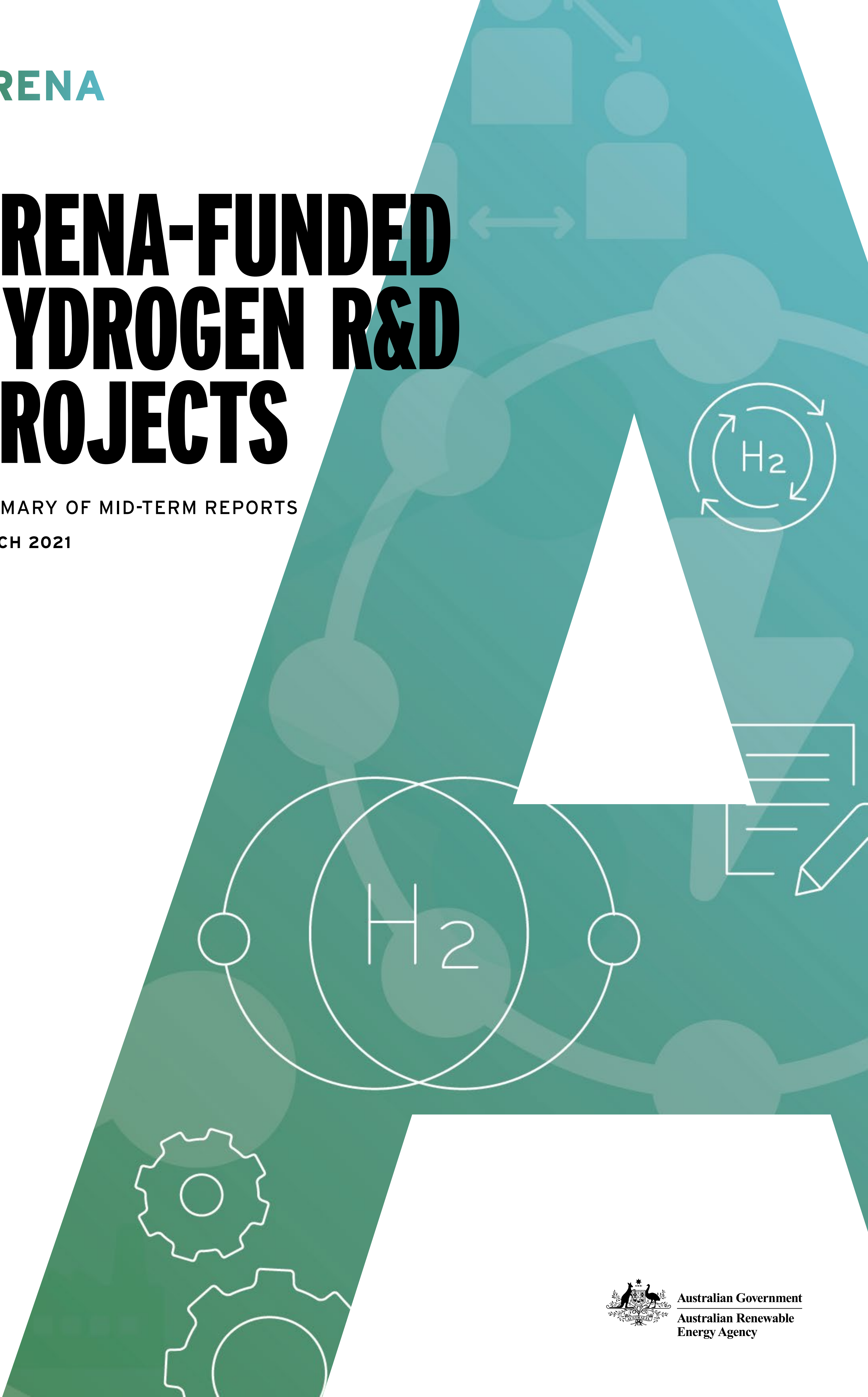
ARENA

ARENA-FUNDED HYDROGEN R&D PROJECTS

SUMMARY OF MID-TERM REPORTS

MARCH 2021



Australian Government
Australian Renewable Energy Agency

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BACKGROUND

In December 2017 ARENA launched a research and development funding round (https://arena.gov.au/blog/22-million-to-unlock-hydrogen-potential/) focused on accelerating the development of a potential **renewable energy export supply chain** based on hydrogen, with the topics covering the supply chain as depicted in Figure 1.

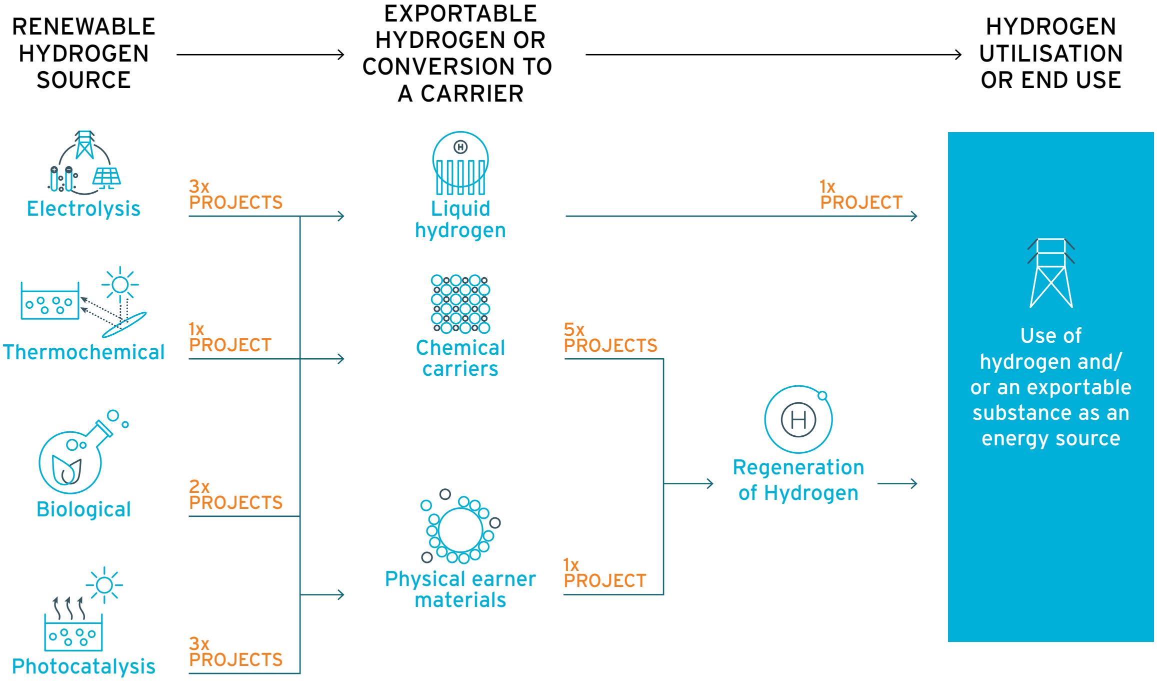

Figure 1: The potential role of ARENA's Research and Development projects in the Hydrogen Export Supply Chain

ARENA's Hydrogen R&D Funding Round granted a total of $22.1 million, shared between sixteen separate research projects that will all be completed by early 2022. The projects each focus on a particular part of the supply chain, as summarised in Table 1.

PROJECT FOCUS	LEAD INSTITUTIONS	SUPPLY CHAIN CATEGORY	ARENA FUNDING AMOUNT (TOTAL PROJECT COST) $ MILLIONS	EXPECTED COMPLETION DATE
Solar Thermochemical Hydrogen	CSIRO	Production	$2.0 ($4.0)	Dec 2021
Direct Water Electrolysis	Australian National University	Production	$1.3 ($3.5)	Sept 2021
Water Splitting Electrodes	Monash University	Production	$1.1 ($3.7)	Jan 2022
Hydrogen Generation by Electro-Catalytic Systems	Australian National University	Production	$0.6 ($1.8)	July 2021
Solar Hydrogen Generation	Australian National University	Production	$1.6 ($4.3)	Sept 2021
Photovoltaic Electrolysis to Generate Hydrogen	University of NSW	Production	$1.3 ($5.0)	Jan 2022
Biological Hydrogen Production	Macquarie University	Production	$1.1 ($2.8)	Aug 2021
Waste Biomass to Renewable Hydrogen	University of NSW	Production	$1.0 ($2.5)	Jan 2022
Ammonia Production from Renewables	Monash University	Carriers and Transport	$0.9 ($2.7)	Jan 2022
Hydrogen Process	Queensland University of Technology	Carriers and Transport	$3.4 ($7.7)	July 2021
Methane Fuel Carrier	CSIRO	Carriers and Transport	$1.1 ($2.2)	May 2021
Hydrogen to Ammonia	CSIRO	Carriers and Transport	$1.2 ($2.8)	Aug 2021
Hydrogen Storage and Transport	RMIT, University of Melbourne	Carriers and Transport	$0.8 ($1.8)	Aug 2021
Methanol from Syngas	University of Western Australia	Carriers and Transport	$1.1 ($2.9)	Jan 2022
Liquid Fuel Carrier	CSIRO	Carriers and Transport	$1.0 ($2.5)	Aug 2021
Hydrogen Fuelled Reciprocating Engines	University of Melbourne	Utilisation	$2.6 ($8.6)	Jan 2022

The Commonwealth Government's First Low Emissions Technology Statement (LETS)[1] released in September 2020 set a priority technology stretch goal of less than $2 per kilogram for clean hydrogen production to underpin domestic and export supply opportunities. The sixteen projects selected in 2018 for ARENA funding include hydrogen source projects covering a range of technologies that could contribute to achieving this LETS' stretch goal together with a range of complementary conversion and utilisation projects to fully cover the export supply chain.

1 Read more about the LETS (https://www.industry.gov.au/data-and-publications/technology-investment-roadmap-first-low-emissions-technology-statement-2020).

HYDROGEN PRODUCTION PROJECTS

The hydrogen production projects cover thermochemical cycles, electrolysis, photocatalysis and biological (e.g., dark fermentation) processes as well as hybrid energy systems including thermal + electrical (e.g., high-temperature electrolysis), electrical + photonic (e.g., photovoltaic electrolysis), and photonic + biochemical (e.g., photo-fermentation). In comparison with the non-hybrid systems, the hybrid systems are generally more thermodynamically favourable as a part of the required energy is substituted with a cheaper or renewable resource, consequently lowering the overall operation cost and activation barrier and improving the chemical reaction kinetics and hydrogen production rate.[2]

The key challenges for next-generation technologies for hydrogen generation are to increase the yield per unit of input energy (i.e., increase efficiency of production); decrease the capital cost per unit of hydrogen produced; and increase the stability/longevity of materials used, particularly catalysts. The diverse range of hydrogen production technologies in this funding round all are firmly focused on overcoming these key challenges, with some examples of results achieved so far being:

› Biological production of hydrogen by re-engineering, using gene-to-protein editing, of a naturally occurring hydrogen producer that is demonstrating dramatic increases in yield from fermentation of sugar.

› An all-integrated and simplified solar hydrogen cell that allows thermal integration of solar and catalytic elements to improve solar-to-hydrogen (STH) conversion efficiency, with more than 16% STH efficiency achieved and targeting above 20% by the project's end.

› A next generation solid oxide electrolyser that can provide an efficient route for hydrogen and liquid fuels production using waste carbon dioxide (CO2), with a matching solar energy input and downstream process for synthesis of renewable fuels.

› A highly efficient photovoltaic-electrolysis system that uses the full spectrum of sunlight to deliver an STH above 26% already and aiming for more than 30%.

› A thermochemical hydrogen system using a novel beam-down solar concentrator system, next generation catalyst materials and a new high temperature (1,300 °C) fluidised bed reactor design for high efficiency hydrogen production.

Currently available electrolysers use approximately $2.50 to $3.00 in electricity (assuming it can be sourced at 5 c/kWh) to produce a kilogram of hydrogen, already well above the LETS target of $2 per kg and before capital, operating costs or business profitability are considered.

Eliminating the need for electricity (e.g., such as by biological or thermochemical production) and/or significantly increasing the conversion efficiency (e.g., STH efficiency) are necessary if hydrogen is to become economically competitive. While the projects above are only at the research phase, if the promising technical results they are already achieving can be sustained as they are taken through consecutive scale-up projects to commercial readiness then they will enable hydrogen to meet its market potential globally and support achievement of Australia's potential as a viable supplier into global hydrogen export markets.

HYDROGEN CARRIER PROJECTS

A range of hydrogen carriers are being researched including methane, ammonia, methanol and hydrogenated carbon. Some example results to date are:

› A greatly simplified ammonia production route that delivers energy and capital cost savings as well as offering a route to decentralised production of ammonia, with results to date of up to 11.5% hydrogen to ammonia conversion efficiency at low (30 bar) pressure (compared to approximately 15% with the commercial Haber-Bosch process that operates at approximately 150 bar pressure).

› Synthetic methane production with processes to capture CO2 from the air, using novel solvents, that could be as low as $100 per tonne in an integrated CO2 capture-methanation process.

› A novel proton flow reactor system for electrical energy storage and bulk export of hydrogenated carbon-based material has been experimentally demonstrated, with overall retention of hydrogen in the 75-80% range.

2 S Y Tee at al, Recent Progress in Energy-Driven Water Splitting, Adv. Sci. **2017**, 4 (DOI: 10.1002/advs.201600337)

Even if the LETS hydrogen production cost target of $2 per kg can be achieved, there remains the challenge of economically moving it from point of production to point of use. Increasing the efficiency of conversion processes and reduction in the capital and operating costs of such plants is necessary for all hydrogen carriers. The above projects are already demonstrating technical progress to these goals and, as for the earlier production projects, if the promising technical results they are already achieving can be sustained as they are taken through consecutive scale-up projects to commercial readiness then they will support achievement of Australia's potential as a viable supplier into global hydrogen export markets.

HYDROGEN UTILISATION PROJECT

A project to demonstrate the performance and value of highly efficient reciprocating engines operating on hydrogen is already demonstrating performance exceeding 40% thermal efficiency for a spark-ignition engine fuelled by hydrogen alone and 40-45% thermal efficiency for a compression ignition engine using up to 50% hydrogen, which is about twice as much hydrogen as other dual-fuel compression ignition engines.

INTELLECTUAL PROPERTY DEVELOPED

Adding to the background intellectual property brought into the sixteen projects in the round, an additional six patent applications have been filed already and a number of invention disclosures lodged. By the time of their completion, a number of projects also expect patent applications to be filed to protect the novel materials and technologies being developed.

COMMERCIALISATION PROSPECTS

Many of the projects in this hydrogen funding round involve national and/or international industry partners, a clear indication of those companies' interest in the technical outcomes of the projects and their possible interest to invest further to progress the technologies towards commercialisation.

One significant development is that the novel ammonia synthesis project has already seen a spin out company formed. Backed by high-net-worth Australian investors, this company is focused on advancing the technology's technical and commercial maturity so as to lay a foundation for next-stage progression towards commercialisation.

COVID-RELATED CHALLENGES ENCOUNTERED

To greater and lesser degrees for each project, a significant challenge faced by all sixteen projects has been disruption and delays caused by COVID-19 restrictions on access to laboratories and working within them. Delays and their cost are being managed between ARENA and each project's lead organisation to ensure contracted outcomes have a high prospect of being delivered.

MAKING A DIFFERENCE

Many of the projects incorporate techno-economic modelling to predict, within reasonable accuracy limits at this still early stage, likely costs of production at commercial scale. Such modelling will underpin business cases for the considerable additional investment and time required to complete development and demonstration projects that scale-up the technologies to high technology readiness levels and move them into readiness for full commercial take-up.

There is, however, a risk that each project's techno-economic models will be sufficiently different in methodology and assumptions used that the output data from each model will not be able to be compared. A standard approach to the techno-economic modelling therefore should be used, particularly for calculating such key metrics as levelised cost of hydrogen (LCOH) produced or delivered (for hydrogen carriers).

Overall, at this mid-point in the projects' timelines, the technologies ARENA has invested in for this hydrogen R&D round have the potential to make a considerable contribution to meeting the hydrogen production goal of less than $2 per kilogram and providing routes to cost-effective hydrogen carriers, thus underpinning the viable development of an Australian renewable hydrogen export supply chain. That is, ARENA's investment already has been effective in moving these technologies further up the technology readiness level scale.

There may be more hydrogen production, carrier and use technologies in Australia that would benefit from research funding support, assuming they can meet the requirements of an ARENA funding round. It would be prudent of ARENA to determine the quantity of such need and if it is sufficiently high to consider conducting another hydrogen research funding round.

ARENA currently is supporting hydrogen projects at early TRL (i.e., research) and late TRL/early-to-middle CRI (i.e., deployment) stages. Of equal importance is fostering by ARENA of the progression of technologies from this 2018 research round that gain industry interest and need to be taken through scale-up steps towards commercial readiness.

Further information is available at
arena.gov.au

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