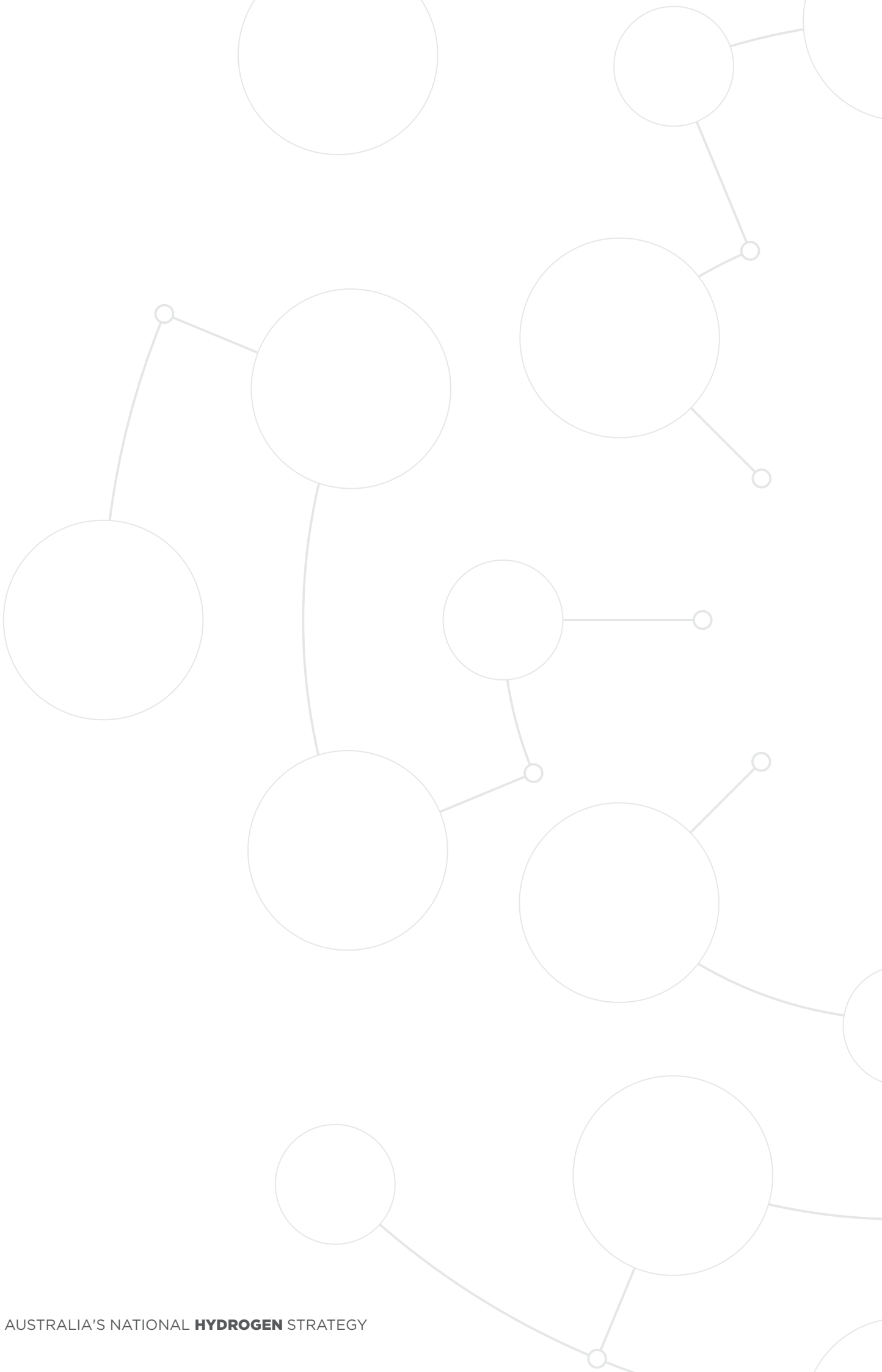
COAG Energy Council

AUSTRALIA'S NATIONAL **HYDROGEN** STRATEGY



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FOREWORD

As the Commonwealth Ministers representing Australia's energy and resources sectors, we are pleased to present Australia's National Hydrogen Strategy.

Technological developments that support energy affordability, improve energy system reliability and contribute to long-term emissions reductions will be vital as global energy markets continue to evolve. Hydrogen is one of the many tools that can help us on this evolution and Australia is in a unique position to maximise on this opportunity.

The development of our hydrogen resources could enhance Australia's energy security, create Australian jobs and build an export industry valued in the billions. We have all the pieces needed to create this new industry and supply clean hydrogen to the world: the energy resources, expertise, and infrastructure.

This Strategy sets a path to build Australia's hydrogen industry. We plan to accelerate the commercialisation of hydrogen, reduce technical uncertainties and build up our domestic supply chains and production capabilities. The Strategy looks to initially concentrate hydrogen use in niche hubs that will foster domestic demand. A strong domestic hydrogen sector will underpin Australia's exporting capabilities, allowing us to become a leading global hydrogen player.

The Australian Government has already committed over $146 million to hydrogen projects. These projects will help us learn more about how hydrogen can form part of Australia's energy mix to help drive down prices and emissions, as well as provide a foundation of expertise to build a competitive export industry.

Every state and territory in Australia has regions with excellent prospects for hydrogen production. Through this Strategy, all of Australia's governments are committing to remove barriers to industry development. This includes through nationally consistent and smart regulation, enhanced engagement with customer countries, and in ensuring safety concerns are addressed. The Australian Government will track progress and monitor emerging industry changes here and overseas so that all jurisdictions can respond to market developments.

It is important that governments provide the right support at the right time for emerging technologies, and this Strategy will give us an adaptive pathway to do so. Ultimately, business and industry will be the ones to carry technology through to commercial scale when the time is right.

We thank the members of Energy Council for their commitment to this Strategy, and the resources they allocated to its development. We look forward to future-proofing our position as a world leader of this transformative technology.

The Hon Angus Taylor MP
Minister for Energy and Emissions Reduction

Senator the Hon Matthew Canavan
Minister for Resources and Northern Australia

MESSAGE FROM THE CHAIR

In 1874, science fiction author Jules Verne envisioned a future in which

> *'water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable. Someday the coal-rooms of steamers and the tenders of locomotives will, instead of coal, be stored with these two condensed gases, which will burn in the furnaces with enormous calorific power.'*

Verne's prescient vision has inspired governments and entrepreneurs in the 145 years since, but two factors stood in the way of lift-off: the expense of manufacturing clean hydrogen and the durability of the equipment. Until now. Science and technology, and manufacturing experience in solar and wind electricity generation, have given wings to Verne's vision. Clean hydrogen as a fuel is now poised to become a reality. Around the planet the pace of research, demonstrations, product development and pilot projects is accelerating, seemingly by the day. For the anxious, progress is too slow, but look back a few decades from now and history will record the hydrogen industry as an overnight success.

Energy is the foundation of civilisation. To meet future demand while avoiding the by-products of our current energy sources we have to find alternatives. These will be a mix of primary energy sources such as solar and wind electricity, and secondary energy carriers, of which hydrogen will make an essential contribution as a high-density, zero-emissions fuel.

The potential to export clean hydrogen is substantial, with the International Energy Agency and the World Energy Council both identifying Australia as a potential hydrogen production powerhouse. We can become a leader in the new industry I call 'shipping sunshine', with our hydrogen exports being additional to our other energy exports.

Domestic use of hydrogen will give us opportunities to expand into new and revitalised industries while helping us to develop the skills and credibility that will contribute to the development of our export industry.

In our research and consultations, the COAG Energy Council Hydrogen Working Group has found that Australian companies and investors are ready to apply their ingenuity and considerable experience to activating the supply of hydrogen. The challenge is to develop the early demand that will enable the suppliers to begin their journey down the cost curve. The best way to start this journey is for governments and industry to work together in the manner outlined in this Strategy.

I take this opportunity to thank each of the Commonwealth, State and Territory energy and resources ministers for inviting me to lead the development of this National Hydrogen Strategy. This Strategy's implementation now rests with them and the governments they represent. I was privileged to meet many of them throughout the process to seek their advice and to make sure we captured their aspirations and addressed their concerns.

I have been ably supported by a taskforce of public service personnel who brought deep expertise, knowledge and commitment to the project. Together we have been guided by our steering committee, drawn from public service leadership around the country, as well as a stakeholder advisory panel. I deeply thank them and the many companies, institutions and individuals who made submissions in response to our calls. I also thank my colleagues and new acquaintances who have provided advice along the way.

Travelling around the country I have witnessed an extraordinary degree of passion for this industry from ministers, public servants, investors, industrialists and the general public. The future for hydrogen is bright and it is ours to seize.

Dr Alan Finkel AO
Australia's Chief Scientist
Chair, COAG Energy Council Hydrogen Working Group
22 November 2019

CONTENTS

EXECUTIVE SUMMARY

In December 2018, the Council of Australian Governments Energy Council set a vision for a clean, innovative, safe and competitive hydrogen industry that benefits all Australians and is a major global player by 2030. The Council agreed to establish a Hydrogen Working Group, chaired by Australia's Chief Scientist, Dr Alan Finkel, to develop a National Hydrogen Strategy that can achieve this vision.

Australia has the resources, and the experience, to take advantage of increasing global momentum for clean hydrogen and make it our next energy export. There is potential for thousands of new jobs, many in regional areas – and billions of dollars in economic growth between now and 2050. We can integrate more low-cost renewable generation, reduce dependence on imported fuels, and help reduce carbon emissions in Australia and around the world.[i]

Much of how this opportunity will evolve remains uncertain, but there are risks in not acting early. Australia's Strategy will follow an adaptive approach. It will focus on actions that remove market barriers, efficiently build supply and demand, and accelerate our global cost-competitiveness. These will equip us to scale up quickly as markets develop.[ii]

A key element of Australia's approach will be to create hydrogen hubs – clusters of large-scale demand. These may be at ports, in cities, or in regional or remote areas, and will provide the industry with its springboard to scale. Hubs will make the development of infrastructure more cost-effective, promote efficiencies from economies of scale, foster innovation, and promote synergies from sector coupling. These will be complemented and enhanced by other early steps to use hydrogen in transport, industry and gas distribution networks, and integrate hydrogen technologies into our electricity systems in a way that enhances reliability.[iii]

Building and demonstrating broad capability in making, moving, and using clean hydrogen is only part of the story. We will set clear regulatory frameworks and ensure development has a positive influence on energy prices and energy security. Through our international engagement, Australia will work with other countries to develop a scheme to track and certify the origins of internationally traded clean hydrogen. We will work constructively to shape international markets and open new frontiers for trade.[iv]

Australians will want the new jobs and growth of clean hydrogen to be achieved without compromising safety, cost of living, water availability, access to land or environmental sustainability. Governments and industry have the responsibility to ensure community safety, confidence and trust in the new industry, and deliver benefits for all Australians.[v]

The vision we set today, and the actions we plan, are not enough if we aren't prepared to measure our progress and ultimately our successes. Nor can we be adaptive if we aren't monitoring global developments. For the next decade, the Strategy identifies indicators that will show where technology and markets are advancing quickly, and where they are moving slowly or falling behind. At the same time, tracking our progress on clear measures of success – such as being a top three supplier to the Asian market, and maintaining an impeccable safety record – will ensure we are accountable to the high expectations of the Australian public.[vi, vii]

The Strategy is the culmination of considerable analysis, consultation with experts, industry and the public, and an extensive body of original research. It is designed to be a 'living document' – updated and revisited as the industry develops.

In total, the Strategy identifies 57 joint actions.[viii] These actions by themselves will not achieve the vision laid out by Ministers. They are first steps, on which later actions can build. Actions are themed around national coordination, developing production capacity, supported by local demand; responsive regulation; international engagement; innovation and research and development (R&D); skills and workforce; and community confidence. The actions consider hydrogen in relation to exports, transport, industrial use, gas networks, electricity systems, and cross-cutting issues such as safety, skills, and environmental impacts.

All levels of government, private industry, and the research community have the opportunity to help Australia realise its hydrogen potential and reap rewards for the economy, the community and the environment to 2030 and beyond. Success will rely on working together. The possibilities are exciting: our Strategy will help us realise the vision.

Endnotes

i See Australia's clean hydrogen potential, from page 1
ii See Making and taking Australia's opportunity, from page 21
iii See The journey to hydrogen powerhouse, from page 31
iv See Enabling industry growth, from page 49
v See Building benefits for the Australian community, from page 57
vi See Tracking success, from page 67
vii See Appendix E
viii See Strategic Actions, from page 78

TAKING ACTION – THE ADAPTIVE PATHWAY

FOUNDATIONS AND DEMONSTRATIONS → TO 2025

Scale-up activities

- Advance priority pilots, trials and demonstration projects
- Build demonstration scale hydrogen hubs
- Assess supply chain infrastructure needs
- Develop supply chains for prospective hydrogen hubs

Hubs are regions where various users of hydrogen across industrial, transport and energy markets are co-located.

Scale-up support

Create, test and prove Australia's clean hydrogen supply chains, encourage global markets and develop cost-competitive production capability

Provide targeted support for pilot, trial and demonstration projects, to:

- drive technology development
- develop industry expertise
- promote international collaboration
- prove hydrogen supply chains at scale.

Many projects are already in their early stages.

- Incentivise growth of hydrogen hub demonstrations
- Develop country-to-country agreements
- Support efficient hub supply chains
  - complete the National Hydrogen Infrastructure Assessment
  - support targeted and coordinated infrastructure investments

Enabling activities

Enabling activities to support the adaptive pathway throughout the decade include:

- Responsive regulation: review and reform underpinning regulatory legal frameworks, develop consistent approaches for efficient supply chains and markets, ensure a supportive investment environment, robust training requirements and safety standards.
- Strategic and coordinated international outreach, focused on key markets, harmonising standards and encouraging global trade to emerge.
- Develop a scheme with other countries to track and certify the origins of internationally traded clean hydrogen.

FROM 2025 → **LARGE-SCALE MARKET ACTIVATION**

Identify signals that large-scale hydrogen markets are emerging

Build and maintain robust and sustainable export and domestic markets and supply chains

Scale up projects to support export and domestic needs

Enable competitive domestic markets with explicit public benefits

Build Australian hydrogen supply chains and large-scale export industry infrastructure

Supply chain infrastructure includes powerlines, pipelines, storage tanks, refuelling stations, ports, roads and railway lines and any other facilities needed for hydrogen supply.

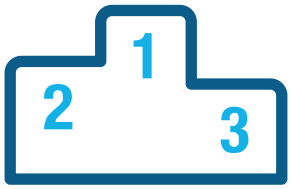
Additional actions to scale up the industry and activate markets in light of global signals

Supporting actions could include:

- Financing of clean hydrogen supply chains or other policies that attract private investment
- Policies to build widespread domestic hydrogen demand, including measures that enable:
  - using clean hydrogen for industrial feedstocks and heating
  - blending of hydrogen in gas networks
  - using hydrogen for long-distance heavy-duty transport and development of associated refuelling infrastructure
- Ensure community safety and confidence, deliver benefits for all Australians, and protect the environment.
- Provide long-term governance structures, and support market settings to foster industry growth and competition.

- Building industry capability and capacity through improving skills and establishing training regimes.
- Earning community confidence by focusing on safety, explicitly providing community benefits, keeping the community informed and by addressing community concerns.
- Providing targeted support for hydrogen research and development activities to drive technology improvements, ensure safety, minimise environmental impacts, inform project scale up and stimulate collaboration and knowledge sharing.
- Enabling adaptation by monitoring global indicators of technology and market development.
- Tracking progress on measures of success.

MEASURES OF SUCCESS



AUSTRALIA
is one of the top three exporters of hydrogen to Asian markets

AUSTRALIA
has an excellent hydrogen-related safety track record

HYDROGEN
is providing economic benefits and jobs in Australia

AUSTRALIA
has a robust, internationally accepted, provenance certification scheme in place

CONVERSIONS AND UNITS

Currency

Unless otherwise stated, all currency amounts in this report are in Australian dollars (AUD).

Energy content of hydrogen

In this report, when referring to the energy content of hydrogen we use the lower heating value of 120 MJ/kg (equivalent to 33 kWh/kg).[i]

References to hydrogen

Unless otherwise indicated, references to hydrogen in this report refer to clean hydrogen. Clean hydrogen is produced using renewable energy or using fossil fuels with substantial carbon capture and storage (CCS). This definition reflects a technology-neutral stance.

Breakeven price points

This table shows the delivered prices hydrogen would need to achieve against competitor fuels.

Competitor fuel service	**Hydrogen breakeven price** ($/ kg H_2)
Drive 100 km using petrol (retail price $1.43/ L)[ii]	$13.31
Drive 100 km using diesel (retail price $1.50/ L)[iii]	$11.21
Deliver 1 GJ heat using natural gas (wholesale price approximately $10/ GJ)[iv]	$1.20

Water inputs

Producing 1 kg of hydrogen requires at least:[v]	
Electrolysis	9 L
Coal gasification	9 L
Steam Methane Reforming (SMR)	4.5 L

These are theoretical amounts of water based on the chemical pathway for each process. In practice water requirements for hydrogen production will vary depending on production method and technology, water content of inputs, and additional water needs for processes like cooling and input water purification.

Emissions intensity of production

Production technology	**Emissions** (kg $CO_{2\text{-}e}$/kg hydrogen)[vi]
Electrolysis – Australian grid electricity[vii]	40.5
Electrolysis – 100% renewable electricity	0
Coal gasification, no CCS[viii]	12.7 – 16.8
Coal gasification + CCS – best case[ix]	0.71
Steam methane reforming (SMR), no CCS[x]	8.5
SMR + CCS – best case[xi]	0.76

HOW MUCH HYDROGEN IS THAT?

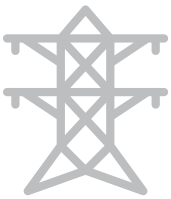
1 kg of hydrogen is enough to travel up to **100 km** in a **Hyundai Nexo**

Travelling in a **Hyundai Santa Fe** uses **7.5 L** of diesel or **9.3 L** of petrol

Driving a **Hyundai Nexo** compared to a diesel **Hyundai Santa Fe** avoids **0.2 kg CO_2-e / km** driven or **20 kg CO_2-e per kilogram** of hydrogen used

1 kg of hydrogen in a fuel cell could power a **1,400 watt** electric split-cycle air conditioner for **14.5 hours**

Replacing Australian grid electricity with electricity from **hydrogen** avoids **0.75 kg CO_2-e / kWh**, or **15 kg CO_2-e per kilogram** of hydrogen used



1 tonne of **hydrogen** is equivalent to around **3.4 times** the average annual consumption of an Australian house with **gas heating**

Replacing **natural gas** with **hydrogen** avoids **0.052 tonnes CO_2-e / GJ** of **natural gas** or **6.2 tonnes CO_2-e per tonne** of **hydrogen**

Endnotes

i Department of Energy USA 2001, *Hydrogen Fuel Cell Engines and Related Technologies*, p 21, https://www1.eere.energy.gov/hydrogenandfuelcells/tech_validation/pdfs/fcm01r0.pdf, accessed 7 November 2019

ii Calculation based on driving a Hyundai Santa Fe for 100 km compared to driving a Hyundai Nexo for 100 km. *Source for petrol price: Australian Institute of Petroleum Weekly petrol prices report: week ending 10 November 2019*, 2019, https://www.aip.com.au/sites/default/files/download-files/2019-11/Weekly%20Petrol%20Prices%20Report%20-%2010%20November%202019.pdf, accessed 11 November 2019

iii Calculation based on driving a Hyundai Santa Fe for 100 km, compared to driving a Hyundai Nexo for 100 km. *Source for diesel price: Australian Institute of Petroleum Weekly diesel prices report: week ending 10 November 2019*, 2019, https://www.aip.com.au/sites/default/files/download-files/2019-11/Weekly%20Diesel%20Prices%20Report%20-%2010%20November%202019.pdf, accessed 11 November 2019

iv Wholesale gas price derived from Australian Competition and Consumer Commission 2019, *Gas inquiry 2017-2020 interim report June 2019*, https://www.accc.gov.au/system/files/Gas%20inquiry%20July%202019%20interim%20report.pdf, p43, accessed 12 November 2019.

v Bruce, S, Temminghoff, M, Hayward, J, Schmidt, E, Munnings, C, Palfreyman, D & Hartley, P 2018, *National hydrogen roadmap CSIRO*, p12, p20.

vi Scope 1 and scope 2 emissions only.

vii Calculation based on electrolyser efficiency of 54 kWh/kgH2 and Australian average emissions intensity of 0.75 kg CO_2 / kWh. Source for electrolyser efficiency: Bruce, S, Temminghoff, M, Hayward, J, Schmidt, E, Munnings, C, Palfreyman, D & Hartley, P 2018, *National hydrogen roadmap, CSIRO*, p79. Source for electricity emissions: Clean Energy Regulator, *Electricity sector emissions and generation data 2017–18*, http://www.cleanenergyregulator.gov.au/NGER/Pages/Published%20information/Electricity%20sector%20emissions%20and%20generation%20data/Electricity-sector-emissions-and-generation-data-2017-18-.aspx, accessed 12 November 2019.

viii CSIRO calculation based on Burgt, M.v.d. & Higman, C. 2011, *Gasification, 2nd edn*, Elsevier Science & Technology, Oxford.

ix Bruce, S, Temminghoff, M, Hayward, J, Schmidt, E, Munnings, C, Palfreyman, D & Hartley, P 2018, *National hydrogen roadmap, CSIRO*, p67

x Office of Air and Radiation, 2008, Technical support document for hydrogen production: proposed rule for mandatory reporting of greenhouse gases, US Environmental Protection Authority, viewed 12 May 2019, https://www.epa.gov/sites/production/files/2015-02/documents/sub-partp-tsd_hydrogenproduction.pdf

xi Bruce, S, Temminghoff, M, Hayward, J, Schmidt, E, Munnings, C, Palfreyman, D & Hartley, P 2018, *National hydrogen roadmap, CSIRO*, p67

AUSTRALIAN GOVERNMENT

The Australian Government supports growth of a clean, innovative, safe and competitive Australian hydrogen industry.

Priorities

Smart, consistent, light-touch regulation

The Australian Government will drive national regulatory reform to help all jurisdictions remove barriers to industry development, while keeping Australians safe and protecting the environment.

We will ensure Commonwealth laws are reviewed and reformed where necessary, to allow for the development of a strong hydrogen industry in Australia. We will ensure baselines under the Safeguard Mechanism are appropriate and provide investment certainty for new hydrogen facilities.

We support the Australian Hydrogen Council's efforts to develop and implement industry undertakings to guide the development of Australia's hydrogen industry, safeguard the community, communicate issues and engage with regulators.

Shaping international markets

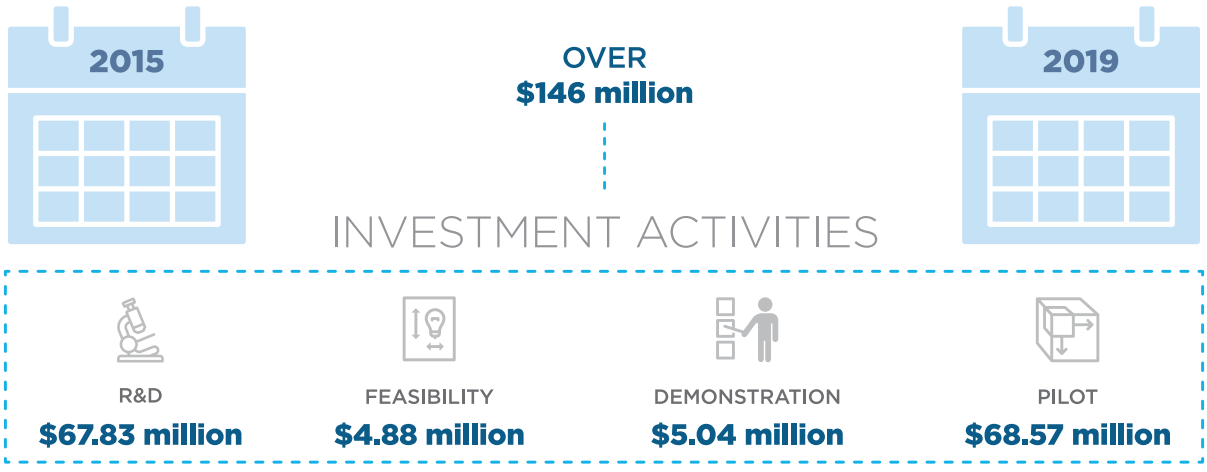
The Australian Government will establish agreements with key international markets to underpin investment. We have already signed a cooperation agreement with Japan and a letter of intent with Republic of Korea.

Australia will spearhead development of an international certification scheme for hydrogen, working closely with local and international companies. We will ensure the emerging global rules and regulations for hydrogen trade do not disadvantage Australia, by working with like-minded countries and in multi-lateral forums.

Accelerating technology commercialisation

The Australian Government supports clean energy technology, including hydrogen, from research and development through to commercialisation through the Australian Research Council, the CSIRO, the Australian Renewable Energy Agency (ARENA), the Clean Energy Finance Corporation and the Northern Australia Infrastructure Fund. Through these investments, we are building the pipeline of technologies needed to meet our Paris target and achieve emissions reductions beyond 2030.

Since 2015, the Australian Government has committed over $146 million to hydrogen projects along the supply chain.



ACTIONS

Hydrogen mission

CSIRO is developing a hydrogen mission that will bring together industry, government and other research organisations to deliver research, development and demonstration projects. The mission will de-risk and fast-track emerging hydrogen technologies and catalyse industrial demonstration of critical elements, linking Australian activities with international projects. The overall focus will be on enabling Australiaís domestic and export hydrogen industries.

Hydrogen Industry Cluster

National Energy Resources Australia (NERA) will support SMEs to take advantage of opportunities in the hydrogen industry by forming an industry-led hydrogen cluster. The Hydrogen Industry Cluster will help build capabilities and drive industry collaboration across the hydrogen value chain. This will maximise economic benefits by ensuring Australian companies are well placed to supply new technology, products and services to Australia's hydrogen industry and export markets.

International collaboration on safety

The Australian Government is a member of the U.S. Center for Hydrogen Safety. This gives all Australian governments access to some of the worldís foremost expertise in hydrogen safety.

National Hydrogen Infrastructure Assessments

The Australian Government will lead a National Hydrogen Infrastructure Assessment that will guide government and private sector investment as the industry grows.

CSIRO'S vanadium membrane technology enables ammonia to be used as a carrier material for hydrogen storage and transport – Image courtesy of CSIRO.

NEW SOUTH WALES

New South Wales (NSW) has a large and expanding renewable energy sector, natural resources, skills and research capacity, which will make it well positioned for the future development of hydrogen sector.

NSW is already home to an established hydrogen-based industry. The foundations for a significant expansion of an innovative and dynamic hydrogen sector in NSW are being put in place.

NSW is an important energy exporter with significant developed black coal resources and established international-scale ports. Newcastle and Port Kembla are potential export ports for hydrogen.

There are also local market opportunities for hydrogen producers in NSW. NSW has an established industrial base, extensive transport networks and major metropolitan and regional population centres.

NSW also has a large and skilled workforce that has proven to be adaptable to changing skill requirements and includes expertise in gas transmission and safety protocols. The 'Smart and Skilled' program can provide subsidised training packages for business to create the new skills in the workforce they need.

As well, NSW is the home of significant research and innovation capability, including in hydrogen. Over 60 hydrogen-related research and innovation projects are in train in seven of the state's universities, the CSIRO and in private industry.

Priorities

Develop the supporting infrastructure and capabilities

The New South Wales Government is aware of the high level of investor interest in its hydrogen industry and is looking to encourage the development of domestic hydrogen production capabilities for domestic or export purposes.

By working with the renewable energy and resources sectors, and an existing industrial sector that already utilises hydrogen, the New South Wales Government will assess developing the supporting infrastructure and capabilities which would eventually underpin a larger scale hydrogen sector, including an export market for North Asia and beyond.

The NSW Transmission Infrastructure Strategy is the New South Wales Government's plan to unlock private sector investment in priority transmission infrastructure projects, which can deliver least-cost energy to customers to 2040 and beyond.

Planning approval and infrastructure development

The NSW planning system provides a coordinated framework for state significant projects, including most large hydrogen projects.

The system of Special Activation Precincts (SAP) in NSW offers a mechanism that can align with the development of hydrogen hubs in regional areas. SAPs are one of the focus areas of the $4.2 billion Snowy Hydro Legacy Fund and offer fast track planning, tailored infrastructure development and government engagement to business development.

Regulatory oversight

The New South Wales Government is considering whether the regulatory environment needs updating to ensure it is compatible with the development of a safe and expanding hydrogen sector.

Support for business and R&D

There are a number of New South Wales Government programs in place that hydrogen researchers and businesses can access that are beneficial for their business and research. The Investment Concierge provides a facilitation service including coordinating other government departments, creating connections with potential partner organisations and providing the latest information on available government assistance such as the Regional Investment Attraction Package and other programs.

The Office of the NSW Chief Scientist and Engineer provides co-investment support to collaborative R&D initiatives, in particular Australian Research Council Centres of Excellence, Australian Research Council Industrial Transformation Research Program, Cooperative Research Centres-Projects, National Collaborative Research Infrastructure Strategy facilities and new innovative devices through the Physical Sciences Fund. As well, TechVouchers provide matched funding to small and medium sized enterprises for co-partnered research projects with universities or the CSIRO.

Coal Innovation NSW is also leading the NSW CO2 Storage Assessment Program to identify opportunities across the state for the safe and secure geological storage of CO_2, which could potentially be used to support fossil-fuel based hydrogen production.

JEMENA WESTERN SYDNEY GREEN GAS PROJECT

The Western Sydney Green Gas Project involves designing and constructing a Power-to-Gas facility which will convert solar and wind power into hydrogen via electrolysis.

The $15 million project, co-funded by the ARENA, will inject and store a small percentage of hydrogen (less than 2% by volume) into part of the Jemena Gas Network, Australia's largest gas distribution network. This will demonstrate how existing gas pipeline infrastructure can be used to store excess renewable energy.

The hydrogen injected into the network can be used to provide energy for up to 250 homes, and the hydrogen generated onsite can provide responsive generation to the grid via a micro-turbine as well as supply hydrogen to a future vehicle refuelling station.

Artist impression of Jemena's Western Sydney Green Gas Project – Image courtesy of Jemena .

VICTORIA

The Victorian Government is embracing the opportunities that come with the clean energy transformation, and hydrogen could play a pivotal role in this.

As the energy sector transitions, the Victorian Government is putting in place a broad range of programs and initiatives to support emerging industries and position Victoria at the forefront of the transition to clean energy.

Victoria continues to demonstrate leadership through its integration of climate and energy policy. Local governments and community groups across Victoria are already identifying opportunities for hydrogen-based projects on a local and regional level.

We have legislated a world-leading climate change framework with a commitment to net zero greenhouse gas emissions by 2050.

We have set strong renewable energy generation targets, including a goal of 50% renewable energy generation by 2030.

We are leveraging our extensive natural resources, infrastructure and skills to reduce emissions and create economic opportunities for the state, working closely with industry to encourage private investment by creating an environment for innovation and new market development.

Victoria also has a skilled workforce and leading educational institutions that are well placed to develop and deliver a clean hydrogen industry.

Priorities

Delivering the Victorian Hydrogen Investment Program

The Victorian Hydrogen Investment Program (VHIP) is supporting the development of a green hydrogen industry through market testing, policy development and a targeted investment program.

The VHIP aims to:

- build an understanding of Victorian industry capability and capacity;
- identify pathways for government, businesses, academics and the community to address barriers constraining development of a hydrogen economy;
- establish a program of support for hydrogen research, trials, pilots and demonstrations, creating a strong base of industry knowledge and skills;
- identify the best way for government to create an enabling environment; and
- align with the National Hydrogen Strategy.

A follow-up discussion paper will seek further feedback on how to effectively build a Victorian hydrogen industry.

Delivering Victoria's Zero-Emissions Vehicle Roadmap

A Zero-Emissions Vehicle Roadmap is planned for release in 2020. Key priorities include:

- identifying actions to address barriers;
- integrating planning for zero-emissions vehicles (ZEVs) with government policies for the energy system transition and energy infrastructure planning;
- identifying economic opportunities; and
- capturing the environment and health impacts of ZEVs for all Victorians.

Exploring hydrogen opportunities to decarbonise Victoria's gas networks

Victoria has the highest rate of access to the reticulated gas network and uses a significant amount of natural gas. As part of Victoria's commitment to net zero emissions by 2050, the government is exploring opportunities to decarbonise the gas network while still meeting the needs of consumers.

New energy technologies and research

The new energy technologies sector is one of the government's priority sectors for development in Victoria. The Victorian Government was a sponsor and member of the Government Advisory Group of the CSIRO National Hydrogen Roadmap and continues to support CSIRO's hydrogen work by sponsoring a forthcoming report on research, demonstration and development contributions to hydrogen technologies.

Victoria is also actively pursuing opportunities to use its brown coal resource in new ways, consistent with the Statement on Future Uses of Brown Coal. The production of hydrogen from brown coal, when coupled with CCS presents a significant opportunity and comparative advantage for Victoria. The conveniently located CarbonNet Project could enable production of clean hydrogen for domestic and export markets.

Building international partnerships and investment

Victoria has 23 trade and investment offices around the world that are focused on building international partnerships and investment. Hydrogen opportunities are being pursued as part of the overarching work program.

WORLD FIRST FULLY INTEGRATED HYDROGEN SUPPLY CHAIN

The Hydrogen Energy Supply Chain (HESC) Pilot Project is demonstrating a full supply chain starting with hydrogen production from brown coal in the Latrobe Valley and ending with its transportation to Japan.

The four year (2018–2021) HESC Pilot Project comprises multiple stages to produce and export hydrogen to Japan from the Latrobe Valley, using established and scientifically proven technologies. The Pilot Project is the world's largest hydrogen demonstration project and includes the transportation of liquified hydrogen in a world-first, purpose-built liquified hydrogen carrier.

The Pilot Project is delivered by a consortium of reputable companies with expertise across the entire hydrogen supply chain – Kawasaki Heavy Industries, Ltd (KHI), Electric Power Development Co., Ltd (J-Power), Iwatani Corporation, Marubeni Corporation, Sumitomo Corporation and AGL. The Pilot Project is also supported by the Japanese, Australian and Victorian governments.

This project is also underpinned by the Japanese Government's desire to decarbonise the Japanese economy and build a hydrogen society.

A commercial hydrogen supply chain from Victoria to Japan would be in operation by the 2030s. Any commercial HESC project is dependent on a successful pilot, and a commercial decision by the project consortium.

A commercial HESC requires a low-CO_2 hydrogen energy supply chain. A carbon sequestration solution, such as the CarbonNet project, could provide this service for commercial HESC operations in the 2030s. The Australian and Victorian governments have together invested $150 million in the development of the CarbonNet project in the Gippsland Basin, and its commercialisation timelines are expected to align with those of the HESC.

The HESC project provides Victoria with the opportunity to be at the forefront of the developing hydrogen industry in Australia, accelerating research and development collaborations, helping to build the necessary skills and expertise and large-scale infrastructure required to support the emergence of a hydrogen industry at a scale that enables both domestic supply and international exports.

Image courtesy of HySTRA.

QUEENSLAND

Queensland is well placed for renewable hydrogen production with significant renewable energy resources and existing and planned renewable energy projects.

In addition to domestic uses, Queensland has the potential to become a global player in the production and export of hydrogen, helping to meet the world's growing demand for renewable energy.

The Queensland Hydrogen Industry Strategy 2019–2024 (Queensland Hydrogen Strategy) sets a vision that 'by 2030, Queensland is at the forefront of renewable hydrogen production in Australia, supplying an established domestic market and export partners with a safe, sustainable and reliable supply of hydrogen.'

Priorities

Implement the Queensland Hydrogen Strategy

The Queensland Hydrogen Strategy includes the $15 million Hydrogen Industry Development Fund, providing funding for investors developing hydrogen projects in Queensland. The strategy focuses on five areas:

- supporting innovation
- facilitating private sector investment
- ensuring an effective policy framework
- building community awareness and confidence
- facilitating skills development for new technology.

International technology exchange, attracting investment and creating new export markets

In addition to domestic opportunities for renewable hydrogen, priorities include: attracting investment, collaborative research and development, and creating new export markets through our international partnerships. In 2019, Queensland signed a Memorandum of Understanding with the Japan Oil, Gas and Metals National Corporation (JOGMEC) to cooperate on hydrogen and a Statement of Intent with the University of Tokyo's Research Center for Advanced Science and Technology (RCAST). Professor Masakazu Sugiyama from the University of Tokyo, a leading expert in renewable energy and hydrogen technologies, was also announced as Queensland's Hydrogen Envoy in Japan.

Planning and development framework for large scale industrial development

Queensland has an established and well-coordinated planning and development framework. Dedicated State Development Areas for large scale industrial development are located throughout the State. The independent Coordinator-General administers land within the State Development Areas, and has extensive powers to assist with the coordination and streamlining of the assessment of large industrial projects across the State. The State is working with a large number of private sector proponents to support the delivery of their renewable hydrogen projects.

Supporting innovation and hydrogen research

The Queensland Government's Redlands Research Facility will establish the Hydrogen Process Research and Development Project. The project will use existing solar array technologies to experiment and undertake integrated modelling of a hybrid renewable energy process that utilises solar power, energy storage and non-potable water to produce, store, and use hydrogen. With funding in excess of $8 million from the Queensland Government, ARENA, national and international research partners and industry, the facility will be an important platform. It will optimise the integration of components in a hybrid renewable energy system to model system performance for translation to megawatt scale implementation.

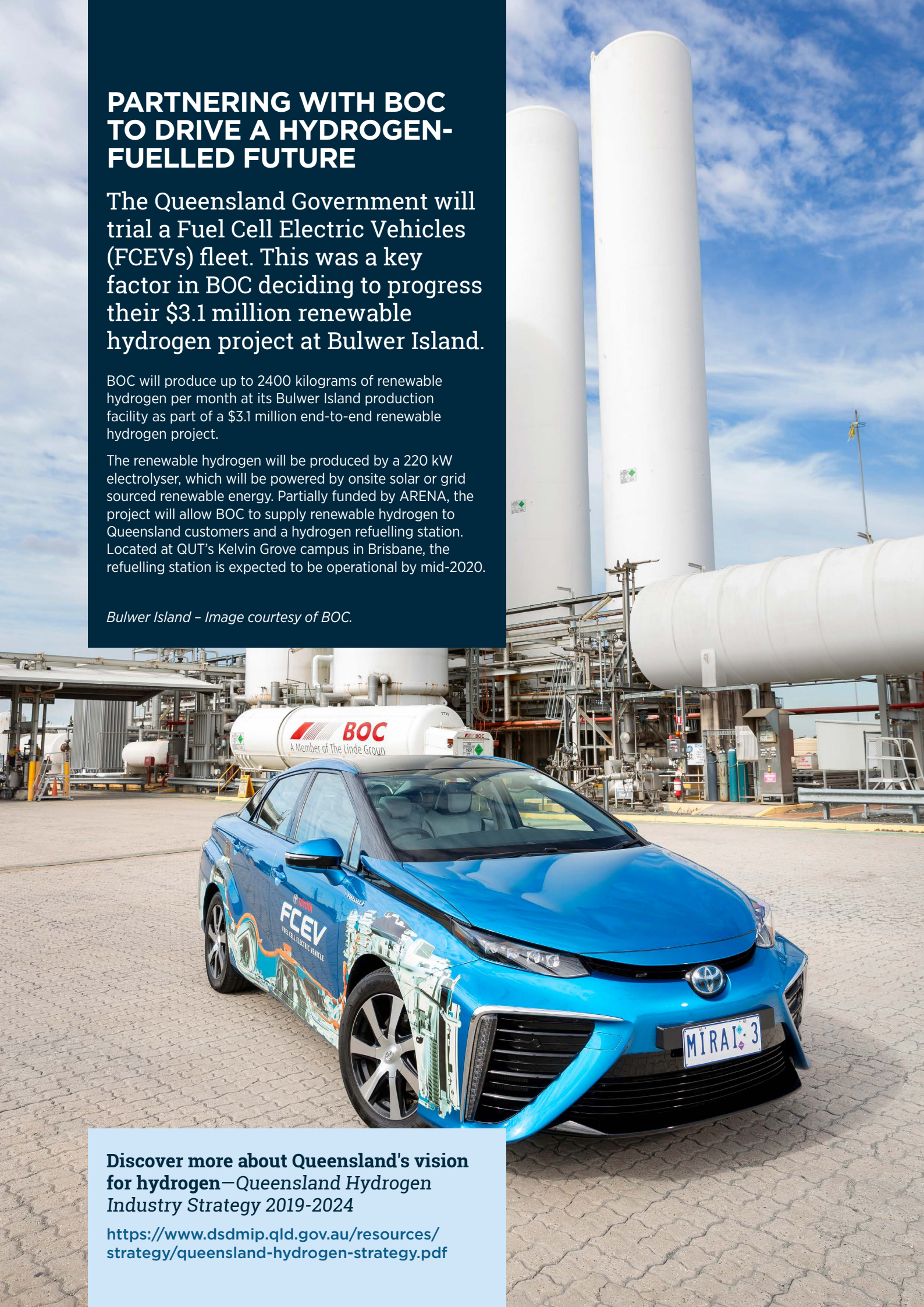
PARTNERING WITH BOC TO DRIVE A HYDROGEN-FUELLED FUTURE

The Queensland Government will trial a Fuel Cell Electric Vehicles (FCEVs) fleet. This was a key factor in BOC deciding to progress their $3.1 million renewable hydrogen project at Bulwer Island.

BOC will produce up to 2400 kilograms of renewable hydrogen per month at its Bulwer Island production facility as part of a $3.1 million end-to-end renewable hydrogen project.

The renewable hydrogen will be produced by a 220 kW electrolyser, which will be powered by onsite solar or grid sourced renewable energy. Partially funded by ARENA, the project will allow BOC to supply renewable hydrogen to Queensland customers and a hydrogen refuelling station. Located at QUT's Kelvin Grove campus in Brisbane, the refuelling station is expected to be operational by mid-2020.

Bulwer Island – Image courtesy of BOC.



Discover more about Queensland's vision for hydrogen—*Queensland Hydrogen Industry Strategy 2019-2024*

https://www.dsdmip.qld.gov.au/resources/strategy/queensland-hydrogen-strategy.pdf

WESTERN AUSTRALIA

Western Australia's world-class renewable energy resources, established energy production and export industry, and proximity to key international markets make it well placed to produce, use and export renewable hydrogen for economic and environmental benefit.

Western Australia has a strong foundation for a renewable hydrogen industry including:

1. **High-intensity renewable energy resources** – including among the highest solar irradiance in the world and, due to being on the western edge of the continent, excellent wind resources.
2. **Land** – with an area of 2.5 million km^2 (one-third the Australian continent), low-intensity land use, and low population density, Western Australia is an ideal location to develop large-scale renewable energy generation.
3. **Infrastructure** – world-class industrial and export infrastructure that can accommodate a hydrogen industry.
4. **Skilled workforce** – Western Australia has a technically skilled workforce, expertise across the energy sector and relevant research capabilities.
5. **Established LNG industry with strong international partnerships** – many of the world's largest oil and gas companies have a local presence in Western Australia and are looking at transitioning to a hydrogen future.
6. **Access to international markets** – Western Australia is Australia's western gateway to Asia and has a long term partnership with Asian economies, in particular in the energy sector.

Priorities

Western Australia will develop industry and markets to be a major exporter of renewable hydrogen. To facilitate the export of hydrogen, Western Australia will develop domestic production capabilities and applications of renewable hydrogen, improving the State's hydrogen industry expertise, contributing to global decarbonisation and decarbonising the State's economy.

Western Australian Renewable Hydrogen Strategy

Released in July 2019, the Western Australian Renewable Hydrogen Strategy details the vision, goals and implementation pathways required for Western Australia to be a significant producer, exporter and user of renewable hydrogen.

Strategic Focus Areas

- export
- remote applications
- blending in the gas network
- transport

The role that renewable hydrogen could play in other areas such as stabilising the electricity network and in decarbonising industry is also acknowledged.

Partnerships

The Western Australian Government will actively support industry efforts to accelerate the development of the renewable hydrogen industry in Western Australia. Government actions and investment in partnerships, seed funding and fit-for-purpose regulatory support as well as efficient approval processes will assist the industry to overcome its economic, regulatory and technical challenges.

Investment

The Renewable Hydrogen Fund aims to facilitate private sector investment and other avenues for financial support to the renewable hydrogen industry. The Fund provides financial support for feasibility studies and capital works projects.

Regulations

The Western Australian Government will continue to work closely with the Australian Government and relevant bodies to support regulatory reform that will enable the growth of the renewable hydrogen industry while ensuring strong safety and consumer protections.

Collaborations

The Western Australian Government will continue to strengthen international partnerships, identify opportunities and secure technology partnerships with a focus on Asia and Europe.

ATCO CLEAN ENERGY INNOVATION HUB

ATCO's industry leading Clean Energy Innovation Hub (CEIH) is a test bed for solar photovoltaics, battery storage, hydrogen production and use as well as hydrogen blending with natural gas infrastructure.

This $3.53 million project is located at ATCO's operations and training facility in Jandakot. Supported with $1.66 million in Australian Renewable Energy Agency funding it was opened in July 2019.

The CEIH incorporates the production, storage and use of hydrogen produced by solar powered water electrolysis. The hydrogen is injected into a demonstration gas network and is also being tested in a fuel cell generating electricity as well as a direct and blended combustion fuel for domestic appliances.

The trial is addressing several safety and technical challenges including optimising hydrogen storage and gas distribution network requirements for blending hydrogen with natural gas.

The solar photovoltaic array is 300 kW and the site also has a 400 kWh battery bank. When the battery is full and the site is consuming less than the solar output, the excess solar is used to produce hydrogen. This approach sets this project apart from other hydrogen trials currently underway in Australia.

Compressed hydrogen storage tank and gas blending pipes at ATCO's Clean Energy Innovation Hub in Jandakot – Image courtesy of ATCO.

Discover more about Western Australia's vision for hydrogen—*Western Australia Renewable Hydrogen Strategy*

http://www.drd.wa.gov.au/Publications/Documents/wa_renewable_hydrogen_strategy.pdf

SOUTH AUSTRALIA

South Australia is committed to leveraging its wind, sun, land, infrastructure and skills through effective collaboration between government and industry to become a world-class renewable hydrogen exporter.

The Government of South Australia was the first jurisdiction to publish a hydrogen strategy, in 2017, and to date has committed more than $40 million in grants and loans to the development of hydrogen projects.

Building on this investment, the government released South Australia's Hydrogen Action Plan in 2019, setting out the next steps for the development of the state's hydrogen industry.

The opportunity

South Australia is Australia's leading mainland state for renewable energy penetration. The state is almost 1 million square kilometres, with expansive areas available for co-located wind and solar energy generation projects, which can be used to create renewable green hydrogen.

The Government of South Australia is investor-focused, working to showcase investment opportunity while creating an effective, transparent regulatory environment that provides certainty and advocates for internationally harmonised codes and standards.

Working in collaboration with the leading international regulation, codes, and safety standards organisations, including the International Association for Hydrogen Safety and the Centre for Hydrogen Safety, the state government is developing consistent training material, guidelines and procedures involving the production, handling, transportation and use of hydrogen.

The Government of South Australia is working proactively with the community and industry to increase knowledge and support for a growing hydrogen industry.

To support investor decision making, the South Australian Government has an Interactive Hydrogen Map and is developing a Hydrogen Export Modelling Tool.

Priorities

Implement South Australia's Hydrogen Action Plan

Launched at the International Conference on Hydrogen Safety hosted in Adelaide in September 2019 the Action Plan will help underpin a safe and secure export sector as well as accelerate hydrogen into the South Australian domestic economy. Twenty actions across five key areas intend to achieve its objective of scaling-up renewable hydrogen production for export and domestic consumption:

1. Facilitate investments in hydrogen infrastructure
2. Establish a world class regulatory framework
3. Deepen trade relationships and supply capabilities
4. Foster innovation and workforce skills development
5. Integrate hydrogen into our energy system

Develop South Australia's Hydrogen Export Modelling Tool

A key commitment of South Australia's Hydrogen Action Plan is the development of a South Australian Hydrogen Export Modelling Tool to inform the establishment of renewable hydrogen export supply chains.

The Government of South Australia is engaged with hydrogen consortia, international customers, infrastructure developers and investors to address the key strategic questions about hydrogen exported from South Australia.

Examples of areas the prospectus will consider are:

1. South Australian locations suited to large-scale hydrogen production and export facilities (land, renewable electricity and water availability, infrastructure)
2. Timeframes and estimated capital cost associated with development of renewable hydrogen production and export facilities
3. Estimated production volumes and cost per kilogram from those South Australian locations

Key findings will be summarised as a modelling tool and detailed prospectus to be made available in 2020.

COORDINATED REGULATORY APPROACH FOR HYDROGEN PROJECTS

South Australia's regulatory expertise, close collaboration with the national and international hydrogen communities and our focus on safety, is developing a world-leading hydrogen regulatory regime designed to meet the needs of investors and the community.

As one of the top regulatory regimes in the world for tight and shale gas, South Australia has a proven record of providing effective, transparent regulatory frameworks that facilitate economic growth.

Working in close collaboration with our international and national colleagues, we are advocating for best practice and harmonised codes and standards, making it simpler and more efficient for investors working across multiple jurisdictions and delivering consumer benefits.

Our Hydrogen Regulatory Working Group is currently supporting three megawatt-scale projects the South Australian Government has co-invested in with over $40 million in grants and loans:

1. **Hydrogen Park South Australia** - Australian Gas Networks
2. **Renewable hydrogen and green ammonia supply chain demonstrator** - The Hydrogen Utility™ (H2U)
3. **Hydrogen Superhub** - Neoen Australia

These projects will generate learnings for industry and regulators, grow community awareness and understanding and develop workforce skills.

The South Australian Government is continuing to maintain and further develop its strong international hydrogen network, and working with other internationally respected organisations in the research and development of hydrogen technologies and its safe use, as part of our ambition to reach net 100% renewables in the 2030's.

Waterloo Wind Farm, South Australia – Image courtesy of Milton Wordley.

Discover more about South Australia's vision for hydrogen—*South Australia's Hydrogen Action Plan*

http://www.hydrogen.sa.gov.au

TASMANIA

Tasmania is uniquely placed to develop a competitive large-scale renewable hydrogen industry using its abundant existing and expandable world-class renewable wind energy firmed by hydro power, abundant fresh water, and access to industrial zones with high quality infrastructure.

The Tasmanian Government's vision is for Tasmania to use its abundant renewable energy resources to be a significant supplier of renewable hydrogen to meet emerging export and domestic demand.

Tasmania's key attributes include:

- Highly cost-competitive and reliable hydro and wind generation, reflecting the world-class nature of Tasmania's renewable energy resources, with close to three gigawatts of installed renewable energy capacity.
- A very high renewable energy contribution, with Tasmania on track to meet its target to be self-sufficient in renewables by 2022, making it the first state or territory in Australia with 100% renewable power generation. This is almost unique globally, and provides Tasmania with the capacity to develop a large-scale renewable hydrogen industry now.
- Feasible and abundant further renewable energy development potential, including approximately eight gigawatts of wind and multiple gigawatts of pumped hydro identified through the Battery of the Nation initiative, which could support hydrogen production on a multi-gigawatt scale over the longer term.
- The combination of predominately wind power and capacity firming hydro power (and proposed future pumped hydro schemes) that can provide a high electrolyser utilisation, compared to regions which have wind and solar generation, but limited firming of variable renewable generation.
- Access to a highly skilled and innovative workforce, supporting Tasmania's renewable energy and major industries, and world-class educational and research institutions. This includes the Blue Economy Cooperative Research Centre which is investigating renewable hydrogen production and use in Australia's marine environments.

Priorities

Facilitate the development of a hydrogen industry

The Tasmanian Office of the Coordinator General is actively working with a range of proponents to facilitate investment in renewable hydrogen production for both domestic use and export, with a focus on developing the Bell Bay Advanced Manufacturing Zone as a hydrogen hub. The Tasmanian Government will work with proponents to assist in navigating the State regulatory and planning approval processes, with a key focus on timely assistance that puts community safety and social acceptance at the forefront.

Utilise Tasmania's renewable energy for hydrogen production

Over the past 100 years Tasmania has built its economy around renewable energy developments, through Government-owned hydro power and network assets, with the existing power system supporting a range of energy intensive major industries across the State.

The high capacity factors of Tasmanian renewable generation, together with the firming capability of hydro power, allows for high utilisation of Tasmanian renewable hydrogen production, ultimately improving its economic competitiveness. In addition to renewable energy, Tasmania has an abundance of available fresh water that could be used for large-scale renewable hydrogen production.

Facilitate the development of an export based industry

The potential scale and competitiveness of Tasmanian renewable hydrogen production, in industrial precincts with existing and adaptable deep-water ports, makes Tasmania ideally suited to be a significant exporter of renewable hydrogen to supply emerging global demand.

Identify opportunities for domestic hydrogen demand

While supporting the development of a hydrogen export sector is a strategic priority for the Tasmanian Government, the creation of a domestic market for hydrogen in parallel is recognised to be equally important.

Tasmania is well placed to integrate renewable hydrogen into a range of domestic end-uses, including; blending of hydrogen into the existing hydrogen-compatible natural gas network, as a carbon-neutral feedstock in Tasmanian industries, and using hydrogen to support; fuel cell electric vehicles (e.g. light vehicles, buses and trucks), marine applications (e.g. passenger ferries), and remote power supplies (e.g. Bass Strait island power stations).

BELL BAY ADVANCED MANUFACTURING ZONE – AN IDEAL HYDROGEN HUB

The Bell Bay Advanced Manufacturing Zone (the 'Zone') is Tasmania's premier major industrial-zoned precinct that has available land and is ideally suited to large-scale renewable hydrogen industry development for export and for domestic applications.

The Zone has a suite of existing infrastructure well-suited to renewable hydrogen production, including access to high voltage transmission assets, and fresh water. In addition, there is good access to the Zone by rail, road, air and sea links, with close proximity to an adjacent deep-water port which handles domestic and international bulk goods, and could be adapted for hydrogen exports.

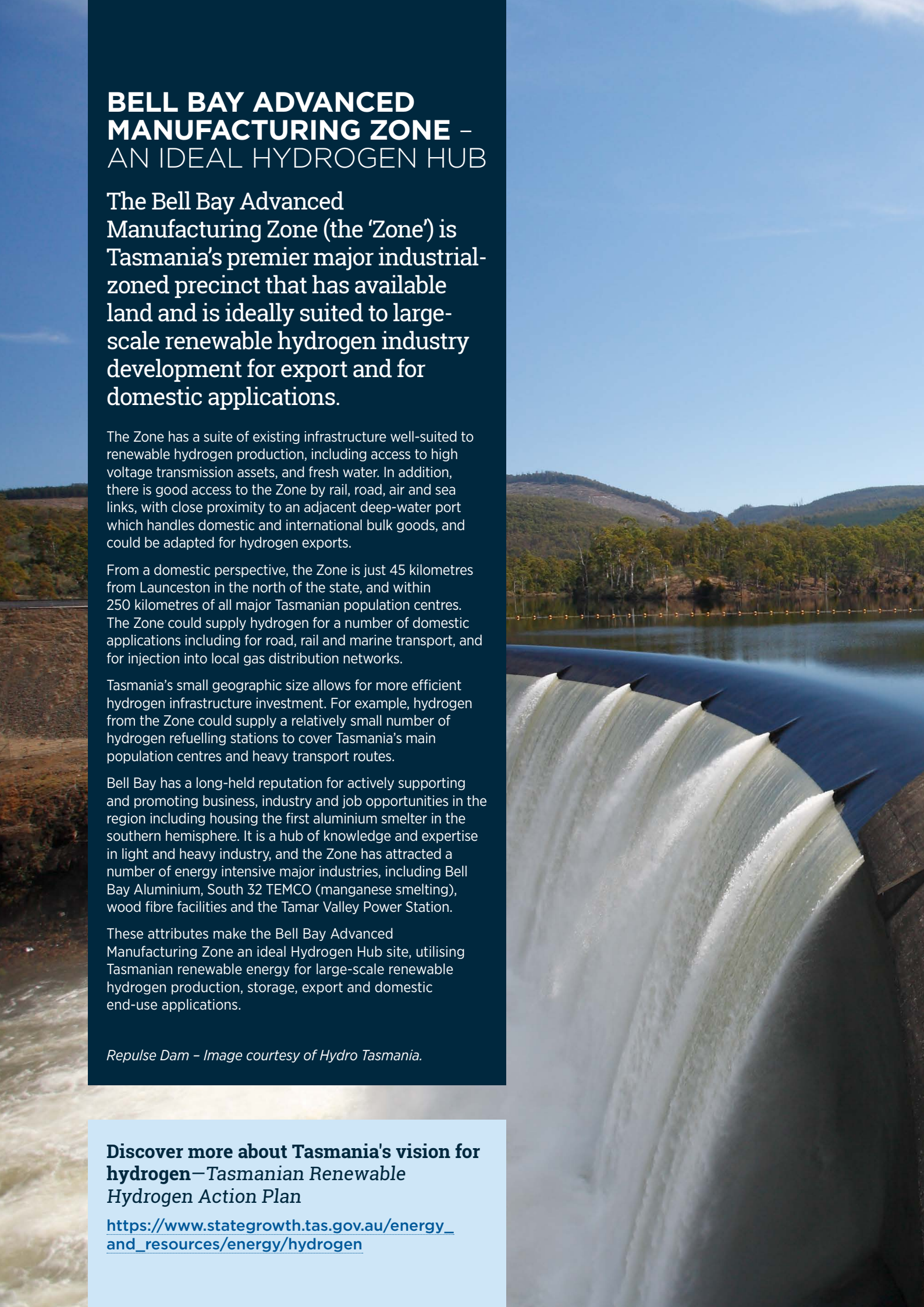
From a domestic perspective, the Zone is just 45 kilometres from Launceston in the north of the state, and within 250 kilometres of all major Tasmanian population centres. The Zone could supply hydrogen for a number of domestic applications including for road, rail and marine transport, and for injection into local gas distribution networks.

Tasmania's small geographic size allows for more efficient hydrogen infrastructure investment. For example, hydrogen from the Zone could supply a relatively small number of hydrogen refuelling stations to cover Tasmania's main population centres and heavy transport routes.

Bell Bay has a long-held reputation for actively supporting and promoting business, industry and job opportunities in the region including housing the first aluminium smelter in the southern hemisphere. It is a hub of knowledge and expertise in light and heavy industry, and the Zone has attracted a number of energy intensive major industries, including Bell Bay Aluminium, South 32 TEMCO (manganese smelting), wood fibre facilities and the Tamar Valley Power Station.

These attributes make the Bell Bay Advanced Manufacturing Zone an ideal Hydrogen Hub site, utilising Tasmanian renewable energy for large-scale renewable hydrogen production, storage, export and domestic end-use applications.

Repulse Dam – Image courtesy of Hydro Tasmania.



Discover more about Tasmania's vision for hydrogen—*Tasmanian Renewable Hydrogen Action Plan*

https://www.stategrowth.tas.gov.au/energy_and_resources/energy/hydrogen

NORTHERN TERRITORY

The Northern Territory's vision is to produce renewable hydrogen to strengthen and diversify the Territory economy and to expand into new energy export markets.

The Northern Territory is in an ideal position to develop a renewable hydrogen industry and is already a key energy exporter to Asia. With one of the best solar resources in the world, expertise, and existing energy export infrastructure, the Northern Territory has the capacity to not only integrate renewable hydrogen across the Territory's economy, but also to export to domestic and international markets.

Priorities

New energy export markets

The Northern Territory is seeking investment and collaborative partnerships to develop projects that are aligned with our strategic areas of focus. Strategic focus areas include:

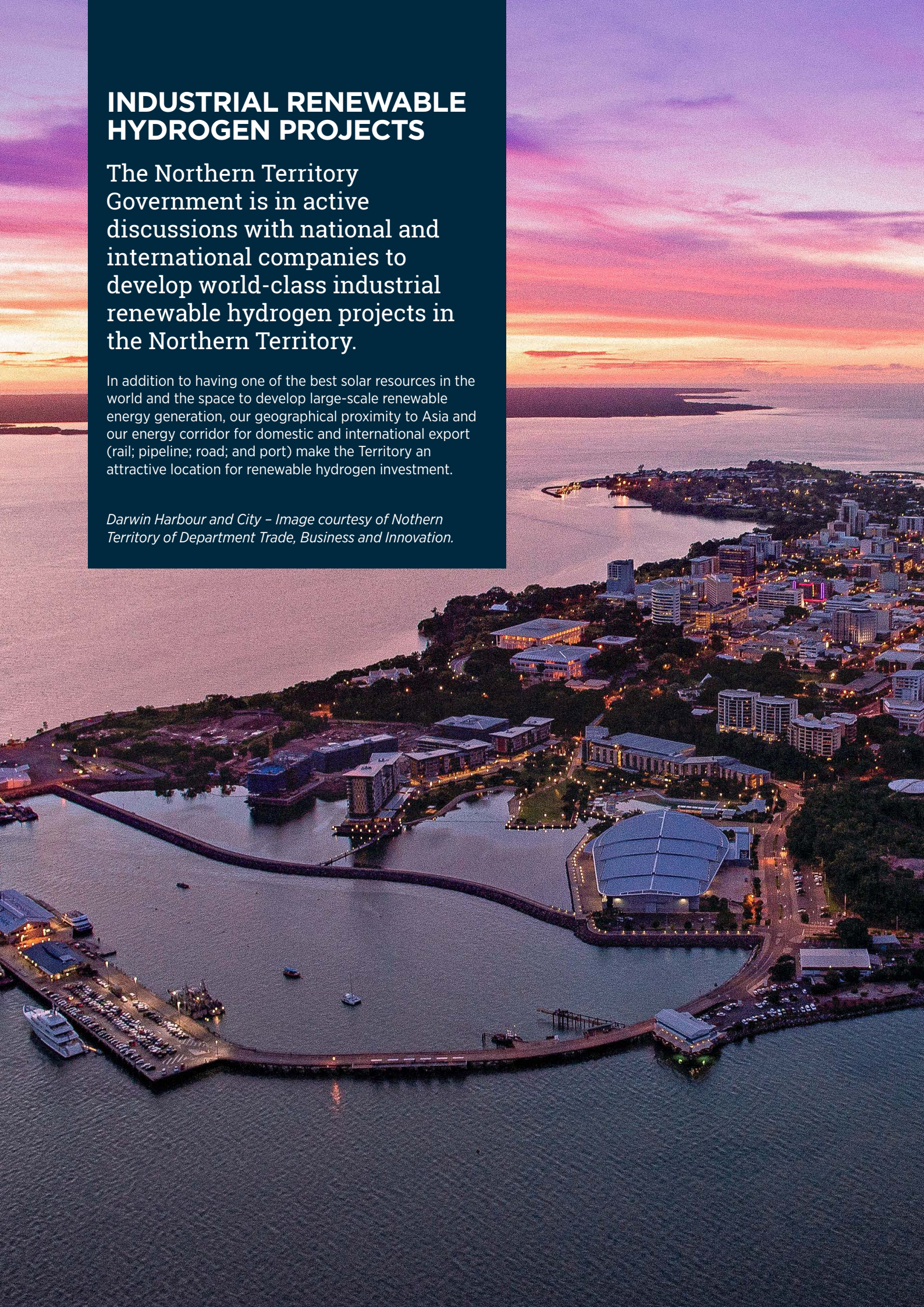
- exports
- enhancing renewable energy access and energy security in remote areas
- blending of hydrogen to provide low-carbon gas
- green ammonia production
- combined desalination and solar electrolysis systems.

In addition to participating in the National Hydrogen Strategy through COAG and developing the renewable hydrogen strategy, the Northern Territory Government has a 50% Renewable Energy Target by 2030 that serves to complement the development of a renewable hydrogen industry.

INDUSTRIAL RENEWABLE HYDROGEN PROJECTS

The Northern Territory Government is in active discussions with national and international companies to develop world-class industrial renewable hydrogen projects in the Northern Territory.

In addition to having one of the best solar resources in the world and the space to develop large-scale renewable energy generation, our geographical proximity to Asia and our energy corridor for domestic and international export (rail; pipeline; road; and port) make the Territory an attractive location for renewable hydrogen investment.



Darwin Harbour and City – Image courtesy of Nothern Territory of Department Trade, Business and Innovation.

AUSTRALIAN CAPITAL TERRITORY

The Australian Capital Territory (ACT) is an internationally recognised centre for renewable energy research and innovation and continues to deliver world-leading policies and programs.

This is demonstrated by the Territory's legislated 100% renewable electricity by 2020 target, its legislated net zero emissions by 2045 target, and renewable energy research investment.

The ACT offers an excellent test environment for demonstrating hydrogen technologies and is leading Australia in several hydrogen R&D trials across a wide spectrum, including hydrogen production (electrolysis), vehicle refuelling and vehicle use, blending hydrogen in gas networks, and regulatory reform.

The ACT's legislated 100% renewable electricity by 2020 target will attract over $2 billion investment in large-scale renewables over the 20-year life of existing contracts and has demonstrated the ACT's national and international leadership as a renewable energy and climate action capital.

Priorities

Net Zero Emissions Territory

The ACT Climate Change Strategy 2019–2025 sets out the next steps in how the ACT Government will work with the community to respond to climate change and achieve net zero emissions by 2045.

When the ACT achieves 100% renewable electricity in 2020, natural gas and transport will become the largest remaining contributors to the Territory's greenhouse gas emissions. In response to this, the Government will:

- develop a plan for achieving net zero emissions from natural gas use by 2045
- facilitate the transition to zero emissions vehicles, including by transitioning to a zero emissions bus fleet by 2040.

As a result, the ACT is actively looking at innovative research and development solutions to support this transition, including renewable hydrogen.

Research and development capital

The ACT Government fosters R&D opportunities and collaboration between Canberra's world class education and research institutions.

The Australian National University has a broad portfolio of hydrogen research spanning across the hydrogen value chain, including technological expertise in hydrogen production, transportation and storage, as well as social license issues, governance, and economics to address prerequisites and underpinnings of an Australian hydrogen economy.

The ACT gas network operator Evoenergy has established Australia's first 100% hydrogen test site at the Canberra Institute of Technology. The facility aims to test 100% hydrogen on existing materials, equipment and work practises. The facility will be used to train and equip tradespeople with skills well into the future.

Renewable Energy Innovation Fund

The ACT Government will seek to recapitalise its Renewable Energy Innovation Fund and make further investments in ACT energy industry development, following the completion of the next renewable electricity auction.

HYDROGEN FOR TRANSPORT PILOT

The first public hydrogen refuelling station in Australia will be built in Canberra and is on track to be operational in early 2020.

The ACT Government has partnered with Neoen, Hyundai and ActewAGL on a hydrogen mobility demonstration project, which includes refuelling infrastructure and the integration of 20 hydrogen fuel cell vehicles into the ACT Government fleet. The construction of the station and provision of vehicles are being funded by industry, at no cost to the ACT Budget, as a project funded from the ACT's renewable electricity reverse auction.

This project will allow Canberra-based industry and researchers to gain valuable firsthand knowledge of hydrogen refuelling operating models, transport supply chains, and consumer refuelling patterns.

The ACT Government offers stamp duty exemption for new zero emissions vehicles, including hydrogen fuel cell vehicles, and offers a 20% discount on registration fees for zero emissions vehicles.

Image courtesy of ActewAGL.

1 AUSTRALIA'S CLEAN HYDROGEN POTENTIAL

A global transformation of the energy sector is underway. To support a future where all our energy comes from clean sources, the world needs clean, flexible, storable and safe fuels. Hydrogen has all of these characteristics. When used as a fuel, it produces no carbon emissions, only water. It can be safely used in a broad range of applications.

Australia is well-placed to make hydrogen its next big export. We have all the natural resources needed to produce it, a track record in building large-scale energy industries and a reputation as a proven partner to Asia's biggest energy importers.

An Australian hydrogen industry could generate thousands of jobs, many of them in regional areas. It could add billions of dollars to GDP over coming decades. Managed well, it could help us to reliably integrate extensive renewable generation into the electricity grid. Using hydrogen, we can reduce dependence on imported fuels. And we can reduce carbon emissions, in Australia and around the world.

The National Hydrogen Strategy aims to lay the foundation for Australia to capture the hydrogen opportunity and become a leading player in a growing global market.

GLOBAL ENERGY IS CHANGING

Energy markets across the globe are undergoing substantial change, driven by the need to reduce carbon emissions while meeting growing demand for energy.

The falling cost of new energy technologies is aiding the change. The result will transform the ways energy is produced and used.

We are already seeing unprecedented growth in low-emissions electricity generation. However, in other energy-consuming sectors, such as heavy transport, heavy industry and providing heat, the journey to clean energy is less advanced. Decarbonising these sectors is an urgent challenge.

A FUEL FOR THE 21ST CENTURY

Hydrogen is a flexible, safe, transportable and storable fuel. It can be used to power vehicles and generate heat and electricity. It is a key ingredient for producing chemicals such as ammonia and methanol.

When used as a fuel, hydrogen's only by-product is water. There are no carbon emissions. But whether hydrogen is truly a zero or low-emissions fuel depends on how it is produced. Pure hydrogen is not found naturally on Earth. It must be extracted from the substances that contain it – water mainly, but also coal, natural gas and biomass – and this takes energy. Because of this, hydrogen is better thought of as an energy carrier than an energy source.

Producing clean hydrogen

Hydrogen can be produced from water in three main ways. One way is through a process known as electrolysis, which extracts hydrogen from water using electricity. If renewable electricity is used, this process produces no carbon emissions. We can call this clean 'renewable hydrogen'. The other two ways are through thermochemical reactions, using coal (in a process known as gasification) or natural gas (in a process known as steam methane reforming). These latter two techniques are how most hydrogen is now produced. Using fossil fuels means there are carbon emissions, but if these emissions can be captured at a high level and permanently stored, clean 'CCS hydrogen' can be produced.

Figure 1.1 demonstrates the three main pathways to produce clean hydrogen. Hydrogen is versatile and can be used in a broad range of applications, as shown in Figure 1.2.

Figure 1.1 Production pathways for clean hydrogen

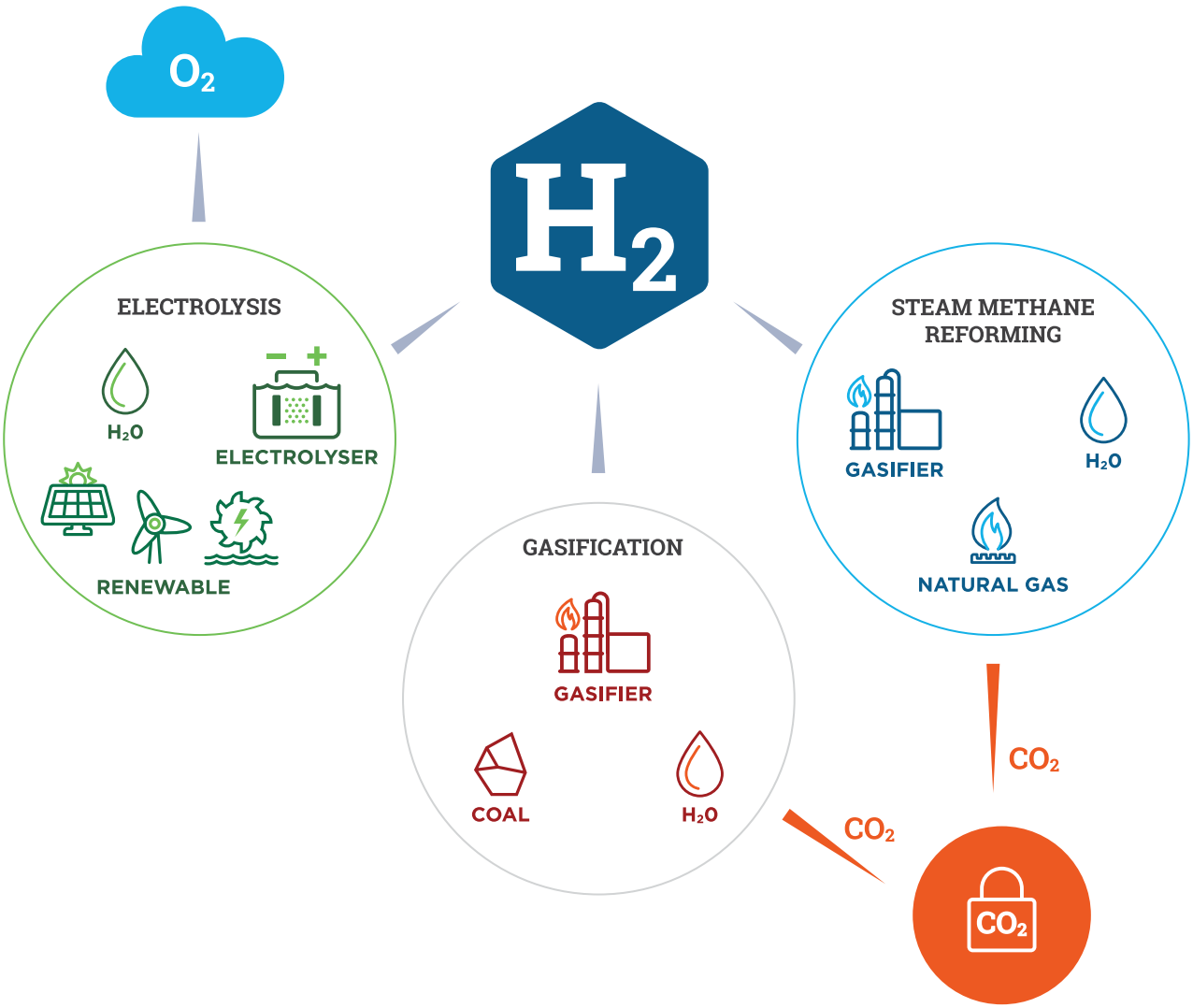
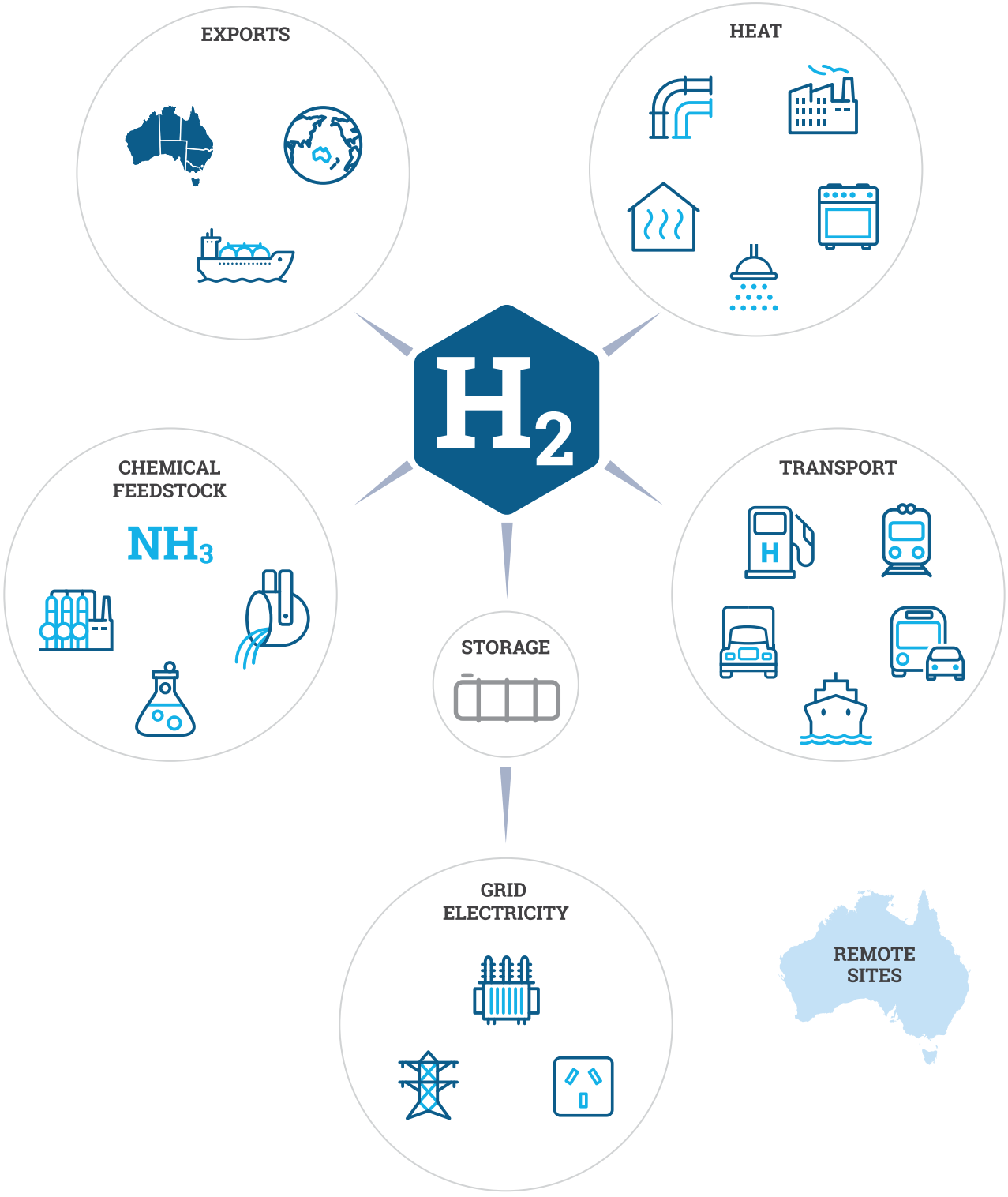


Figure 1.2 Potential uses of Australian hydrogen



Using hydrogen

Hydrogen can be used, like natural gas, to heat homes and industry, and for cooking. Delivery of hydrogen for these uses would most likely be via new or existing gas networks. Hydrogen can also be blended with natural gas for heating and cooking.

Hydrogen can power fuel cell electric cars, trucks, buses and trains. The advantages of hydrogen powered vehicles compared to battery electric vehicles are faster refuelling times and the ability to travel longer distances carrying larger loads before refuelling. Refuelling hydrogen vehicles requires a network of refuelling stations, similar to what exists for petrol and diesel.

Hydrogen can also be used to generate electricity (through fuel cells or being burned to drive turbines). If made when there is surplus or cheap electricity available, hydrogen can be stored and then used to produce electricity when there is insufficient electricity available from other sources. Hydrogen can also be used in combination with renewable electricity to power remote sites like mines and small regional communities.

Finally, hydrogen can be exported, either as an energy carrier or for use as a chemical feedstock – hydrogen's most common use today is as a chemical ingredient.

The world already safely uses hydrogen

Globally, hydrogen makers now produce about 70 million tonnes of hydrogen per year.[1] A further 48 million tonnes is produced as a by-product of other industrial processes. The large majority of all hydrogen produced comes from fossil fuels without carbon capture and storage. Renewable electricity is used to produce less than 0.3%.[1]

Hydrogen is used for refining petrochemicals and making ammonia (which in turn is used mostly to make fertilisers). It is used in smaller volumes to make chemicals and metals, and in the electronics and glass making industries. Though demand for it as an energy carrier is still small, there is growing interest in its use for such things as fuel cell vehicles.

The safety expertise, standards and regulations that industries have developed over decades of large-scale hydrogen use provide a solid platform on which to prepare for more widespread hydrogen use. Developing protections for the safe use of hydrogen are discussed in **Chapter 5**.

GLOBAL MOMENTUM FOR CLEAN HYDROGEN

Three of Australia's top four trading partners – Japan, the Republic of Korea and China – have already made clear commitments to use clean hydrogen to decarbonise their energy systems.

Clean hydrogen is also gaining interest in Europe, especially in transport applications such as trains and light vehicles. The United States is seeing similar growth.

Globally, industries such as shipping, steel making and chemical production see hydrogen as a long-term alternative to their dependence on fossil fuels.

Interest has been bolstered by the falling costs to produce and use hydrogen. Over the past decade, for example, the cost of generating electricity from wind has fallen by about 70%, and from solar PV by about 80%. The cost to make a hydrogen fuel cell, meanwhile, has fallen by about 60% since 2006.[2] With foreseeable technology improvements and higher manufacturing volume, it is anticipated that the cost of fuel cells might fall by about another 30% by 2025.[2] The cost of storing hydrogen will also become cheaper with scale, technology and efficiency improvements – by up to 40% as ammonia and up to 80% as liquid hydrogen.[3]

As costs fall, clean hydrogen will become increasingly competitive. When and where this occurs will also depend on factors such as the cost of alternatives. This will vary across different uses of hydrogen. In certain sectors, notably transport and industrial uses, the cost gap with other fuels is narrow and competitiveness in Australia appears likely within a decade, as shown in Figure 1.3.[4]

Figure 1.3 Breakeven cost of hydrogen against alternative technology for major applications, in 2030.

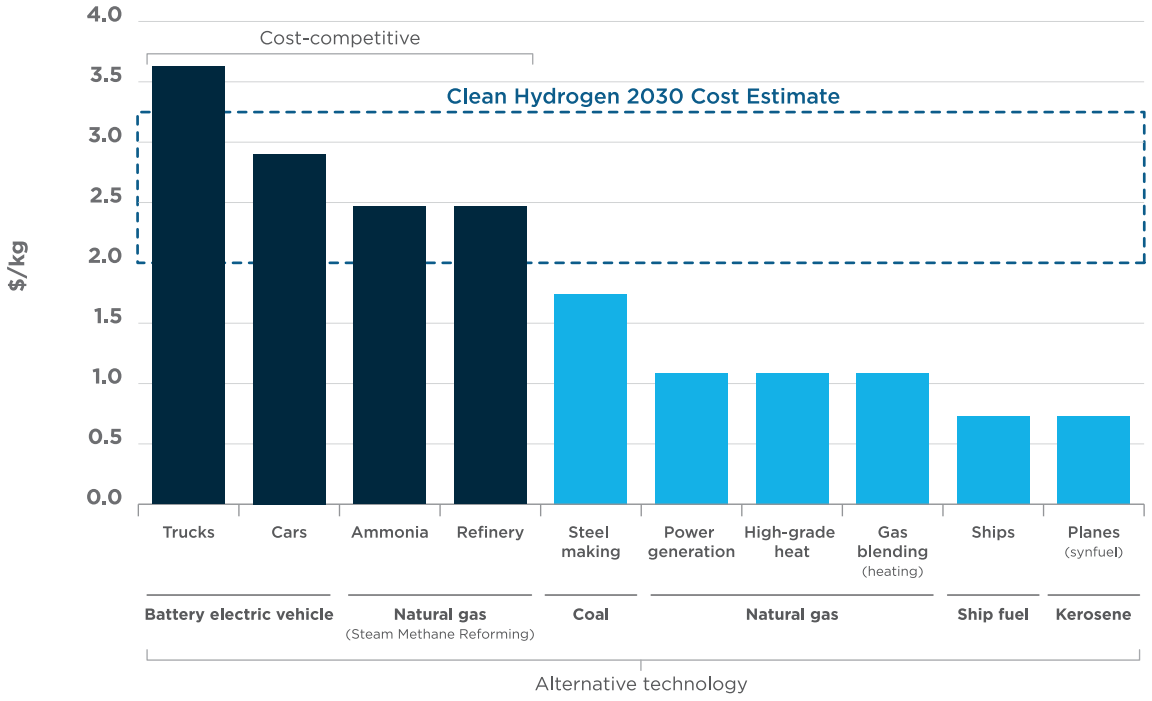


Chart is illustrative, as the exact breakeven point will be region-specific, and will be different when comparing to other alternatives (such as petrol or diesel).[6]

Global strategies support hydrogen's future

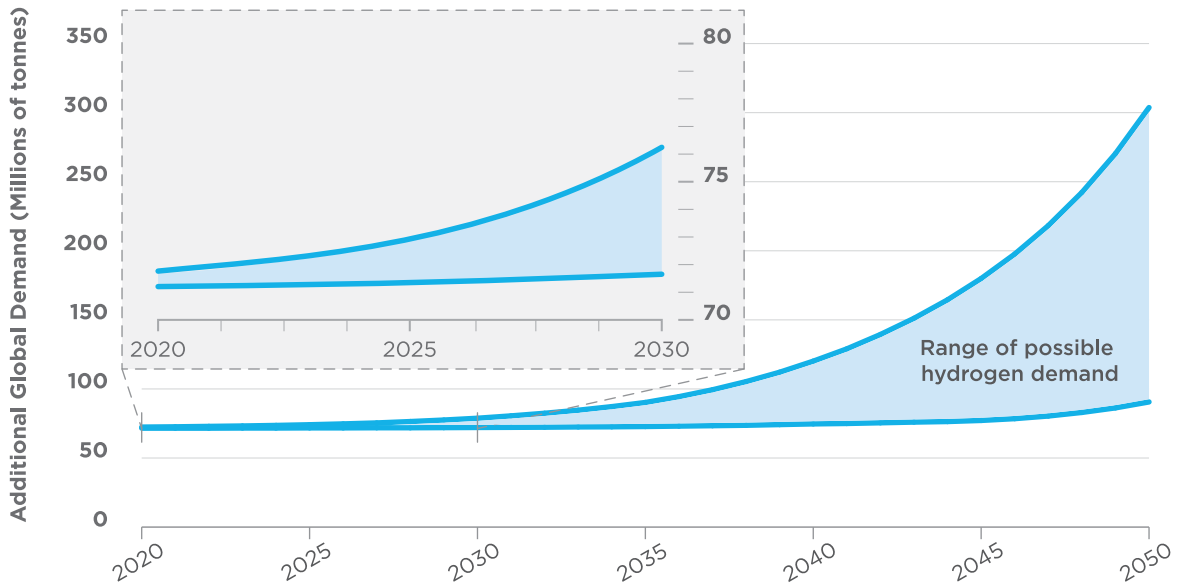
Japan, the Republic of Korea, China, Germany, Britain, the European Union and New Zealand all have plans for clean hydrogen.[5] In fact, around the world there are 19 other hydrogen strategies and roadmaps. The Future Fuels Cooperate Research Centre (CRC) has identified key points in these plans:

- The drive to reduce carbon emissions has led to considerable interest in rapidly deploying hydrogen technologies over the next several decades.
- This could give rise to export opportunities for countries with a comparative advantage in producing hydrogen.
- There is uncertainty about how quickly costs will drop and efficiencies improve for hydrogen and competing technologies.
- Only a few countries are focusing on producing hydrogen, while many are focusing on using hydrogen.
- The core focus of new strategies should reflect the broader international environment, address barriers, and build on comparative advantages.
- The timing and scale of activities should reflect the transition to hydrogen and how it can be practically achieved.
- Access to low-cost and low-emissions electricity is likely to be critical to hydrogen export trade in the medium term, along with the availability of carbon capture and storage.
- International producers and users of hydrogen will need to collaborate on standards, technology and hydrogen certification.

The general consensus appears to be that large-scale and rapid deployment of hydrogen technologies will emerge from 2030 onwards.

The International Energy Agency and International Renewable Energy Agency are among those predicting significant growth in global demand for hydrogen. Analysis undertaken for the Strategy also indicates growth in demand.[6] Figure 1.4 shows a range of possible global demand outcomes to 2030 and 2050. The actual trajectory will depend on factors such as technological developments, policy settings and consumer uptake. **Chapter 2** explores possible scenarios in greater detail.

Figure 1.4 Range of possible hydrogen demand over the next three decades



AUSTRALIA AS A SUPPLIER OF CLEAN HYDROGEN

The global interest in clean hydrogen presents a major opportunity for Australia.

Australia has significant competitive advantages for developing a substantial hydrogen export industry. It has all the natural resources needed to make clean hydrogen. It has a track record in building large-scale energy industries. It has an established reputation as a trusted energy supplier to Asia. It can compete with any other nation.[6]

Renewable energy

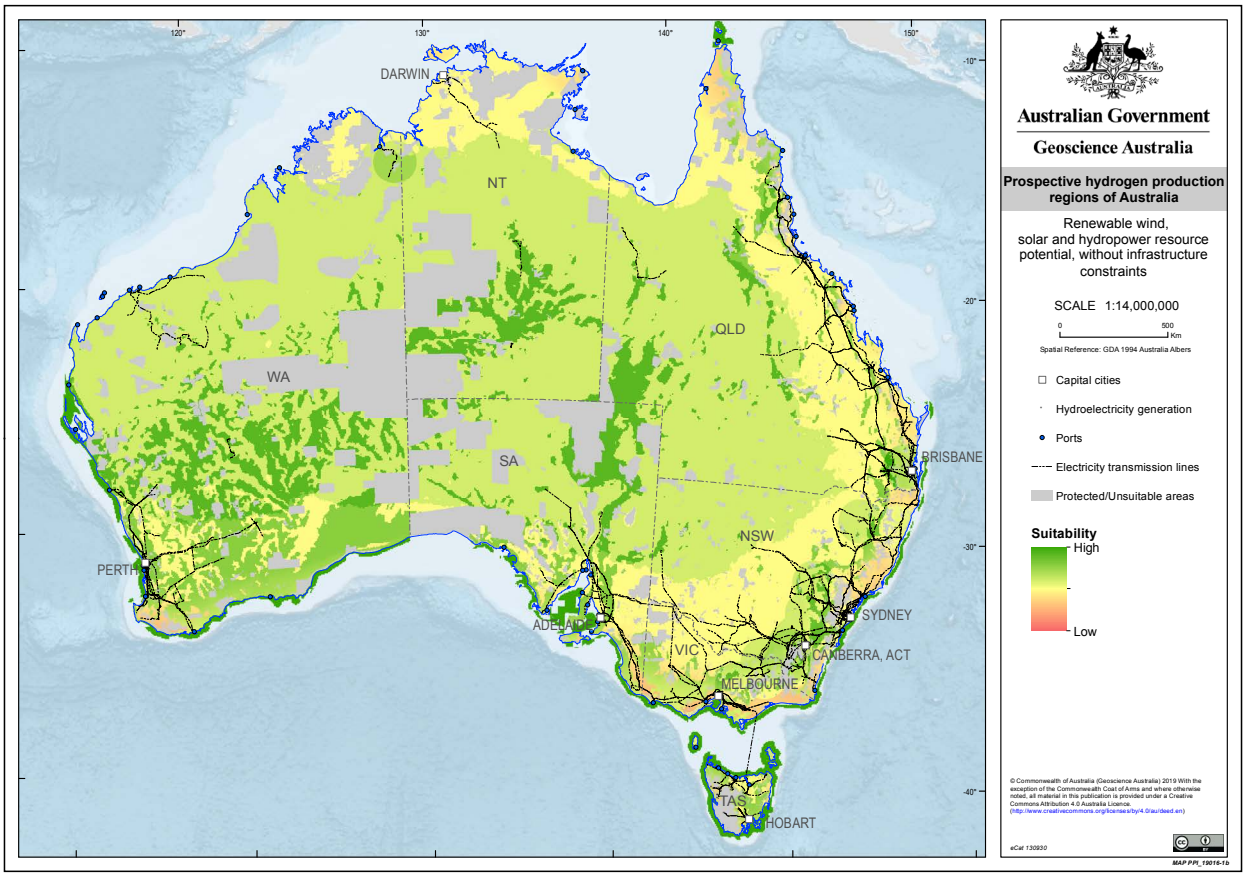
There is arguably no country better placed than Australia to harness solar energy. We have some of the world's best wind resources, especially on our southern and western coastlines. Tasmania, Victoria and New South Wales also have major hydroelectric resources.

Based on the quality of wind, solar and hydro resources alone, Geoscience Australia estimates about 11% of Australia (872,000 square kilometres) could be highly suitable for renewable hydrogen production, as shown in Figure 1.5.[7]

However, producing hydrogen also requires water. So the most ideal sites for production facilities will have access to renewable electricity and water supplies. Using desalinated seawater or waste water, if available, may be the most feasible approach.

Figure 1.6 shows the coastal areas highly suitable for hydrogen production using electricity from renewable sources. These areas occupy about 3% of Australia (262,000 square kilometres).[7] Analysis indicates this amount of land could be used to make more than the global demand predicted by the Hydrogen Council for 2050. It is worth noting that access to inland water would increase the area of Australia suitable for hydrogen production from renewable electricity.

Figure 1.5 Renewable hydrogen potential, without infrastructure constraints



Tools to estimate Australia's hydrogen production potential

Australia has developed an interactive tool for hydrogen.

Potential investors can explore various hydrogen production scenarios and identify project sites by varying the priority of spatial data relevant to hydrogen production site selection - with a range of criteria. These include criteria such as: proximity to relevant renewable and fossil fuel energy sources, water, electricity power lines, gas pipeline easements, ports, CCS storage basins and industrial zones.

Geoscience Australia has also published a report, *Prospective hydrogen production regions of Australia*.[7] Geoscience Australia's tool and report are available from its website.

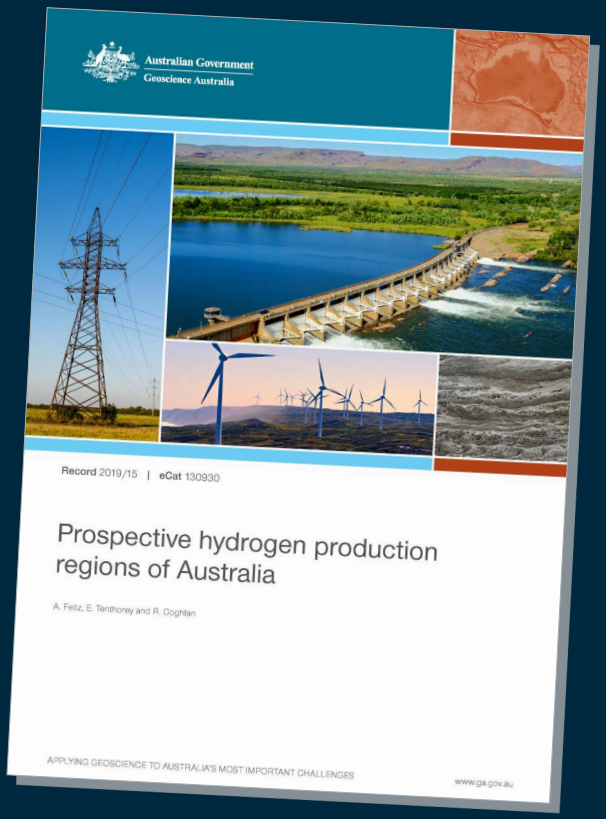
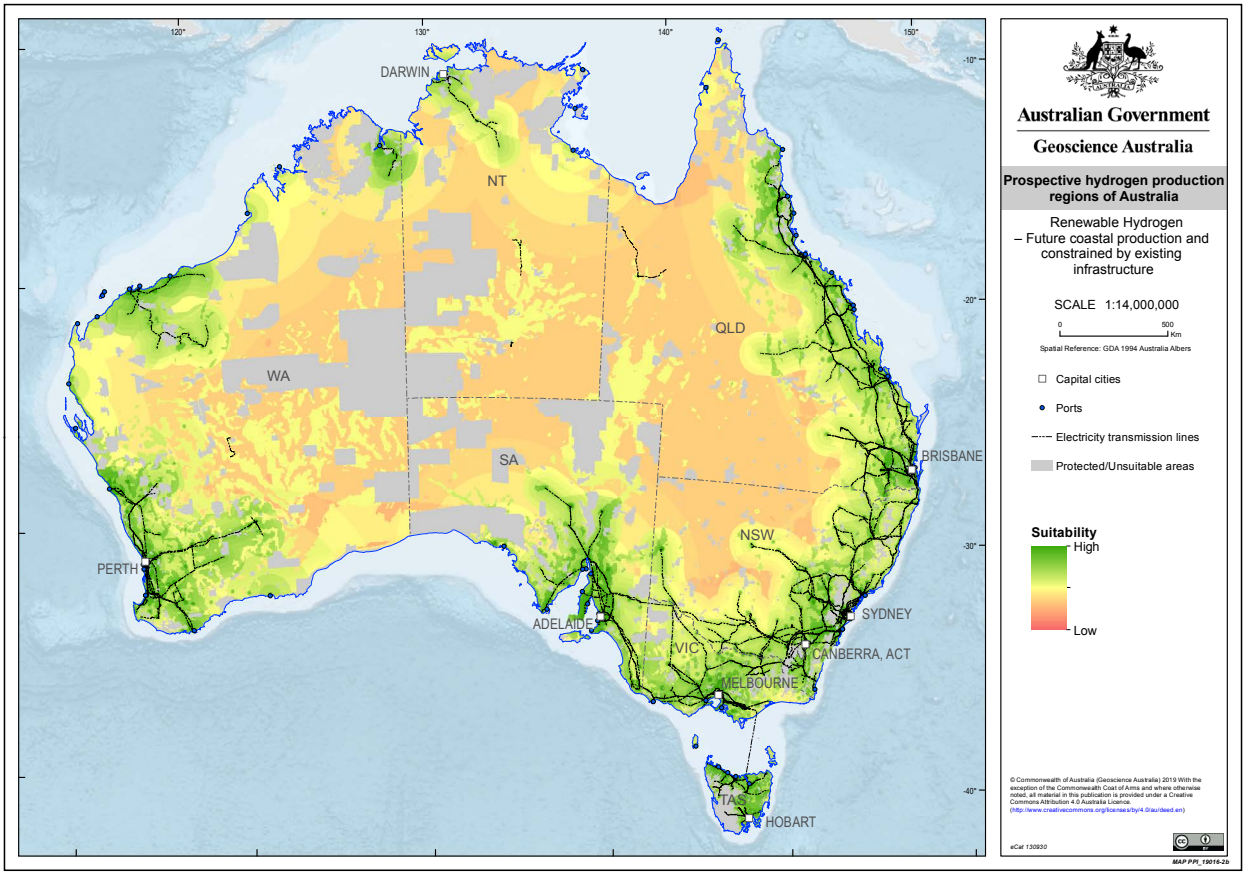


Figure 1.6 Renewable hydrogen potential, including access to water, ports, pipeline easements and electricity infrastructure



WATER FOR HYDROGEN PRODUCTION

While the water required for a large-scale hydrogen production industry will be significant, it is not unusual compared with other industrial uses.

Figure 1.7 shows the theoretical amount of water needed to produce a kilogram of hydrogen for each production pathway.

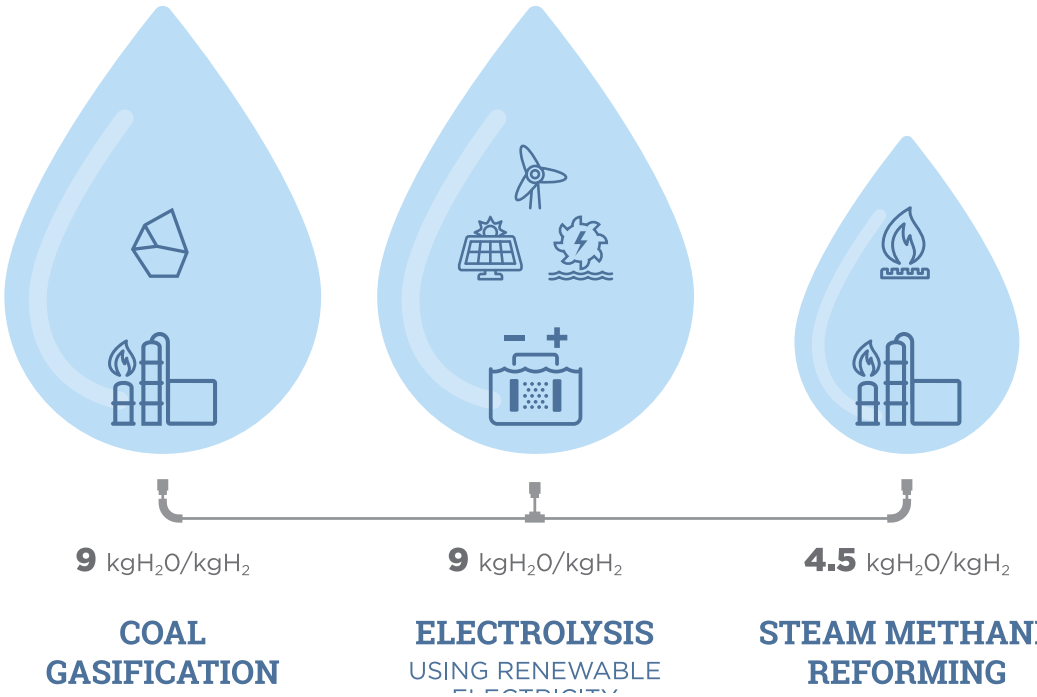
In practice water requirements for hydrogen production will vary depending on factors including production method and technology, the water content of the input fuel and the need for additional water for indirect production requirements such as cooling and input water purification. Different electrolysis technologies have differing water consumption requirements. Coal gasification water requirements will vary widely depending on the coal's moisture content and how the coal is prepared and processed.

To produce enough hydrogen to satisfy Japan's projected annual imports in 2030 would require less than one per cent of the water now used by Australia's mining industry each year. To be a major supplier of a large-scale global hydrogen industry in 2050, however, would require more water. Under strong hydrogen growth settings, water consumption in 2050 in Australia may be the equivalent of about one-third of the water used now by the Australian mining industry.

Australia will therefore need to consider how to balance hydrogen's demands with other water priorities. In many areas there will be limited capacity given existing demand from agriculture, industry, mining and households. Other uses for water may have higher economic, social or cultural value. Social acceptance of hydrogen production will depend on it not unduly affecting these existing uses.

Some regions, such as Tasmania, have abundant fresh water. There are also options to increase supply, including recycling and desalination. The cost of the electricity to desalinate seawater to produce hydrogen is minor – likely less than five cents per kilogram of hydrogen.

Figure 1.7 Theoretical water consumption by three production pathways



These are theoretical amounts of water based on the chemical pathway for each process. In practice water requirements for hydrogen production will vary depending on production method and technology, water content of inputs, and additional water needs for processes like cooling and input water purification.

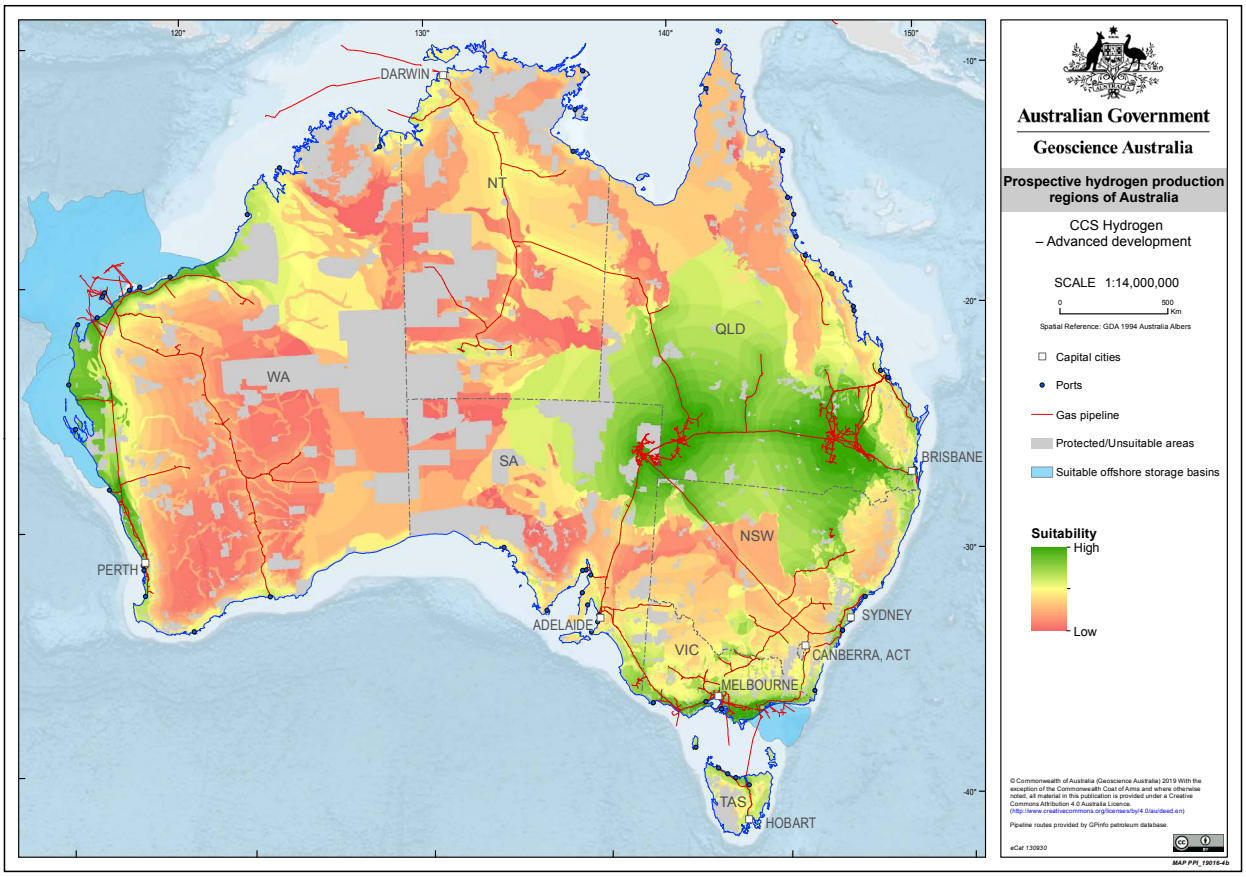
Fossil fuels and carbon capture and storage

Australia is also well situated to take advantage of carbon capture and storage technologies to produce low-emissions hydrogen from coal and natural gas. Carbon capture is likely to be more cost-effective for hydrogen production than for electricity generation. This is because the carbon emissions are separated as part of the hydrogen production process. They are easier to capture because the gas mixture produced during coal gasification and steam reformation is at much higher pressure than the flue gases produced during electricity generation. To produce hydrogen from natural gas or coal at acceptably low levels of carbon emissions, capture rates of 90% or more will likely be required. These rates are technically feasible.[8]

The best areas for CCS hydrogen production would be close to coal or gas sources and to subsurface storage for carbon dioxide. Geoscience Australia has identified Australia's most prospective areas, considering these two requirements along with pipeline access and availability of water (in this case, not limited to desalination).[7] Figure 1.8 shows these areas. In the near term, the best CCS opportunities are in the Carnarvon Basin; off-shore Western Australia (the site of one of the world's largest carbon capture and storage projects on Barrow Island); in the Gippsland Basin, in offshore Victoria (site of the CarbonNet project); and onshore regions near the Cooper Basin (Queensland and South Australia), and Surat Basin (Queensland).

Given interest from international partners in projects such as the Hydrogen Energy Supply Chain in the Latrobe Valley – a pilot project looking at the viability of producing hydrogen from the valley's coal reserves and exporting it to Japan – CCS hydrogen may be an acceptable option in some potential markets to meet decarbonisation goals. Establishing carbon capture and storage sites will, of course, require close engagement with nearby communities.

Figure 1.8 Fossil fuel with CCS production potential, based on proximity to advanced CCS sites



Supportive environment for industry

Government policies and regulatory settings support industry development. Australia is one of the easiest places in the world to do business, especially in comparison to other potential hydrogen producers.[9] We welcome foreign investment, and our record with investors in large-scale export industries is regarded as being exemplary. Development finance facilities such as the Clean Energy Finance Corporation, the Northern Australia Infrastructure Fund and various state initiatives can provide tailored support for hydrogen-related investments.

Growing hydrogen expertise

Australia sits near the top of global research impact rankings for hydrogen, and it leads the world on Normalised Citation Impact for research into storage, distribution and use.[10] Australia's research, development and demonstration community works extensively with other prominent hydrogen-active countries, providing a strong foundation for further future collaboration. More than 30 pilot projects across Australia are developing capability in producing, storing, transporting and using hydrogen, supported by Commonwealth, state and territory governments.

Gas and renewable energy expertise

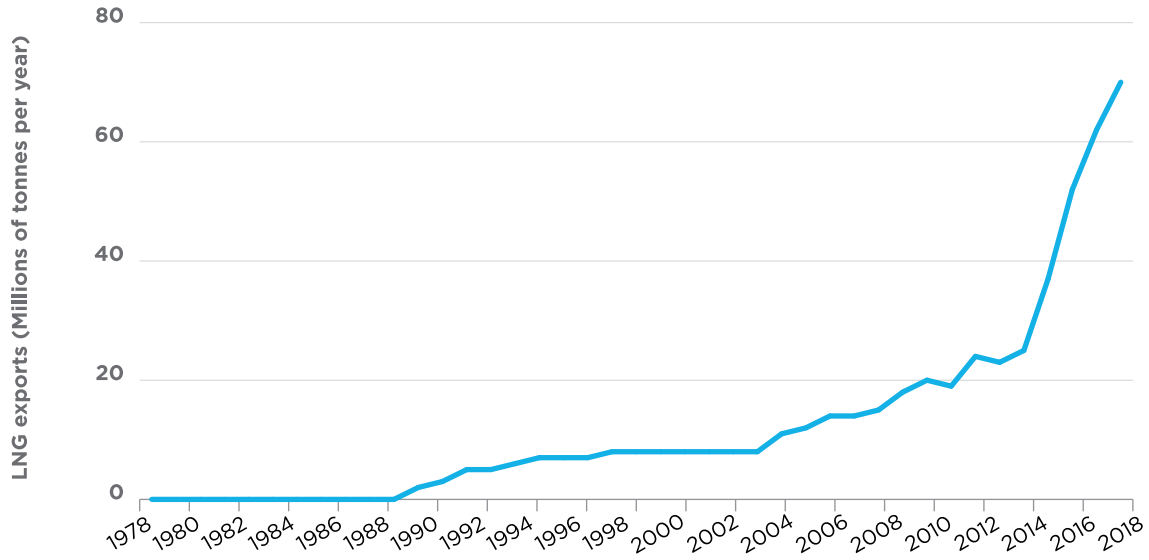
Australia has useful expertise in building new large-scale industries, notably the liquefied natural gas export industry and the renewable energy sector. Since the 1960s, the Australian LNG industry has grown to become one of the world's biggest exporters of LNG. More recently, Australia has become a world leader in renewable energy deployment.

CREATING A NEW ENERGY INDUSTRY FOR AUSTRALIA, PART ONE: THE LNG EXAMPLE

Australia now exports $50 billion of LNG a year. Australia is vying with Qatar as the world's largest exporter of LNG, accounting for more than 20% share of global exports.[11]

To get to this position took decades of vision, learning from experience, and a willingness of industry and government to take risks together, and leverage the connection between domestic and export opportunities.

Figure 1.9 LNG exports over the past three decades [12]



1963 Woodside granted North West Shelf oil and gas tenements

1967 Commonwealth Government introduces the *Petroleum (Submerged Lands) Act 1967*

1979 Western Australian Government underwrites the future LNG export industry by entering long-term take-or-pay contracts for the North West Shelf Venture (NWSV)

1981 NWSV signs formal LNG sales agreement with eight Japanese gas and power companies

1984 First domestic gas delivered to WA by NWSV.

1989 First export of LNG from Australia by NWSV.

1995 Discovery of the Bayu-Undan field north-west of the Northern Territory

1999 Commonwealth establishes annual Offshore Petroleum Exploration Acreage Release to promote oil and gas exploration

2000 Queensland Government announces 13% Gas Scheme, sparking an estimated $1 billion of coal seam gas development over the next seven years[24]

2006 First LNG exports from the Northern Territory

2008 LNG production commences at the fifth and final LNG processing train at the NWSV Karratha Gas Plant

2009 Blueprint for Queensland's LNG industry released

2012 LNG production commences at Woodside's Pluto LNG Plant near Karratha, Western Australia

2015 First LNG exports from Queensland

2015 Australia becomes second-largest LNG exporter in the world

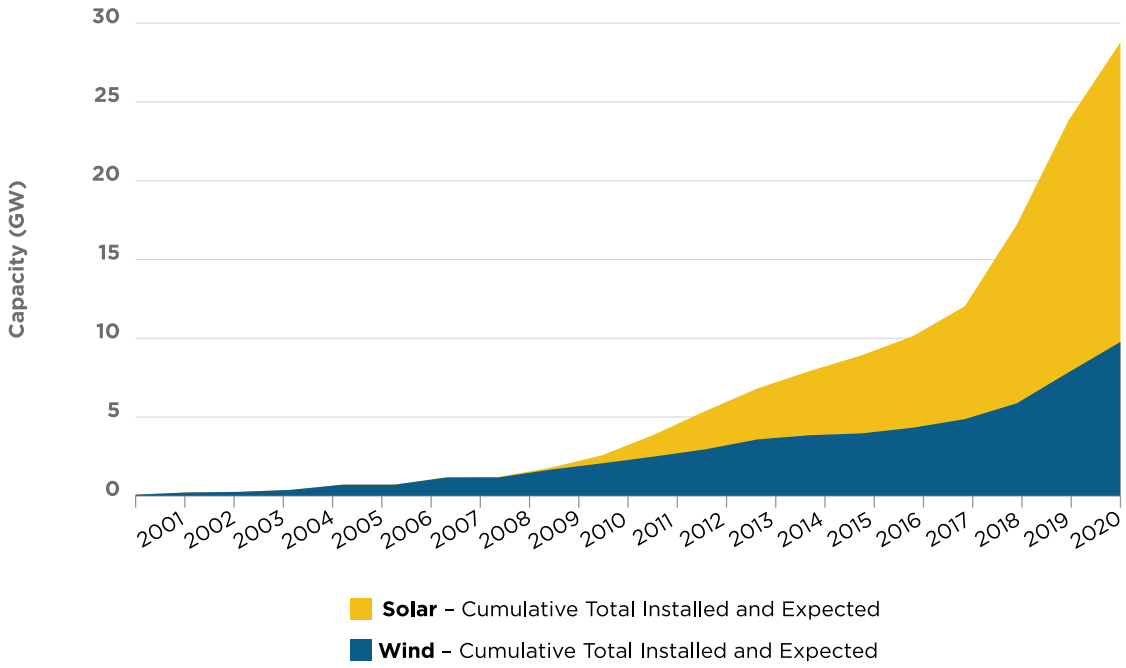
2016 LNG production commences at Gorgon Gas Plant at Barrow Island, Western Australia

2017 LNG production commences at Wheatstone Gas Plant near Onslow, Western Australia

CREATING A NEW ENERGY INDUSTRY FOR AUSTRALIA, PART TWO: WIND AND SOLAR ENERGY IN AUSTRALIA

Australia can also build on world-class renewable electricity experience. Between 2018 and 2020, we will install more than 16 gigawatts of wind and solar, an average rate of 220 watts per person per year. This is four to five times the rate in Europe, Japan, the US or China, and ten times the world average.[13] Australian governments have created enabling conditions for much of this investment.

Figure 1.10 Growth of Australian wind and solar capacity [14]



1997 First grid-connected wind turbine installed at Kooragang Island, NSW (600 kW)

1998 First solar farm installed at Singleton, NSW (200 kW)

2001 Mandatory Renewable Energy Target commences with target of an extra 9,500 GWh in 2010

2010 Renewable Energy Target expands with legislated target rising to 45,000 GWh (amended to 33,000 GWh in 2015)

2012 Australian Renewable Energy Agency created to increase supply and competitiveness of renewable energy

2012 Clean Energy Finance Corporation created to facilitate investment in clean energy

2013 Number of homes with solar panels reaches 1 million

2015 ARENA co-funds development of 500 MW large-scale solar competitive round

2018 Number of homes with solar panels reaches 2 million

2020 Renewable Energy Target expected to be reached

BENEFITS FOR ALL AUSTRALIANS

Seizing the hydrogen opportunity can benefit all Australians. A new industry will create jobs and economic growth, contribute to a cleaner environment, strengthen industrial competitiveness and enhance Australia's fuel security.

Jobs and prosperity

A cautiously optimistic scenario could see an Australian hydrogen industry generate about 7,600 jobs and add about $11 billion a year in additional GDP by 2050.[6] If global markets develop faster, it could mean another ten thousand jobs and at least $26 billion a year in GDP.

The jobs created will include technicians, tradespeople, engineers and professionals. Many of the jobs will be in regional areas, especially around ports and industrial clusters where development is most likely to occur.

Like other resource industries, an Australian hydrogen industry could also export more than the commodity. There could be a valuable secondary market in expertise, selling technical skills, equipment, intellectual property, education and training.

Hydrogen can be used to refine minerals, produce chemicals or manufacture steel. These are currently emissions-intensive industries. A local supply of clean hydrogen gives domestic businesses an opportunity to create jobs and take a share of potential future markets for low-carbon products such as green ammonia, green fertilizer and green steel.

A resilient and diverse energy system

Hydrogen technologies are well-suited to balancing supply and demand in an electricity grid that increasingly relies on variable renewable sources such as solar and wind. If managed well, this could lower electricity costs for consumers.

In a rapid demand-response scenario, when electricity supply exceeds conventional demand, hydrogen electrolysis can be ramped up within seconds; when electricity demand exceeds supply, hydrogen electrolysis can be equally rapidly ramped down. This makes hydrogen production from electrolysis well-suited to renewable electricity generation – it can run when renewable electricity is abundant and use electricity which would otherwise be curtailed. This can improve project economics.

In areas where renewable energy varies with the seasons, hydrogen can be produced in large volumes during times of plentiful supply, such as in summer for predominantly solar regions. It can then be used in times of limited supply to generate electricity through fuel cells or gas turbines. Or, it can be stored as gas for winter heating.

A cleaner environment

Australia's potential to produce clean hydrogen doesn't just support carbon emissions reduction. Its potential as an industrial and transport fuel provides a pathway to eliminate the nitrous oxides, sulfur oxides and particulate pollution associated with burning fossil fuels. Improved air quality is likely to reduce a range of respiratory ailments, cancers, and the health costs associated with them.

Fuel security

Using locally made hydrogen can help reduce Australia's heavy dependence on importing liquid fuels, especially for transport. This would potentially strengthen Australia's strategic security and maximise our energy resilience. The Australian Government has considered the opportunity for hydrogen along with other alternative fuels to improve Australia's resilience to disruptions in fuel supply through the Liquid Fuel Security Review.[15] Reducing fuel imports could also improve Australia's terms of trade.

CAPTURING AUSTRALIA'S CLEAN HYDROGEN OPPORTUNITY

Australia must be strategic to capture the hydrogen opportunity and be one of the world's great energy players.

The Australian Government has supported nine projects in the past two years alone. The state and territory governments have also made early moves through supporting specific projects and in some cases, releasing their own hydrogen strategies.

These strategies allow them to prioritise action areas that make sense for their resources, needs and strengths. The purpose of the National Hydrogen Strategy is to coordinate all these actions and provide a strategic vision for Australia's national hydrogen industry.

Endnotes

1 International Energy Agency 2019, *The Future of Hydrogen*, https://webstore.iea.org/the-future-of-hydrogen

2 United States Department of Energy 2017, *DOE Hydrogen and Fuel Cells Program Record*. Accessed from: https://www.hydrogen.energy.gov/pdfs/17007_fuel_cell_system_cost_2017.pdf

3 Bloomberg New Energy Finance 2019, *Hydrogen: The Economics of Storage*, p. 2

4 McKinsey & Company 2019, *The hydrogen opportunity for Australia* (presentation to Australian Energy Week, sources for analysis include: McKinsey project team, DoE, BNEF, Energy Insights, IEA, IHS Markit)

5 Kosturjak, A, Dey, T, Young, M, D, Whetton, S, 2019, *Advancing hydrogen: Learning from across the globe*, Future Fuels Cooperative Research Centre, https://www.futurefuelscrc.com/files/download/450181d39712b07, accessed 11 November 2019

6 Deloitte 2019, *Australian and Global Hydrogen Demand Growth Scenario Analysis,* http://www.coagenergycouncil.gov.au/publications/reports-support-national-hydrogen-strategy

7 Geoscience Australia 2019, *Prospective Hydrogen Production Regions of Australia*, https://d28rz98at9flks.cloudfront.net/130930/Rec2019_015.pdf, accessed 11 November 2019

8 Bui, M, et. al 2018. Carbon capture and storage (CCS): the way forward. Energy & Environmental Science, 11(5), 1062-1176, p. 1078

9 The World Bank, 2019 *Ease of doing business index*, https://data.worldbank.org/indicator/ic.bus.ease.xq, accessed 11 November 2019

10 Normalised Citation Impact (NCI) measures citation impact relative to a world average. It is one of the most robust metrics available and is used by leading international bibliometric institutions, though there are others. Further discussion of Australia's current research strengths will be available in a forthcoming CSIRO report, *National Hydrogen Research, Development and Demonstration (RD&D) Priorities & Opportunities for Australia*.

11 Commonwealth of Australia 2019, *Resources and Energy Quarterly June 2019 Historical Data*; https://publications.industry.gov.au/publications/resourcesandenergyquarterlyjune2019/index.html, accessed 11 November 2019.

12 Hydrogen Strategy Group 2018, *Hydrogen for Australia's Future*, p. 50 https://www.chiefscientist.gov.au/wp-content/uploads/HydrogenCOAGWhitePaper_WEB.pdf

13 Stocks, M, Baldwin, K, Blakers, A, 2019, *Powering ahead: Australia leading the world in renewable energy build rates*. https://energy.anu.edu.au/files/Renewable%20energy%20target%20report%20September%202019_1_0.pdf accessed on 11 November 2019

14 Data (actual and forecast) from the Clean Energy Regulator, provided on 17 October 2019.

15 Commonwealth of Australia 2019, *Liquid Fuel Security Review – Interim Report*, Commonwealth of Australia 2019, p 54-55. https://www.environment.gov.au/system/files/consultations/7cf6f8e2-fef0-479e-b2dd-3c1d87efb637/files/liquid-fuel-security-review-interim-report.pdf accessed 11 November 2019

2 MAKING AND TAKING AUSTRALIA'S OPPORTUNITY

Australia's natural resources, investment environment and track record as an energy exporter provide a strong foundation to build a clean hydrogen industry. Even so, there is a need to be strategic, with scale and timing depending on how global demand evolves.

All decisions to act in an uncertain environment come with risks. These must be balanced against the risks from not acting. A strategic approach is an adaptive approach, taking the steps that position us for growth without losing the ability to adjust to changing circumstances.

Imagining alternative future scenarios can help us shape that adaptive approach, by identifying the outcomes and events that could trigger decisive steps.

POSSIBLE HYDROGEN FUTURES

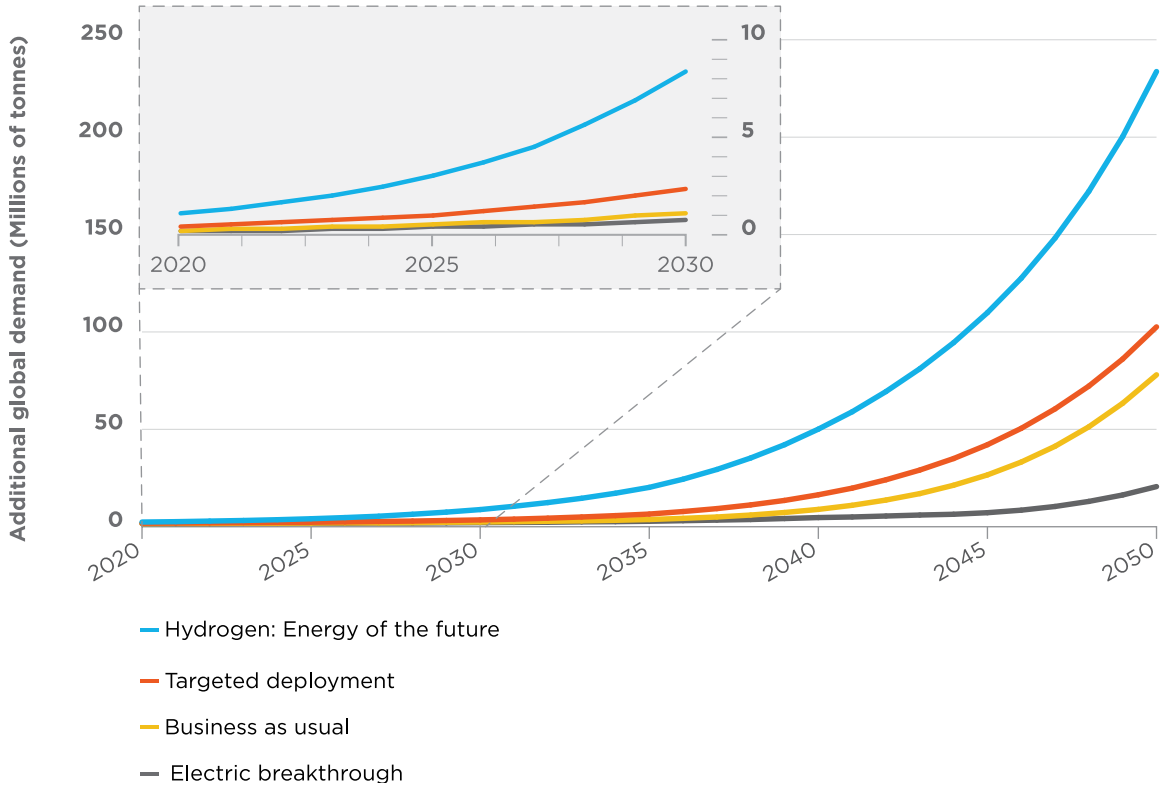
The global energy system has many dynamically evolving and interrelated parts. The size and timing of Australia's hydrogen opportunity could play out in many different ways.

Industry strategies and policy choices in other countries, including for emissions reductions and for economic growth, will influence their future energy choices. Expected technology cost reductions are promising but yet to be realised. History has shown, though, that technology developments can occur faster than expected and competition can emerge from many corners. Other countries are already moving to establish trading arrangements and position themselves for hydrogen growth.

To identify and shape the path Australia takes, we must understand the drivers behind different futures and what those futures might mean for the scale and timing of hydrogen opportunities. Besides business as usual, the Strategy considers three scenarios (Figure 2.1) for hydrogen growth. These scenarios represent different pathways for technology and market development.[1]

The scenarios consider additional demand from new hydrogen uses in energy or industrial processes. In the future, existing demand for hydrogen, currently met by traditional (non-clean) hydrogen production, could be replaced by clean hydrogen. Current global demand for hydrogen is around 70 million tonnes per year.[2]

Figure 2.1 Global hydrogen market growth scenario outcomes



The scenario outcomes (see Appendix A) emphasise the diversity of pathways that could lie ahead. The range of additional global demand is between 2 and 9 million tonnes in 2030; and from around 20 to over 230 million tonnes in 2050.

An Australian hydrogen industry could generate about 7,600 jobs and $11 billion in GDP in 2050 with targeted global deployment; if global markets develop faster, consistent with the energy of the future scenario, estimates rise to around 17,000 jobs and $26 billion in GDP.

- **Deep and rapid global decarbonisation**
- **Australia leads in thriving global market**
- **Hydrogen is a fuel of choice for importers, industry, transport and heating**

SCENARIO
Hydrogen: energy of the future

This scenario provides insights into what very strong adoption of hydrogen in global energy systems could mean for Australia. There is strong uptake of hydrogen across all promising uses, including for pipeline gas, transport fuel, steel making, and industrial and domestic heating. Uptake is driven by strong and early global commitments to reduce carbon emissions, supported by deep decarbonisation of electricity generation. Australia acts to create cost and innovation advantages over export rivals in a thriving global market, and supplies up to about 30% of demand in some Asian markets.

- **Enhanced global efforts on emissions reduction**
- **Australia competitive in strong global market**
- **Hydrogen complements other energy innovations, with promising niches in industry and heavy transport**

SCENARIO
Targeted deployment

This scenario envisages growing hydrogen use, targeted in high-value sectors. For example, sectors with fewer low-emissions alternatives – such as steel making and other niche industrial and heavy transport applications – may adopt hydrogen intensively even if uptake is low in other sectors such as light vehicles and domestic heating. This uptake is driven by a step up in global efforts to reduce carbon emissions, supported by progress towards lower emissions electricity. Australia is an export leader in a smaller, but active, international hydrogen market.

- **Global emissions reduction aligned with current policy announcements**
- **Australia loses competitiveness relative to export rivals**

SCENARIO
Business as usual

This scenario assumes the global market grows in line with existing emissions reduction efforts, but Australia falls behind others. Without the leadership of a major supplier of Australia's calibre, hydrogen's global prospects are diminished. At the same time, export rivals develop capability faster. Technology learning is slower, costs higher and demand more subdued.

- **Enhanced global efforts on emissions reduction**
- **Minimal new demand, with breakthroughs in other energy technology**

SCENARIO
Electric breakthrough

This scenario imagines technology breakthroughs that mean clean electricity (in combination with battery and pumped hydroelectricity storage) can meet almost all energy needs. Electricity replaces the use of gas for heating and cooking, and the use of petrol and diesel in road transport. Consequently, despite strong global commitments to reduce carbon emissions, there is minimal uptake of hydrogen for energy.

HOW THE SCENARIOS COMPARE[1]

The scenarios are not forecasts. They are possible futures. Comparisons with other published estimates are presented in Figures 2.2 and 2.3.

Figure 2.2 Comparing 2030 global hydrogen demand growth estimates

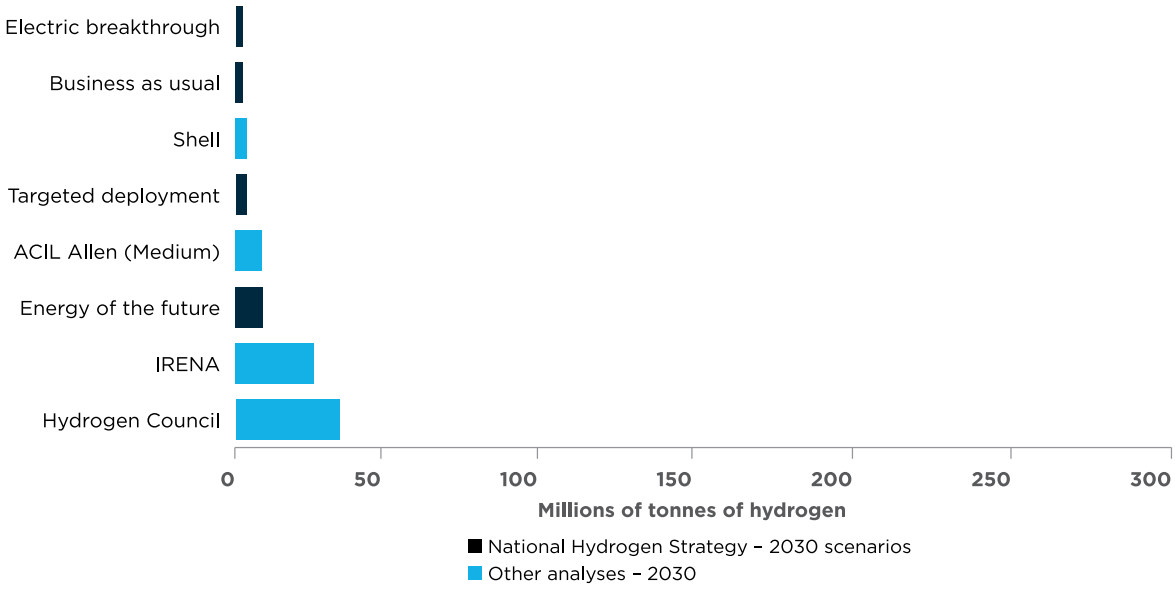
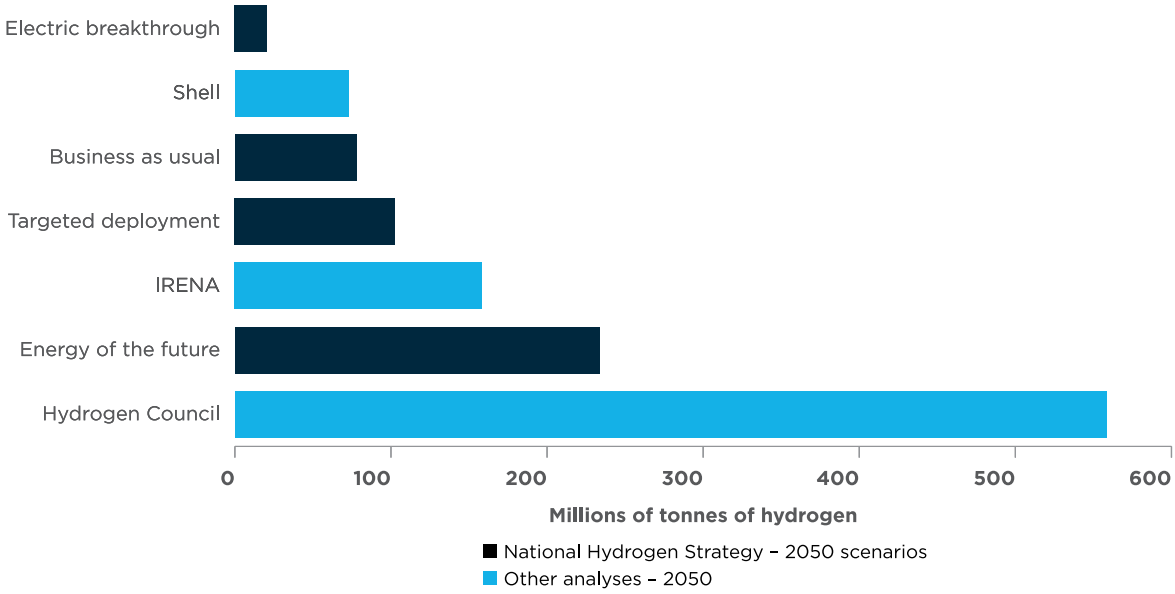


Figure 2.3 Comparing 2050 global hydrogen demand growth estimates



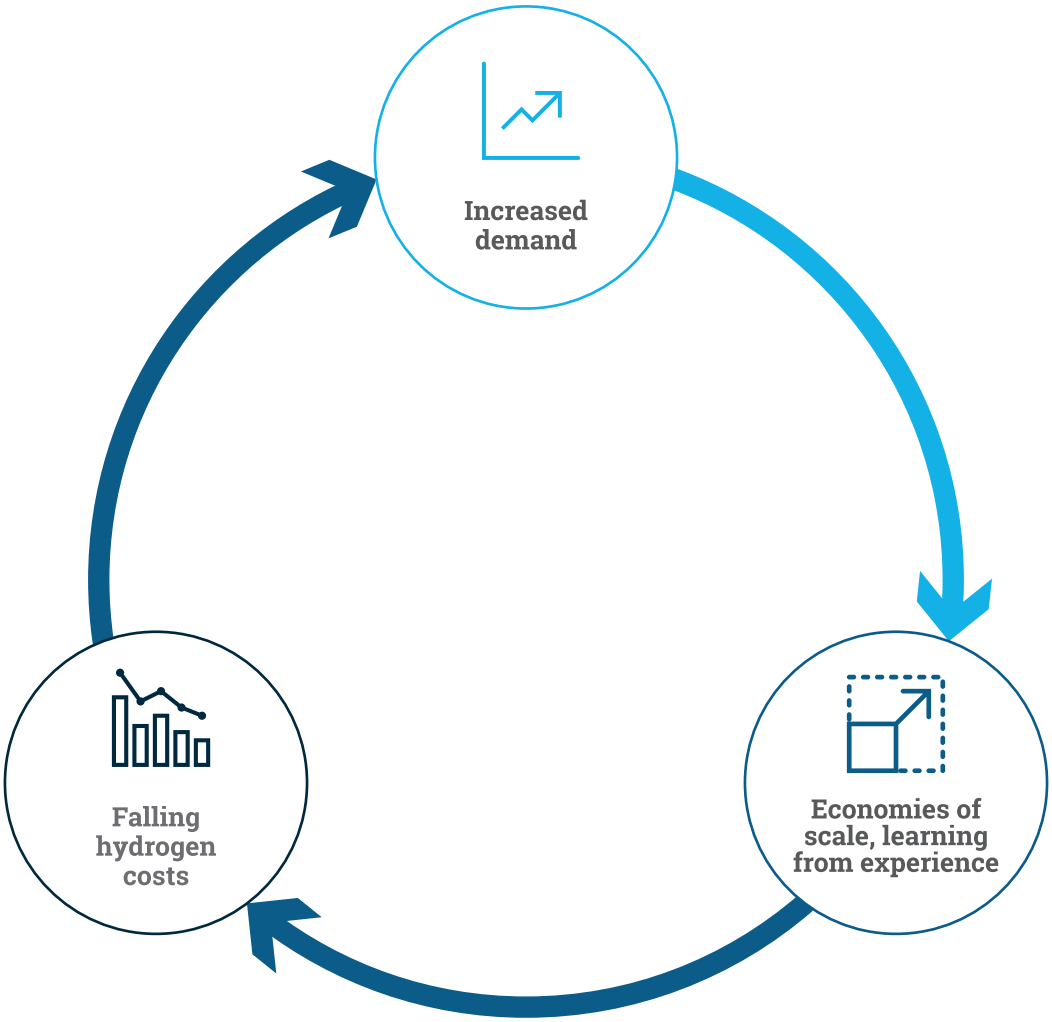
CREATING A GLOBAL HYDROGEN FUTURE

Despite the uncertainty about the extent of global hydrogen demand growth over coming decades, the case to act quickly to realise our full potential is clear. The business as usual scenario underlines the strategic, economic and environmental benefits Australia may forego by taking a passive approach.

For a market to develop, it's not just a matter of waiting for demand to occur. Australia has a role to play on the supply side. Investments in research and development that reduce production costs, for example, will increase demand. This in turn will create incentives to invest in more production capacity and technological development, unlocking economies of scale, reducing prices further and stimulating more demand. This mutually reinforcing cycle is shown in Figure 2.4.

We can watch for indicators of how this cycle is progressing, which scenarios are becoming more likely, and where we can take action to drive the process for Australia's benefit. **Chapter 6** describes the tracking and monitoring functions that will allow Australia to determine what kind of future is emerging and how we can influence it.

Figure 2.4 Cycle of technology learning



AN ADAPTIVE PATHWAY TO CLEAN HYDROGEN GROWTH

Australian governments support an adaptive approach that means we can be ready to move quickly to scale up as signs of large-scale markets emerge.

A 'review-revise-adapt' feedback loop will support and refine actions as technology and markets change (Figure 2.5). Some early actions are 'no regrets' steps we can take now. Others are steps we should identify and plan for now, but only act on when the time is right.

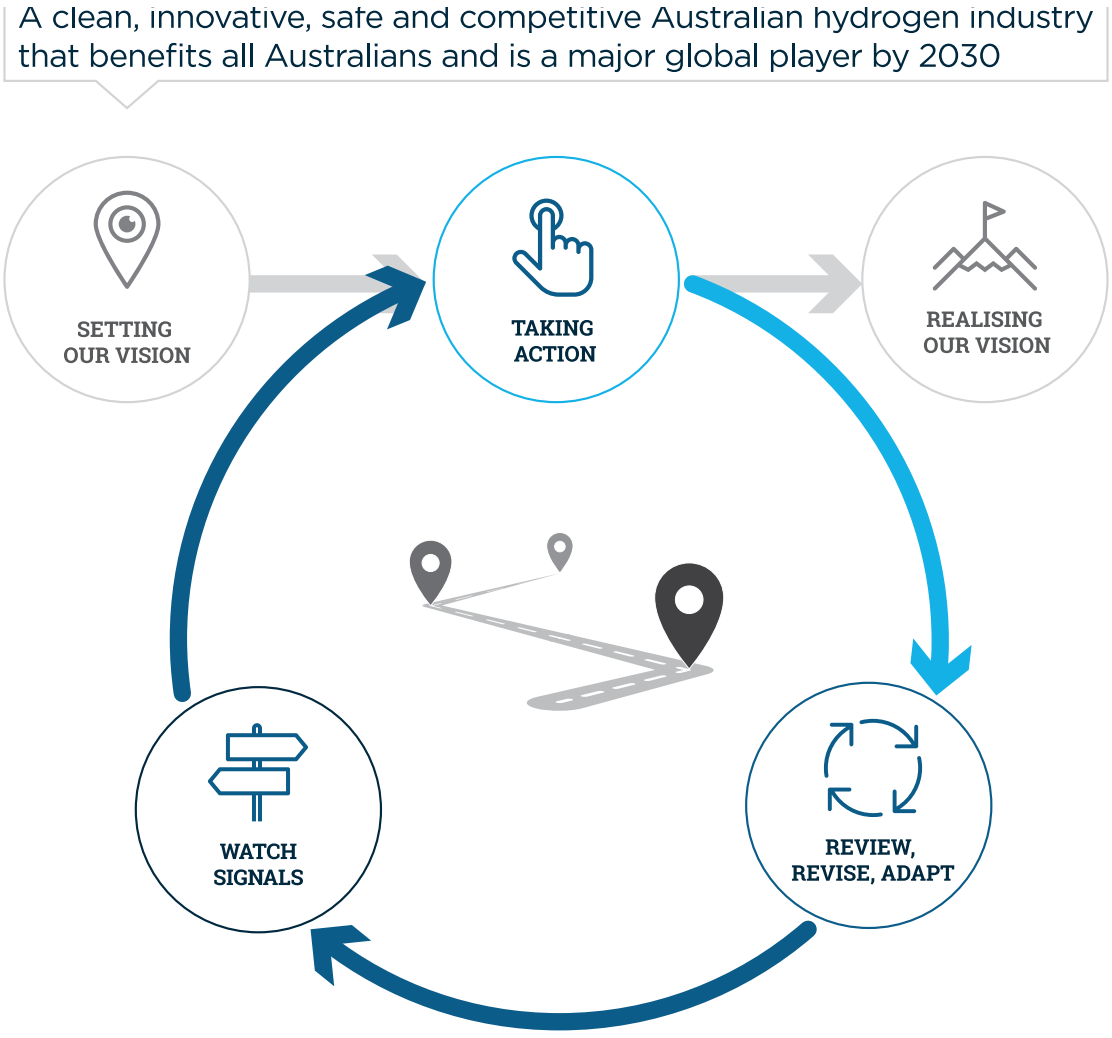
This allows us to proceed without overreaching, locking out the ability to move quickly, or locking in actions that make it difficult to change course.

The adaptive approach is focused on actions that remove market barriers, efficiently build supply and demand, and accelerate the global cost-competitiveness of Australia's hydrogen industry.

The approach is guided by four principles:

1. Take an adaptive and nationally coordinated approach to support industry development, including regular reviews
2. Prioritise regulatory consistency and a coordinated approach to project approvals
3. Support partnerships to activate the market
4. Put safety, environmental sustainability and benefits to Australians at the forefront.

Figure 2.5 Adaptive approach to industry development



The actions by Australian governments are themed around seven areas.

- National coordination
- Developing production capacity, supported by local demand
- Responsive regulation
- International engagement
- Innovation and R&D
- Skills and workforce
- Community confidence

However the global market develops, Australian governments support a pathway for developing a local industry, initially by removing regulatory barriers to hydrogen use and encouraging it through policies to help overcome investment barriers.

Mandating use of hydrogen will require evidence there will be a net benefit to consumers, and that industry can meet regulated requirements.

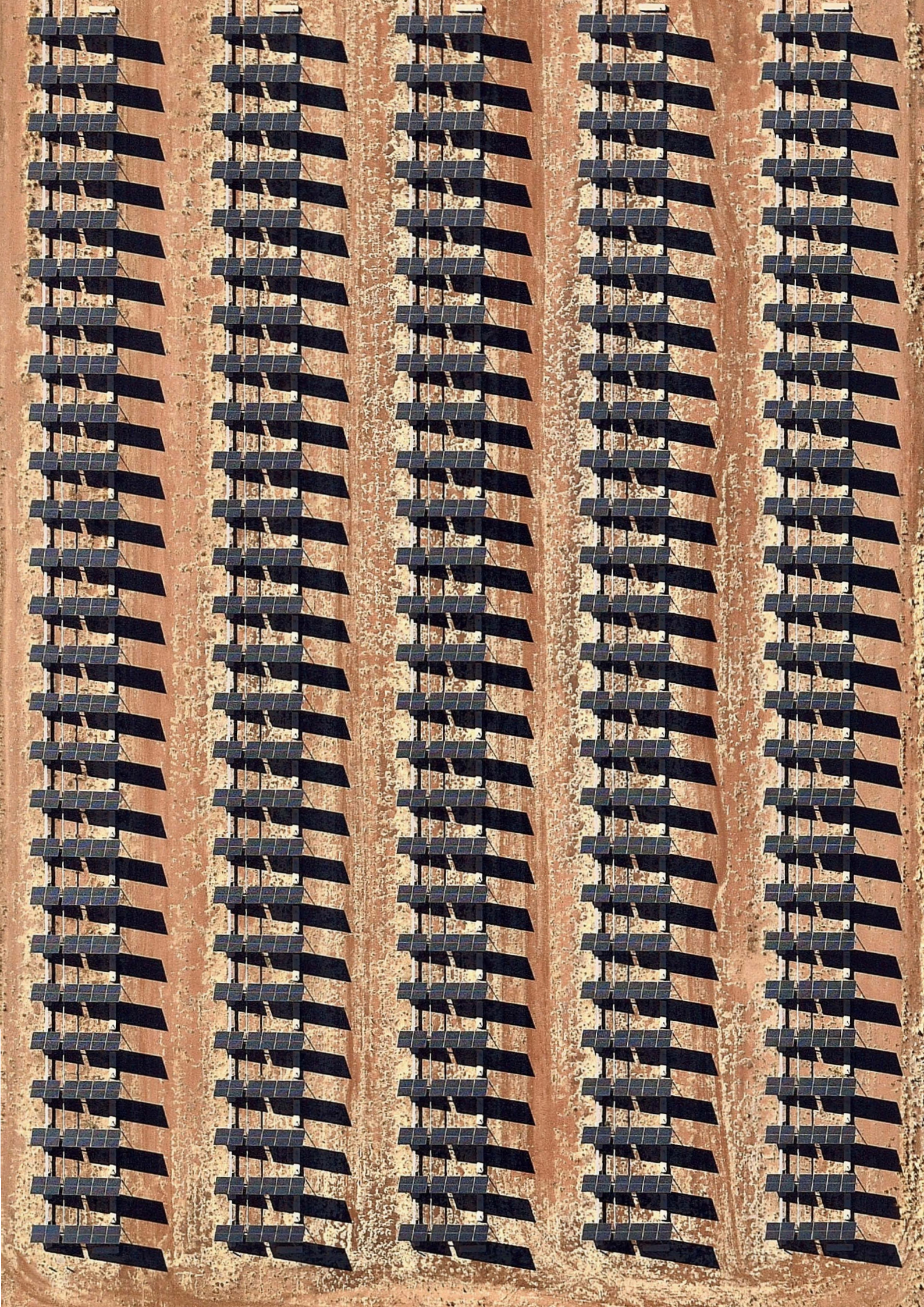
SHAPING THE FUTURE

Australia's clean hydrogen opportunities are ours to make and take. Our own history shows us what it takes to become an energy exporting powerhouse. Governments and industry have worked together before to leverage global energy opportunities. It can be done again.

Endnotes

1 Deloitte 2019, *Australian and Global Hydrogen Demand Growth Scenario Analysis,* http://www.coagenergycouncil.gov.au/publications/reports-support-national-hydrogen-strategy

2 International Energy Agency 2019, The Future of Hydrogen, p.32 https://webstore.iea.org/the-future-of-hydrogen



3 THE JOURNEY TO HYDROGEN POWERHOUSE

The first steps in Australia's adaptive approach position us to build a large-scale clean hydrogen industry as international demand grows.

A key to Australia's approach will be creating hydrogen hubs – regions where users of hydrogen are co-located – in metropolitan, regional and remote areas.

These hubs will help the hydrogen industry in the early stages of development. They will make infrastructure more economic, allow for efficiencies from scale, foster innovation, facilitate the sharing of expertise and services and promote sector coupling.

IMPLEMENTING AN ADAPTIVE APPROACH

Australia will take an adaptive approach to capitalise on growth in domestic and global hydrogen demand.

The early steps in this approach make sense under all the scenarios outlined in **Chapter 2** because the pathways are largely the same until at least 2030. Development across the upcoming decade is likely to fall into two phases.

Foundations and demonstrations

In the first phase (already underway), our objectives are to:

- create, test and prove Australia's clean hydrogen supply chains
- encourage global markets to emerge in line with mutual interests
- build cost-competitive production capability.

Early actions will focus on developing clean hydrogen supply chains to service new and existing uses of hydrogen (such as ammonia production) and developing capability for rapid industry scale-up. Demonstration scale hydrogen hubs will help prove technologies, test business models and build capabilities.

Activities in this phase include:

- **Developing supply and demand:** Pilots, trials and demonstration projects will drive technological development, develop industry expertise, promote international collaboration, enable business model innovation and prove hydrogen supply chains at scale. Many projects that support this are already in their early stages.
- **Responsive regulation:** Review and reform underpinning regulatory and legal frameworks, to develop consistent approaches for:
  - efficient supply chains and markets
  - a supportive investment environment
  - robust training requirements and safety standards.
- **International engagement:** Strategic and coordinated international outreach, focused on key markets, to harmonise standards and encourage trade.
- **Skills and workforce:** Improve workforce skills and establish training regimes.
- **Community confidence:** Work with industry to earn the community's trust and build confidence in hydrogen.
- **Innovation and R&D:** Provide targeted support for research and development activities, with a focus on international collaboration and Australian priorities.

Large-scale market activation

In this phase, which is likely to emerge later in the coming decade, activities will broaden towards supply chain scale-up and large-scale market activation, as signals around the global hydrogen market become clearer.

Many projects that will underpin this phase are already on the drawing board but it will take significant investment and clear demand to make them a reality. Creating an attractive environment for industry scale-up and supply chain development will be a shared responsibility of governments and industry.

Governments will consider the most appropriate support to scale up the industry and activate markets in light of global signals. Support may include financing to support the development of clean hydrogen supply chains, policies to create hydrogen demand or other policies that stimulate private investment.

Building widespread domestic hydrogen demand could include measures for:

- using clean hydrogen for industrial feedstocks and heating
- blending of hydrogen in gas networks
- using hydrogen for long-distance heavy-duty transport and development of associated refuelling infrastructure.

It is too early to say whether setting targets for hydrogen use in any sector would be warranted in Australia. Governments have agreed that mandatory national targets would not be appropriate at this time, but will revisit this question periodically as the market develops.

Activities in this phase would build on lessons from early projects. Scale-up and widespread deployment will enable business model innovation, economies of scale, and improvements in processes, incremental technology costs and safety. Activities to advance legal and regulatory reforms, engage internationally, build skills and workforce capability and earn community confidence would continue. Targeted support for research and development will focus on step-change technology improvements, ongoing cost reductions and operational efficiencies.

As the industry matures, governance structures and market settings will ideally emerge to foster industry growth and competition, ensure community safety, protect the environment, provide broader benefits to Australians and support ongoing innovation for cost reductions and operational efficiencies.

HYDROGEN HUBS AS A SPRINGBOARD TO SCALE

Scale is key to becoming a globally competitive supplier. The International Energy Agency and other analysts have identified the development of hydrogen hubs as a cost-effective route to achieving scale.

Hubs aggregate various users of hydrogen into one area. Doing so minimises the cost of providing infrastructure – such as powerlines, pipelines, storage tanks, refuelling stations, ports, roads or railway lines – and supports economies of scale in producing and delivering hydrogen to end users. Hubs also help focus efforts for innovation and building a 'hydrogen-ready' workforce.

Hydrogen hubs could be situated to take advantage of existing users or potential hydrogen markets. Supplying hydrogen to ammonia makers and oil refineries, for example, are clear early opportunities.

Some hubs will likely be located near port facilities, for access to export opportunities. Stakeholder consultations and research has identified more than 30 ports as potential hub locations. These are outlined in the ARUP report, *Australian Hydrogen Hubs Study*.[1]

Other hubs may be near or in cities or in regional and remote areas with high demand (such as a large mine site, for example). A number of metropolitan and regional councils across Australia are looking at opportunities to use hydrogen in their communities.

Factors influencing hubs site choice include:

- access to demand
- land availability and ownership
- port potential (including current capacity, shipping distance and scalability)
- grid connectivity
- road and rail infrastructure access
- access to existing gas transmission pipeline easements
- water access
- economic, social and environmental factors (such as workforce access, weather, safety and other factors)
- stakeholder and community interest and acceptance
- proximity to prospective hydrogen production regions
- potential for hydrogen storage
- electricity pricing.

Figure 3.1 overleaf shows a conceptual overview of a hydrogen hub.

Coupling of the electricity and export sectors

Sector coupling can provide additional value streams for hydrogen projects and other sectors. For example, effective coupling of hydrogen production for export with electricity system operation could benefit both the electricity and export sectors.

Electrolysers, which use electricity to produce hydrogen, can take advantage of excess power when wind and solar generators are operating at capacity. They can be rapidly ramped up or down to provide demand response and frequency control services to the electricity grid. At times when the electricity grid is under pressure, hydrogen production can be halted, and stored hydrogen converted back to electricity when needed to meet peak electricity system needs. Used effectively this could allow for better integration of renewable energy technologies into Australian electricity grids and improved investment confidence for renewable energy projects. Further, it would increase options for electricity market operators to maintain power supplies in an emergency, improving energy supply security and reliability.

A more secure and reliable grid will help to ensure constant energy supply to underpin hydrogen production. Changes to energy market operation may be needed to fully enable these benefits. Actions to consider integration of hydrogen into energy markets are discussed further in **Chapter 4**.

Hubs and sector coupling

Hubs can facilitate sector coupling – integration of hydrogen production and end-use sectors to maximise services and benefits. For example, in the future, hydrogen production and use will more closely link operation of the electricity grid, the gas distribution network for building heating and the infrastructure supplying fuel for vehicles. Hydrogen production by electrolysis will use substantial quantities of electricity and could provide grid firming and stabilisation services, while the hydrogen produced could be used to refuel fuel cell vehicles, add to gas supply, provide feedstocks or heat or be exported overseas.

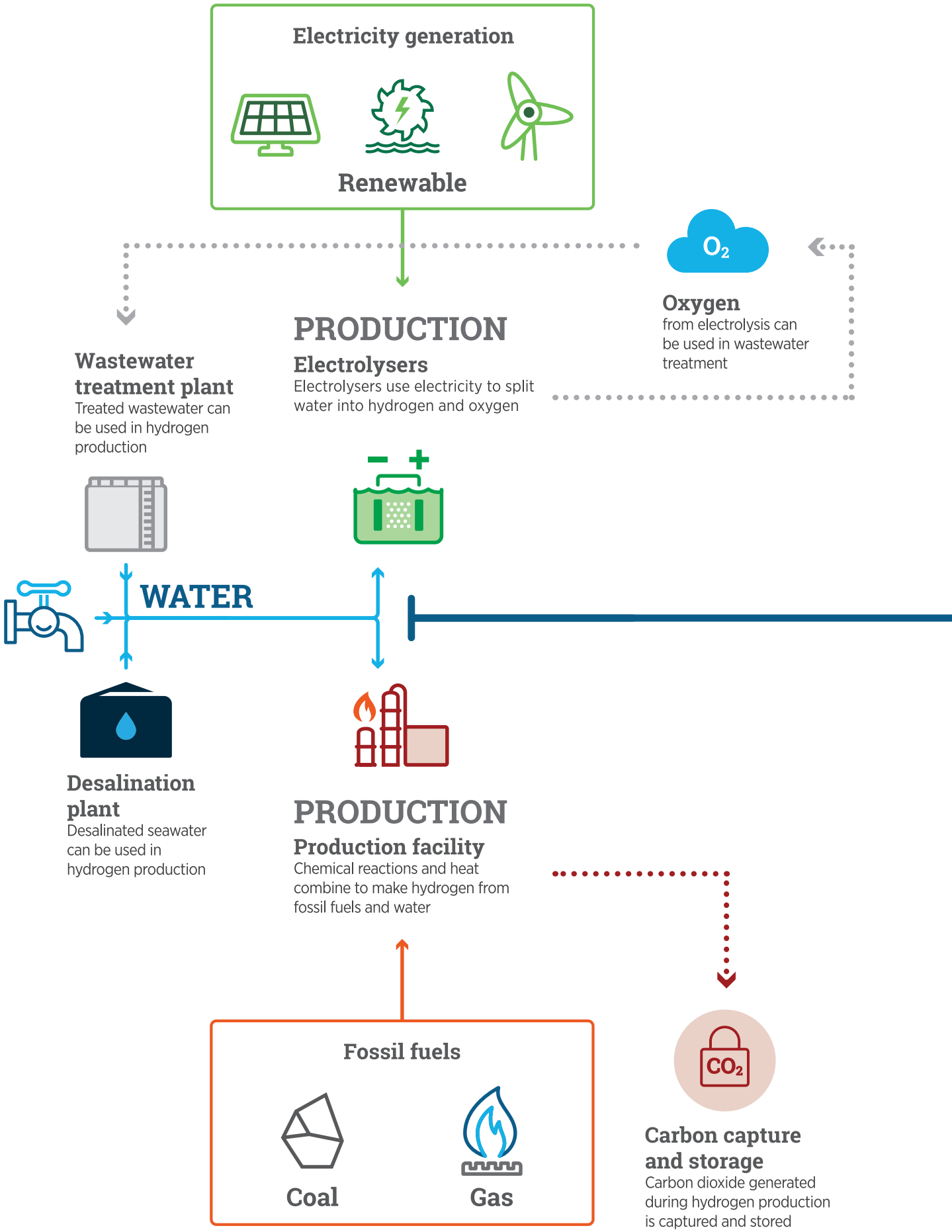
Intelligently co-optimising these links could create additional benefits such as greater fuel security, energy storage, improved use of gas and electricity assets or better ability to integrate variable renewable electricity sources such as wind and solar energy into electricity supply. These benefits will be easier to realise in the early days through co-locating users in hubs.

Government action for hydrogen hubs

Australian governments support the hub model as a prospective early-stage approach to achieve the scale needed for a competitive industry. Most Australian jurisdictions have existing industry incentives that could apply to hubs, such as concessional finance, access to funding for new public infrastructure, favourable zoning, prioritisation of planning approvals and public-private partnerships to share the cost and risk of infrastructure development.

Governments will consider respective planning and funding timelines, and to the extent possible, harmonise funding application processes for hub projects.

While hubs are expected to be early focal points for growth, governments and industry may choose to support projects outside of hubs. Not all hydrogen uses will necessarily occur in or around hydrogen hubs – back-up power supplies, remote area farms and defence facilities, for example. Pilots and trials outside hubs may have other advantages. The development of hubs should be complementary to a range of applications for hydrogen. It will be important to be flexible and consider the merits of specific projects on a case-by-case basis.


Electricity generation
Renewable
O_2
Oxygen
from electrolysis can be used in wastewater treatment
PRODUCTION
Electrolysers
Electrolysers use electricity to split water into hydrogen and oxygen
Wastewater treatment plant
Treated wastewater can be used in hydrogen production
WATER
Desalination plant
Desalinated seawater can be used in hydrogen production
PRODUCTION
Production facility
Chemical reactions and heat combine to make hydrogen from fossil fuels and water
Fossil fuels
Coal
Gas
CO_2
Carbon capture and storage
Carbon dioxide generated during hydrogen production is captured and stored

HYDROGEN HUB

Hubs make the development of supply chain infrastructure more cost-effective by aggregating various users of hydrogen into one area. These may be at ports, cities or remote areas. Hubs could also foster innovation and promote sector coupling.

Industrial use

Hydrogen can be used by industry as a chemical feedstock or as a fuel for heating, electricity generation or mobility applications.

STORAGE

Hydrogen is stored under pressure

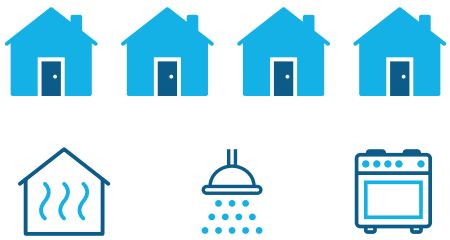
Exports

Hydrogen is liquefied or converted to another chemical for shipping

Natural gas distribution network

Gas blending

Hydrogen can be blended with natural gas to supply lower emissions heating and cooking



Transport

Hydrogen can power buses, cars, ships, trains and trucks.

Assessing hydrogen infrastructure needs

The growth of hydrogen hubs will increase the use of local infrastructure, such as for water, electricity, gas and transport. Managing these new demands and expanding infrastructure capacity will require strategic planning and coordination at all levels of government.

Australia will complete a National Hydrogen Infrastructure Assessment by the end of 2022, led and coordinated by the Australian Government. The assessment will consider hydrogen supply chain needs such as electricity and gas networks, water supply networks, refuelling stations, roads, rail and ports, while taking into account local community concerns and priorities.

The Assessment will be reviewed and updated at least every five years to highlight priorities for future infrastructure for competitive hydrogen supply chains.

The Assessment will be a useful tool to help inform government decisions around future support for pilots, trials, demonstration projects, approval processes and future hydrogen infrastructure.

Sector coupling in the blue economy

Clean hydrogen from offshore renewable energy could offer beneficial synergies by coupling with other marine industries, potentially in offshore hydrogen hubs. For example, co-locating electrolysers with offshore wind turbines can do more than just make hydrogen for exports and land-based users. It could supply oxygen to aquaculture industries in the same location, and provide fuel for vessels. Existing parts of platforms from offshore oil and gas facilities could potentially be repurposed or reused to support hydrogen production.

Australia is exploring these and other opportunities through the Blue Economy Cooperative Research Centre. The Tasmanian-based Centre brings together national and international expertise in aquaculture, marine renewable energy and offshore engineering. It is supported by the Australian and Tasmanian Governments.

ACTIONS FOR DOMESTIC GROWTH

Over the next five years, with international markets still emerging and domestic demand uncertain, investing in hydrogen production and use will be quite high-risk. But not investing is even riskier.

Without early-stage investment, Australia will fail to secure important supply relationships and capture the market share on which further growth will be built. Governments can help industry to manage this risk by encouraging both supply and demand during this critical phase.

Supporting research, pilots, trials and demonstrations along the supply chain

CSIRO regards Australia's research, development and demonstration (RD&D) capability as well-positioned to support hydrogen industry development.[2] Australian RD&D has the potential to reduce capital and operating expenses through incremental improvements to mature technologies. We have the expertise to deliver new technologies that offer step-change benefits to hydrogen supply chains. RD&D will also help ensure and demonstrate safety across production, storage, transport and use of hydrogen; and in understanding and minimising environmental impacts of a large-scale hydrogen industry.

As well, our researchers and innovators will be able to provide clear direction on demonstration and scale-up requirements and help to maintain focused effort and a long-term perspective. Our RD&D capability can support and encourage participation in both domestic and international forums. Many in the Australian research and innovation community are already participating in national and international collaboration and knowledge sharing.

Research institutions can also support efforts to educate the public about hydrogen and its benefits, with demonstration projects showing it can be used safely. This is particularly important given recent findings that Australians view research institutions, such as CSIRO and universities, as a trusted and non-biased source of information.[3] While recognising that other innovation priorities may emerge, governments agree that the following areas should be priorities for research, pilots, trials and demonstration projects:

- Switching current industrial hydrogen users to clean hydrogen
- Investigating new opportunities for clean hydrogen such as clean ammonia exports, clean fertiliser exports, industrial heating, iron ore processing and steel making
- Using hydrogen in remote applications, such as in microgrids for mining and remote communities, in farming and marine applications, at remote defence facilities and as fuel for heavy-duty mining vehicles
- Opportunities for backup power supply, such as for mobile phone towers, hospitals and other critical infrastructure
- Enabling blending of hydrogen with natural gas and eventual use of 100% hydrogen in gas networks
- Using hydrogen for transport, with a focus on heavy and long-range road transport, rail and shipping
- Optimising hydrogen and electricity system interactions, such as through timing hydrogen production to match variable renewable generation and through use of hydrogen for storage and dispatchable generation
- Testing and proving technologies that reduce the cost of making, moving, storing and using hydrogen
- Using water from sustainable sources, such as waste water or from seawater for hydrogen production
- Developing cross-sector linkages and deriving value from sector coupling.

Further details about research priorities and opportunities for Australia can be found in the CSIRO report, *Hydrogen research, development and demonstration: Opportunities and priorities for Australia*.[4]

Australian governments support improved knowledge sharing from hydrogen-related projects, to help remove some of the information barriers the hydrogen industry faces and improve community awareness and rate of scale-up.

Jurisdictions often have funding arrangements in place to support industry pilots, trials and demonstrations. Governments may consider coordinating their respective funding arrangements to facilitate larger hydrogen projects.

The ammonia advantage

The single biggest current use for hydrogen globally and in Australia is for making the chemical ammonia. Ammonia production could be a key driver in creating a clean hydrogen industry.

Ammonia, comprised of hydrogen and nitrogen, has been used in industrial applications for more than a century. Its major uses are in fertiliser, explosives and production of plastics, textiles, pesticides, dyes and other chemicals. Although ammonia is toxic in its concentrated form, industry has a good safety record in handling, storing and transporting it.

Globally, more than half of hydrogen produced goes to making ammonia.[4] In Australia, it is almost three-quarters, amounting to more than 350,000 tonnes of hydrogen a year. As typically occurs elsewhere around the world, that hydrogen is currently made using natural gas without CCS.

Ammonia made from clean hydrogen provides an opportunity for Australia to jump-start large-scale production of clean hydrogen for other uses.

Not only is potential global demand for ammonia produced from clean hydrogen a future export market in itself, ammonia is also an immediately available carrier to export clean hydrogen. There are currently no commercially available ships to transport liquefied hydrogen, but ammonia is already commonly transported in tankers. It can be used as a carrier of hydrogen (just as hydrogen is a carrier of energy). It is easier to transport and store, can be used as a fuel and can be separated back to hydrogen and nitrogen when needed.

While it does take energy to turn hydrogen to ammonia and back again, CSIRO has developed a game changing technology that makes extracting hydrogen from ammonia much easier.

Given its potential as a cost-effective low carbon energy source, there is growing consideration of using ammonia (produced with clean hydrogen) directly as a fuel.

Because of its toxicity, it is likely using ammonia for fuel will be limited to large-scale industrial activities. Applications being explored include its direct use as fuel for ships, burning it alongside coal in existing coal-fired power stations and directly using it in fuel cells for electricity generation. These and other new uses for ammonia made from clean hydrogen could provide significant future growth for ammonia in an otherwise relatively mature industry.

CSIRO'S BREAKTHROUGH MEMBRANE TECHNOLOGY

CSIRO researchers have developed a new game changing technology to convert ammonia to high-purity hydrogen at its point of use. The technology uses thin vanadium membranes to allow hydrogen to pass through, while blocking all other gases.

CSIRO is currently completing a two year research project to develop and demonstrate a hydrogen production system that uses its vanadium membrane technology.

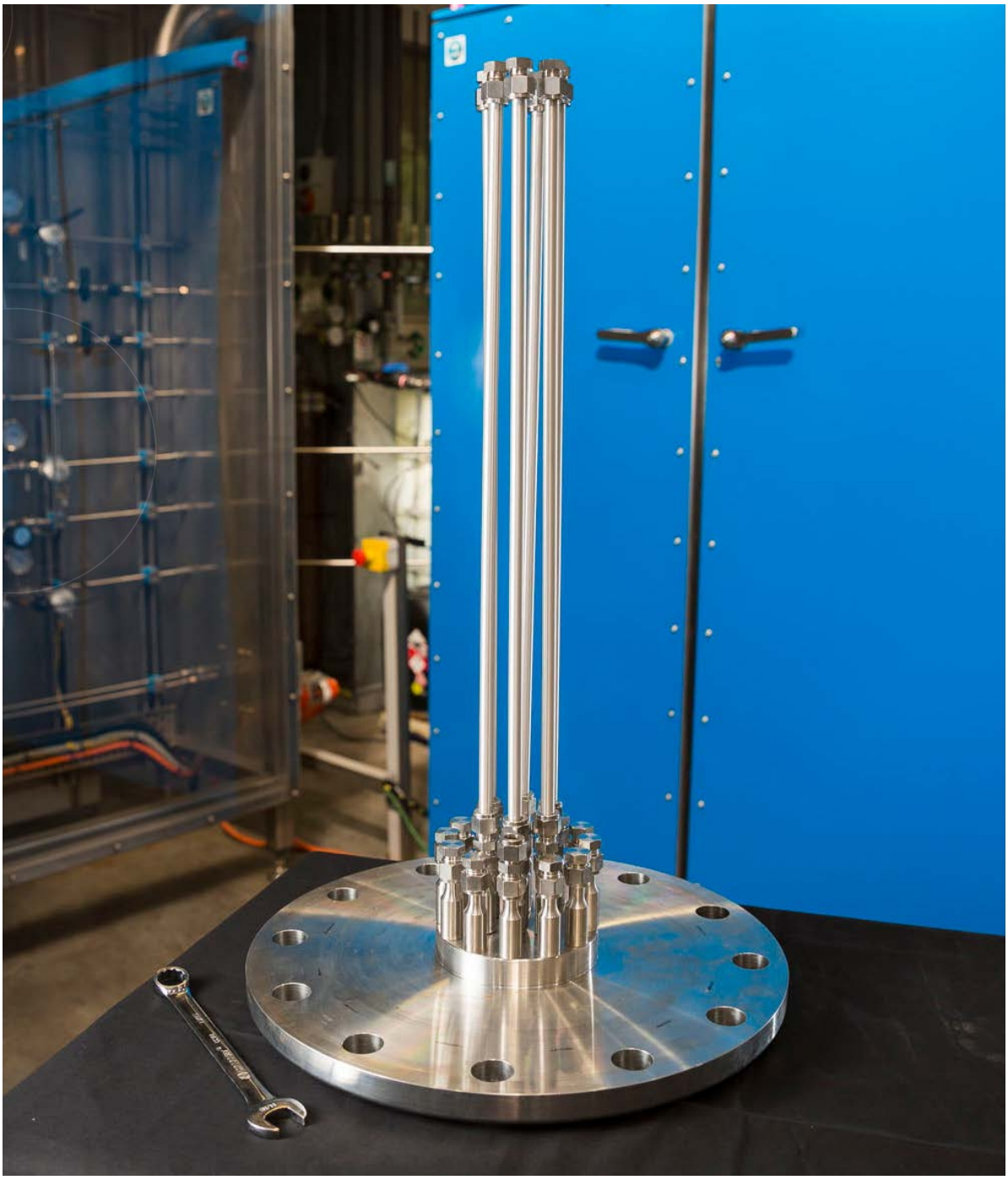


Image courtesy of CSIRO – CSIRO's vanadium membrane technology, which enables ammonia to be used as a carrier material for hydrogen storage and transport. © John Nguyen Photography.

Using clean hydrogen in Australian gas networks

Adding clean hydrogen in Australian gas distribution networks has advantages for stimulating early hydrogen demand growth. This is because governments can directly influence when and by how much demand for hydrogen is increased, whereas other sources of hydrogen demand depend on market uptake of hydrogen end-use technologies.

However, it is clear that further research and reforms are needed before widespread hydrogen blending in gas distribution networks can occur. For example:

- Analysis of the effects of gas blending on gas end users (including user piping and appliances) is still underway. Many existing residential gas appliances are tested to operate under limited conditions with hydrogen at levels of 13%. This is to factor in a safety margin well above the likely naturally occurring levels of hydrogen in natural gas, and is not meant to represent a safe upper limit for general appliance operation.
- It is unclear whether the definition of natural gas in the National Gas Law captures blended gas. The extent to which the existing regulatory framework applies to blended gas and the implications of this for blending activities are uncertain.
- Better understanding is needed of the technical and regulatory effects on gas networks and end users and the changes required for blending above 10% and of switching to 100% hydrogen in Australian gas networks.
- Agreement is needed on how to determine and set safe upper limits for the injection of hydrogen in gas networks, considering issues including appliance readiness and end user and market effects.
- Additional economic analysis is needed to understand the relative costs and benefits of blending and of switching to 100% hydrogen into Australian gas networks.
- Analysis is needed of consumer experiences from blending trials currently underway.

Further details of required research and reforms can be found in the reports *Hydrogen in the Gas Distribution Networks* and *Hydrogen impacts on downstream installations and appliances* developed by GPA Engineering.[8, 9]

Clean Gas Supply Using Hydrogen

Efforts are underway globally to investigate whether hydrogen can replace natural gas to decarbonise the gas supply. In Australia, these considerations raise three questions: Is Australia's gas infrastructure physically suitable? Is using hydrogen achievable at a reasonable cost? Will consumers accept it?

Early investigations suggest hydrogen can be safely blended into Australia's gas distribution networks at low volumes, at yet to be determined limits. Preliminary technical and regulatory investigations have not found any significant implications for gas quality or safety from blending up to 10% hydrogen by volume in gas distribution networks, where the gas mixture is homogenous throughout the network.[5]

Changes will be needed to appliances and to gas networks to manage the different properties of hydrogen compared to natural gas once these limits are achieved. A switch to 100% hydrogen use would be required at this time.

High level modelling of two pathways to decarbonise Victoria's gas consumption – full conversion to renewable electricity for existing uses of electricity and natural gas, and the use of hydrogen as a means of decarbonising gas use – suggests that replacing natural gas use with hydrogen using existing infrastructure may be up to 40% less expensive than full electrification.[6]

Preliminary consumer research by the University of Queensland reveals that safety is consumers' primary concern when it comes to hydrogen use in homes and in the community. However, most of those surveyed indicated they trusted that there would be adequate safety precautions in place should hydrogen use become widespread.[7] They wanted more information about the costs of appliance upgrades. Most people interviewed, however, were unconcerned about blends of up to 10% hydrogen by volume.[8]

These results suggest that further investigation of the benefits of using hydrogen in future gas supply is warranted.

To help to inform this research and any reforms, governments support continuing pilots, trials and demonstrations of hydrogen in gas distribution networks, where distributors can satisfy relevant regulators that:

- The distribution network is comprised of materials confirmed to be safe and suitable for hydrogen blending
- End user gas supply infrastructure (including appliances) is safe and suitable for hydrogen blending
- The distributor has adequate safety and training procedures in place
- The effects of blending for gas network users who currently use natural gas as chemical feedstock have been considered and mitigated.

Government action from 2020

Governments will complete a review by the end of 2020. The review would:

- Consider the application of the National Gas Law and relevant jurisdictional laws and regulations to hydrogen and advise the COAG Energy Council of recommended options to best address regulatory ambiguity, remove unnecessary regulatory barriers and improve the consistency of laws across jurisdictions.
- Consider the economics of blending and of eventual use of 100% hydrogen in Australian gas networks.
- Advise the COAG Energy Council recommended options for setting and allowing updates of upper limits on the volume of hydrogen allowed to be blended in gas networks. This will focus on keeping consumers safe, encouraging innovation and effectively managing any appliance readiness, end user and market effects issues.

Once this review and any actions that might arise from the review are completed, governments may support changes to gas networks and markets to allow widespread blending, and later, sole use of hydrogen in gas networks. This would only occur where such use of hydrogen in gas networks:

- Carries an acceptably low level of safety risk
- Is broadly supported by affected communities, and
- Minimises impacts on gas prices and is in the long-term interests of consumers.

Australian governments may develop incentives to support the widespread blending of hydrogen in Australian gas distribution networks at a later date. Where governments introduce such blending incentives, Australian governments agree that, amongst other objectives, these incentives will:

- Where appropriate, encourage blending to occur in a manner that supports the development of hydrogen hubs
- Be consistent with the COAG Principles of Best Practice Regulation, in particular with respect to net benefits to consumers.

Hydrogen in gas transmission networks

Lastly, regarding use of hydrogen in existing high pressure gas transmission networks, research has identified potential pipeline safety and longevity issues. Australian governments will not support the blending of hydrogen in existing gas transmission networks until such time as further evidence emerges that hydrogen embrittlement issues can be safely addressed. Options for setting and allowing for ongoing updates of safe limits for hydrogen blending in transmission networks will form part of the review in 2020. Industry and researchers will continue to complete relevant research through initiatives such as the Future Fuels Cooperative Research Centre.

AGIG BUILDS 1.25 MW HYDROGEN PLANT FOR LOW-CARBON GAS

Australian Gas Infrastructure Group (AGIG) – the nation's largest gas distribution business – will produce hydrogen from mid-2020 from a new $11.4 million demonstration plant. The hydrogen will be blended with natural gas and provided to nearby homes and businesses.

AGIG's facility will be called Hydrogen Park SA (HyP SA) and feature a 1.25 MW electrolyser to produce hydrogen using renewable electricity from the grid and on-site solar. The electrolyser will play a role in showing how this technology can be integrated into electricity networks to help stabilise grid supply, providing an important service supporting renewable electricity generation. The South Australian Government supported HyP SA with a $4.9 million grant.

Artist impression of AGIG's proposed Hydrogen Park SA (HyP SA), featuring a 1.25 MW electrolyser capable of supplementing electricity grids with power generated from renewable sources.

Initial steps towards using hydrogen for transport

One of the most exciting prospects for hydrogen is the transport sector – Australia's largest end user of energy.[10] Analysis by the International Energy Agency already shows hydrogen to be cost-competitive in selected uses.[11]

Hydrogen fuel carries much more energy than the equivalent weight of batteries. It complements battery electric vehicle technology, by providing a viable alternative for powering buses, trucks and ships carrying heavy loads and travelling long distances. Shorter refuelling times can support business productivity and consumer convenience, especially for consumers without off-street parking.

Further, public benefits such as improved fuel security (through greater choice of fuel supply options and reduced dependence on fuel imports), reduced carbon emissions, cleaner urban air and noise reduction provide added incentives for use.

Recognising these advantages, governments have a shared vision of hydrogen being a clean, cost-competitive fuel option for Australian land and marine transport, in particular for heavy-duty and long-range transport applications.

Governments support an adaptive approach to building demand for hydrogen as a transport fuel. The initial focus will be on transport tasks that do not require an extensive network of refuelling stations and offer compelling performance and industry development advantages.

Refuelling station viability can be improved where demand can be concentrated or coupled with other uses of hydrogen. Refuelling stations established for large users could support hydrogen access for smaller users, such as light vehicles. Governments also support refuelling stations on major freight and passenger road corridors to support greater range for hydrogen vehicles. Preliminary work to map some of these requirements has already begun.[12]

Refuelling stations and hydrogen supply should develop in step with hydrogen vehicle deployment. This will ensure refuelling stations are commercially viable. Fuel infrastructure priorities will be included in the proposed National Hydrogen Infrastructure Assessment so Ministers can periodically reconsider the need for action and calibrate relevant support mechanisms.

Early opportunities for hydrogen vehicles include industrial users, such as at ports, or remote industrial sites; 'back to base' transport applications, such as fleet vehicles and metropolitan public transport; and freight transport.[13] These and other opportunities are explored in the Aurecon report, *Hydrogen for Transport: Prospective Australian use cases*. Governments will consider opportunities for new vehicle technologies, including hydrogen vehicles, in government fleets and large government contracts.

Consortium models that bring together vehicle manufacturers, hydrogen producers and fuel suppliers could be used by industry to build up supply and demand at the same time and lower project risk.[13] These multi-partner approaches can be effective for overcoming different supply and demand side barriers in a coordinated way. Governments will encourage consortium-based approaches to building refuelling infrastructure, with industry contributing to associated costs to promote long-term commercial viability.

Governments agree if providing support for refuelling infrastructure, to promote open access wherever practical. This would encourage projects to unlock further investments, maximise public benefit and minimise barriers to scaling up the industry.

The COAG Transport and Infrastructure Council will finalise a work program in 2020 to address barriers for low and zero emission vehicles, including hydrogen vehicles, in Australia. Key themes will include government leadership, infrastructure availability, upfront purchase costs and model availability, and access to public information. It will complement and build on the National Hydrogen Strategy.

Actions to build hydrogen supply and demand are only one part of building a flourishing hydrogen industry. Other actions are also needed to remove unnecessary market barriers, create an attractive investment environment and build relationships to underpin global supply chains.

Endnotes

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7 Lambert, V., and Ashworth, P. 2018, *The Australian public's perception of hydrogen for energy* https://arena.gov.au/assets/2018/12/the-australian-publics-perception-of-hydrogen-for-energy.pdf

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11 International Energy Agency 2019, *The Future of Hydrogen*, p 135

12 Bureau of Infrastructure, Transport and Regional Economics 2019, *Location options for a freight-based limited initial deployment of hydrogen refuelling stations*.

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TOYOTA AUSTRALIA'S HYDROGEN CENTRE

Up to 60 kg of hydrogen will be produced each day from Toyota's new renewable energy hub in Altona, Victoria.

Toyota is building a new Hydrogen Centre as part of a larger plan to transform Toyota's former manufacturing site. An electrolyser and hydrogen refuelling station will be fully operational by late 2020. It will be Victoria's first commercial-scale station for refuelling hydrogen fuel cell vehicles. Solar PV and battery storage will contribute to the incremental energy needs of the site.

An education centre is expected to be open in 2020. The Australian Renewable Energy Agency (ARENA) will contribute $3.1 million to the centre, with Toyota investing $4.3 million.

Artist impression. Part of Toyota Australia's former Altona manufacturing facility will be transformed in a Hydrogen Centre, set to be Victoria's first commercial-scale refuelling station.

4 ENABLING INDUSTRY GROWTH

For Australia to become a global leader in clean hydrogen by 2030, governments, industry and the community need to work together towards a common vision.

This common vision includes:

- An environment conducive to investment, through better and more consistent regulation
- Helping to build relationships with future country markets
- Supporting early stage technology development, then stepping back and letting the market take over as the industry matures.

Governments also recognise the role regulation can play in driving change and promoting technology switching. In tandem, industry can drive growth by taking risks on new ideas and technology.

There are practical and immediate actions that we can undertake to improve the regulatory environment and build international relationships.

RESPONSIVE REGULATION

Governments play an important role in ensuring the regulatory environment is consistent and predictable to support industry investment and innovation. While safety is paramount, regulation should also be efficient to secure opportunities for jobs and economic development.

While existing regulations already apply to industrial applications of hydrogen in Australia, there is a need to prepare the legal framework for the large-scale production and use of hydrogen as an energy carrier.

A preliminary legal review across the jurisdictions has identified about 730 pieces of legislation and 119 standards potentially relevant to hydrogen industry and supply chain development. Of greatest priority for further detailed legal review are the subset of these laws and standards identified as directly applicable to hydrogen's production, transport to market, use as a fuel, use in gas networks, safety, project approvals, environmental protection and economic effects of the industry.[1]

Governments will review existing legislation, regulations and standards (legal frameworks) as needed to address whether their respective legal frameworks can support hydrogen safety and hydrogen industry development. In their reviews, governments will consider the principles and prioritisation criteria set out in the preliminary legal review, and the legislation, regulations and standards it identified.

Governments agree to coordinate reviews of legal frameworks where practical, and work together to:

- Support the development of technical safety standards for the hydrogen industry, noting the role of Standards Australia (refer to the box below).
- Consider and evaluate, with the aim of developing a nationally consistent approach as far as practicable, regulatory models to address and support:
  - hydrogen safety, noting the role of SafeWork Australia (refer to the box below) and state-based safety agencies
  - hydrogen industry development

  with the aim of developing a nationally consistent approach as far as practicable.
- Where necessary, amend existing legislation and regulations or draft new legislation to address hydrogen safety and support hydrogen industry development.

Standards Australia and SafeWork Australia

Standards Australia has formed a Hydrogen Technologies technical committee to facilitate developing national hydrogen standards. Key functions of the committee include synchronising with international standards and the national standards of trade partners, and working with other bodies to include specific requirements for hydrogen in other standards frameworks.

SafeWork Australia is an Australian Government statutory body established in 2008 to develop national policy relating to work health and safety (WHS) and workers' compensation. It is jointly funded by the Commonwealth, state and territory governments through an Intergovernmental Agreement. As a national policy body, SafeWork Australia does not regulate WHS laws. Australian, state and territory governments retain responsibility for regulating and enforcing WHS laws in their jurisdictions.

Shared principles for nationally consistent regulation

Delivering nationally consistent regulation is best supported by shared principles. For any new regulations associated with hydrogen, Australian governments will follow the COAG Principles of Best Practice Regulation.[2] Further, the following will be important to advance industry growth:

- **Collaboration:** aligning national and international regulations, considering the broader regulatory ecosystem. Governments should share expertise to promote consistent frameworks
- **Fit for purpose:** taking a systems approach to regulation, focusing on outcomes and performance. Governments should ensure regulation is consistent with strategic objectives
- **Flexibility:** recognising that, as the industry evolves, regulatory frameworks may require continuous adjustment. Governments should use adaptive, iterative approaches, and use standards, codes of conduct and other tools to allow flexibility
- **Innovation:** fostering innovation and using models such as regulatory sandboxes and accelerators to test new ideas. Governments should be open to experimentation and new approaches to frameworks appropriate for an emerging industry.

A coordinated approach to planning and regulatory approvals for hydrogen projects

Most Australian governments have processes to facilitate their planning and regulatory approvals. This includes coordinating the requirements of their various departments and regulatory agencies to give project proponents a visible single entry point to access multiple regulatory approvals.

To improve their 'hydrogen-ready' capabilities in performing these functions, several state and territory governments have established cross-government working groups to develop competency in and awareness of hydrogen across government. These groups identify and address regulatory gaps, and provide advice to proponents of hydrogen projects to ensure compliance with existing requirements. These groups include emergency services personnel and workplace safety, environmental, planning and technical regulation authorities involved in the permitting of hydrogen facilities.

To encourage private investment in hydrogen projects, governments will develop and incorporate 'hydrogen-ready' capabilities into planning and regulatory approval mechanisms where required. For example, more knowledge of how hydrogen projects work may be required to understand how they should be treated under government approval processes.

Industry associations should also play a role by sharing knowledge with their member businesses about navigating approval processes. This includes informing members and regularly providing feedback to governments on how processes are working from industry's perspective.

BUILDING MARKETS AND ATTRACTING INVESTMENT

Integrating hydrogen into energy markets

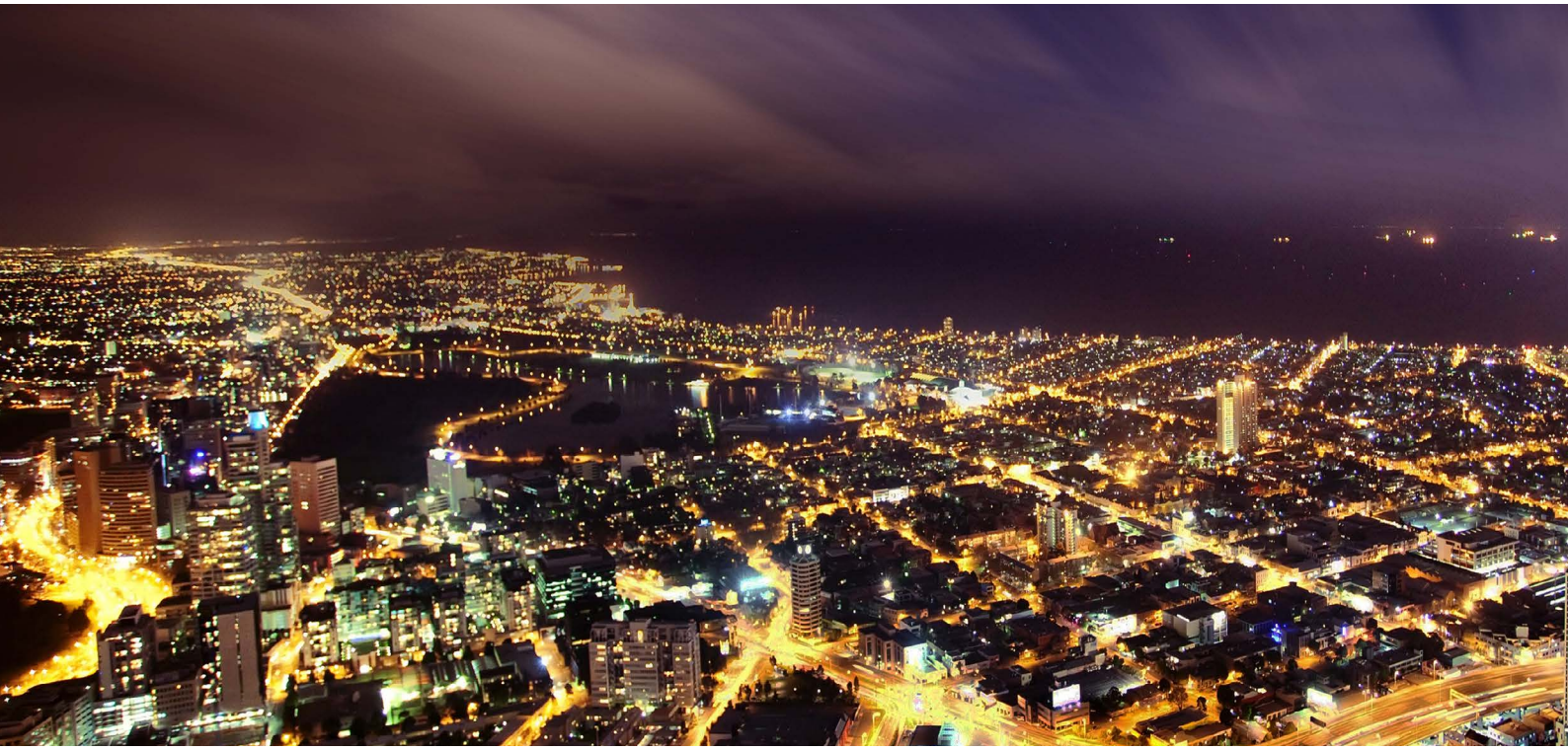
As discussed in previous chapters, hydrogen enables energy to flow between the electricity, gas, and transport sectors. Electrolysers, as large electrical loads, can be ramped up and down to provide demand response and frequency control services for electricity systems. Hydrogen from electrolysis can be blended with natural gas, stored as a gas, used as a fuel for transport or converted back to electricity as needed to manage daily and seasonable variability in renewable energy supply or to meet peak energy system needs.

Future energy market planning and reforms will need to account for how hydrogen will change the way energy systems and markets operate. For example, AEMO's Integrated System Plan and current and future electricity market reforms should consider the impact of electrolyser loads and increased need for generation in electricity systems. Other areas where large-scale hydrogen production may affect energy markets include:

- ancillary services
- grid connection arrangements
- demand response mechanisms
- investment coordination
- the value of energy storage
- management of distributed energy resources
- network system strength and likely future congestion.

Governments will ask energy market bodies to account for the possible effects of hydrogen industry growth in their planning and future reforms. Industry will need to communicate its preferred market settings early to help guide market bodies.

Governments further agree to a future review, drawing on experience from pilot projects, trials and demonstrations, to consider options for energy market reforms to improve the integration of hydrogen into energy markets and to deliver additional benefits from hydrogen to consumers. The review will be completed by 2024.



Hydrogen's role in a secure and affordable energy supply

The domestic production and use of hydrogen offers potential energy security benefits for Australia. These benefits could include improved ability to manage the integration of variable wind and solar generation into electricity supply, improved electricity system resilience to generation and transmission disturbances, greater diversity in energy supply options and reduced reliance on fuel imports.

To capitalise on these benefits, governments will consider the role of hydrogen in supporting Australian energy security by 2025. Areas for consideration will include:

- **National Energy Security Assessments** – reviews of Australia's energy needs, and assessments of risks to energy supply and costs
- **Electricity, gas and liquid fuel emergency provisions** – government powers and response plans that apply in emergencies
- **Mandatory reporting requirements**, such as those under the *Petroleum and Other Fuels Reporting Act 2017* – requirements for the Commonwealth Department of the Environment and Energy to collect data and report on the production and stockholdings of liquid fuels in Australia.

The ongoing availability and affordability of energy is key to Australia's economic prosperity. This is particularly important for large industrial business consumers who need affordable energy to remain competitive. Large-scale domestic hydrogen production and use may drive changes to the distribution of energy costs and availability of hydrogen for consumers.

To support continued energy affordability for all consumers, governments will monitor the impacts of hydrogen on energy costs, and where necessary, consider the need for changes to energy affordability and consumer protection policies.

Governments do not see a need to apply market constraints, such as domestic hydrogen reservations or price caps, at this time. However, this stance will be revisited periodically as the market develops.

Certainty around taxation, excise and other fees or levies for hydrogen

Most energy commodities produced are subject to taxation, excises, fees or levies. Hydrogen is not explicitly considered as an energy source in these regimes. As hydrogen production and use grows, appropriate taxation, excises, fees or levies could help ensure that the community shares in the economic benefits from developing a hydrogen industry. Australian governments recognise the importance of the Australian public receiving a share of future benefits from a hydrogen industry and for investors to have certainty about future revenue arrangements.

Governments will continue with the revenue arrangements that now apply to hydrogen, but may review them in the future. Governments will consult industry and the community before making any changes to current revenue arrangements that are specific to hydrogen. For indicators that may inform these reviews refer to **Chapter 6**.

INTERNATIONAL OUTREACH AND ENGAGEMENT

Partnerships for a global hydrogen market

Australia is already a valued and experienced energy provider to the Asian economies set to become major hydrogen importers, such as Japan, Republic of Korea, Singapore, and Taiwan. Australia's proximity to Asia, abundant renewable energy assets and experience developing resources and energy projects position it to be the hydrogen supplier of choice.

Bilateral partnerships to build markets

Australia sees bilateral agreements as crucial to indicate our commitment and capability as a hydrogen partner of choice. Australia will be actively seeking to establish these partnerships and ensure they meet our national interests.

Bilateral agreements between Australia and partner countries will ideally showcase both countries' level of ambition, areas of mutual benefit and areas of comparative advantage. Agreements would also include a commitment to work together to develop common standards and international regulations, and encourage industry participation in these processes. This could include participating in and promoting an international hydrogen certification scheme. Joint actions to address safety challenges will also be important to Australia.

Australia will also seek to work with bilateral partners to promote trade and investment in hydrogen. This will include advocating for Australian industries' engagement in the design of market settings that facilitate trade, long-term investment, regional price transparency, efficient market operation, and commitment to sharing industry knowledge and skills between partners.

Australia also considers bilateral technical collaborations important to support the pace of research, development and deployment, and similarly, cooperation on pilot projects. Australia is already working with Japan on one such pilot project – the Hydrogen Energy Supply Chain.

Multilateral forums to promote efficient hydrogen trade and innovation

Australia already engages on hydrogen-related issues across multilateral and regional organisations. To provide our hydrogen industry with the best opportunity to develop and compete internationally, Australia will prioritise participating in forums that demonstrate leadership, shape the rules for hydrogen trade and investment, foster heightened sharing of best practices across research, development, deployment, and community engagement, and foster private sector investment that helps develop hydrogen production and use.

Leadership

The G20 and the Hydrogen Energy Ministerial have shown strong leadership in advancing international support for industry development. Australia is an active member of both and looks forward to continuing this engagement.

Shaping the rules

Australia will participate in forums such as the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), and others that focus on technical hydrogen industry standards and protocols to underpin trade and investment. These could include issues like safety standards, developing regulations, codes and standards and certification, trading and statistics benchmarks, intellectual property protection, and recognition of education and skills.

Sharing best practices

Australia will use forums like the Clean Energy Ministerial, Mission Innovation and the Center for Hydrogen Safety to advance international coordination, collaboration and sharing of best practices, including for emergency services. Australia's participation in the Center for Hydrogen Safety is discussed further in **Chapter 5**.

Our participation in these forums will help Australia influence the global pace of innovation, encourage our industry's engagement and provide opportunities for research and development collaboration. These forums also provide communication, education and outreach activities to increase government, industry and communities' understanding of hydrogen.

Fostering private sector investment

Australia will work through the Clean Energy Ministerial and the Leadership Group for Industry Transition to promote private sector investment in transitioning carbon-intensive industries such as steel making from fossil fuels to hydrogen.

Australia's participation in global hydrogen forums

Australian governments, businesses and researchers already participate in the following forums to progress hydrogen development:

- Asia-Pacific Economic Cooperation (APEC)
- Finance Ministers' Coalition on Climate Action
- Global Green Growth Institute (GGGI)
- Green Ammonia Consortium
- Hydrogen Council
- International Association for Hydrogen Safety (HySafe)
- International Energy Agency (IEA) forums, including the *Hydrogen Technology Collaboration Programme*, the *Advanced Fuel Cells Technology Collaboration Programme* and *Tracking Clean Energy Progress*
- International Maritime Organization Maritime Safety Committee
- International Standards Organization (ISO) and International Electrotechnical Commission (ITC)
- Mission Innovation and the Mission Innovation Clean Hydrogen Challenge
- Organisation for Economic Co-operation and Development (OECD)
- United Nations Framework Convention on Climate Change (UNFCCC)

Australia will continue to engage and work collaboratively with these initiatives where appropriate.

Hydrogen certification

Hydrogen consumers here and overseas will expect transparency around the environmental impacts of the hydrogen they use. While certification schemes generally focus on carbon emissions, there may also be scope to consider other impacts, such as water consumption.

Ideally a single global certification scheme will emerge that facilitates international trade as well as providing domestic consumers with the assurances they seek. Australia wants to be a leader in developing an international scheme. As far as practicable, any Australian domestic scheme should build on or harmonise with international certification schemes. We encourage Australian industry and customers to have a role in the design and development of the scheme. Consideration will be given to the European CertifHy framework in developing a certification scheme.

Australia does not want to see any international disagreement about certification delaying investment in hydrogen production. One way to avoid this would be to quickly establish a minimal certification scheme that verifies and tracks production technology, scope 1 and scope 2 carbon emissions, and production location. The scheme could be expanded later to include water consumption and other factors. Such an approach would allow countries to set their own definitions of 'green' or 'low-emissions' hydrogen, with reference to agreed international standards.

Building community confidence

As the hydrogen industry scales up and Australia becomes a major exporter, a certification scheme will be just one of the measures needed to meet community expectations and build trust and confidence. Measures will also be needed to ensure compliance with environmental and safety regulations and standards, and that the Australian public benefits through jobs and economic development.

Endnotes

1 Clayton Utz, 2019, Hydrogen Industry Legislation, http://www.coagenergycouncil.gov.au/publications/reports-support-national-hydrogen-strategy

2 Council of Australian Governments, 2007, *Best Practice Regulation: A guide for Ministerial Councils and National Standard Setting Bodies*, p 4, https://www.pmc.gov.au/resource-centre/regulation/best-practice-regulation-guide-ministerial-councils-and-national-standard-setting-bodies accessed 11 November 2019

5 BUILDING BENEFITS FOR THE AUSTRALIAN COMMUNITY

Building a clean hydrogen industry requires public trust and confidence.

While a clean hydrogen industry will create new well-paid jobs and contribute to the nation's economic prosperity, Australians expect this can be achieved without compromising safety, cost of living, water availability, access to land or environmental sustainability.

This chapter outlines the actions governments will take to ensure benefits and impacts are shared fairly and that community concerns are heard and responded to.

COMMUNITY CONFIDENCE AND EDUCATION

Australian governments recognise a large-scale hydrogen industry can only be created with community support. Central to earning public trust and confidence in the industry is ensuring that the production, storage, transport and use of hydrogen is safe, environmentally friendly and in the public interest.

Community expectations about hydrogen are not unique: any proposed large industrial, renewable electricity or resource project needs to address local concerns to earn the public's confidence. This requires engaging with local communities to ensure governments and industry take into account societal expectations and respond accordingly.

Work to date has identified that raising public knowledge and awareness of hydrogen and its benefits is critical to success. Lessons learned from other sectors show it is important for project proponents and governments to be visible and readily available to local people in areas being considered for projects. Insights can be drawn from capturing real-time community feedback and providing immediate information to answer concerns as they are raised. Ensuring the community has factual information from a source they trust is fundamental.

Building community support will be easier when there are explicit community benefits. These might be, for example, a reliable and affordable supply of hydrogen for heating, or new jobs.

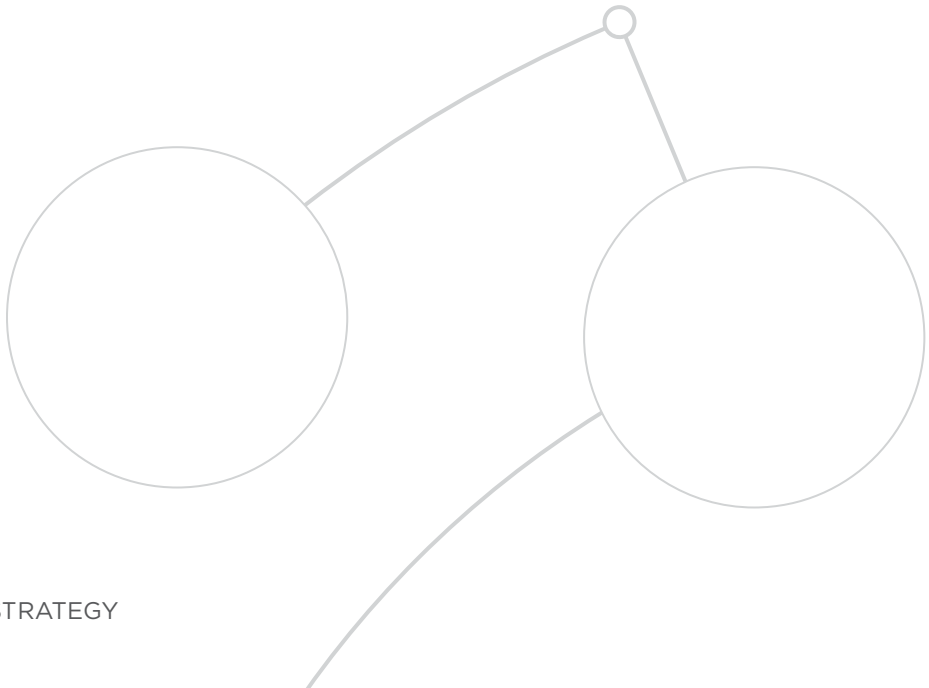
A robust regulatory and enforcement regime for safety standards, and the presence of trained emergency services personnel will also be required to ensure hydrogen is seen as safe.

Building community knowledge about hydrogen

Enhanced understanding of hydrogen is another key to increasing public confidence in a hydrogen industry. A University of Queensland study suggests the more Australians know about hydrogen, the more likely they are to support developing a hydrogen industry.

While acceptance of hydrogen is likely to grow of its own accord as people get used to its everyday use, public education will help accelerate the process. The University of Queensland study suggests Australians want governments and trusted research institutions, such as the CSIRO and universities to provide them with accessible, easy to understand information about the emerging hydrogen industry.[1] Community consultations to inform the Strategy suggest the same.

To begin building community knowledge, Australia will develop a community education program to provide clear and accessible information about hydrogen's risks, benefits and safe use. The program will communicate the particular benefits hydrogen development can bring to regions as well as more general benefits such as economic growth, lower carbon emissions and reduced air pollution.



BRINGING THE MESSAGE HOME

Following the 8th International Conference on Hydrogen Safety, held in Adelaide, in September 2019, the South Australian Government hosted a hydrogen safety public forum, attended by students, representatives from community organisations and interested members of the public.

International and local hydrogen experts spoke about how hydrogen is being delivered safely across many applications. Attendees had a chance to inspect hydrogen vehicles and eat sausages cooked on a hydrogen-fuelled barbeque.

Providing such opportunities for the public to see hydrogen used in day-to-day activities is an ideal way to increase confidence in its large-scale use.

Enjoying a barbecue cooked with hydrogen. Image courtesy of Andre Gascoigne, South Australian Department for Energy and Mining.

Providing for community engagement

Giving local communities a say at the early stages of hydrogen project development is critical to building trust. There is an opportunity to draw on lessons from other sectors to ensure best practice in community engagement.

Communities are diverse, and effective community engagement requires understanding those differences.[2] There is often benefit to building and maintaining ongoing relationships between businesses, conservation groups, Indigenous groups and other interested stakeholder groups, the project developer and local governments. Building such relationships takes time and will include a range of activities from one-on-one individual meetings, to small group discussions, as well as specific activities such as focus groups, participatory planning exercises and public meetings. The test of these efforts and activities is that they lead to meaningful outcomes for communities.[2]

A review by the University of Queensland of national and international resources to inform the Strategy provides guidelines and tools for best practice community participation and engagement.[2] The review suggested criteria for best practice community engagement including:

- have a clear purpose
- be inclusive
- be timely
- be transparent
- build relationships
- create positive images around the momentum for change
- be well-resourced in both time and money
- be tailored to local needs

Australian governments support best practice for community engagement and its use to build community awareness and ensure community engagement for large or significant projects.

Responsible industry development

Australians expect the hydrogen industry to listen and respond to community concerns, operate in a safe and acceptable way and protect the environment.

Focus group results suggest specific community interest in the number and type of local jobs the industry might create, especially where hydrogen production facilities will take land away from other uses and whether hydrogen production will put more pressure on water resources.[2] Land and water concerns were particularly pointed in farming communities, especially those with recent experience of drought.

Key to building community confidence will be providing accurate information and responding to these community concerns in a way that meets both legislative requirements and community expectations.

One opportunity is to work with local communities to ensure benefits are distributed as fairly as possible. A focus on local outcomes will help to build trust in both project developers and government regulators.

Australian governments support the development and implementation of a set of industry undertakings to address community concerns and guide the development of Australia's hydrogen industry. This work will be led and designed by the Australian Hydrogen Council in collaboration with governments. It will specify appropriate principles to safeguard the community, communicate issues and engage with regulators.

WHAT DO AUSTRALIANS THINK OF HYDROGEN?
RESULTS FROM 2019 FOCUS GROUPS

In 2019, nine focus groups were conducted in Townsville, Warrnambool and Darwin. Within each city, two focus groups included the general public split into two age demographics (18-35 years and 35-65+ years), while a third comprised influential stakeholders. Across the three groups a total of 72 people participated: 25 in the 18-35 age group, 27 in the 35-65+ age group and 20 influential stakeholders.

Overall support for Australian hydrogen industry development

Across all public focus groups, only two participants had heard about the National Hydrogen Strategy, with neither being able to provide any details about it. However, just over half of the influential stakeholders had heard of the Strategy, and were aware of many of the details.

After watching a video[3] introducing hydrogen in the Australian context, participants were enthusiastic about the potential of hydrogen both within their respective regions, as well as Australia more broadly. Many noted how their level of understanding and support had improved as a result of the focus group, and many were eager for more information. Support grew when participants heard about the environmental benefits and the potential for more regional jobs. They acknowledged the need to maintain safety and manage community expectations about realistic timelines, and in particular, not creating false hope.

What about water?

In Townsville and Darwin, there were mixed responses around water availability. In Townsville, some felt there was plentiful water with the Burdekin River being nearby, while others were more skeptical. Concerns were raised around competing uses for fresh water and the issues that arose with the Murray Darling Basin. There were questions raised about the likely by-products from desalination and implications that may arise for the Great Barrier Reef.

Renewable energy projects for towns

For large-scale solar developments, participants had mixed responses. In Warrnambool, influential stakeholders mentioned the Camperdown solar farm failed to gain approval due to concerns over co-existence issues with agricultural land and with landscape impacts. In contrast large scale wind developments were seen to be more accepted by the community as there were a number of local wind farms already in use.

WHAT DO AUSTRALIANS THINK OF HYDROGEN?
RESULTS FROM 2019 FOCUS GROUPS

Mixed feelings about carbon capture and storage

Some participants in Townsville and Darwin were very supportive of the concept of CCS hydrogen, but others expressed reservations about whether CCS was really solving the problem of carbon emissions. In contrast, all three focus groups in Warrnambool acknowledged CCS has potential to reduce global emissions.

Economic benefits need to be shared fairly

Participants in Townsville and Darwin were positive about the potential for hydrogen export to create jobs and benefit the local economy. However, some participants in Darwin were concerned about a boom-and-bust situation developing, and that a 'fly-in fly-out' workforce might result. Older participants in Warrnambool expressed concern about jobs being created in metropolitan areas rather than regional areas.

Local interests come first

While the development of an export industry was generally seen as a positive opportunity for Australia, participants across all three cities thought the domestic benefits from hydrogen should be prioritised, and that a national strategy should 'look after the locals'.

People want to know more

Participants wanted access to factual information with up-to-date information on costs, risks and benefits. They wanted information from trusted sources, such as governments and research institutions. Companies operating in the hydrogen industry were also seen to have a role to talk about specific projects and being able to answer questions as needed.

Role of governments

Participants tended to see the Commonwealth as primarily having an enabling and coordinating role. They were very keen for the federal government to ensure a level playing field between regions and states. There was some concern about states and territories competing with each other to host facilities. Therefore, it was seen as critical that the Commonwealth foster a collective rather than competitive approach to developing the industry in Australia.

EDUCATION AND TRAINING

An important part of ensuring a clean hydrogen industry benefits Australians is providing opportunities for the education and training needed to work in the industry.

As noted in **Chapter 1**, the industry could provide about 7,600 jobs in 2050 with targeted global deployment – more if global markets develop faster.

Jobs will include engineers, technicians, gas fitters, plumbers and builders and other associated trades and services. While many skills will be transferable from other sectors, 'hydrogen-ready' workers will have to be qualified and licensed to safely and legally work with hydrogen. New training opportunities will also be needed to avoid skills shortage in other sectors.

Technical and professional education

Governments, industry, educational institutions and registered training organisations will need to work together to develop and deliver quality education and training. Courses and qualifications will need to take account of standards and codes as they are developed and reviewed over time, both internationally and domestically.

Governments will develop nationally consistent training materials and guidelines for procedures to do with the production, handling, transport and use of hydrogen. The South Australian Government will work with relevant agencies and industries from other states and territories to develop these guidelines and training materials and facilitate knowledge sharing on safe work practices.

Work already underway

In the gas sector, the Gas Industry Reference Committee has a proposed schedule of work to review and update training packages (made up of units of competency, skill sets and qualifications) to include hydrogen by 2020–21, in relation to nationally recognised Vocational Education and Training qualifications for the gas sector.

In other sectors, relevant Industry Reference Committees should also review and update their respective training packages, to be ready for hydrogen uptake. If Industry Reference Committees recognise an urgent need for this work be completed, the COAG Energy Ministers could ask the Australian Industry and Skills Committee to assist.

Reviewers of training packages should consult with occupational licensing regulators to ensure updated training will lead to suitable licensing outcomes. The COAG Skills Council will endorse new and updated units of competency and qualifications once they are approved by the Australian Industry and Skills Committee.

Interstate workforce mobility is facilitated by the *Mutual Recognition Act 1992*. Under this Act, a person who is licensed or registered in one state or territory, is entitled to be licensed or registered in another state or territory for an equivalent occupational licence or registration, if one exists, in that state or territory. The *Trans-Tasman Mutual Recognition Act 1997* supports a similar arrangement between Australia and New Zealand.

State and territory governments could consider a system of automatic mutual recognition arrangements across jurisdictions for hydrogen-related occupations. These are arrangements that permit a license holder working in another state or territory, without needing an additional licence or registration. These arrangements are negotiated on a bilateral or multilateral basis between participating states and territories.

In the longer term (2025–2030), Australian governments and industry will work together to ensure:

- Industry Reference Committees are reviewing, updating and developing units of competency and qualifications, as hydrogen becomes relevant to the training packages of more industry sectors
- clear pathways are established between hydrogen-related education and training and hydrogen-related employment, including recognition of prior learning and credit
- clear and accurate information is available to anyone interested in hydrogen-related education, training and careers.

The COAG Skills Council will be responsible for endorsing any changes to hydrogen-related education, training and career pathways as they are developed by Industry Reference Committees and approved by the Australian Industry and Skills Committee.

Hydrogen training for Australian emergency services

It is important to maintain a safe environment for the community, emergency services and industry. Appropriate training for emergency services on how to deal with a hydrogen-related incident is essential to minimise the risk to themselves, others, and property and equipment. In the United States, for example, concerted effort has gone into training firefighters, police and ambulance officers to respond to incidents that involve hydrogen. Involving emergency services in planning projects increases community confidence and the likelihood of local support. As hydrogen technology becomes more widespread, new and refresher training and assessments will be required to ensure hydrogen incidents are appropriately dealt with and affected areas are safe.

COAG Energy Ministers will ask the Australian Industry and Skills Committee and Public Safety Industry Reference Committee to update training packages for hydrogen safety, including the Public Safety Training Package that contains training materials and guidelines for managing emergencies. This training package will be updated by creating or importing hydrogen-related units, drawing on work by the International Association for Hydrogen Safety (HySafe) and the US Center for Hydrogen Safety. To enable this process, COAG Energy Ministers will write to the Chair of the Skills Council, which directs the work of the Australian Industry and Skills Committee.

Hydrogen training for regulators

Ensuring government regulators adequately understand hydrogen infrastructure, projects and technologies will help to achieve coordinated and efficient planning approvals processes. With appropriate knowledge, regulators will also be able to help hydrogen project proponents navigate government processes (which consultation has identified as a problem, especially in 'first-of-a-kind' projects). To develop an attractive investment environment, governments will need to prioritise prompt resolution of new issues and ensure learnings are effectively shared.

Australian governments will review training and upskilling arrangements to ensure regulators have adequate understanding of hydrogen infrastructure, projects and technologies.

Australian governments and industry will be at the forefront of responding transparently to community interests and expectations, and will not wait for community concerns to emerge or accidents to happen before putting measures in place.

Endnotes

1. Lambert, V., and Ashworth, P., 2018, *The Australian public's perception of hydrogen for energy*, https://arena.gov.au/assets/2018/12/the-australian-publics-perception-of-hydrogen-for-energy.pdf accessed 11 November 2019
2. Ashworth, P., Witt, K., Ferguson, M., & S. Sehic 2019, *Developing Community Trust in Hydrogen*, http://www.coagenergycouncil.gov.au/publications/reports-support-national-hydrogen-strategy
3. Commonwealth of Australia 2019, *Australia's hydrogen opportunity*, https://www.youtube.com/watch?v=nO63TyoTNxE accessed 11 November 2019

AUSTRALIA COLLABORATES WITH GLOBAL HYDROGEN COMMUNITY ON SAFETY AND BEST PRACTICES

The Center for Hydrogen Safety is a globally oriented non-profit organisation dedicated to promoting hydrogen safety and best practices worldwide.

The Center identifies and addresses concerns regarding the safe use of hydrogen as a sustainable energy carrier, in commercial and industrial applications and in hydrogen and fuel cell technologies. The United States is leading the Center in collaboration with 60,000 members from 110 countries.

Australia is a member of the Center and is exploring opportunities for Australia's emergency service personnel to learn best practices in hydrogen safety. Membership gives Australia access to accredited training and outreach materials and to the Hydrogen Safety Panel – a team of experts who can provide independent advice on safety aspects of hydrogen projects, infrastructure and regulation.

In a further example of international collaboration on hydrogen safety, Adelaide hosted the 8th International Hydrogen Safety Conference in September 2019 organised by the International Association of Hydrogen Safety (HySafe). This biennial conference is a platform for presenting and discussing new findings and information on hydrogen safety.

Community engagement on gas innovation. Image courtesy of Andre Gascoigne, South Australian Department for Energy and Mining.

6 TRACKING PROGRESS

The actions we are taking now are the start of a long journey. Building a new industry is not something that can happen overnight. It will take time and we will need to be agile, innovative and coordinated in our actions.

We will need to monitor global hydrogen industry development and make judgements based on how the industry evolves. To help with this process, we have developed a set of industry development signals.

We have also developed 15 measures of success, which align with the Strategy's vision for the industry in 2030.

Through comprehensive analysis of the future energy scenarios discussed in **Chapter 2**, we have developed a set of signals for global industry development. They focus on indicators of growth along the supply chain, including investment, production project scale, hydrogen cost-competitiveness and hydrogen use. Progress in research, development and demonstration is also featured, highlighting that innovation and commercialisation is still required in parts of the supply chain.

2020 → 2025

	Clean hydrogen advances quickly	Clean hydrogen advances slowly
Investment	Corporate investment has taken a larger share in mainstream hydrogen technologies than government investment	Corporate investments in hydrogen technology are not seen as viable and investor interest is increasingly directed to other technologies
Project scale	Hydrogen production projects are at 100-300 MW or equivalent	Hydrogen production projects are still at 1-10 MW or equivalent
Cost-competitiveness	Hydrogen technology breakthroughs are occurring and uptake is driving cost reductions. Hydrogen scale is driving supply chain costs down rapidly	No or few hydrogen technology breakthroughs and there are minimal trials underway, meaning costs are not falling
Australia's exports	Capital is going into hydrogen supply chain infrastructure. Export agreements exist	There have been no front end engineering design studies commenced or completed for any commercial scale hydrogen export facility
Chemical feedstock	Industrial users of hydrogen as a chemical feedstock are starting to place additional value on clean hydrogen. Clean hydrogen is being blended into production at demonstration scale (>10 MW)	Industrial users of hydrogen as a chemical feedstock continue to use traditional methods for producing hydrogen, rather than trialling clean hydrogen production
Electricity grid support	Trials using grid connected electrolysis units for load balancing, grid firming and ancillary services are occurring	No or few trials underway using grid-connected electrolysis units for balancing, firming or ancillary services
Mining and off-grid	Hydrogen is being trialled with large-scale renewables in off-grid electricity generation to displace diesel	No off-grid hydrogen trials have occurred
Heavy transport	Research, development and demonstration of hydrogen heavy vehicles is progressing favourably. Initial heavy haulage projects exist and vehicle availability is being addressed	Hydrogen starts to become cost-competitive with fossil fuels but other low-emissions technologies are attracting more investment than hydrogen heavy vehicles
Light transport	Hydrogen refuelling infrastructure is being deployed in major centres to service regular use	Hydrogen starts to become cost-competitive but other low-emissions technologies are attracting more investment than hydrogen vehicles
Gas networks	Cities and regions are pursuing opportunities to blend hydrogen or even use 100% hydrogen in gas networks	Gas blending occurs in a piecemeal approach and, in some cases, cities and regions begin turning to other low-emissions technologies
Electricity generation	Projects are underway internationally to co-fire or use hydrogen based fuels for electricity generation	Limited or no trials underway internationally to co-fire or use hydrogen based fuels for electricity generation
Steel making	Research and development in hydrogen utilisation in steel making is occurring, moving the process towards economic and technical viability	There is limited or no use of hydrogen in steel making and the process is not being widely pursued in research and development
Industrial heat	Hydrogen is being trialled in at least niche applications, if not more widely, and industrial stakeholder acceptance of hydrogen is increasing	Hydrogen is being trialled in a few niche applications but other low-emissions technologies are preferred

2030

	Clean hydrogen continues to advance	Clean hydrogen is falling behind
Investment	Corporate investment in hydrogen-related technologies are commonplace and risks of investing are well understood. Government grant support no longer necessary to bridge economics	Corporate investment in hydrogen-related technologies is minimal or not occurring at all, with other technologies providing low-emissions solutions for most or all sectors
Project scale	A clean hydrogen production project is at 500-1000 MW or equivalent	There are few, if any, large-scale clean hydrogen production projects
Cost-competitiveness	Hydrogen is cost-competitive compared to alternative fuel sources for some, if not most, hydrogen applications	Hydrogen is not cost-competitive and other technologies are the preferred low-emissions option in most, if not all, sectors
Australia's exports	Australia is a major global supplier of hydrogen and is leading innovation providing a cost advantage relative to other countries	The costs of hydrogen technologies in Australia are not decreasing and a large-scale clean hydrogen export market has not emerged
Chemical feedstock	The cost of clean hydrogen is reducing as a result of major advances in technology and major users are upgrading their facilities to use clean hydrogen	A small number of industrial users are placing additional value on clean hydrogen but most do not
Electricity grid support	Grid connected electrolysis units are commonly used to provide electricity system support services. At least one trial using hydrogen for seasonal energy storage is underway	Electricity sector is using other balancing, firming and ancillary service technologies
Mining and off-grid	Off-grid electricity systems commonly incorporate renewables with hydrogen acting as the load balance and seasonal battery	Off-grid trials have not been expanded due to economics or other technologies
Heavy transport	Hydrogen used in multiple heavy vehicle applications rapidly becoming the choice for new sales of on road heavy vehicles	Innovation and efficiency gains in other low-emissions technologies for heavy vehicles leads to low uptake of hydrogen heavy vehicles
Light transport	Widespread deployment of hydrogen refuelling infrastructure in major centres and on highways to service regular use	Innovation and efficiency gains in other low-emissions technologies for light vehicles lead to low uptake of hydrogen vehicles, even in niche applications
Gas networks	Large-scale gas blending has occurred or is planned to occur	Gas blending is occurring in some places, while others may be looking to other low-emissions technologies
Electricity generation	Large-scale projects using hydrogen-based fuels for electricity generation are under development internationally	Limited or no activity beyond trials internationally to co-fire or use hydrogen based fuels for electricity generation
Steel making	Steel making becomes a targeted application for hydrogen and all new facilities producing steel from iron ore use hydrogen	The use of hydrogen in steel making is limited to 'green steel' or bespoke applications but is becoming cost-competitive with steel made using metallurgical coal
Industrial heat	Hydrogen is being deployed in at least niche applications, if not more widely, and manufacturers are making equipment that can accept 100% hydrogen	Innovation and efficiency gains in other low-emissions technologies lead to low uptake of hydrogen as a low-emissions heating option

MEASURING SUCCESS

In addition to looking out for signals, clear measures of success will also help guide decision making during implementation of the Strategy. Australian governments have developed 15 measures of success, which align with the Strategy's vision for the industry.

These measures will need to be compared to a baseline, which could be the state or value of each identified measure in 2020. It is likely that in many cases, the baseline is effectively zero, as the industry is yet to develop. In other cases, the baseline might not be zero but we may not have an accurate starting value, in which case we will provide our best guess. Again, this is an acknowledgement that the industry is still very much in the early phases of forming.

A clean, innovative, safe and competitive industry

The first component of the vision is that the industry is clean, innovative, safe and competitive. A clean industry is one that is low-emissions. An innovative industry is one that is continuously improving its processes and technologies to be more efficient, have less impact on the environment and to bring costs down. A safe industry is one in which safety is at the forefront of decisions and all those who interact with hydrogen systems are educated about safe work practices and procedures. A competitive industry is one that provides a globally cost-competitive product. A competitive industry is also customer focused and is supported by an appropriately skilled, 'hydrogen-ready' workforce. Table 6.1 presents the 2030 measures of success to indicate we have developed a clean, innovative, safe and competitive industry.

Table 6.1 2030 Measures of success for a clean, innovative, safe and competitive industry

	2030 Measures of Success
Clean	Carbon intensity of Australian hydrogen production meets community, customer and consumer expectations and is decreasing over time Australia has a robust certification scheme in place that is internationally accepted
Innovative	Australia is regarded as having a highly innovative hydrogen industry and supportive research and development environment The sustainability of water use for Australian hydrogen production continues to improve
Safe	Australia has an excellent hydrogen-related safety track record
Competitive	Australian hydrogen is cost-competitive domestically and internationally Australia has a 'hydrogen-ready' workforce that is responsive to industry's needs

Benefits all Australians

The second component of the vision is an industry that benefits all Australians. Benefits can be in the form of jobs and prosperity, or in supporting communities that support the industry. Benefits can also be realised through the domestic use of hydrogen, as use of hydrogen has the potential to reduce emissions and air pollution, and provide Australians with a greater choice in energy and fuel sources.

Table 6.2 presents the 2030 measures of success that will show we've created an industry that benefits all Australians.

Table 6.2 2030 Measures of success for an industry that benefits all Australians

	2030 Measures of Success
Jobs and prosperity	Hydrogen is providing economic benefits and jobs
Supported communities	Benefits are flowing back to communities where hydrogen industries are located
Domestic use	The cost of clean hydrogen continues to decrease in part due to technology developments and in part due to scale achieved in the development of a hydrogen export industry Hydrogen production and use is integrated into energy market structures

A major global player

The third component of the vision is to be a major global player by 2030. Being a major global player means we are, or are positioned to be, a supplier of choice to partner countries. To achieve this goal, we'll first need investment in the industry. We'll then need to demonstrate that we can supply a cost-competitive product that meets our customers' requirements. It will also be important that our hydrogen capability is demonstrated and recognised.

Table 6.3 presents the 2030 measures of success that will show we've created an industry that is a major global player.

Table 6.3 2030 Measures of success for being a major global player

	2030 Measures of Success
Hydrogen exports	We are among the top three exporters of hydrogen to Asian markets
Investor confidence	Australia is seen as a destination of choice for international investors in hydrogen We have major offtake or supply chain agreements in place with importing countries
Hydrogen capability	We have demonstrated our hydrogen capability in all links of the supply chain

NATIONALLY COORDINATING OUR EFFORTS

Our shared vision alone is not enough to achieve our goals. With interdependent actions spanning state, territory and Commonwealth governments, following an adaptive pathway to clean hydrogen growth calls for coordinated effort and clear direction.

State and territory governments have identified their specific priorities and areas of strategic advantage. At the same time, much of the enabling work stemming from the Strategy will need to be cooperatively pursued by all Australian governments. The Strategy accommodates both these imperatives.

The Australian public has high expectations that governments will work together and be accountable for achieving our goals. In addition, to be adaptive, we need to monitor global hydrogen developments and refine our actions where necessary.

To track our progress against our measures of success and respond to indicators of global industry growth outlined in this Chapter, the Australian Government will coordinate and publish an annual 'State of Hydrogen' report. This will be informed by rigorous and objective technical advice.

AUSTRALIA IN 2030

Achieving the measures outlined above by 2030 will indicate we've been successful in building an Australian hydrogen industry. More importantly, they'll set us up for the decades that follow, in which we'll continue to build the industry and help the world meet its energy needs and decarbonise its energy supply.

7 BEYOND 2030

The long-term future of Australia's hydrogen industry looks bright. While we can't see all its detail, we are encouraged by the signals from our major trading partners and the trajectory of technological development.

If industry and governments work together to build on our strong starting position and navigate uncertainties well, we will reap rewards at an ever increasing pace beyond 2030.

THE HYDROGEN HORIZON

Australian energy ministers share a vision for a clean, innovative, safe and competitive hydrogen industry that benefits all Australians and is a major global player by 2030. But 2030 is just one milestone on Australia's hydrogen journey. More exciting possibilities lie beyond it.

Our major energy trading partners have set clear targets as waypoints to becoming 'hydrogen societies'. By 2050, Japan alone intends to import up to 10 million tonnes of hydrogen per year.[1] The Republic of Korea, China, and the United States will have millions of hydrogen vehicles on their roads.[2] The European Union will be using hydrogen for heating, transport and industrial applications to meet its 2050 target of net zero emissions.[3]

Beyond 2030, the cost of making, storing, moving and using clean hydrogen will become increasingly competitive with other fuels in an energy-hungry world. In a decade, leading energy analysts estimate that in some applications, such as transport, the cost of clean hydrogen will be the same as or even cheaper than using fossil fuels.[4, 5]

Abundant clean hydrogen will present the opportunity to decarbonise sectors currently dependent on coal, gas and liquid fossil fuels, to revitalise old industries and start new ones. It could give Australian manufacturers of energy-intensive products such as steel a comparative market advantage because they will be able to use low-cost hydrogen near where it is produced.

Clean ammonia will be increasingly produced at large scale, including as an input for sustainable fertiliser.

Gas networks and appliances could be converted to 100% hydrogen, allowing households and businesses access to zero emissions heating and cooking, without losing the convenience to which Australians are accustomed.

Mining vehicles, long-distance trucks and trains could be early adopters of hydrogen at scale, reducing our need for imported oil and thereby enhancing Australia's fuel security. By avoiding harmful local air pollution, Australians would also enjoy cleaner air.

Today, the cargo and container ships ploughing the oceans are responsible for a significant proportion of global emissions of carbon dioxide and pollutants. Beyond 2030, these giant ships could be powered by clean ammonia made from hydrogen, or powered directly by compressed or liquefied hydrogen.

High above the land and oceans, it is possible that hydrogen or its derivatives will be powering long-distance aeroplanes, helping to decarbonise the most challenging area of transport.

Back on land, hydrogen stored in giant underground formations could provide seasonal storage to improve reliability in our major electricity networks.

Large solar and wind generation facilities for hydrogen production located in remote regions may be connected to our electricity networks by long-distance, high-voltage transmission lines. They could provide our electricity systems with a cost-effective adjunct to battery storage and pumped hydro storage.

In the long term, the cost of shipping hydrogen will be substantially reduced. Where it is shipped as liquefied hydrogen, the significant energy required for liquefication will be supplied by low-cost renewables. Where the hydrogen is shipped as ammonia, the efficiency of turning the ammonia back into hydrogen at the import terminal will be enhanced by breakthrough separation processes, possibly based on membrane technology already in development at the CSIRO.

The large-scale industries Australia could build would mean a new generation of investment. Many new jobs that arise would be familiar to Australians, including regional Australians, who have prospered under earlier waves of resource expansion.

Like our existing resource industries, an Australian hydrogen industry could also export more than the commodity. We could offer expertise, equipment, technology, education and training. Most of all we could offer innovation, with our researchers and companies at the forefront of developing solutions for the world.

THE FUTURE OF HYDROGEN IS OURS TO MAKE

Being ready for this future calls for action.

Governments and industry can work together to make and take Australia's global hydrogen opportunities.

With partnerships and technology improvement, we can open new markets at home and abroad. We can keep pushing costs down through innovation, learning-by-doing and economies of scale.

Australia has the resources and the experience as one of the world's great energy exporters and renewable energy pioneers to be a clean hydrogen powerhouse. Creating a consistent policy and regulatory environment that encourages innovation will attract investment and make this new industry prosperous, safe, environmentally sustainable and beneficial to all Australians.

The journey will not be easy, nor predictable. We cannot change the wind, but we can adjust our sails. We can also influence the rules of the race. Our adaptive approach will ensure we keep all hydrogen possibilities on the table. By starting early and being vigilant, we will see and seize opportunities as they emerge.

The opportunities are vast.

Endnotes

1 Ministry of Economy, Trade and Industry 2017, *Basic Hydrogen Strategy Key Points*, https://www.meti.go.jp/english/press/2017/pdf/1226_003a.pdf, accessed 6 November 2019

2 Kosturjak, A, Dey, T, Young, M, D, Whetton, S, 2019, *Advancing hydrogen: Learning from across the globe*, Future Fuels Cooperative Research Centre

3 European Commission 2018, A Clean Planet for all: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy, https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1560755311425&uri=CELEX:52018DC0773 , accessed 14 November 2019

4 Bloomberg New Energy Finance 2019, *Hydrogen: The Economics of Production from Renewables*

5 International Energy Agency 2019, *The Future of Hydrogen, p. 170*

STRATEGIC ACTIONS

The nationally coordinated government actions as outlined in the National Hydrogen Strategy are listed below.

The first action item appears in Chapter 2.

ACTION

An adaptive pathway to clean hydrogen growth

2.1 Support an adaptive approach to industry development that means Australia can be ready to move quickly to scale up as signs of large-scale markets emerge. A 'review-revise-adapt' feedback loop will support and refine actions as technology and markets change. This adaptive approach will focus on actions that remove market barriers, efficiently build supply and demand, and accelerate the global hydrogen cost-competitiveness of Australia's hydrogen industry.

2.2 Support an approach guided by four underpinning principles, namely to:

- Take an adaptive and nationally coordinated approach to support industry development, including regular reviews
- Prioritise regulatory consistency and a coordinated approach to project approvals
- Support partnerships to activate the market
- Put safety, environmental sustainability, and benefits to Australians at the forefront.

2.3 Support actions themed around seven areas: developing production capacity, supported by local demand; responsive regulation; international engagement; innovation and R&D; skills and workforce; community confidence; and national coordination.

2.4 Support a pathway for developing a local industry, initially by removing regulatory barriers to hydrogen use and encouraging it through policies to help early movers overcome investment barriers. Mandating use of hydrogen will require evidence that a net benefit to consumers will result, or there is a consumer willingness to pay where appropriate, and that industry can meet regulated requirements.

Large-scale market activation

3.1 Agree that early actions will focus on developing clean hydrogen supply chains to service new and existing uses of hydrogen (such as for ammonia production) and developing capability for rapid industry scale–up.

3.2 Agree to consider the most appropriate support to scale up the industry and activate markets in light of global signals.

3.3 Agree that mandatory national targets would not be appropriate at this time but should be re-considered periodically as the market develops.

Hubs and sector coupling

3.4 Support the hub model as a prospective early-stage approach to achieve the scale needed for a competitive industry.

3.5 Agree to consider each governments' respective planning and funding timelines, and to the extent possible, harmonise funding application processes for hub projects.

ACTION

Assessing our hydrogen infrastructure needs

3.6 Agree to complete an inaugural National Hydrogen Infrastructure Assessment by 2022 led and coordinated by the Commonwealth Government. The assessment will consider hydrogen supply chain needs such as electricity and gas networks, water supply networks, refuelling stations, roads, rail and ports, while taking into account local community concerns and priorities.

3.7 Agree to review and update the Hydrogen Infrastructure Assessment at least every five years, to highlight priorities for future infrastructure needs for competitive hydrogen supply chains.

Supporting research, pilots, trials and demonstrations along the supply chain

3.8 Agree that while other innovation priorities may emerge, the following areas should be priorities for research, pilot projects, trials, and demonstration projects:

- Switching current industrial hydrogen users to clean hydrogen
- Investigating new opportunities for clean hydrogen such as clean ammonia exports, clean fertiliser exports, industrial heating, iron ore processing and steel making
- Using hydrogen in remote applications, such as in microgrids for mining and remote communities, in farming and marine applications, at remote defence facilities and as a fuel for heavy-duty mining vehicles
- Opportunities for backup power supply, such as for mobile phone towers, hospitals and other types of critical infrastructure
- Enabling blending of hydrogen with natural gas and eventual use of 100% hydrogen in gas networks
- Using hydrogen for transport, with a focus on heavy and long-range road transport, rail and shipping
- Optimising hydrogen and electricity system interactions, such as through timing hydrogen production to match variable renewable generation and through use of hydrogen for storage and dispatchable generation
- Testing and proving of technologies that reduce the cost of making, moving, storing and using hydrogen
- Using water from sustainable sources, such as waste water or seawater for hydrogen production
- Developing cross-sector linkages and deriving value from sector coupling.

3.9 Support improved knowledge sharing from hydrogen-related projects, to help remove some of the information barriers the hydrogen industry faces and improve community awareness and rate of scale–up.

3.10 Agree to consider options to facilitate larger hydrogen projects through coordinating respective funding arrangements.

Using clean hydrogen in Australian gas networks

3.11 Support continuing pilots, trials and demonstrations of hydrogen in gas distribution networks, where distributors can satisfy relevant regulators that:

- The distribution network is comprised of materials confirmed to be safe and suitable for hydrogen blending
- End user gas supply infrastructure (including installations and appliances) is safe and suitable for hydrogen blending
- The distributor has adequate safety and training procedures in place
- The effects of blending for gas network users of natural gas as chemical feedstock or for compressed natural gas have been considered and mitigated.

ACTION

3.12 Agree to complete a review by the end of 2020. The review would:

- Consider the application of the National Gas Law and relevant jurisdictional laws and regulations to hydrogen and advise the COAG Energy Council of recommended options to best address regulatory ambiguity, remove unnecessary regulatory barriers and improve the consistency of laws across jurisdictions.
- Consider the economics of blending and of eventual use of 100% hydrogen in Australian gas networks.
- Advise the COAG Energy Council recommend options for setting and allowing updates of upper limits on the volume of hydrogen allowed to be blended in gas networks. This will focus on keeping consumers safe, encouraging innovation and effectively managing any appliance readiness end user and market effect issues.

3.13 Agree to consider changes to gas networks and markets to allow widespread blending, and later sole use of hydrogen, where such changes:

- Take place after the review at 3.12 and any actions that might arise from the review are completed
- Carry acceptably low levels of safety risk
- Are broadly supported by affected communities, and
- Minimise impacts on gas prices and are in the long term interests of gas consumers.

3.14 Agree that, amongst other objectives, any government incentives to support the widespread blending of hydrogen in Australian gas distribution networks will:

- Where appropriate, encourage blending to occur in a manner that supports the development of hydrogen hubs
- Be consistent with the COAG Principles of Best Practice Regulation, in particular with respects to net benefits to consumers.

3.15 Agree to not support the blending of hydrogen in existing gas transmission networks until such time as further evidence emerges that hydrogen embrittlement issues can be safely addressed. Options for setting and allowing for ongoing updates of safe limits for hydrogen blending in transmission networks will form part of the review in 2020.

Initial steps towards using hydrogen for transport

3.16 Agree to a shared vision of hydrogen being a clean, cost competitive fuel option for Australian land and marine transport, in particular for heavy duty and long range transport applications.

3.17 Support an adaptive approach to building demand for hydrogen as a transport fuel. The initial focus will be on transport tasks that do not require an extensive network of refuelling stations and offers compelling performance and industry development advantages.

3.18 Support refuelling stations on major freight and passenger road corridors, to support greater range for hydrogen vehicles.

3.19 Agree to include fuel infrastructure priorities in the proposed National Hydrogen Infrastructure Assessment so Ministers can periodically reconsider the need for action and calibrate relevant support mechanisms.

3.20 Agree to consider opportunities for new vehicle technologies, including hydrogen vehicles, in government fleets and large government contracts.

3.21 Support consortium based approaches to building refuelling infrastructure, with industry contributing to associated costs to promote long-term commercial viability.

3.22 Agree to promote open access to any government supported refuelling infrastructure, wherever practical.

ACTION

Responsive regulation

4.1 Agree for each jurisdiction to review its existing legislation, regulations and standards as needed to determine whether their respective legal frameworks can support hydrogen safety and hydrogen industry development.

4.2 Agree to consider the principles and prioritisation criteria set out in the preliminary legal review, and the legislation, regulations, and standards it identified when undertaking the reviews outlined in 4.1.

4.3 Agree to coordinate reviews of legal frameworks where practical, and work together to:

- Support the development of standards for the hydrogen industry, including technical safety standards, noting the role of Standards Australia
- Consider and evaluate regulatory models to address and support:
  - hydrogen safety, noting the role of SafeWork Australia and state-based safety agencies
  - hydrogen industry development

with the aim of developing a nationally consistent approach as far as practicable

- Where necessary, amend existing legislation and regulations or draft new legislation to address hydrogen safety and support hydrogen industry development.

Shared principles for nationally consistent regulation

4.4 Agree to seek national regulatory consistency for any new regulations associated with hydrogen, that follows the COAG Principles of Best Practice Regulation.

A coordinated approach to planning and regulatory approvals for hydrogen projects

4.5 Agree to develop and incorporate 'hydrogen-ready' capabilities into planning and regulatory approvals mechanisms where required.

Integrating hydrogen into energy markets

4.6 Agree to ask energy market bodies to account for the possible effects of hydrogen industry growth in their planning and future reforms.

4.7 Agree to a future review, drawing on experience from pilot projects, trials and demonstrations, to consider options for energy market reforms to improve the integration of hydrogen into energy markets and to deliver additional benefits from hydrogen to consumers.

4.8 Agree the review in 4.8 will be completed by 2024.

Hydrogen's role in secure and affordable energy supply

4.9 Agree to consider the role of hydrogen in supporting Australian energy security by 2025. Areas for consideration will include:

- National Energy Security Assessments
- Electricity, gas and liquid fuel emergency provisions
- Mandatory reporting requirements, such as those under the Petroleum and Other Fuels Reporting Act 2017.

4.10 Agree to monitor impacts of hydrogen on energy costs, and where necessary, consider the need for changes to energy affordability and consumer protection policies.

4.11 Agree to not apply market constraints, such as domestic hydrogen reservations or price caps, at this time, but to revisit this stance periodically as the market develops.

ACTION

Certainty around taxation, excise and other fees or levies for hydrogen

4.12 Agree to continue with the revenue arrangements that now apply to hydrogen, with the option to review them in the future.

4.13 Agree to consult with industry and the community before making any changes to current revenue arrangements that are specific to hydrogen.

Bilateral partnerships to build markets

4.14 Support development of bilateral agreements to indicate our commitment and capability as a hydrogen partner of choice and ensure arrangements meet our national interests.

4.15 Agree to work with bilateral partners to promote trade and investment in hydrogen, including advocating for Australian industries' engagement in the design of market settings that facilitate trade, long-term investment, regional price transparency, efficient market operation, and commitment to sharing industry knowledge and skills between partners.

Hydrogen certification

4.16 Agree that Australia will seek to play a lead role in the design and development of an international guarantee of origin scheme.

4.17 Agree that, as far as practicable, any Australian domestic scheme should build on or harmonise with international certification schemes.

4.18 Agree to initially develop an international certification scheme that verifies and tracks:

- Production technology
- Carbon emissions associated with production (scope 1 and scope 2)
- Production location.

4.19 Agree that in addition to the above, any subsequent expansion of an international certification scheme could include water consumption and other factors.

Building community knowledge and engagement

5.1 Agree to develop a community education program to provide clear and accessible information about risks, benefits and safe use. The program will communicate the particular benefits hydrogen development can bring to regions as well as more general benefits such as economic growth, lower carbon emissions and reduced air pollution.

5.2 Support best practice for community engagement and its use to build community awareness and ensure community engagement for large or significant projects.

Responsible industry development

5.3 Support the development and implementation of a set of industry undertakings to guide the development of Australia's hydrogen industry. This work will be led and designed by the Australian Hydrogen Council in collaboration with governments. It will specify appropriate principles to safeguard the community, communicate issues and engage with regulators.

ACTION

Skills and training for the hydrogen economy

5.4 Agree to develop nationally consistent training materials and guidelines for procedures to do with the production, handling, transport and use of hydrogen. The South Australian Government will work with agencies and industries from other states and territories to develop these guidelines and training materials and facilitate knowledge sharing on safe work practices.

5.5 Agree to ask the Australian Industry and Skills Committee to bring forward the hydrogen-related reviews and updates of training packages if Industry Reference Committees recognise an urgent need for this work be completed.

5.6 Agree to work together with industry to ensure in the longer term (2025–2030):

- Industry Reference Committees are reviewing, updating and developing units of competency and qualifications, as hydrogen becomes relevant to the training packages of more industry sectors
- Clear pathways are established between hydrogen-related education and training and hydrogen-related employment, including recognition of prior learning and credit
- Clear and accurate information is available to anyone interested in hydrogen-related education, training and careers.

5.7 Agree that state and territory governments could consider a system of automatic mutual recognition across jurisdictions for hydrogen-related occupations under equivalent occupational licenses or registration.

Hydrogen training for Australian emergency services

5.8 Agree to ask the Australian Industry and Skills Committee and Public Safety Industry Reference Committee to update training packages for hydrogen safety, including the Public Safety Training Package that contains training materials and guidelines for managing of emergencies. This training package will be updated by creating or importing hydrogen-related units, drawing on work by the International Association for Hydrogen Safety (HySafe) and the U.S. Center for Hydrogen Safety. To enable this process, COAG Energy Ministers will write to the Chair of the Skills Council, which directs the work of the Australian Industry and Skills Committee.

Hydrogen training for regulators

5.9 Agree to review training and upskilling arrangements for regulators to ensure they have adequate understanding of hydrogen infrastructure, projects and technologies.

National coordination

6.1 Agree that establishing Australia as a major player in a global hydrogen industry by 2030 requires all jurisdictions to work cooperatively towards this goal.

6.2 Recognise that jurisdictions will progress actions in line with their own priorities and areas of strategic advantage.

6.3 Note that the Commonwealth will coordinate and publish an annual ‘State of Hydrogen’ report, informed by rigorous and objective technical advice.

APPENDICES

APPENDIX A: SCENARIO ANALYSIS

APPENDIX B: ABBREVIATIONS, ACRONYMS AND GLOSSARY

APPENDIX C: SUPPORTING REPORTS

APPENDIX D: CONSULTATION

APPENDIX E: TERMS OF REFERENCE

APPENDIX F. COAG HYDROGEN WORKING GROUP

APPENDIX G: ACKNOWLEDGEMENTS

APPENDIX A: SCENARIO ANALYSIS

The tables below summarise analysis undertaken by Deloitte for the COAG Hydrogen Working Group. This analysis was scenario-based, not predictive, and is based on specific assumptions, including that the over-riding influence on investor decision-making will be technology and supply chain costs.

In practice, investors in hydrogen will consider costs amongst other factors, such as ease of doing business, risk appetite and exposure, customer views on associated emissions, regulatory settings, access to capital, and their own views and forecasts of future growth scenarios. For these reasons, the results below should be considered as guides to the range of possible outcomes, rather than definitive trajectories that directly result from starting assumptions.

All the figures provided in these tables are from Deloitte's A*ustralian and Global Hydrogen Demand Growth Scenario Analysis* report unless stated otherwise.

YEAR 2019	GLOBAL DEMAND (MT H2)	AUSTRALIAN PRODUCTION (MT H2)
Current	70	0.5

YEAR 2030	HYDROGEN: ENERGY OF THE FUTURE	HYDROGEN: TARGETED DEPLOYMENT	ELECTRIC BREAKTHROUGH	BUSINESS AS USUAL (BAU)
Global hydrogen demand above or below 2030 BAU (Mt H_2)	6	1	-0.3	-
Additional Australian hydrogen production above or below 2030 BAU (Mt H_2)	1	0.2	0.1	-
Additional GDP above 2030 BAU (A$ billion)	0.6	0.2	Not modelled	-
Additional jobs above 2030 BAU (FTE)	487	145	Not modelled	-
Water requirements (GL)	16	5	3	2
Ratio of global emissions avoided to emissions produced from Australian hydrogen (Mt CO_2-e / Mt CO_2-e)[1]	6	0.6	0.5	0.3
Additional hydrogen produced by electrolysis (Mt H_2)[1]	0.5	0.2	0.2	-
Additional electricity requirements for electrolysis (TWh)	19	3	3	-
Land requirements for electrolysis if using 100% renewable electricity (square kilometres)[2]	191 (solar) 1,234 (wind)	32 (solar) 209 (wind)	35 (solar) 228 (wind)	3 (solar) 21 (wind)

YEAR 2050	HYDROGEN: ENERGY OF THE FUTURE	HYDROGEN: TARGETED DEPLOYMENT	ELECTRIC BREAKTHROUGH	BUSINESS AS USUAL
Global hydrogen demand above or below 2050 BAU (Mt H_2)	156	25	-57	-
Additional Australian hydrogen production above or below 2050 BAU (Mt H_2)	18	6	-0.3	-
Additional GDP above 2050 BAU (A$ billion)	26	11	Not modelled	-
Additional jobs above 2050 BAU (FTE)	16,923	7,628	Not modelled	-
Water requirements (GL)	207	91	15	24
Ratio of global emissions avoided to emissions produced from Australian hydrogen (Mt CO_2-e / Mt CO_2-e)[1]	27	1.2	0.5	0.6
Additional hydrogen produced by electrolysis (Mt H_2)[1]	18	4	2	-
Additional electricity requirements (TWh)	912	188	65	-
Land requirements for electrolysis if using 100% renewable electricity (square kilometres)[2]	9,291 (solar), 60,160 (wind)	1,917 (solar), 12,415 (wind)	666 (solar), 4,312 (wind)	56 (solar), 363 (wind)

Table notes:

1. Derived from Deloitte's results.
2 Amount of land required for either solar or wind generation if all electrolysers deployed in this scenario used 100% renewable electricity

APPENDIX B: ABBREVIATIONS, ACRONYMS AND GLOSSARY

AEMO – Australian Energy Market Operator, responsible for operating Australia's largest gas and electricity markets

Ancillary services – used by electricity grid operators to manage power systems safely, securely, and reliably. These services maintain key technical characteristics of the electricity system, including standards for frequency, voltage, network loading, and system restart processes

ARENA – Australian Renewable Energy Agency

ABS – Australian Bureau of Statistics

BEV – battery electric vehicle, fully electric vehicle with rechargeable batteries and no internal combustion engine

Carbon emissions – carbon dioxide released to the atmosphere from burning fossil fuels, manufacturing, mining, land use and other activities

CarbonNet – a project investigating the potential for establishing a commercial-scale carbon capture and storage (CCS) network. The network would bring together multiple carbon dioxide (CO_2) capture projects in Victoria's Latrobe Valley, transporting CO_2 via a shared pipeline and injecting it into deep underground, offshore storage sites in Bass Strait

CCS or **Carbon Capture and Storage –** the process of capturing and permanently storing carbon emissions

CEFC – Clean Energy Finance Corporation

CEM or **Clean Energy Ministerial –** a global forum held to promote policies and to share best practices with the aim of accelerating a transition to clean energy. The forum includes partnerships and collaboration between the private sector, public sector, non-governmental organisations, and others

Center for Hydrogen Safety – a not-for-profit, membership organisation established by the American Institute of Chemical Engineers to promote the safe operation, handling and use of hydrogen

CertifHy – a project that operated from 2014 to 2016 to develop a common European-wide definition of green hydrogen and hydrogen guarantee of origin scheme

Clean hydrogen – hydrogen produced using renewable energy or fossil fuels with substantial carbon capture and storage

CHP – combined heat and power

CNG – compressed natural gas, generally used as a transport fuel

CO_2 – carbon dioxide

CO_2-e – carbon dioxide equivalent, a metric used to compare the emissions from various greenhouse gases to determine their individual and total contributions to global warming

CO2CRC or **CO_2 Cooperative Research Centre –** an industry-led research organisation to research and demonstrate CCS technology. The CO2CRC is supported by the Australian Government's Cooperative Research Centres Program

CSIRO or **Commonwealth Scientific and Industrial Research Organisation –** Australia's national science research agency

Demand response – a planned change in the power consumption of an electricity user to assist in matching electricity demand and supply

Electrolysis and **electrolysers –** electrolysis is the process of using electricity to split water into hydrogen and oxygen. This reaction takes place in a unit called an electrolyser

Energy market bodies – bodies which have a role regulating and operating Australian energy systems and markets

Energy markets – commodity markets that deal specifically with the trade and supply of energy, generally electricity, gas, and liquid fuels

Energy systems – includes energy markets and energy supply networks

Excise – a tax on manufactured goods that is levied at the moment of manufacture, rather than at scale

FCEV – fuel cell electric vehicle – an electric vehicle that uses electricity from a fuel cell powered by hydrogen, rather than electricity from batteries

Future Fuels Cooperative Research Centre – an industry-led research organisation supporting Australian energy sector transition to low-carbon fuels

G20 or Group of Twenty – an international forum for the governments and central bank governors from 19 countries and the European Union (EU)

Gasification – a process that converts fossil fuel based materials into gases

GDP – gross domestic product

GJ – gigajoule, a unit of electrical energy equal to 1,000,000 kilojoules

GWh – gigawatt hour, a measure of electrical energy in terms of the use of one gigawatt of power for one hour, equal to 1,000 MWh

Hydrogen – a colourless, odourless, tasteless, flammable substance that is the simplest chemical element in the periodic table. It is virtually non-existent in its free form on Earth, and requires energy to liberate it from the material forms in which it is found. See also clean hydrogen

Hydrogen Energy Ministerial (HEM) – an annual Ministerial forum initiated by Japan in 2018

HESC – Hydrogen Energy Supply Chain Project, a pilot project to produce and transport clean hydrogen from Victoria's Latrobe Valley to Japan

Hydrogen hubs – aggregations of various users of hydrogen in one area. They may be in ports, cities, or remote areas

ICE – internal combustion engine, typically running on petrol or diesel fuel

IEA – International Energy Agency

Intergovernmental Agreement – an agreement made between two or more Commonwealth, state and territory governments that details commitments to cooperate on a specific matter of mutual interest

Integrated System Plan – a whole-of-system plan that provides an integrated roadmap for the efficient development of the National Electricity Market (NEM) over the next 20 years and beyond

IPHE – International Partnership for Hydrogen and Fuel Cells in the Economy

IRENA – International Renewable Energy Agency

JAEPA – Japan-Australia Economic Partnership Agreement

kWh – the amount of electrical energy provided by one kilowatt of power for one hour

Leadership Group for Industry Transition – an international public-private collaboration to drive decarbonisation in carbon and energy-intensive sectors of the economy. It was launched under the Industry Transition Track of the UN Secretary-General's Climate Summit

LNG – liquefied natural gas, the form in which natural gas is transported over long distances

METI – Ministry of Economy, Trade and Industry (Japan)

Mission Innovation – a global initiative of 24 countries and the European Commission to accelerate clean energy innovation

MWh – the amount of electrical energy provided by one megawatt of power for one hour. Equal to 1,000 kWh

NAIF – Northern Australia Infrastructure Facility

National Energy Security Assessments – reviews conducted by the Australian Government of Australia's energy needs, and assessments of risks to energy supply and costs

NEM – National Electricity Market – a wholesale electricity market that interconnects Queensland, New South Wales, Victoria, South Australia, Australian Capital Territory, and Tasmania

PJ – petajoule, a unit of electrical energy equal to 1,000,000 gigajoules

Public-private partnership – a long-term contract between a private entity or consortium and a government, typically used by governments to pay for the delivery of public infrastructure, assets or services.

R&D – Research and development

RD&D – Research, development and demonstration

Renewable energy – energy that is collected from renewable resources, which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat.

Revenue arrangements – contributions to government revenues, which can be levied by governments on sources including income, business profits, or added to the cost of certain goods, services, and transactions. Taxes, excises, fees and levies are examples of revenue arrangements

Scope 1 emissions – released into the atmosphere as a direct result of an activity, or series of activities at a facility

Scope 2 emissions – indirect emissions from consumption of purchased electricity, heat or steam. Most scope 2 emissions represent electricity consumption, but can include other forms of energy transferred across facility boundaries.

Sector coupling – the increased linking of sectors through technology or product changes. Where this linking is well managed, this creates opportunities for new or additional benefits and services. Hydrogen creates novel opportunities for sector coupling across electricity, transport, heating and industry, allowing energy to be used in new ways to benefit users and the environment

Standards Australia – Australia's peak standards development body. Standards Australia facilitates technical committees made up of stakeholders from government, business, industry, community, academia and consumers to develop standards and technical specifications

Steam methane reforming – a method to extract hydrogen using natural gas. It involves catalytically reacting natural gas with steam to produce hydrogen and carbon monoxide (a mixture known as syngas). A subsequent reaction involving more steam produces further hydrogen while also converting carbon monoxide (CO) to carbon dioxide (CO_2)

Supply chain – activities involved to make, move, store and use a product

TWh – Terawatt hour, the amount of electrical energy provided by one terawatt of power for one hour, equal to 1,000 GWh

VRE – Variable Renewable Energy – sources of renewable energy that fluctuate depending on resource availability, such as wind, solar, wave and tidal power

APPENDIX C: SUPPORTING REPORTS

A number of reviews, studies, research and analysis have informed development of the Strategy. Supporting reports are listed below and accessible on the COAG Energy Council website http://www.coagenergycouncil.gov.au/publications/reports-support-national-hydrogen-strategy.

Commissioned reports

Australian Hydrogen Hubs Study
Consultancy: ARUP Australia Pty Ltd
Published: November 2019

Hydrogen for Transport: Prospective Australian Use Cases
Consultancy: Aurecon Australia
Published: October 2019

Hydrogen Industry Legislation
Consultancy: Clayton Utz
Date published: November 2019

Australian and Global Hydrogen Demand Growth Scenario Analysis
Consultancy: Deloitte
Published: November 2019

Hydrogen in the Gas Distribution Networks
Consultancy: GPA Engineering
Published: November 2019

Hydrogen Impacts on Downstream Installations and Appliances
Consultancy: GPA Engineering
Date published: November 2019

Developing community trust in hydrogen
Consultancy: University of Queensland
Published: October 2019

Additional reports

International outreach kick-start project report
Consultancy: The Australian Trade and Investment Commission (Austrade)
Published: November 2019

Hydrogen as a Transport Fuel:
Location options for a freight-based limited initial deployment of hydrogen refuelling stations
Consultancy: Bureau of Infrastructure, Transport and Regional Economics (BITRE)
Published: October 2019

Prospective hydrogen production regions of Australia
Consultancy: Geoscience Australia
Published: 24 September 2019
Available at: https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/130930

Hydrogen Research, Development and Demonstration: Priorities & Opportunities for Australia
Consultancy: CSIRO
Expected publication date is December 2019

APPENDIX D: CONSULTATION

The COAG Energy Council Working Group has prioritised consultation with industry and community to develop the Strategy. During 2019 the Working Group undertook a number of consultations and workshops, and participated in hydrogen-related events to inform development of the Strategy. A summary is set out below:

1. Discussion paper March 2019

https://consult.industry.gov.au/national-hydrogen-strategy-taskforce/national-hydrogen-strategy-request-for-input/

The discussion paper was designed to encourage conversations about Australia's emerging hydrogen industry and seek public input to help inform the Strategy. The paper outlined hydrogen's potential as a clean fuel and the approach to developing the Strategy.

This consultation received a total of 118 submissions, 29 of which were confidential.

Organisations and individuals who submitted public responses

3R Consultants
ActewAGL
ADME Fuels
AGL Energy Limited
Ammonia Energy Association
ATCO
Aurecon
AusIndustry
AusNet Services
Australia Institute
Australian Academy of Science
Australian Academy of Technology and Engineering
Australian Conservation Foundation
Australian Energy Council
Australian Gas Infrastructure Group
Australian Pipeline Limited
Australian Pipelines and Gas Association (APGA)
Australian Strategic Policy Institute
Beyond Zero Emissions, Queensland Conservation Council, Greenpeace, Community Power, Renew (joint submission)
Construction Forestry Maritime Mining and Energy Union (CFMMEU) Mining & Energy Division - Victoria
Chamber of Commerce and Industry of Western Australia
Chiyoda Corporation
City of Ballarat
Clean Energy Council
Climate Council of Australia
CO2 Cooperative Research Centre (CRC)
COAL21
Simon Coburn
Countrywide Renewable Energy Pty Ltd
CSIRO
Davanz
Susan Dwyer
Energy Change Institute, Australian National University
Energy Networks Australia
Energy Transition Hub
Engie Australia and New Zealand
Engineers Australia
Environmental Sciences Australia Pty Ltd
Federal Chamber of Automotive Industries
Friends of the Earth Australia
Gas Energy Australia
Rob Gaulton
GHD (two submissions)
Gladstone Regional Council
Global CCS Institute
Grattan Institute
H Energy Electrical
Hydricity Systems
Hydro Tasmania
Hydrogen Energy Supply Chain (HESC) Project Partners
Hydrogen Mobility Australia (now Australian Hydrogen Council)
Institute for Integrated Economic Research Australia
Invest Victoria
ITM Power
Jemena
KPMG
Meridian Energy Australia
Mondo
Motor Trades Association Australia and Motor Trades Association New South Wales
National Measurement Institute
Northern Tasmania Development Corporation
Northern Territory Government
NTSF Developments Ltd
Origin Energy
Parramatta Climate Action Network (ParraCAN)
PwC
Renewable Hydrogen Pty Ltd (two submissions)
Roads Australia
Shell Australia
Siemens
Southern Green Gas
Standards Australia

Star Scientific
Rupert Steiner
Thinkstep
TransGrid
University of Adelaide
University of Melbourne (two submissions)
University of Queensland (two submissions)
University of Sydney
Voices of the Valley
Dr Derek Walter
Roger West
Woodside Energy
WorleyParsons Group
Zen Clean Energy Solutionsns

2. Issues papers July 2019

https://consult.industry.gov.au/national-hydrogen-strategy-taskforce/national-hydrogen-strategy-issues-papers/

Building on previous engagement, nine thematic issues papers were released seeking feedback on the potential role of policies and actions in realising hydrogen opportunities.

This consultation received a total of 77 submissions, 23 of which were confidential.

Organisations who submitted public responses

AGL Energy
ALCOA Australia
APA Group
ARUP
ATCO
AusNet Services
Australian Academy of Technology and Engineering
Australian Association for Hydrogen Energy
Australian Energy Council
Australian Gas Infrastructure Group (AGIG)
Australian Pipelines and Gas Association (APGA)
Australian Renewable Energy Agency (ARENA)
Australian Trucking Association
Bennett Clayton Pty Ltd
BOC, Coregas and Viva Energy (joint submission)
BP
Clean Energy Council
CO2 Cooperative Research Centre (CRC)
COAL21
CSIRO
Curtin University
Doctors for the Environment Australia
Energy Change Institute, Australian National University
Energy Estate
Energy Networks Australia
Engie
Environmental Clean Technologies Limited
Ethical Developments Pty Ltd
Gas Appliance Manufacturers Association of Australia (GAMAA)
GHD
Global CCS Institute
Grattan Institute
Hazer Group
Hydricity Systems
Hydro Tasmania
Hydrogen Energy Supply Chain (HESC) Project Partners
Hydrogen Mobility Australia (now Australian Hydrogen Council)
Institute for Integrated Economic Research Australia
Institute for Sustainable Futures, University of Technology Sydney
Joint Accreditation System of Australia and New Zealand (JAS-ANZ)
Maritime Union of Australia
Meridian Energy Australia
MM Technology
Mondo Power
National Farmers' Federation
Origin Energy
Protos Consulting
Public Interest Advocacy Centre (PIAC)
Redland City Council
Renew
Renewable Hydrogen Pty Ltd
Rheem Australia
Roads Australia
Woodside Energy

Engagement

In addition to the targeted workshops and roundtable events, the Chief Scientist, Taskforce Leader, and Working Group members presented and participated in many events across Australia and overseas. Attendance at these events was often combined with face-to-face meetings and stakeholder briefings.

Roundtables and workshops

The Working Group held 14 theme-based stakeholder roundtables and workshops across Australia:

Date	Themes	Location
4-5 April 2019	Industry and Government Workshop	Canberra, Australian Capital Territory
10 April 2019	Industrial Users	Darwin, Northern Territory
6 May 2019	Research and Development	Sydney, New South Wales
6 May 2019	Industrial Users	Sydney, New South Wales
6 May 2019	Workforce Skills	Sydney, New South Wales
7 May 2019	Exports	Melbourne, Victoria
7 May 2019	Industrial Users	Melbourne, Victoria
9 May 2019	Gas	Melbourne, Victoria
9 May 2019	Electricity	Melbourne, Victoria
29 May 2019	Industrial Users, Transport, Electricity and Finance	Brisbane, Queensland
4 June 2019	Transport	Sydney, New South Wales
17 June 2019	Gas and Electricity	Perth, Western Australia
17 June 2019	Export and Industrial Users	Perth, Western Australia
13 September 2019	Industry and Communities Workshop	Canberra, Australian Capital Territory

International engagements

Air Liquide, France
Alstom, France
American Association for the Advancement of Science
Argonne National Laboratory, United States (US)
Ballard Power Systems, Greenlight Innovation, Vancouver, Canada
British Columbia's Innovation Commissioner, Canada
California Air Resources Board
California Energy Commission
California Energy Market Policy and Regulation
California Governor's Office
California Secretary for Environmental Protection
Canadian National Research Council
Center for Strategic and International Studies, US
CertifHy, European Union (EU)
Council on Competitiveness, US
Department for Business, Energy and Industrial Strategy, United Kingdom (UK)
Department of Energy, US
Directorate-General for Energy (DG-ENER), European Commission
Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG-Grow), European Commission
Directorate-General for Research and Innovation (DG-ENER), European Commission
Engie, France
EPA, US
Federal Chancellery - Industry, Innovation, Energy and Transport Section, Berlin, Germany
Federal Ministry for Economic Affairs and Energy (BMWI), Germany
Federal Railroad Administration, Department of Transportation, US
Federal Transit Administration, Department of Transportation, US
Fraunhofer Institute, EU
French Alternative Energies and Atomic Energy Commission (CEA)
Fuel Cell and Hydrogen Energy Association, US
Fuel Cells and Hydrogen Joint Undertaking (FCH JU), EU
Fuel Cell Technologies Office (FCTO), Department of Energy, US
Global Regulations and Public Affairs, France
Hydrogen Europe
HyStock Power Plant, The Netherlands
International Association for Hydrogen Safety (HySafe), Belgium
International Energy Agency (IEA)
International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)
National Aeronautics and Space Administration (NASA), US
National Energy Technology Laboratory, US
National Renewable Energy Laboratory, US
Natural Resources Canada (NRCan)
Northern Gas Networks, UK
Northern Innovation Board, The Netherlands
Nuon Magnum Power Plant, The Netherlands
Plug Power, US
Sandia National Laboratory, US
Sempra Utilities, California, US
White House Office of Science and Technology Policy, US
White House, US

APPENDIX E: TERMS OF REFERENCE

In December 2018, Australia's Chief Scientist, Dr Alan Finkel, submitted a proposal for a national hydrogen strategy to COAG Energy Council.[1] The proposal suggested supporting the development of a clean, innovative and competitive hydrogen industry that benefits all Australians and is a major global player by 2030.

On 19 December 2018, COAG Energy Council agreed to establish a dedicated Working Group, chaired by the Chief Scientist, to lead activities that achieve this vision.

Key priorities for the Working Group included:

- the development of a national hydrogen strategy for 2020-2030, and
- a coordinated approach to projects and programs that support industry development.

The following six work streams were identified for the Working Group:

- hydrogen exports
- hydrogen for transport
- hydrogen in the gas network
- hydrogen for industrial users
- hydrogen to support electricity systems
- cross-cutting issues.

Ministers asked that the Strategy adhere to the following principles:

1. be ambitious
2. prioritise safety and benefits to customers
3. have clear goals and objectives
4. use partnerships
5. be technology neutral
6. consider the distribution of costs and benefits for Australians
7. be commercially focused
8. be consistent with sustainable environmental management

The Working Group was asked to work closely with industry on the development of the Strategy, and to take into account views of experts, end users, and environment and community groups. In considering policies and measures for the national strategy, the Working Group was asked to consider international trends and best practices, reducing red tape and encouraging innovation, and also potential co-benefits, like fuel security, regional development, and non-greenhouse gas air pollution.

On the Chief Scientist's advice, COAG Energy Council tasked the Working Group with carrying out three projects during 2019, to set the stage for implementation of the national strategy and begin building Australia's standing within international markets as a major player. These projects were done in partnership with industry and the community, and have engaged towns and cities across the country. Reports on each of these projects will be made available on the COAG Energy Council website.

Endnotes

1. Dr Alan Finkel AO, 2018, Proposal for a national hydrogen strategy http://www.coagenergycouncil.gov.au/publications/establishment-hydrogen-working-group-coag-energy-council

APPENDIX F: COAG HYDROGEN WORKING GROUP

National Hydrogen Strategy Steering Committee

Membership	Organisation	Jurisdiction
Alan Finkel (Chair)	Office of the Chief Scientist	Commonwealth
Jo Evans	Department of Environment and Energy	Commonwealth
Mike Lawson	Department of Industry, Innovation and Science	Commonwealth
Andrew Lewis	Department of Planning, Industry and Environment	New South Wales
James Hay	Department of Planning, Industry and Environment	New South Wales
Anthea Harris	Department of Environment, Land, Water and Planning	Victoria
John Lewis	Department of State Development, Manufacturing, Infrastructure and Planning	Queensland
Stephanie Jolly	Department of Natural Resources, Mines and Energy	Queensland
Niegel Grazia	Department of Primary Industries and Regional Development	Western Australia
Paul Heithersay	Department for Energy and Mining	South Australia
Sue Morrison	Department of State Growth	Tasmania
Sean Terry	Department of State Growth	Tasmania
Geoffrey Rutledge	Environment, Planning and Sustainable Development Directorate	Australian Capital Territory
Shaun Drabsch	Department of Trade, Business and Innovation	Northern Territory

National Hydrogen Strategy Taskforce

Commonwealth Government

Alison Reeve (Taskforce Leader)	**Department of the Environment and Energy**
Jason Russo (co-leader)	Department of Industry, Innovation and Science
Serina Bird	Department of Foreign Affairs and Trade
Kate Boston	Office of the Chief Scientist
Cameron Byers	Department of the Environment and Energy
Tom Calthorpe	Department of the Environment and Energy
Sarah Chapman	Department of Industry, Innovation and Science
Hollie Dawes	Department of Industry, Innovation and Science
Adele Henry	Department of Industry, Innovation and Science
Nicole Henry	Department of Industry, Innovation and Science
James Hetherington	Department of the Environment and Energy
Jessica Lane	Department of the Environment and Energy
Suchi Misra	Department of the Environment and Energy
Kim van Netten	Department of Industry, Innovation and Science

With contributions and support from:

William Blomfield, Sarah Brown, Tom Campey, Amanda Caldwell, Shaneen Coulson, Nicholas Covy, Lesley Dowling, Karen Elliott, Jodie Fairall, Phil Fitzgerald, Sophie Francis, Doug Gorrel, Paul Gunning, Tegan Hedington, Leigh Kennedy, Ashley Kerrison, Young Lee, Haakon Marold, Andrew Morris, Ruth Oettle, Jason Potkins, Mily Quinn, Matthew Stuchbery, Ayumi Sakamoto, Helen Thai, Matthew Wagner, Natasha Wallis, Emma Wisdom, and Marianne Zakman.

New South Wales Government

David Moore (Lead)	**Department of Planning, Industry and Environment**
Colette Grigg	Department of Planning, Industry and Environment
Evan Walker	Transport for New South Wales

With contributions and support from:

Lindsay Cohen, Liz Devlin, Katharine Hole, Anissa Levy, Alexandra Meldrum, Michael Molitor, and Michael Norris, with additional support from representatives from a number of NSW State Government agencies.

Victorian Government

Sharn Enzinger (Lead)	**Department of Environment, Land, Water and Planning**
Barbara Blake	Department of Environment, Land, Water and Planning
Gabrielle Henry	Department of Environment, Land, Water and Planning
Felicity Sands	Department of Environment, Land, Water and Planning

With contributions and support from:

Katerina Alexsoska, Jane Burton, Vanya Kumar, David Oglesby, and Mayuran Sivapragasam.

Queensland Government

Carlye Sycz (Lead)	**Department of Natural Resources, Mines and Energy**
Joel Lindsay	Department of Natural Resources, Mines and Energy
Karen Knight	Department of Natural Resources, Mines and Energy

With contributions and support from:

Ian Chapman, David Shankey, Kathie Standen, the Department of State Development, Manufacturing, Infrastructure and Planning and other representatives from various Queensland Government agencies.

West Australian Government

Amy Tait (Lead)	**Department of Primary Industries and Regional Development**
Fabrice Gregoire	Department of Jobs, Tourism, Science and Innovation
Rosh Ireland	Energy Policy WA
Joanne Keeling	Department of Primary Industries and Regional Development
Eamonn McCabe	Department of Primary Industries and Regional Development
Joe Wyder	Department of Primary Industries and Regional Development

With contributions and support from:

Michelle Carter and other representatives from various WA State Government agencies.

South Australian Government

Richard Day (Lead)	**Department for Energy and Mining**
Ben Macey	Department for Energy and Mining
Edit Mucsi	Department for Energy and Mining
Owen Sharpe	Department for Energy and Mining
Nick Smith	Department for Energy and Mining
Kara Turner	Department for Energy and Mining
Debbie Wielgosz	Department for Energy and Mining

With contributions and support from:

Wayne Barbour, Andre Gascoigne, Rebecca Knights, Vick Koster, Mary Lewitzka, Alan Richards and Jemma Temby

Tasmanian Government

Marcus McKay (Lead)	**Department of State Growth**
Thomas Butler	Department of State Growth

With contributions and support from:

David Middleton, Andrew Rayner, Gary Swain.

Northern Territory Government

Louis Gomatos (Lead)	**Department of Primary Industry and Resources**
Gibson Porkime	Department of Primary Industry and Resources
Howard Smith	Department of Trade, Business and Innovation
Jason Howe	Department of Trade, Business and Innovation

With contributions and support from:

Rod Applegate, Samantha Byrne, Bruce Michaels, Jason Schoolmeester.

Australian Capital Territory Government

Tracy Cui (Lead)	**Environment, Planning and Sustainable Development Directorate**
James Priestley	Environment, Planning and Sustainable Development Directorate

With contributions and support from:

Kate Holland and Hugo Temby.

Stakeholder Advisory Panel

As a part of the development of the Strategy, a Stakeholder Advisory Panel was established to provide support to the Steering Committee. The Panel was chaired by the Chief Scientist and included representation and expertise from the following fields:

- safety and communities
- gas transmission and distribution
- electricity industry
- transport sector
- energy users
- environment, water and emissions
- finance, industry development and export
- hydrogen production
- research, development and innovation
- standards and regulations
- energy security

The Stakeholder Advisory Panel met three times during the development of the Strategy.

Membership	**Organisation**
Peta Ashworth	University of Queensland
John Blackburn	Defence and National Security Systems Consultant
Richard Bolt	Swinburne University of Technology
Tom Campey	Australian Renewable Energy Agency
Andrew Catchpole	Hydro Tasmania
Billy Chan	BOC Ltd
Matt Clemow	Australian Energy Market Operator
Andrew Dillon	Energy Networks Australia
Gustavo Gomberg	N/A
Shaun Gregory	Woodside
Martin Hablutzel	Siemens
Patrick Hartley	CSIRO
David Havyatt	Energy Consumers Australia
Duncan MacKinnon	Australian Energy Council
Karlene Maywald	Maywald Consultants Pty Ltd
Rebecca Mills	Territory Generation
John Paul Olivier	Fortescue Metals Group
Laura Reed	Epic Energy
Andrew Richards	Energy Users Association of Australia
Fiona Simon	Australian Hydrogen Council
Anna Skarbek	ClimateWorks
Kane Thornton	Clean Energy Council
Ben Wilson	Australian Gas Infrastructure Group

APPENDIX G: ACKNOWLEDGEMENTS

The COAG Hydrogen Working Group would like to thank the following people and organisations who assisted in the development of the Strategy.

Organisations

ARUP
Australian Renewable Energy Agency (ARENA)
Aurecon
Austrade
Australian Consulate and Trade Commission, Vancouver BC
Australian Consulate-General, Los Angeles CA
Australian Embassy, Berlin, Germany
Australian Embassy, Paris, France
Australian Embassy, Seoul, Republic of Korea
Australian Embassy, The Hague, The Netherlands
Australian Embassy, Tokyo, Japan
Australian Embassy, Washington DC
Australian High Commission, London, United Kingdom
Australian Hydrogen Council (formerly Hydrogen Mobility Australia)
Clayton Utz
Clean Energy Finance Corporation (CEFC)
Commonwealth Scientific and Industrial Research Organisation (CSIRO)
CO2 Cooperative Research Centre (CRC)
Deloitte
Future Fuels Cooperative Research Centre (CRC)
Geoscience Australia
Office of the Chief Scientist
Standards Australia
ThinkPlace

Individuals

Peta Ashworth, University of QLD
Jose Aza Flores, Origin Energy
Ken Baldwin, Australian National University
Paul Barrand, AGL
Annika Barton, Austrade
Kobad Bhavnagri, Bloomberg New Energy Finance
Luke Blackbourn, Yara
Sean Blythe, ENGV
Richard Bolt, Swinburne University of Technology
Tim Bradley, Department of Industry, Innovation and Science
Sam Button, Aurecon
Caitlin Caruana, Department of Foreign Affairs and Trade
Drew Clarke, Australian Energy Market Operator
Alex Cooke, Department of Industry, Innovation and Science
Mike Davis, Jemena
Anthony Dobb, ARENA
Alex Dronoff, BOC
Tim Duignan, Territory Generation
Robert Dunlop, Macquarie Capital
Ben Evans, ThinkPlace
Nicole Forrester, CSIRO
Anna Freeman, Clean Energy Council
Michael Gantois, FMGL
Timor Gul, International Energy Agency
Patrick Hartley, CSIRO
David Havyatt, Energy Consumers Australia
Rob Heferen, Department of the Environment and Energy
Trevor Holloway, Department of Foreign Affairs and Trade
Will Howard, Department of the Environment and Energy
Claire Johnson, Hydrolytics
Ashley Kerrison, Academic
Amit Khaira, Austrade
Justine Lacey, CSIRO
Sandra Lau, Viva Energy
John Loughhead, Department for Business, Energy and Industrial Strategy, United Kingdom
Matthew Macleod, Toyota
Brooke Maki, GHD
Samuel Maresh, GE Australia
Scott Nargar, Hyundai
David Norman, Future Fuels CRC
Shannon O'Rourke, Woodside
Briony O'Shea, GPA Engineering
Jacqueline Pham, Department of the Environment and Energy
Morgan Quinn, ATCO
Kristin Ramanm, AGIG
Daniel Roberts, CSIRO
James Rudge, Vestas
Greg Simmons, Lochard Energy
Rosemary Sinclair, Energy Consumers Australia
Vivek Srinivasan, CSIRO
Nina Terrey, ThinkPlace
Nicole Thomas, Department of the Environment and Energy
Rebecca Thompson, Department of the Environment and Energy
Robert Trezona, IP Group
Noe Van Hulst, Ministry of Economic Affairs and Climate Policy, The Netherlands
Kate Vidgen, Macquarie Capital
Tim Wallace, Independent Editorial Consultant
Tony Wood, Grattan Institute
Masako Yoda, Department of Foreign Affairs and Trade