, better risk management of technology implementation
- Low cost and low emission energy alternatives for diverse Australian businesses

Feasibility Studies & Strategy

- Hydrogen industry investment growth by Industry & Government
- Engaged government, industry and R&D for delivering value-added solutions for domestic and export market and driving sustainable growth

Demonstration Projects

- Commercial scale projects operating across mobility, gas network, remote area power, industrial utilization priority areas

Enabling Science & Technology

- Commercial products & processes based on IP & technology proof of concepts
- Robust understanding Australia's Hydrogen RD&D capability builds strength. Partnership with industry leader for long term innovation opportunity within the seafood industry
- Establish CSIRO's competitiveness

Industry & SME partners and stakeholders (Energy/ Mining / Gas Distribution/ Health); ARENA, Dept of Envr, International partners (Govt and Industry); IPCC/UNFCCC, FMG, general public; energy industry; renewable energy sector; State & Federal governments; regulatory bodies; Industry associations;

IMPACT

ECONOMIC IMPACT

- National Economic Performance: A large scale, renewable energy powered hydrogen industry by 2030 making a significant contribution to Australia's GDP
- New services, products, experiences and market niche: A significant contribution from H2 to secure and affordable low emissions energy while creating new market niches and jobs
- Secure, diversified, resilient and cleaner Australian energy sector enabled by lower energy imports and value-added Hydrogen industry-based exports
- Australia's competitiveness in Hydrogen powered industry

ENVIRONMENTAL IMPACT

- Decarbonisation across the energy and industrial sectors
- Improved overall air quality though emission reductions induced by Hydrogen as a fuel in different sectors

SOCIAL IMPACT

- Health and wellbeing
- Access to resources, services and opportunities
- Consumer confidence

Government – Australian & International; industry; general public; regional

FY2016 to FY2040

Figure 3: Impact Pathway: CSIRO's H_2 Generator for refuelling FCEV

Program Inputs

CSIRO's Inputs

- **CSIRO cash funding:** $1.63 mil AUD; For more details see Table 1.
- CSIRO's background work to lower the cost of Hydrogen production and CO_2 capture from coal gasification
- CSIRO's background work/science on the NH_3-to-H_2 membrane technology at lower TRL levels (demonstrated as a separate proof of concept elements, but not together in a combined system)
- Access to high calibre, multidisciplinary CSIRO capability (Energy, Hydrogen, Manufacturing and others)
- Access to infrastructure and resources to execute projects (e.g. Gasification laboratories on CSIRO Pullenvale site, Manufacturing laboratories on CSIRO Clayton site, etc)
- CSIRO's brand recognition, strategic position and existing relationships that enabled successful uptake, adoption and further development of technology.

Partner Inputs

- **External Funding: SIEF cash funding:** 1.66 mil AUD; **BOC**: 100 k AUD (in-kind)
- **Post success of SIEF funded project** Fortescue Metals Group Ltd (Fortescue) entered into a landmark partnership with CSIRO for the development and commercialization of a pilot -scale CSIRO H_2 generator capable of producing approximately 200kg/day of Hydrogen
- **CSIRO engaged with** BOC, Toyota, Hyundai, The Queensland Dept of Environment & Science, Thomson Environmental Systems for this work

Table 1 Financial (in AUD) and in-kind support for the project

Contributor / type of support	2017 ($)	2018 ($)	2019 ($)	Total ($)
Cash				
SIEF	540 k	780 k	340 k	1,660 k
CSIRO	540 k	760 k	330 k	1,630 k
In-kind				
BOC	30 k	70 k	-	100 k
Total	1,110k	1,610k	670k	3,390 k

Activities

Research activities

- Deliver **Feasibility Studies & Strategy** comprising trusted strategic & technical advice to de-risk projects in partnership with industry experts and project proponents
- Enable **Demonstration Projects** through RD&D in support of industrial technology deployment and hydrogen value chain validation
- Develop technologies (including but not limited to experimentation, modelling)

Engagement and Communication activities

- Fundamental science studies in identified gap areas possible linked to FSPs
- Techno-economic assessments
- Collaborative projects across universities and industries. International and domestic collaborations.
- Benchmarking data for monitoring and evaluation
- Development of Comms Marketing Strategy

Translation and BD focus

- Strategic business development and external engagement for project partnerships (domestic and global)
- External steering committee governance
- Shape development and evolution of national strategy

Training and Licencing Activities

Education and Outreach

Outputs

From a technology perspective, this project has moved the TRL of the suite of technologies from 4 to 6, through utilizing the support provided by SIEF i.e.:

- **From TRL 4**, sub-systems being separately validated in a laboratory environment with prototyping field trials in a representative environment
- **To TRL 6,** all sub-systems integrated into a single demonstration system, successfully producing high purity H_2 from ammonia, used to successfully refuel commercial fuel-cell vehicles from Toyota (Mirai) and Hyundai (Nexo).

This is a critical (and difficult) stage of any process moving towards large-scale industrial deployment. Specific Outputs include:

CFD Models for the H_2 Generation System

A 3D computational fluid dynamics (CFD) model of the H_2 generation system, critical to the design of the demonstration-scale system, ongoing technology commercialisation and scale-up.

CSIRO's Metal Membrane Production

An innovative process for manufacturing vanadium alloy tubes, a key component in scaling up this technology from lab to commercialisation scale. This led to the successful manufacture of 20 membrane tubes, at the greater lengths of up to 500 mm.

Demonstration of CSIRO metal membrane as being highly permeable for H_2, resistant to embrittlement and low cost for manufacturing.

CSIRO's H_2 Generation System

The demonstration H_2 generation system, at the scale of 5-15 kg H_2/day operational for > 1,000 hours with an average >80% NH_3 conversion efficiency and >80% H_2 recovery rates, higher than targeted thereby proving the viability of the technology and without any issues with system performance.

H_2 Generation for Fuel-Cell Electric Vehicles (FCEVs)

Demonstration of the higher purity of generated compressed H_2 than required standard purity requirements (ISO14687-2). Further evidence purity analysis will be an ongoing aspect and challenge for the emerging hydrogen energy industry.

Publications

- Dolan, M. D., Viano, D. M., Langley, M. J., & Lamb, K. E. (2018). Tubular vanadium membranes for hydrogen purification. *Journal of Membrane Science, 549*, 306-311. doi:https://doi.org/10.1016/j.memsci.2017.12.031
- Hla, S. S., & Dolan, M. D. (2018). CFD modelling of a membrane reactor for hydrogen production from ammonia. *IOP Conference Series: Materials Science and Engineering, 297*, 012027. doi:10.1088/1757-899x/297/1/012027
- Lamb, K. E., Viano, D. M., Langley, M. J., Hla, S. S., & Dolan, M. D. (2018). High-Purity H2 Produced from NH3 via a Ruthenium-Based Decomposition Catalyst and Vanadium-Based Membrane. *Industrial & Engineering Chemistry Research, 57*(23), 7811-7816. doi:10.1021/acs.iecr.8b0147
- Lamb, K., Hla, S. S., & Dolan, M. (2019). Ammonia decomposition kinetics over LiOH-promoted, α-Al2O3-supported Ru catalyst. *International Journal of Hydrogen Energy, 44*(7), 3726-3736. doi:https://doi.org/10.1016/j.ijhydene.2018.12.123

Outcomes

The technical validity of the technology was demonstrated during the project at CSIRO Pullenvale site on 8 August 2018 where, in conjunction with project partners, CSIRO successfully refuelled two fuel cell electric vehicles, a Toyota *Mirai* and a Hyundai *Nexo*, using hydrogen produced from the demonstration rig. This event was covered by multiple media outlets (Figure 4) and was the *world's first demonstration* of fuel-cell vehicles refuelling with hydrogen derived directly from ammonia.

Uptake

The successful advancement in TRL of the CSIRO technology, coupled with the increased awareness as mentioned above, has led to the execution of a collaborative partnership agreement with *Fortescue Metals Group Ltd* (Fortescue)[3]. The metal membrane technology is now licenced to Fortescue which is funding the development of a larger-scale pilot plant (200 kg/day)[4]. Following the successful outcomes of this project, the team is working on increasing the technology in scale and deploying it in several larger-scale demonstrations in Australia and internationally, in a partnership with Fortescue.

Co-development with Fortescue to commercialise has other benefits that include:

- A local company supporting the commercialisation – more benefits to Australia
- Improving capabilities to support domestic needs (emissions reduction, mining decarbonisation, etc) as well as a new export industry
- Catalysing wider RE/Hydrogen industry growth through bringing in traction from other larger companies.

Figure 4: Refuelling a hydrogen FCEV (using H_2 directly produced from CSIRO's H_2 Generator) by Hon Keith Pitt MP (centre), with Larry Marshall, CEO of CSIRO (right) and Matt McLeod of Toyota Australia (left) on 8 August 2018.

External Engagement

The impacts of this project are both technological and more widely relevant to the emerging hydrogen energy industry. During this project, two press releases were issued by CSIRO team, the first one in May 2017 and the second one in August 2018 on the H_2 refuelling demonstration day. These press releases generated a large number of media queries and stories not only on CSIRO technology but also on the use of hydrogen itself as a sustainable transport fuel for the future. Due to the growing awareness, other Australian initiatives that aim at generating renewable and sustainable hydrogen to export to countries like Japan and Korea, for the development of the FCEV market are gaining traction.

A number of external collaborators/partners made this SIEF EDP project a success. These included:

- *BOC* – which provided over $100,000 of in-kind gas products (including ammonia and hydrogen) and equipment as well as technical expertise.

[3] CSIRO-Fortescue Collaboration
[4] https://energy.anu.edu.au/files/David%20Viano.pdf

- *Toyota* – which provided for the demonstration, two Mirai FCEVs and a hydrogen refuelling truck, which took CSIRO's generated H_2 at 150 bar and compressed this to 700 bar for refuelling the FCEVs.
- *Hyundai* – which also provided their newest FCEV model, the Nexo, for the demonstration.
- *Queensland Department of Environment and Science* and *Thomson Environmental Systems* – which supported in gas analysis for H_2 purity.

CSIRO

Through this partnership and further commercialisation activities, CSIRO has demonstrated its role in showing how RD&D enables and supports new industries. This technology has the potential to be another key enabler and catalyst for the start-up of an Australian hydrogen value chain and export economy.

CSIRO continues to be highly active across the entire hydrogen value chain (including solar photovoltaics, solar thermal, grid management, water electrolysis, ammonia synthesis, direct ammonia utilisation via combustion and/or fuel cells, as well as hydrogen production).

More information on Australia-scale benefits:

- CSIRO's National Hydrogen Roadmap
- CSIRO's Hydrogen Future Science Platform (FSP)
- CSIRO's Hydrogen Mission

Impacts

Table 2: Summary of project impacts using CSIRO's TBL[5] benefit classification approach

TYPE	CATEGORY	INDICATOR	DESCRIPTION
Economic	National economic performance	- Hydrogen exports to other nations in the form of ammonia - Cost-competitiveness of Australia's hydrogen compared to other importers - Lower dependence in Australia's liquid fuel imports	The establishment of a new renewable hydrogen export industry where hydrogen produced from renewable sources can be exported in the form of ammonia. This technology can also improve Australia's fuel security and create new industries/ jobs and market niches
	Australia's Trade and competitiveness		
	Management of Risk and Uncertainty	- Improvement of Australia fuel security - Lower dependence in Australia's liquid fuel imports	Secure, diversified, resilient and cleaner Australian energy sector enabled by lower energy imports and value-added Hydrogen industry-based exports
	New services, products, experiences and market niches	New jobs Revenue from new market segments	
Environmental	- Decarbonisation across the energy and industrial sectors	- Lower emissions - Lower pollution and overall direct and indirect damages caused by it	The uptake of this technology can significantly reduce both national and global emissions from CO_2 as well as other sources such as coal, oil across the transport, power and industrial sectors. It can also improve air quality through the elimination of particulates generated from internal combustion engines and other emissions associated with coal mining.
	- Improved overall air quality though emission reductions induced by Hydrogen as a fuel in different sectors		
Social	Health and wellbeing	- A decline in health issues caused by pollution	Better health and wellbeing associated with hydrogen as a clean energy source. The

TYPE	CATEGORY	INDICATOR	DESCRIPTION
	Access to resources, services and opportunities	- New sources of income - Improved security	revitalisation of regional communities through employment in new hydrogen-based industries.
	Fuel security		

6 Economic Modelling[6,7]

Cost Benefit Analysis

CSIRO's Hydrogen Generator for Refuelling FCEV is a significant work that is attracting early-stage commercial interest (TRL: 6, CRI: 2; See Appendix B). Development of an innovative membrane to separate hydrogen from ammonia for fuel cell vehicles presents a substantial opportunity. Easy conversion from gaseous hydrogen to liquid ammonia offers simple storage and transport of safe, high energy density liquid fuel using the existing global infrastructure. The proposed technology has the potential to turn a commodity into a unique higher value material to generate techno-socio-economic benefits for Australia.

The section aims at evaluating potential future impacts based on interviews of scientific team members, market assessment and published reports. The results from this evaluation will provide a baseline for conducting more robust future evaluations and monitoring progress while identifying ways to support the project in achieving the intended goals.

Focus

<u>For the purpose of economic analysis, our focus is to assess the potential benefits generated from the commercial adoption of CSIRO's "ammonia to hydrogen" technology to support Hydrogen industry in Australia (domestic and export).</u> The analysis presented is based on CSIRO's Hydrogen Generator for Refuelling Fuel-Cell Electric Vehicles (FCEV).

A broad cost-benefit analysis (CBA) of the project would ideally be based on estimates of the following variables:

<u>Benefits</u>

- profit from the sale of any additional hydrogen fuel for FCEVs, both in Australia and overseas, over and above what would have otherwise been sold in the absence of CSIRO-developed membrane technology.
- revenue from any sale or licensing of the membrane technology itself.
- reduction in noxious and greenhouse emissions.

<u>Costs</u>

- development and production of the membrane technology.
- development and construction of membrane-related infrastructure in Australia (but not overseas).
- distribution domestically, or transport overseas, depending on pipelines or truck delivery domestically, and whether export contracts are written in cost, insurance and freight (cif) or free on board (fob) terms.
- depending on the technology used to produce ammonia and hydrogen, disposal of unwanted by-products
- additional resource costs of developing and constructing energy sources (including renewable energy) used to produce ammonia intended for conversion
- additional port or ship infrastructure.

Some of the data required for high-level cost-benefit assessment can be drawn from two source documents:

[6] CSIRO National Hydrogen Roadmap
[7] ACIL Allen Consulting, 2018, Opportunities for Australia from hydrogen exports, Australia (ARENA Report)

- Bruce S, Temminghoff M, Hayward J, Schmidt E, Munnings C, Palfreyman D, Hartley P (2018) 'National Hydrogen Roadmap. Pathways to an economically sustainable hydrogen industry in Australia', CSIRO, Australia.
- ACIL Allen Consulting (2018) 'Opportunities for Australia from hydrogen exports', report to Australian Renewable Energy Agency, Australian Government.

However, the information contained in these two reports is not sufficient to undertake a cost-benefit analysis along the lines of the benefits and costs indicated above.

Although there are insufficient data available at present to carry out a rigorous cost-benefit analysis, the case study presents a useful opportunity to advise CSIRO technical researchers about the nature of the economic data that need to be collected from the outset, to enable the conduct of an evaluation on completion of the project. Estimates or observed values will also be required for related variables such as the rate of adoption of technology for FCEVs domestically and in other countries.

Perspective and stakeholders

For most CSIRO research, the quantification of benefits is kept limited to the national level. The CBA is conducted from Australia's perspective and includes economic costs and benefits arising from CSIRO as well as other potential stakeholders of this project which include:

- Relevant stakeholders in Hydrogen industry (producers, distributors, suppliers etc);
- SIEF
- Consumers and the broad community; and
- Governments

It is important to highlight that Australia's overall share for Hydrogen fuelled transport- passenger vehicle market is relatively insignificant (~2%) and hence the real focus for the uptake of the technology and increases in scale exists overseas. Both application of technology in the domestic market and export of technology to other nations has the potential to generate economic benefits for Australia.

CBA cases

Cost benefit analysis estimates the short-medium term benefits from industry adoption of CSIRO developed liquid ammonia (NH_3) based H_2 generating system on the Australian economy and community. This analysis determines:

- A base case (status quo) – representing counterfactual scenario i.e. absence of this work done by CSIRO.
- Project cases that represent the economic benefits/profit from the sale of any additional hydrogen fuel for FCEVs, both in Australia and overseas, over and above what would have otherwise been sold in the absence of a CSIRO-developed technology.

Program's Counterfactual

The renewable energy export industry will rely on carriers such as liquid H_2 and ammonia. Without this developmental work, Australia may miss the opportunity to become a significant hydrogen supplier in the renewable energy realm. Solutions for renewable hydrogen production at scale would be delayed for the nation. On the other side of the coin, any development costs would be avoided, with research resources directed elsewhere.

Without this SIEF co-funded assistance, Fortescue would not have committed to supporting this work so publicly and so early. That has interesting ramifications around the role of local companies in the global H_2 industry, around the pace of change in Australia and the role of large corporations.

Hydrogen value chain

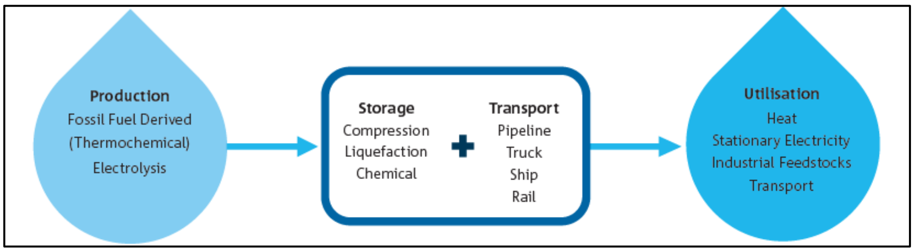

Figure 5: Hydrogen technology value chain. *Source: CSIRO National Hydrogen Roadmap*

In its unpressurised gaseous state, hydrogen retains a relatively low volumetric density (kg/m^3) at atmospheric pressure. There are therefore many technologies that improve the economics of storage (see Figure 5) by increasing the volumetric density of hydrogen (i.e. higher volumetric densities allow for greater quantities of hydrogen to be stored inside a tank of fixed size). Once stored, hydrogen can then be transported from production to point of use via a number of methods.

As round-trip distances (i.e. >4,000km; especially important for export market)[8] and demand for hydrogen increase, technologies with greater hydrogen densities such as ammonia synthesis and liquefaction are likely to be preferred. These technologies are being developed further given their potential role in the export of hydrogen via ship.

7 Economic Assessment Results

High-level quantification of economic benefits

CSIRO's metal membrane technology that addresses the conversion of ammonia back to high-purity hydrogen forms one part and an important enabler of the overall hydrogen technology chain (Figure 5). The ultimate adoption of the technology is contingent upon a number of factors upstream and downstream of this value chain. For conducting an economic assessment of mature technologies Benefit Cost Ratio (BCR or rate of return on investment (ROI)) and Net Present Value (NPV) is generally calculated. The estimation of both these economic indicators need costs and benefits associated with a project. At this stage, we don't have clarity on costs or incremental benefits associated with end to end implementation of the proposed technology. Hence a BCR or NPV cannot be calculated for this assessment. To provide a snapshot of the addressable market, the author has provided high-level data on projected impacts in Table 3 below. It is important to understand that the economic contribution/ benefits provided in the table is from the entire value chain.

[8] CSIRO National Hydrogen Roadmap, Page 17

Table 3: Economic assessment for projected impacts from Hydrogen industry[9]

Parameter	Approach	Estimates					Reference/ Comments
i. **Projected CSIRO Project Costs (in AUD)**	BU + External Funding	**FY2020**	**FY2021**	**FY2022**	**FY2023**	**FY2024**	Estimates, post discussion with the Project Team
		3.3m	4.7m	2.1m	3m	3m	
ii. **Projected hydrogen demand for Australia's potential export partners (in 10^3 Tonnes)**	Low-High range with focus on the key potential export partners for Australia		**2025**		**2030**	**2040**	Given the apparent competitive advantage of Qatar in supplying hydrogen (presented as the 'levelised cost of hydrogen'[10]) to countries like Japan, it would be prudent to use conservative estimates (low) for the level of potential exports of Australian hydrogen in the future for any assessment.
		Japan	88-1,338		875-3,858	1,896-9,573	
		Korea	74-493		373-1,562	1,001-5,304	
		Singapore	3-31		27-103	96-481	
		China	48-698		1,028-7,009	7,853-40,989	
		Other nations	98-1,170		1,053-5,729	4,958-25,758	
		Total	311-3,731		3,357-18,260	15,804-82,105	
iii. **Australia's projected Hydrogen Exports (in 10^3 Tonnes)**	Low-High range	**FY2025**		**FY2030**		**FY2040**	Based on factors such as market size; capacity to meet domestic hydrogen (/energy) demand; existing policies, economic drivers and trade relationships with Australia – Japan, Republic of Korea, Singapore and China have been identified as key potential export partners. The export demand of these countries of interest is assessed upon their national needs and their supply potential. Potential competitors for Australia include Norway, Iceland, the USA, various Middle East or North African countries and Brunei
		26-345		242-1,088		621-3,180	
iv. **Comparison of estimated Hydrogen import prices (in 2025, A\$/kg H_2)**	To potential export partners wrt key importers		**Japan**	**Korea**	**Singapore**	**China**	Hydrogen production costs are projected to reduce significantly between 2018-2025 (and post 2025) for all producers with the advancement of technology, scale of operation and improved capacity factors
		Australia	4.61	4.62	4.52	4.62	
		Norway	5.43	5.40	5.22	5.38	
		Qatar	4.57	4.54	4.36	4.52	
		USA	5.16	5.19	5.34	5.22	
v. **Economic contribution from hydrogen production in Australia (in current prices, A\$ million)**	Low-High range	**FY2025**		**FY2030**		**FY2040**	Based on ACIL Allen Consulting, 2018, Opportunities for Australia from hydrogen exports, Australia (ARENA Report)
	Direct	26-341		230-1,034		562-2,881	
	Indirect	79-1,028		693-3,116		1,696-8,678	
	Total	105-1,369		923-4,150		2,258-11,559	
vi. **Emissions reduction (tonnes of CO_2)**	Comparison on basis of 1 PJ of diesel being replaced by hydrogen consumption	H_2 production using SMR/CCS				63,037	-The overall impact on emissions reduction will be highly dependent upon the technology used to produce Hydrogen. Since the focus of this work is on the utilization of renewable energy resources for energy, operational CO_2 emissions (i.e. kg CO_2/kg H_2) are projected to be 0
		H_2 production using PEM/alkaline electrolysis/ electricity from renewable energy				69,337	

[9] ACIL Allen Consulting, 2018, Opportunities for Australia from hydrogen exports, Australia (ARENA Report)

Employment Contributions

It should be noted that any additional employment (typically stated as "jobs created") is not an economic benefit. Just as for any other resource, use of additional labour resources imposes an opportunity cost on Australian society because those workers cannot be used elsewhere to produce goods or services. In addition, some workers will simply transfer from other jobs (potentially including from CSIRO positions), so the net creation of jobs will be zero. Those workers who are employed in new positions will obtain a wage, but the cost of the wage is borne by employers, so the net benefit to society is zero, except for any additional profit (producer surplus) that is generated. Nevertheless, estimates of job creation opportunities are generally of interest to decision-makers, and they can be reported separately from the cost-benefit analysis to provide a comprehensive outline of expected impacts. For more details see Appendix D.

Key risks

CSIRO's technology

- There is potential that the major uptake of a global hydrogen economy will increase fugitive (uncontrolled) emissions and therefore elevated concentrations of H_2 (or NH_3) in the upper atmosphere. CSIRO is researching to investigate the impact (if any) of higher atmospheric concentrations of hydrogen (H_2) and ammonia (NH_3) on atmospheric chemistry.
- Energy requirements of ammonia synthesis are relatively low when compared with liquefaction; however, there is an additional energy penalty (~ 8 kWh/kg H_2) and cost associated with hydrogen separation at the point of use. Hence a direct comparison with liquefaction cannot be made at this stage.
- Cost and convenience of re-converting ammonia back to hydrogen are unclear at this stage. This is a critical factor affecting the commercial viability of this technology.
- The traditional process of manufacturing ammonia using the Haber-Bosch process (>67%) is very energy and carbon-intensive, generating 1.5 kg of CO_2 for every kilogram of ammonia produced. Either production using renewables resources or other production methods need to be investigated.
- Presence of even traces of ammonia poisons the catalysts used in fuel cells. This is a significant concern and requires additional precautions are necessary to ensure that hydrogen produced from ammonia for use in fuel cells does not contain any traces of ammonia (maximum allowable limit of 0.1 parts-per-million NH_3 according to ISO14687-2).
- The resultant target price of hydrogen in Australia needs to be \$2-\$3/kg H_2 (excluding storage and transport) for our exports to be competitive compared to Qatar and Norway. This has the potential to disrupt incumbent energy carriers (e.g. liquid fuels, batteries and natural gas) and competing with existing uses of higher emissions ('brown') hydrogen.

Australian hydrogen industry scenario

- Australia's ultimate success in hydrogen export industry will be contingent upon a number of factors that include but aren't limited to the scientific edge, economic competitiveness, existing supply chain relationships, investment and trading relationships, macroeconomic frameworks and institutional linkages. Geo-political disruptions emerging from factors like COVID-19 will have a significant (direct and indirect) influence on time and path to market, especially in the short-to-medium term.
- There is a need for significant capital investment and underpinning infrastructure to support the shift to hydrogen industry.
- Battery electric vehicles (BEVs) market would be a significant competitor especially with the rigorous improvements over the years associated with their underlying technology. BEVs are likely to capture most of the independently owned light vehicle market across the globe.
- There is significant uncertainty around how hydrogen might substitute for other energy sources in various sectors at this stage.

- Viable target price of hydrogen for Australia required to be competitive with other exporting countries such as Qatar and Norway.
- The sale of Australian technology to other countries offers a further potential benefit in terms of the profit realised from sales. However, competing for technological developments overseas, and potential path dependence in the uptake of technology, mean that definitive estimates of the potential benefit are too uncertain at this stage, and should be reviewed as CSIRO research progresses.
- Australia's restrictive labour practices, tax rates, uncertain (and therefore inefficient) regulatory environment as well as energy policy instability, can be potential roadblocks in the development of hydrogen industry.

Liquid ammonia (NH3) to H2 refuelling system for FCEVs Project: Current Status and path to market

Table 4: Current status of the project with the view of path to market (incl timeline and key risks)

TRL	CRI	Technology Status	Future Plan		Key Risks
			Expected Timeline	Deliverables	
	4-6	**Commercial Prototype**	2022-30	• Commercial/industrial / government-level partnerships and defined pathways for the design and supply of commercial NH_3-to-H_2 units • Delivery of fully commercial prototypes for CSIRO's Hydrogen Generator, at the production scale(s) that meet market demand.	• Competing technologies and solutions for NH_3-to-H_2 conversion • Competing H_2 carriers (other than NH3) and technologies for the export market (liquid-H_2, MCH, metal hydrides, etc) • Public acceptance (social license) for the H_2 value chain, particularly with safety concerns or any currently unforeseen environmental issues. • Inability to reduce the overall cost of H_2 across the value chain (from ideally renewable H_2 production to end-user) to below $2/kg, with overseas competing regions overtaking Australia. • Slow or no uptake of H_2 fuel-cell vehicles in target export markets (e.g. Asia), due to factors such as slow uptake or intensification of H_2 infrastructure.
8	3	**POC or Demonstration Prototype**	2018-22	• Scale-up of the CSIRO's Hydrogen Generator (NH_3-to-H_2 technology) to 200 kg/day H_2 production. • Demonstration of the prototype in one or more locations (Australia and international).	• COVID-19 disruptions
6	2	**Current Status**	2020		

8 SIEF's Role

Technology development and translation

Before the SIEF project, the CSIRO membrane technology was validated only on a prototype scale in isolation of the NH_3 cracking process, membrane production was limited to laboratory-scale processes, and there was limited understanding of the industrial requirements of large-scale hydrogen energy applications. There was industry uncertainty regarding the quality of the H_2 produced, and a demonstration of the complete technology was needed to allow consideration of new commercialisation pathways.

SIEF funding for this project was instrumental to realize the value-proposition of this work and facilitated the translation of knowledge to a commercial solution. The support enabled successful scaling up of the technology and demonstration of its potential as the critical 'last step' in ammonia-based hydrogen distribution.

This played a key role in leading to a collaboration between Fortescue and CSIRO under a five-year agreement to fund and support select CSIRO technologies in the hydrogen space.

CSIRO's public demonstration of Ammonia to Hydrogen fuelling system (Figure 4), gained substantially more media attention than any other event in CSIRO's history[11].

9 Road Ahead

A successful ammonia-to-hydrogen technology will play a critical role to demonstrate a viable solution. To move to a commercial undertaking, the team is developing internationally linked demonstration projects. Any longer-term outcomes will require the ability to plan and deliver these projects with government and industrial partners.

The final step for commercialisation of this technology requires engagement with H_2 and fuel cell vehicles industries that can facilitate the incorporation of commercial-scale CSIRO H_2 generating system, and provide validation of the first step, for refuelling to day-to-day HFCV for real-life customers.

Compelling case for Australia

- In 2016, Australia ratified the Paris Agreement, committing to achieve a 26-28% reduction in greenhouse gas emissions below 2005 levels by 2030. Transition to Hydrogen can play a cardinal role in helping meet the prescribed decarbonisation targets
- Presence of renewable resources and skills to build commercially viable domestic and export hydrogen industry
- There is concern over Australia's dependence on liquid fuel imports. The nation is currently not meeting domestic fuel reserve targets. Hydrogen can play a key role in protecting Australia from supply shocks by localising liquid fuel supplies (e.g. by producing synthetic fuels) or by displacing their use in both stationary and transport applications[8].
- There is increasing interest from governments all over the world to phase out internal combustion engine (ICE) vehicles to lower carbon footprint and improve air quality; this is expected to catalyse uptake of FCEVs especially in long-distance heavy vehicles (trucks/trains) with more uptake in fleet vehicles
- Through decreasing the need for natural gas, shift to hydrogen is likely to improve the competitiveness of a number of export industries particularly where there is an increasing demand for lower emissions products
- Australia's reputation to supply "quality" hydrogen, skilled labour, a high rank in the financial market development pillar, reliability as a supplier, political and economic stability and prior experience in the LNG industry provides a competitive edge with respect to (wrt) other potential hydrogen exporting countries.
- On the other hand, countries such as Qatar may be able to supply hydrogen at lower cost than Australia.

[11] https://www.ammoniaenergy.org/articles/csiro-demonstrates-ammonia-to-hydrogen-fueling-system/

CSIRO's value proposition for *Liquid ammonia (NH_3) to H_2 refuelling system for FCEVs*

Technology Competitiveness

- Utilization of Ammonia as a hydrogen carrier presents one of the most important options in the context of hydrogen export industry.
- Liquid ammonia stores 35% more energy than liquid hydrogen, is easier to ship and distribute and can use the existing logistics chains for this purpose.
- Singapore, China, South Korea and Japan are key hydrogen export destinations for Australia. For indicative distances of >4,000 km the proposed technology is one of the key storage solutions, given their potential role in the export of hydrogen via ship.
- Australia has established infrastructure to underpin commercialization of hydrogen storage through this pathway
- An increase in the number of ammonia plants set to come online in Asia in the next few years may lead to a glut in the global ammonia market. Global ammonia capacity will soon reach 250 Mt per annum, with current production being at 200 Mt per annum. With these changes, not only can the ammonia industry accommodate a shift to renewable hydrogen production, provide a reliable source of the commodity but this also provides the industry potential opportunity to use the excess capacity.
- Successful development and implementation of technology can play a key role in establishing Australia's competitiveness especially in light of global decarbonisation efforts and new technological trends

10 Limitations of assessment

- Projecting the future global demand for hydrogen in applications where hydrogen is used as an energy source is challenging as technologies are still in a substantially nascent stage of commercial uptake. Currently, overall utilisation of hydrogen is a small fraction and projecting increases from such low basis introduce a large degree of uncertainty.
- Hydrogen is attracting significant attention globally for the potential role it can play for decarbonization. However, as mentioned above the sector is in infancy at this stage with a lot of associated uncertainty with regards to technological development and economic competitiveness of transition to Hydrogen wrt conventional fuels or other alternatives.
- Given the scope, budget and timeline of the analysis, we acknowledge that there are some limitations with regards to the evidence base of impacts.
- Any growth in hydrogen consumption will start from a very low base and there are no consistent official hydrogen demand projections to 2040 for the four selected importing economies based on which economic impacts have been projected.

11 Confidence Rating

CSIRO's Hydrogen Generator for Refuelling FCEVs project is aspirational with the potential to address significant global needs of decarbonising economies. As discussed earlier in the report, projecting the future domestic and global uptake of the technology is a challenging task at this early stage and introduces a significant degree of uncertainty in the analysis.

Due to inherent ambiguity associated with how the future might unfold, and the longer-term time frames of the suggested transition, the confidence rating in the benefits assessment for this study is rated as low by the author. As CSIRO's research progresses, the assumptions listed in this study should be revisited and refined.

Appendix A References

i. International Energy Agency Hydrogen Technology Collaboration Program 2017, Global Trends and Outlook for Hydrogen

ii. https://www.ammoniaenergy.org/articles/csiro-demonstrates-ammonia-to-hydrogen-fueling-system/

iii. https://www.fmgl.com.au/in-the-news/media-releases/2018/11/22/fortescue-and-csiro-enter-into-landmark-partnership-to-develop-and-commercialise-hydrogen-technology

iv. https://energy.anu.edu.au/files/David%20Viano.pdf

Appendix B TRL and CRI on the Technology Development Chain

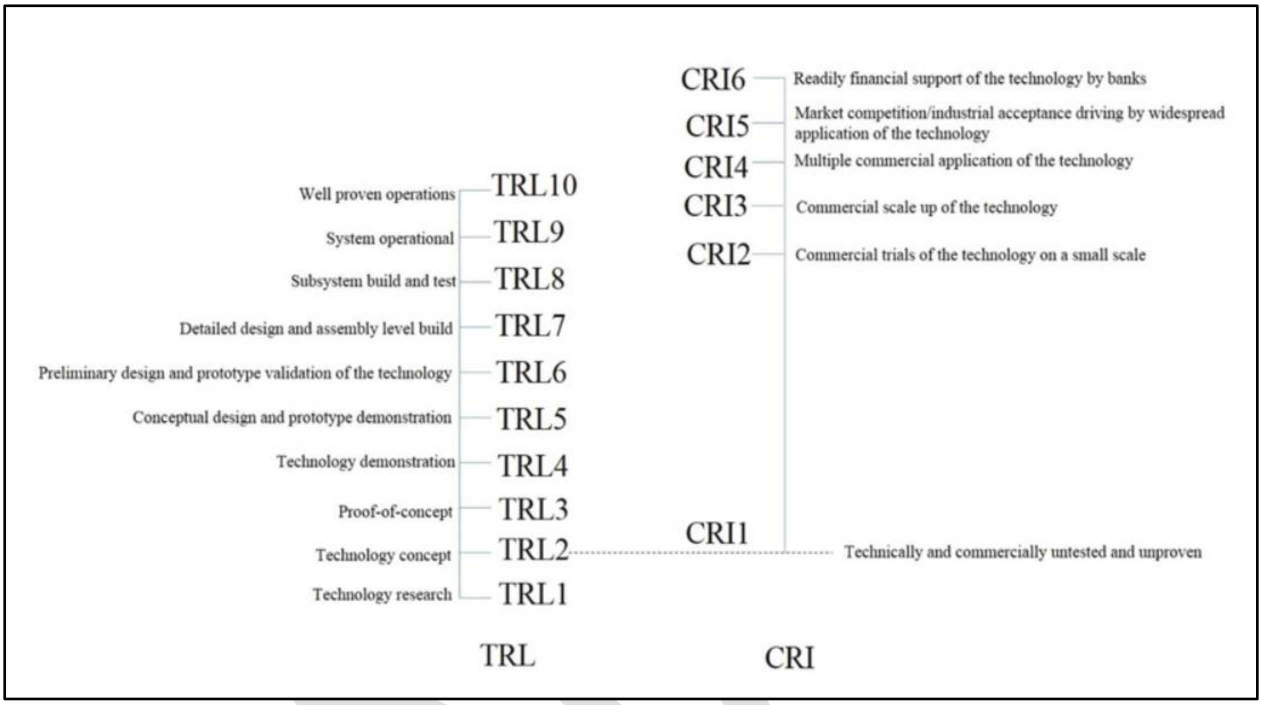

Figure 6: Technical and commercial readiness level indication scale

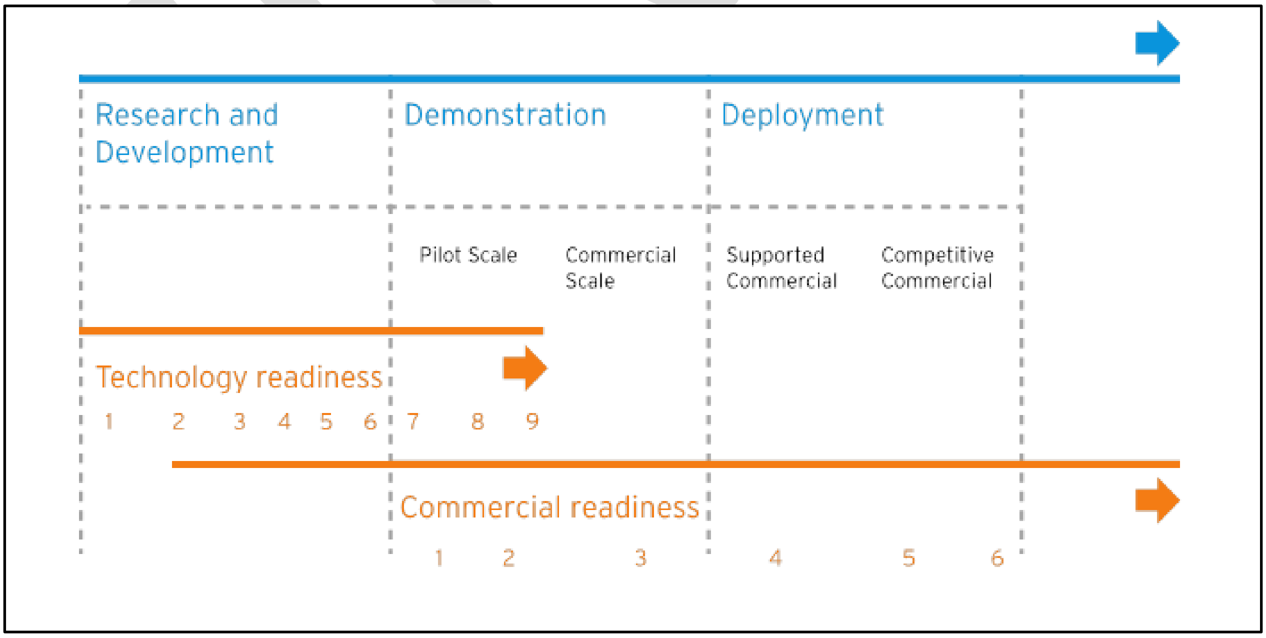

Figure 7: TRL and CRI mapped on Technology Development Chain

Appendix C Growth projections for Hydrogen demand

Table 5: Examples of various projections for the growth of hydrogen demand[12]

Source	Period of Projection	CAGR	Comments
Persistence Market Research	2014 to 2020	3.5%	The projection was for total hydrogen demand. The Asia Pacific market accounted for much of the growth.
Research and Markets	2017 to 2021	6%	The projection was for total hydrogen demand.
Shell's Sky Scenario	2020 to 2040 (only projections to 2050 are shown)	23%	The Sky Scenario models and energy mix was specifically designed to reach the Paris Agreement's goal in a technically possible manner.
Hydrogen Council Scaling Up	2020 to 2050	35% to 2040 28% to 2050	The CAGRs shown are for demand for the use of hydrogen for energy use. Presents an ambitious vision of the future hydrogen sector.

[12] ACIL Allen Consulting, 2018, Opportunities for Australia from hydrogen exports, Australia (ARENA Report), Table 2.1

Appendix D Employment Contributions

It should be noted that any additional employment (typically stated as "jobs created") is not an economic benefit. Just as for any other resource, use of additional labour resources imposes an opportunity cost on Australian society because those workers cannot be used elsewhere to produce goods or services. In addition, some workers will simply transfer from other jobs (potentially including from CSIRO positions), so the net creation of jobs will be zero. Those workers who are employed in new positions will obtain a wage, but the cost of the wage is borne by employers, so the net benefit to society is zero, except for any additional profit (producer surplus) that is generated. Nevertheless, estimates of job creation opportunities are generally of interest to decision-makers, and they can be reported separately from the cost-benefit analysis to provide a comprehensive outline of expected impacts. For more details see Appendix D.

In principle, the engagement of an unemployed worker with no other clear job prospects imposes no opportunity cost on society. In a situation of structural (i.e. non-cyclical) unemployment, therefore, society can benefit from the creation of new jobs that are filled by the unemployed. But this benefit can only be realised if the skills of the currently unemployed workers match the competencies required in the newly-created jobs. Further, any benefit to the newly-employed workers, and hence society, would be offset to some extent by their loss of leisure (i.e. non-work) time, which can also result in social benefits through activities such as child-minding, gardening, relaxation, exercise, etc, that are valued by the worker.

Taxes have a depressive effect on the economy by reducing aggregate demand and/or output. They, therefore, reduce job opportunities and profits. To the extent that the hydrogen project is funded by CSIRO and SIEF (or other sources) through government taxation, there will be some potential loss of jobs in the economy. In other words, it cannot be claimed without qualification that there will be a straightforward increase in employment levels attributable to the hydrogen generation project.