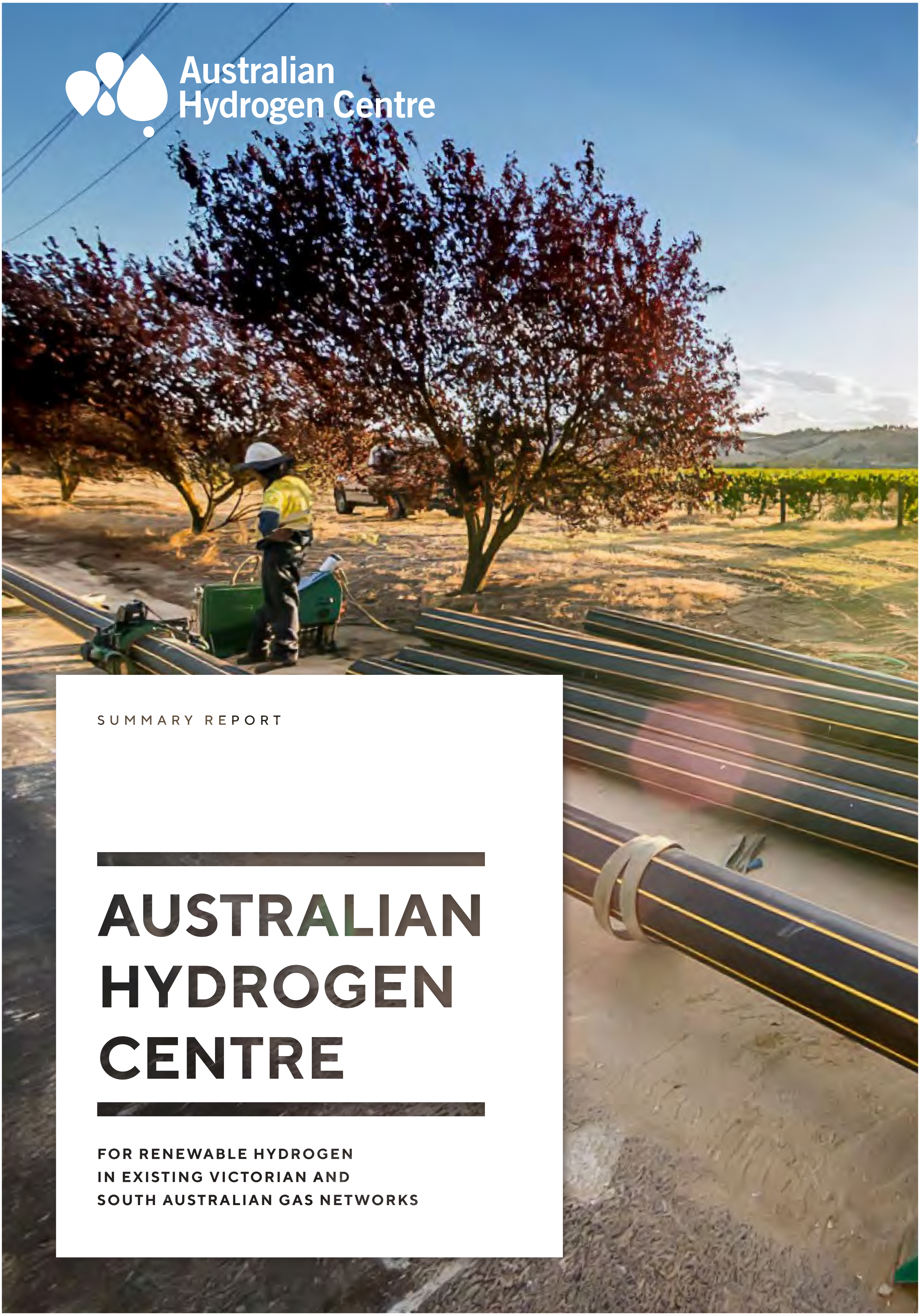

Australian Hydrogen Centre

SUMMARY REPORT

AUSTRALIAN HYDROGEN CENTRE

FOR RENEWABLE HYDROGEN
IN EXISTING VICTORIAN AND
SOUTH AUSTRALIAN GAS NETWORKS

Acknowledgement of Country

The Australian Hydrogen Centre acknowledges Aboriginal and Torres Strait Islander people, and their lands on which we work, which support and sustain the energy systems we study.

We pay our respects to their Elders, past and present. We commit to reflecting that respect in the ways we carry out our work.

Yankalilla SA, Australia
Kaurna Country

DISCLAIMER

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The views expressed herein are not necessarily the views of the Australian Government, the Victorian Government, or the South Australian Government (the Governments). The Governments do not accept responsibility for any information or advice contained within this document.

This project received funding from the Australian Renewable Energy Agency (ARENA) as part of ARENA's Advancing Renewables Program, and the Victorian Government's Victorian Hydrogen Investment Program (VHIP).

> This research shows renewable hydrogen delivers real benefits for all Australians, unlocking greater value from our world-class infrastructure. Our sustainable, circular approach to reducing carbon emissions in both the gas and electricity systems, will minimize disruption for all South Australians as we transition to renewable technologies.
>
> Hon. Tom Koutsantonis MP, South Australia's Minister for Energy and Mining

Government of South Australia
Department for Energy and Mining

> Victoria's Gas Substitution Roadmap is charting an ambitious path out of fossil gas, and renewable hydrogen could play a key role in helping decarbonise transport, industrial processes and other hard to abate sectors.
>
> Hon Lily D'Ambrosio MP, Victoria's Minister for Energy and Resources

> We're proud to work with industry and government on this innovative project to deliver a potential pathway to decarbonise the Victorian and South Australian gas distribution networks.
>
> Tom Hallam, General Manager Regulation, Transmission and Gas, AusNet Services

> By leveraging South Australia's world-class wind resources, Neoen has already shown it is possible to generate highly competitive power for industry and we are exploring opportunities for green hydrogen in a range of domestic and export applications.
>
> Louis de Sambucy, Managing Director, Neoen Australia

> AGIG is committed to using renewable gas, including hydrogen, to decarbonise Australia's world-class gas distribution networks in a way that is safe, cost competitive, maintains energy security, and provides the best outcome for our customers.
>
> Craig de Laine, Chief Executive Officer, Australian Gas Infrastructure Group

Executive Summary

The Australian Hydrogen Centre (AHC) was established to deliver Australian-first feasibility studies of how existing natural gas distribution networks could be used in a system to produce, store, and transport renewable hydrogen, decarbonising gas supply while still meeting the needs of millions of customers.

This follows the Australian National Hydrogen Strategy's (the Strategy) identification of hydrogen in gas networks as one of three large-scale activation markets to build demand.[1] The Strategy outlined that taking early steps to use hydrogen in transport, industrial use and gas networks will complement and enhance the impact of hydrogen hubs on making hydrogen infrastructure more cost-effective, promoting efficiencies, fostering innovation, and encouraging sector coupling synergies.[2]

This Summary Report presents the key findings from a series of technical reports, which can be found in ARENA's Knowledge Bank[3]:

1. 10% Hydrogen Distribution Networks in selected Regional Towns in Victoria and South Australia.
2. 10% Hydrogen Distribution Networks – Victorian and South Australian Feasibility Studies.
3. 100% Hydrogen Distribution Networks – Victorian and South Australian Feasibility Studies.

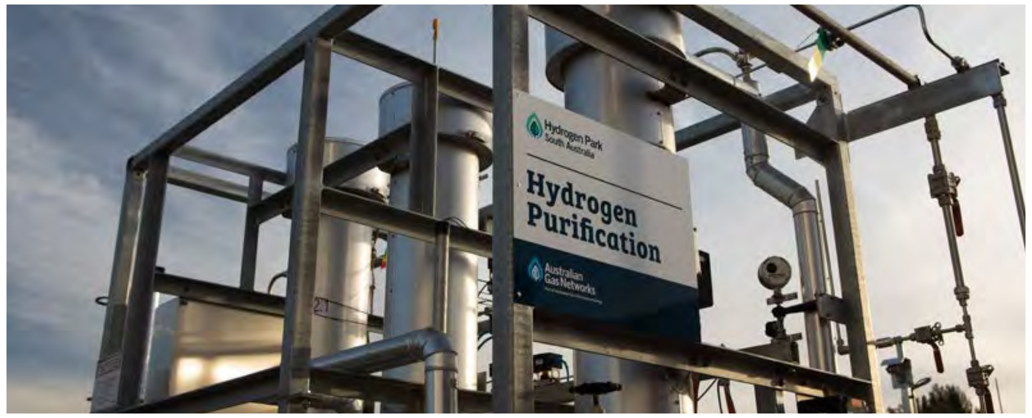
The $4.15 million AHC project, supported by the Australian Renewable Energy Agency (ARENA), the Victorian Government and the South Australian Government, has brought together expertise and knowledge from across the energy supply chain including renewable electricity producers, electricity and gas infrastructure owners, and retailers to produce comprehensive research.

The AHC Reports (The Reports) show that it is technically and economically feasible to use existing gas infrastructure for scaled hydrogen distribution, delivering:

- A net zero carbon emissions gas network;
- Minimised customer disruption whilst retaining security and diversity of energy supply;
- Services to the electricity grid through flexible electricity demand and frequency control;
- 15 gigawatts (GW) of electrolysis supported by over 30 GW of new renewable electricity generation;
- 30 petajoules (PJ) of hydrogen storage to harness the ability of gas to store vast amounts of energy, balancing renewable electricity supply and demand swings between colder and warmer months; and
- Over $1.5 billion in additional economic value a year including more than 12,500 jobs during construction and more than 6,200 jobs during operation.

Supported by a range of independent technical studies, the AHC's focus was to determine how a 100% renewable hydrogen distribution system could optimally be achieved in South Australian and Victoria for supply to households, businesses and industry and is not a detailed scenario analysis on decarbonising the wider economy.

The Reports provide a better understanding of the opportunity to access Australia's world-class gas distribution infrastructure to unlock its hydrogen opportunity whilst retaining energy security and affordability, and identifies a range of low-regret enablers that could trigger coordinated action by government and industry. They also share learnings from Hydrogen Park South Australia (HyP SA), an Australian-first demonstration of hydrogen blending in a gas distribution network.



1. See page 33 of the National Hydrogen Strategy, found here: https://www.dcceew.gov.au/sites/default/files/documents/australias-national-hydrogen-strategy.pdf
2. See page viii of the National Hydrogen Strategy, linked above.
3. ARENA's Knowledge Bank can be found here: https://arena.gov.au/knowledge-bank/

AHC Concept Summary

SUPPLY

RENEWABLE HYDROGEN PRODUCTION

10% renewable hydrogen supply to existing gas distribution networks could be achieved through 670 megawatts (MW) of electrolyser capacity built alongside existing electricity and gas networks.

100% renewable hydrogen networks could be supplied from around 15 GW of large-scale hydrogen production hubs built near Renewable Energy Zones (REZ) with hydrogen supplied to market through pipelines.

SECTOR COUPLING

An innovative model for renewable electricity and gas integration could capture abundant variable renewable electricity supply for storage and later use, harnessing the advantage of gas infrastructure to store vast amounts of energy.

This reduces the cost of electricity for hydrogen produced and provides services to the electricity market through additional demand and grid stabilisation.

SUSTAINABLE WATER SOURCING

Water requirements for 100% hydrogen in existing networks is no more than 0.3% of the annual physical water use in both South Australia and Victoria in 2019-20.

Recognising water is a precious resource, the cost of drawing on lower quality water options such as seawater and recycled wastewater was factored into the AHC's model.

STORAGE AND TRANSPORT

Intra-day storage to balance daily peaks could be co-located with hydrogen production at 10% network penetration, bolstered by new hydrogen pipelines connecting large-scale hydrogen supply to demand centres to deliver 100% hydrogen in networks.

Developing inter-seasonal storage will be key to balance renewable energy supply and demand swings between summer and winter, with further work to determine the most suitable technology including existing geological stores.

NETWORKS

NETWORK READINESS

Australia's gas distribution networks stored and transported approximately 50% hydrogen in 'town gas' made from coal around 50 years ago.

Gas distribution networks, their components, and constituent materials are generally compatible to safely and reliably transport 100% hydrogen. Minimal modification can occur as part of gas network businesses' programmed asset upgrades.

NETWORK PERFORMANCE

Considering the differences in properties of natural gas and hydrogen, 100% hydrogen could reduce the networks overall capacity by around 13%. The network could absorb this reduction and still maintain supply at historic service levels.

Network testing at Hydrogen Park South Australia shows that hydrogen blended into natural gas mixes uniformly with natural gas throughout the existing network, and does not cause network leaks.

NETWORK OPERATIONS

Updates to safety and operating procedures and systems to reflect the differing characteristics between hydrogen and natural gas do not represent a major step-change to current procedures, and can be made in time to support delivery of 100% hydrogen in networks.

NETWORK TRANSITION

A single step transition to 100% hydrogen could efficiently take place from the agreed maximum limit for current gas appliances, currently 10%.

This could be achieved on a section-by-section basis across the networks. It is essential that communication with customers takes place often and early before any conversion works are started.

CUSTOMERS

CUSTOMER EXPERIENCE

Multiple projects in Australia and overseas are already demonstrating the safety and equivalent consumer experience of hydrogen blending and 100% hydrogen appliances.

Customer experience from Hydrogen Park South Australia has been positive with 100% of survey participants saying safe delivery of gas to the home has remained or improved.

APPLIANCE COMPATIBILITY

Domestic appliances are compatible with volumes of up to 10% hydrogen in natural gas, with work underway to determine the maximum upper limit. Research to confirm the compatibility of bespoke commercial and industrial appliances at 10% hydrogen is well progressed.

New appliances or burner parts may be required for 100% hydrogen, however existing gas fittings connecting customers' meters to appliances are compatible.

HYDROGEN-READY APPLIANCES

Hydrogen-ready and 100% hydrogen appliances are being developed and demonstrated in Australia and overseas.

The introduction of hydrogen-ready appliances enables customers to retain their choice of energy supply as existing appliances are retired or replaced, while also reducing disruption at the time of 100% implementation.

CUSTOMER PRICE IMPACTS

High-level modelling of customer price impacts demonstrates delivering 100% hydrogen in networks could be similar to projected customer bills for natural gas only out to 2050.

Modelling does not consider potential upsides delivered by attributing a cost of carbon; using other forms of renewable and carbon neutral gases such as biomethane and hydrogen with carbon capture and storage; and breakthrough technological advances.

DELIVERY

HYDROGEN HUBS INTEGRATION

Delivering 10% hydrogen helps lay the foundations for an emerging hydrogen industry through development of skills, public acceptance and large-scale projects while lowering emissions and retaining energy affordability and reliability.

Delivering 100% hydrogen in networks would mark a mature Australian hydrogen industry, where abundant renewable hydrogen supplied from large-scale hubs competes with traditional fuel sources.

IMPLEMENTATION

Switching from 10% to 100% hydrogen could leverage lessons from similar programs such as existing mains replacement and the move from town gas to natural gas.

This transformational shift in the energy system to achieve common net zero goals requires strong coordinated action between government and industry.

REGULATORY AND LEGAL ASSESSMENT

There is significant work underway at state, federal and international levels to develop regulatory frameworks, specifications and standards for 10% and 100% hydrogen supply in networks.

Low regret enablers considered included to support delivery included mechanisms to promote hydrogen's uptake through the networks, and to secure the uptake of hydrogen-ready appliances to enable a smooth transition of the networks.

ECONOMIC BENEFITS AND OPPORTUNITIES

Achieving 10% and 100% hydrogen in networks could provide a significant direct and indirect economic contributions, including upskilling trades such as gas fitters.

100% hydrogen in Victorian and South Australian networks could add $1.53 billion in economic value a year including 12,509 jobs during construction, and $1.17 billion and 6,225 jobs during operation.

How is this Pathway Achieved?

10% HYDROGEN

Overall Findings
Achieving 10% hydrogen helps lay the foundations for Australia's emerging hydrogen industry through development of skills, public acceptance and large-scale projects while lowering emissions and retaining energy affordability and reliability.

Key features of the transition include:

- 670 MW of electrolyser capacity supported by existing renewable electricity generation;
- 30 tonnes of short-term hydrogen storage; and
- More than 700 jobs during construction, and more than 150 jobs ongoing.

Concept Description
Hydrogen production facilities could be built along locations of existing gas distribution networks for the direct introduction of renewable hydrogen at volumes of up to 10%.

Electrolysers producing the hydrogen are powered by renewable electricity sourced through existing electricity networks via innovative Power Purchasing Agreements (PPAs). The volumes of water required would be low at less than 0.05% of existing water use. It would avoid competition with existing demands where possible by drawing on sustainable sources such as recycled wastewater.

The existing gas distribution network will have sufficient capacity to supply customers with 10% blended gas, with no impact on existing gas appliances.

Key Enablers

- Establishing a renewable gas market framework;
- Building on existing public acceptance programs for renewable hydrogen;
- Updating standards and testing for gas appliances;
- Attaining project-based approvals and investment decisions;
- Procurement for and construction of 10-200 MW hydrogen production facilities up to a total capacity of 670MW; and
- Ongoing monitoring and optimisation of infrastructure to support 100% conversion of gas distribution.

100% HYDROGEN

Overall Findings
Building on the foundations laid through achieving 10% hydrogen in networks, the transition to 100% hydrogen could take place in a single step across networks on a section-by-section basis from the mid-2030s.

Delivering 100% hydrogen in networks marks a mature Australian hydrogen industry, where abundant renewable hydrogen supplied from large-scale hubs competes with traditional fuel sources across the economy with customers continuing to benefit from fuel choice while decarbonising their energy use.

Key features of the transition include:

- 15 GW of electrolysis, supported by more than 30 GW of new renewable generation;
- 30 PJ of long-term hydrogen storage; and
- More than 12,000 jobs during construction, and more than 6,000 jobs ongoing.

Concept Description
Large-scale hydrogen production facilities could be built near REZ and supplied with renewable electricity and sustainably sourced water.

To enable renewable hydrogen to be produced at scale during summer and spring when renewable electricity is abundant, long-term and high volume storage is developed using existing geological stores such as salt caverns or depleted gas fields.

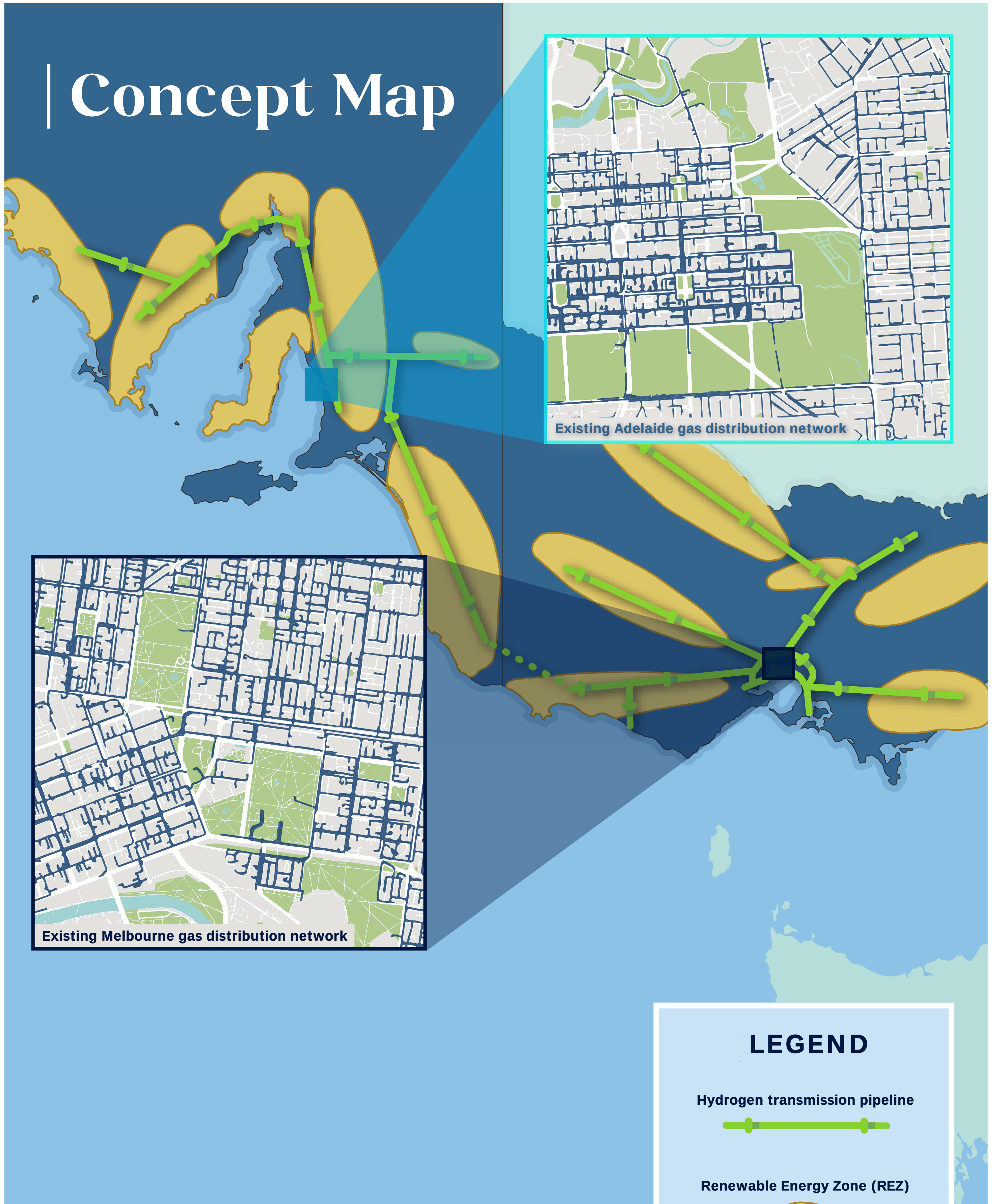
Existing natural gas distribution networks supply hydrogen to residential, commercial, and industrial customers. A smooth appliance changeover process is supported by the introduction of hydrogen-ready appliances replacing existing appliances after their natural retirement, supported by a comprehensive implementation program leveraging lessons from similar programs such as existing mains replacement and the move from town gas to natural gas.

Based on a conservative model considering capital investment and operating costs, estimates show that average residential customer bills in Victoria and South Australia could be similar to projected customer bills for natural gas only out to 2050.

Key Enablers

- Ensuring customer readiness through communications that are often and early;
- Ramping up availability of hydrogen-ready appliances and preparing appliance switch-over and conversion programs;
- Attaining project-based approvals and investment decisions;
- Procurement for and construction of 200 MW – 1 GW scale hydrogen production facilities, and storage and transmission facilities up to a total capacity of 15GW;
- Defining implementation strategies for 100% gas distribution networks and appliances; and
- Updating safety and operating procedures and systems and upskilling key trades including gas fitters to support the transition to 100% hydrogen in networks.

Concept Map



As part of the 100% hydrogen scenario, renewable hydrogen could be produced through electrolysis in REZ and transported to demand centres in new hydrogen transmission pipelines.

These pipelines will connect to existing gas distribution networks which, with minor modifications, supply renewable hydrogen to homes, businesses, and industry.

AHC Members

The AHC is a joint project between its members to investigate the commercial potential of hydrogen blending in the gas distribution network.

The founding members of the AHC include:

Government of South Australia
Department for Energy and Mining

State of South Australia, as represented by the Department for Energy and Mining (DEM) oversees the responsible mining and production of the minerals, metals, and fuels of the future in South Australia. Ensuring the safe and sustainable generation of energy and low carbon products of the future.

VICTORIA State Government | Energy, Environment and Climate Action

State of Victoria, as represented by the Department of Energy, Environment and Climate Action (DEECA) focuses on creating a liveable, inclusive, and sustainable Victoria with thriving natural environments.

AusNet

AusNet Transmission Group Pty Ltd and AusNet Gas Services Pty Ltd. (AusNet) owns and operates the Victorian electricity transmission network, an electricity distribution network and a gas distribution network.

engie

ENGIE ENERGIE SERVICES (ENGIE) are a global reference group in low-carbon energy and services and are committed to accelerating the transition to a carbon-neutral world through more energy-efficient and environmentally friendly solutions.

NEOEN

Neoen Australia Pty Ltd. (Neoen) is the leading French independent producer of renewable energy.

Australian Gas Infrastructure Group

Australia Gas Networks Limited (AGN) part of **Australian Gas Infrastructure Group (AGIG)** owns and operates infrastructure that delivers gas to more than two million Australian homes and businesses. AGIG also delivers gas that supports the Australian economy – for power generators, mines, and manufacturers.

The overall work program from the AHC brings together experts and key stakeholders to deliver detailed feasibility studies for hydrogen in gas networks and to share learnings. In the feasibility stages, knowledge sharing of AHC members is essential to ensure the renewable gas sector can scale up efficiently and safely.

The AHC reports were developed with several independent consultancies selected in a competitive process by a Governance Committee of representatives from AHC members.

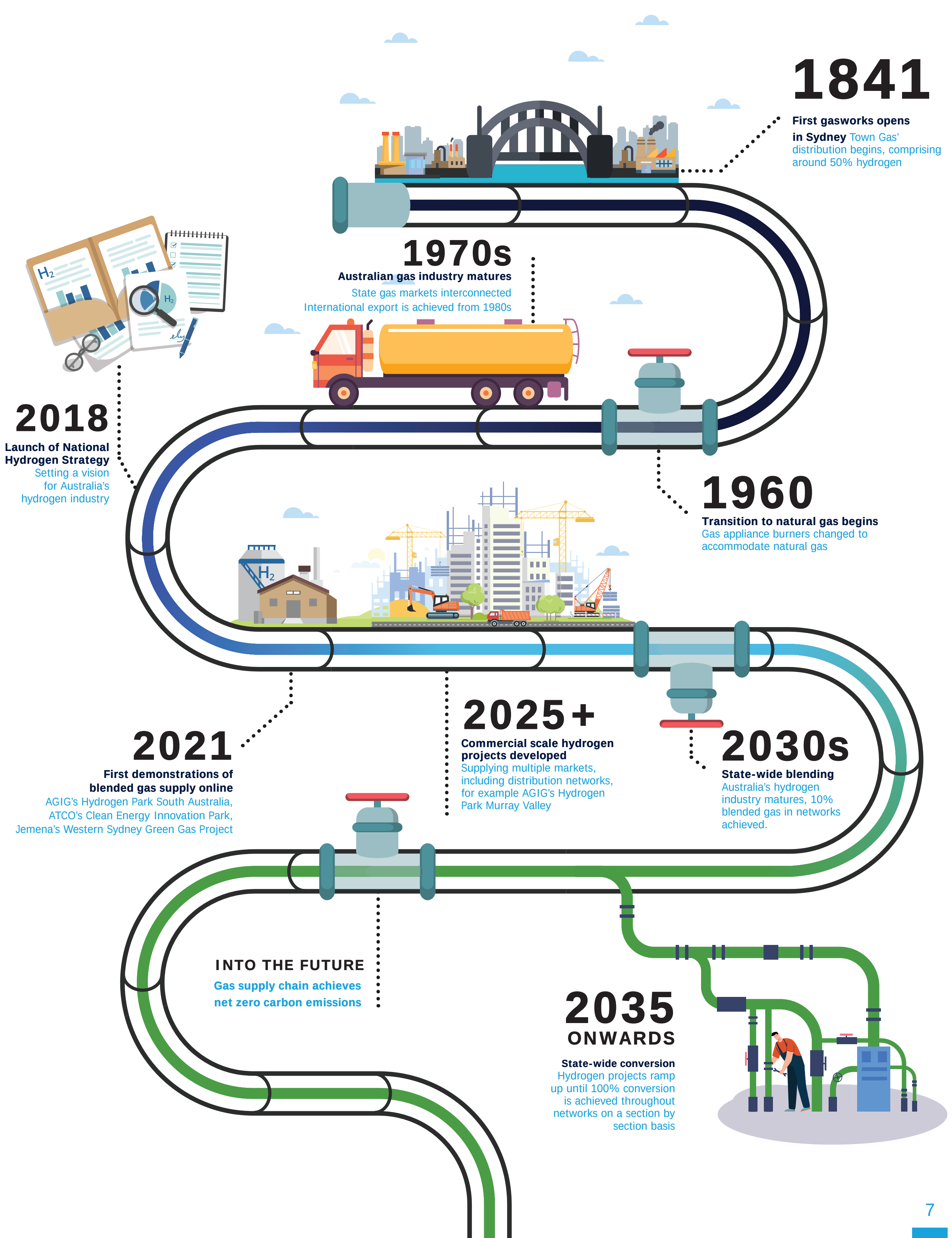
Advisian | ARUP | Ethos Urban | farrierswier | frontier economics | GPA ENGINEERING | Jacobs | Oakley Greenwood

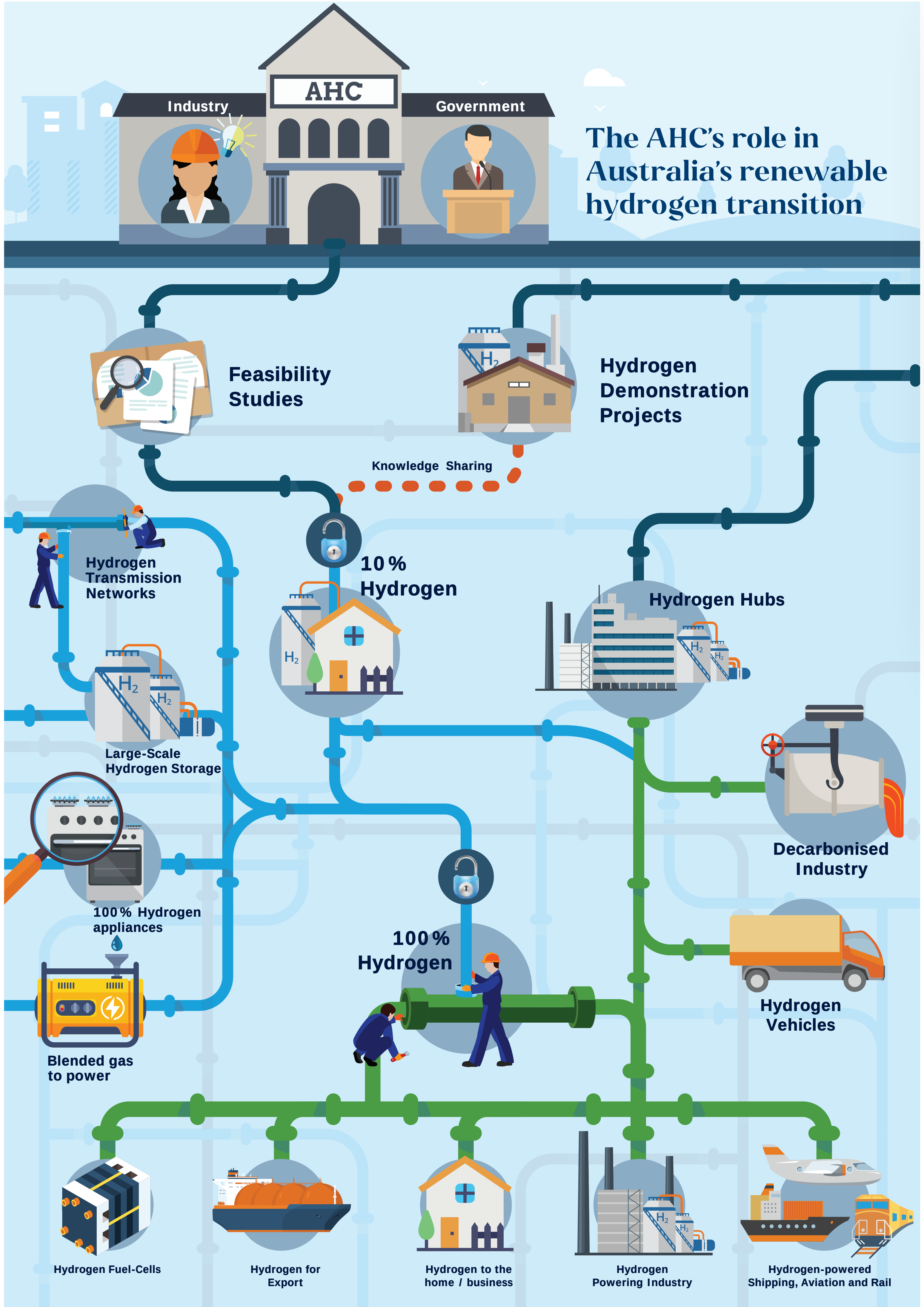
Advisian: Major gas users assessment
ARUP: Hydrogen appliance pathways assessment and implementation plan
Ethos Urban: Economic Impact Assessment
Farrierswier: Regulatory standards and legal considerations
Frontier Economics: Financial modelling
GPA Engineering: Gas distribution network analysis
Jacobs: Renewable hydrogen market study
Oakley Greenwood: Policy frameworks assessment

Australia's Gas Timeline

Gas became a popular source of domestic and industria heat with the development of supply and reticulation technologies in the early 19th century.

Since then, gas supply has witnessed several important innovations. It is essential the pathway to renewable gas leverages these learnings to deliver renewable energy with the same benefits customers enjoy today.



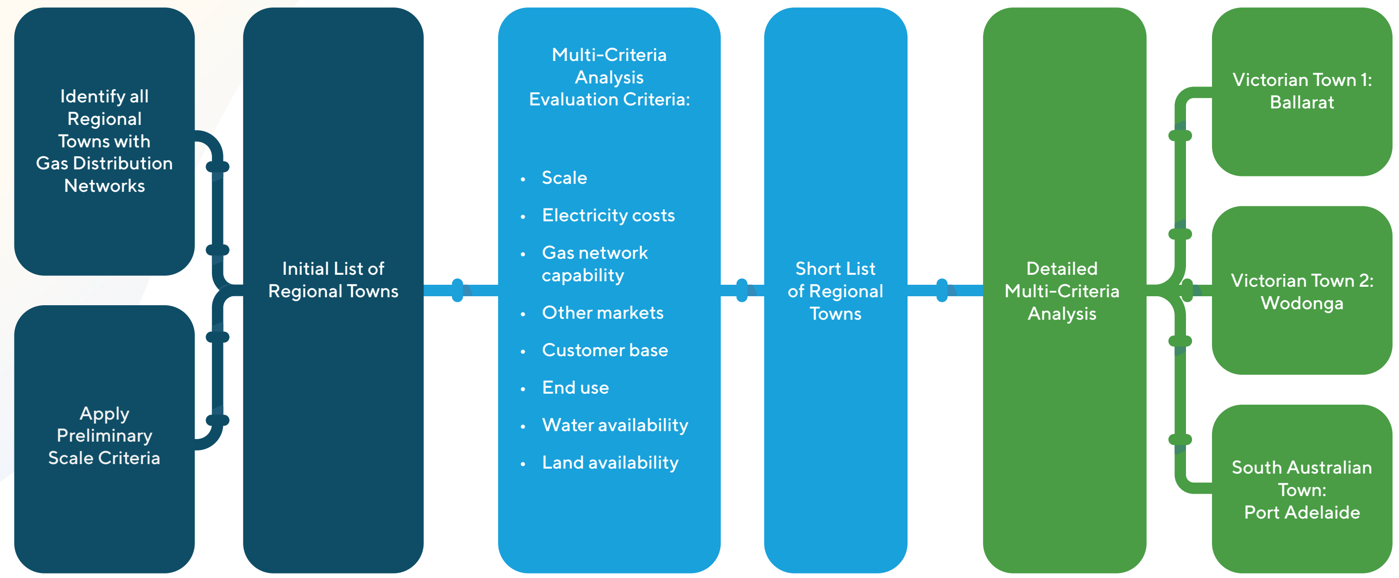


Regional Town Studies

As a first step, the AHC undertook a detailed feasibility study to blend up to 10% gas into the gas distribution networks of selected regional towns in South Australia and Victoria.

The AHC developed and applied an evaluation criterion to 27 regional towns, with Port Adelaide in South Australia, Ballarat and Wodonga in Victoria and progressing to a detailed multi- criteria analysis evaluation as follows:

Step 1	Step 2	Step 3
Applying Screening Muti-Criteria to Develop Initial List	Assessing Technical Viability	Multi-Criteria Analysis



The Regional Towns Studies originated the Hydrogen Park Murray Valley project, which is targeting delivery of up to a 10% (by volume) renewable hydrogen blend to approximately 40,000 residential and commercial gas connections and about 20 industrial customers in Albury and Wodonga.

Pending regulatory, planning, and financial approvals, it will be a significant low carbon innovation for Australia. The project has received conditional funding from ARENA.

LINK: WWW.AGIG.COM.AU/HYDROGEN-PARK-MURRAY-VALLEY

Hydrogen Supply

HYDROGEN PRODUCTION

The AHC modelled the level of hydrogen production needed to meet the forecast gas demand to 2050 using renewable electricity and water to produce hydrogen via electrolysis, resulting in indicative electrolyser configurations for each interval.

TABLE 1: INDICATIVE HYDROGEN CONFIGURATION BY STATE AND INTERVAL

	10%		100%	
	South Australia	Victoria	South Australia	Victoria
Quantity of hydrogen required (t)	5,150	28,000	270,000	1,300,000
Aggregate electrolyser nameplate (MW)	90	580	2,400	12,000
Total electrical load (GWh)	350	2,000	15,000	70,000

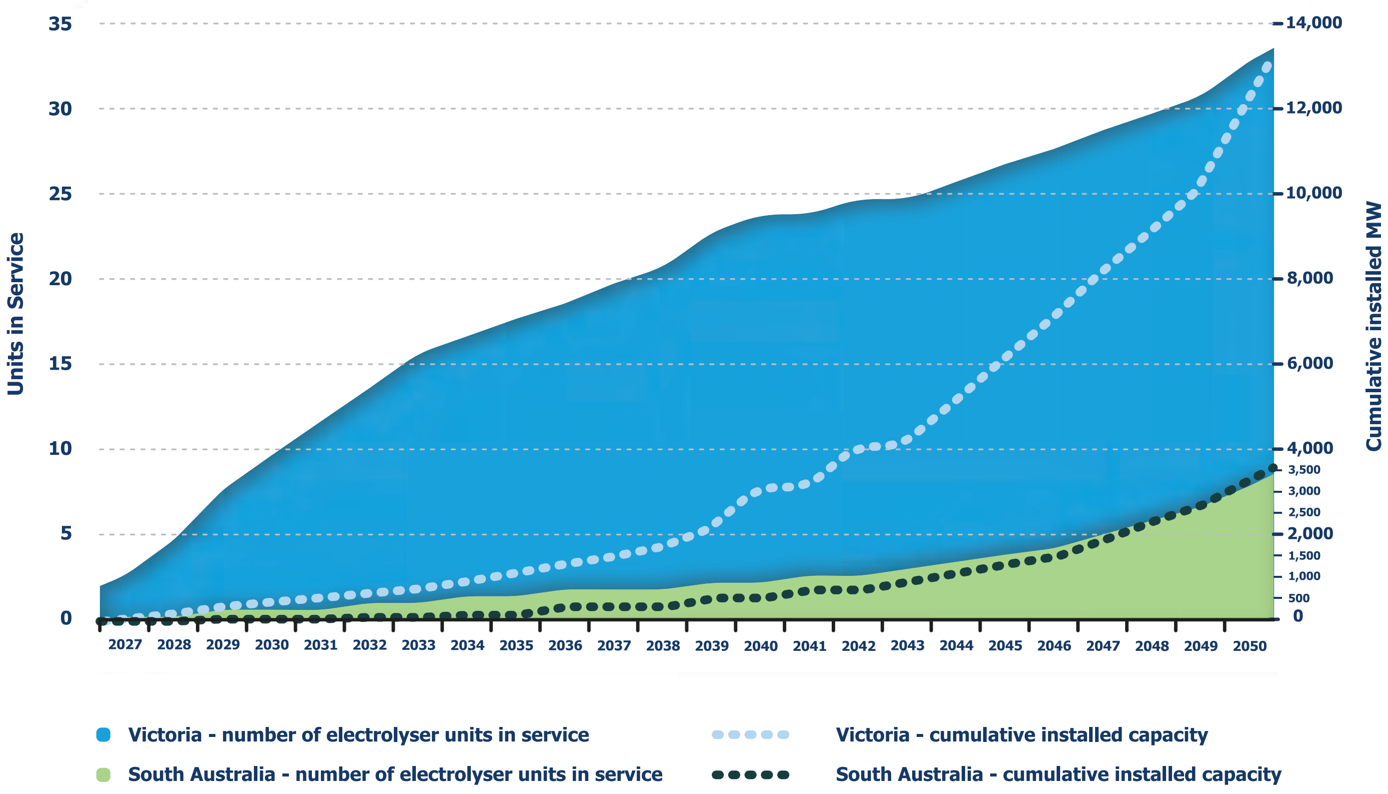
Projected electrolyser development across the two states beginning in 2027 and building capacity over time.

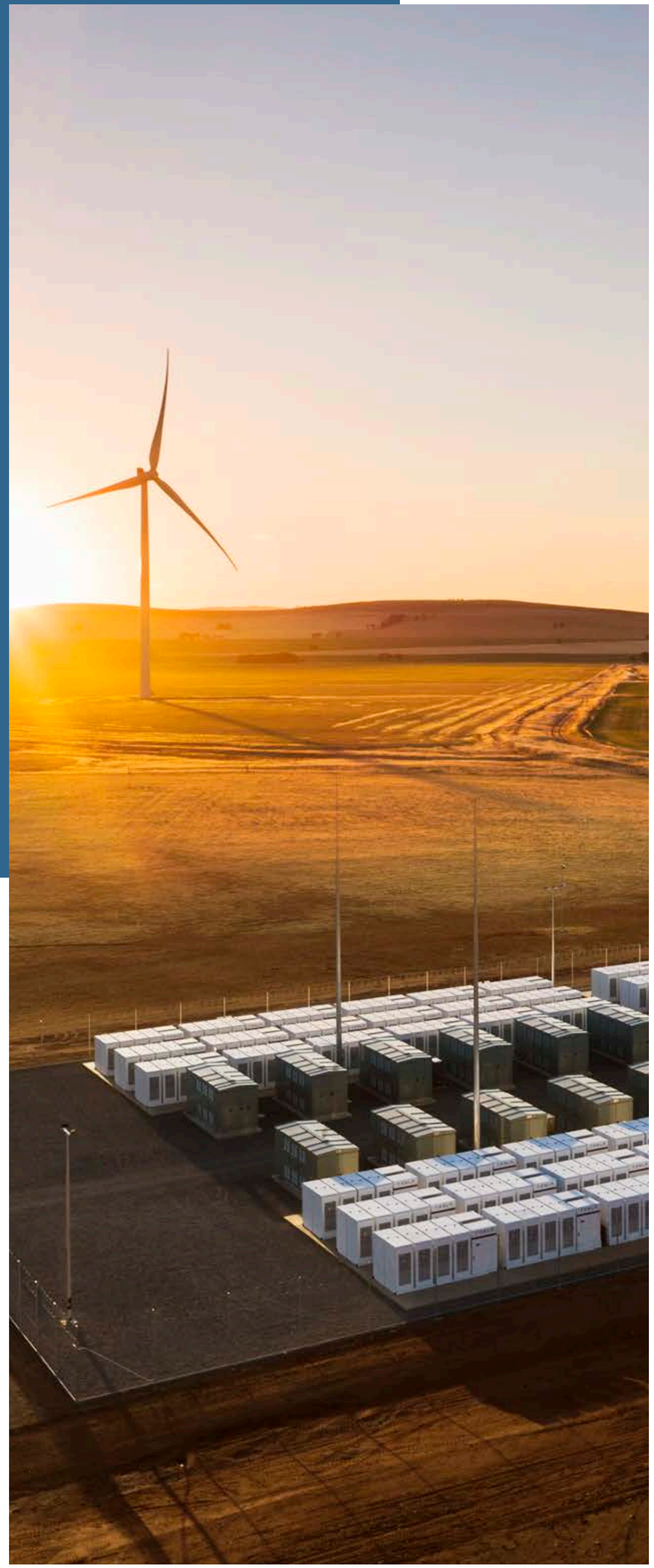
Initially, the scale of electrolyser units deployed could be relatively small, in the order of 10 – 200 MW depending on network demand. These units would be built along existing gas and electricity distribution infrastructure near points of existing supply known as gate stations to enable renewable hydrogen to be blended directly into the network.

Larger scale units could be deployed as demand increases to reach 100% hydrogen in distribution networks. These would be in proximity to REZ and connected to a pipeline transmission system and long-term storage.

Figure 1 demonstrates an annual growth rate of 23% was applied to electrolyser build-out from 10% to 100% hydrogen. It was assumed that as electrolyser technology improves with increased demand and maturity, there will be a tendency to gradually install larger capacity units.

FIGURE 1: BUILD-UP OF ELECTROLYSER CAPACITY, VICTORIA AND SOUTH AUSTRALIA





ELECTRICITY SYSTEM INTEGRATION

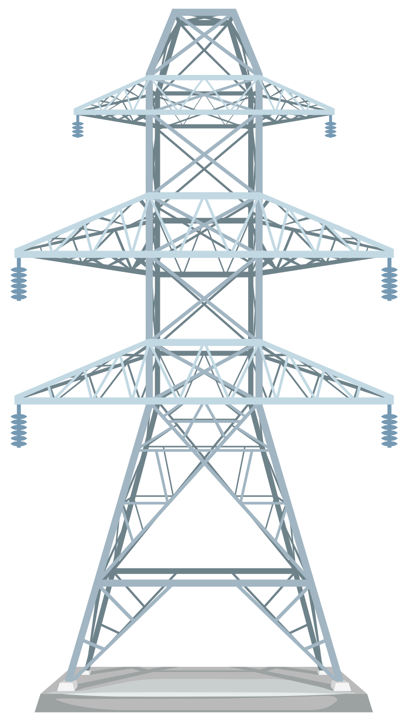
An innovative model for renewable electricity and gas integration was modelled to access electrolyser flexibility and gas storage benefits to shift the electricity load to times of the day when supply is high and demand is low.

To achieve supply for 10% hydrogen in networks, 670 MW of hydrogen production could be supplied using electricity via the grid, harnessing renewable electricity generation that is existing and planned by the market operator.

This could increase the electricity load in South Australia and Victoria by 2-3% on current levels, representing an additional market for solar and wind that is optimised for efficient utilisation.

For 100% hydrogen supply in networks, modelling indicates large scale production facilities drawing on 30 GW of renewable electricity in proximity to REZ with some connected to the grid to benefit from prevailing market conditions. The overall increase in renewable electricity required is less than the increase over the electricity market, due to the flexibility of electrolysers using renewable electricity that would otherwise by curtailed to store and alter deliver to homes and businesses.

Optimum electrolyser capacity factor and electricity generation mix depends on the availability of long-term storage, with more storage allowing less reliance on expensive renewable energy sources that might otherwise be necessary to match the daily load profile of gas.

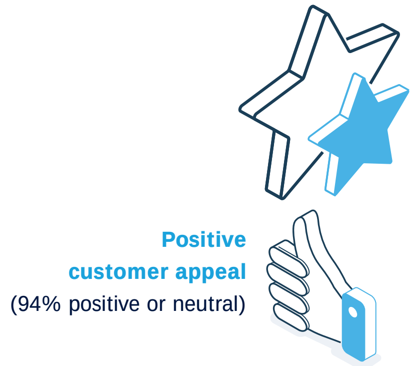


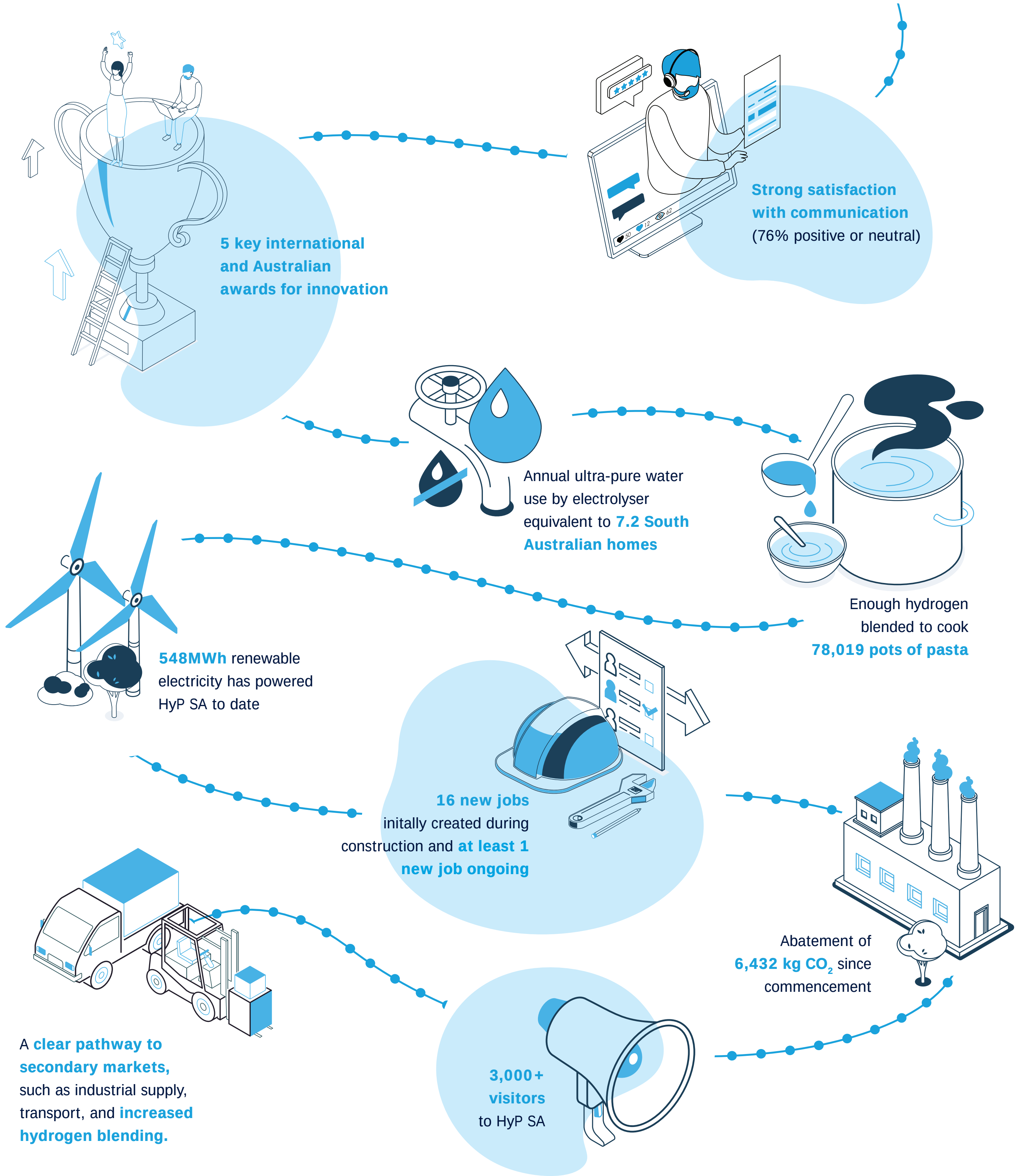
Hydrogen Park South Australia Key Outcomes

Hydrogen Park South Australia (HyP SA) is an Australian-first demonstration of hydrogen blending in a gas distribution network led by AHC Member AGIG.

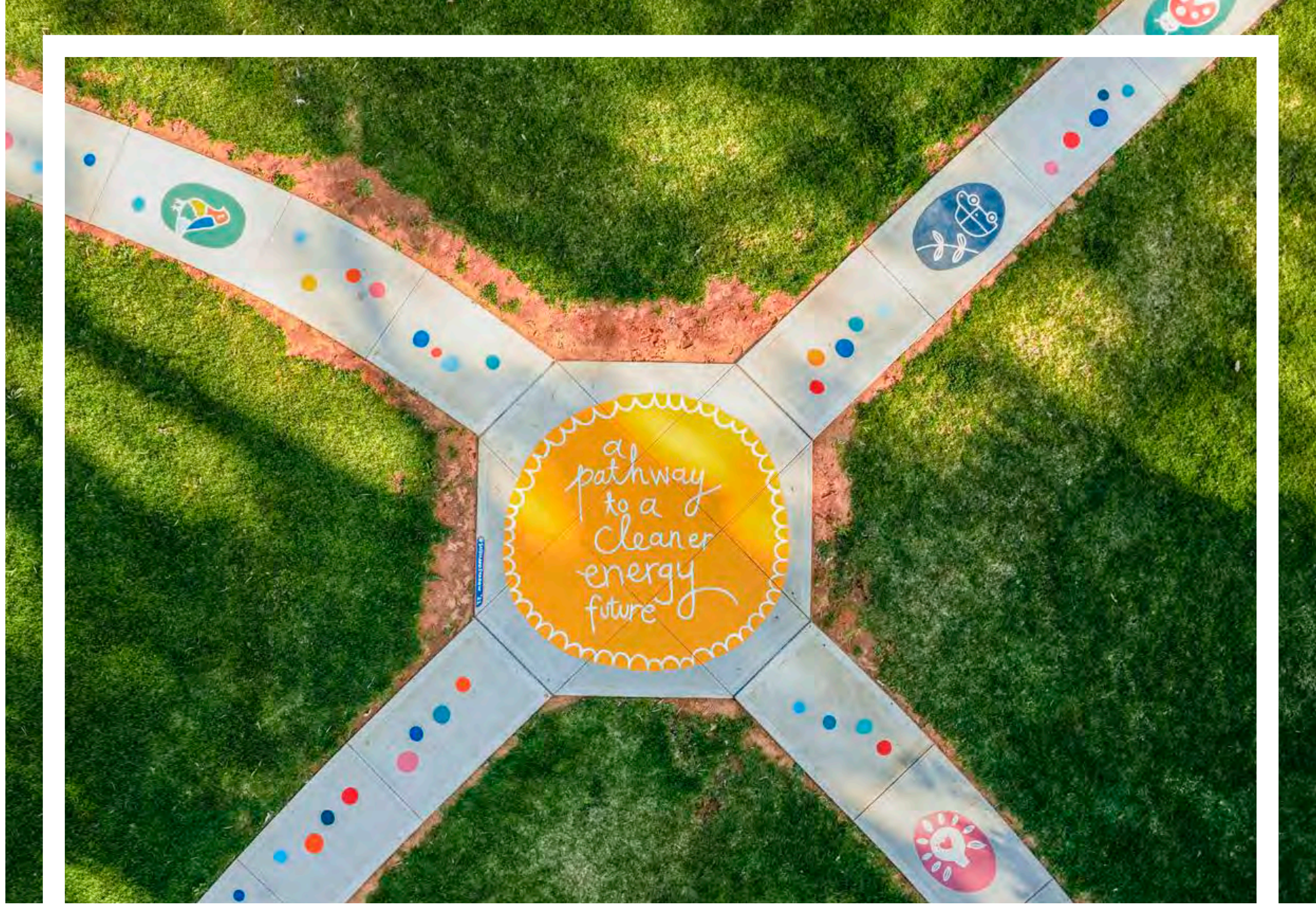
AGIG has produced a Knowledge Sharing report for the AHC on key performance results from HyP SA's first year of operations including plant performance, network performance and community experience[4].

NOTE: Metrics are based on AGIG analysis of HyP SA plant performance, supported by third party engineering and community engagement consultants.





4. The HyP SA Knowledge Sharing Report can be accessed here: https://arena.gov.au/knowledge-bank/



Case Study: HyP SA Community Sentiment

Community Artwork in Mitchell Park

Extensive consultation and engagement with the Mitchell Park community revealed that the residents were proud to be the first suburb in Australia to receive a renewable gas blend.

During these sessions, it was suggested that a public artwork be commissioned to celebrate the project, focusing on innovation, sustainability, and the pathway to a cleaner energy future.

In conjunction with the City of Marion council, AGIG commissioned local artist Elle Dawson-Scott to produce an extensive ground mural in the Quick Road Reserve in Mitchell Park. The mural's design touches on themes of nature and sustainability, renewable energy, hydrogen, cooking, heating, and community.

Refer to Hydrogen Park South Australia's Knowledge Sharing Report for more detailed information.

As Australia's first public renewable hydrogen blending project, securing community acceptance was key to pave the way for future decarbonisation of gas networks and developing a renewable gas source for industry and transport.

To measure knowledge, awareness, community sentiment and experience, longitudinal research (survey) of the community was undertaken between October 2020 and June 2022, showing the community is satisfied with HyP SA's delivery:

- **100% saying safe delivery of gas to the home has remained the same or improved (6% better than before).**
- **Awareness increased from 24% to 55% over the first year of operations.**
- **Appeal has remained strong with 95% of respondents saying the project is either highly appealing, somewhat appeal or neutral.**

These strong engagement outcomes have paved the way for HyP SA's expanded delivery of up to 5% renewable hydrogen (by volume) to an additional 3,000 customers in Mitchell Park, Clovelly Park and parts of Marion – including households, businesses, and schools. This is in addition to the existing industrial supply which commenced via tube trailer in 2022.

HyP SA has received a number of accolades in recognition of its role demonstrating the pathway to a cleaner energy future, including:

- 2022 South Australian Premier's Awards for Energy and Mining
  Community Engagement category winner
- 2022 MENA Future of Hydrogen Awards
  Hydrogen Project of the Year Award winner
- 2020 South Australian Climate Leaders Awards
  'Business and Industry' category winner
- 2020 Australian Pipelines and Gas Association
  Environment Award winner
- 2020 Engineers Australia
  Australian Engineering Excellence Award winner

Case Study: HyP SA Electrolyser Performance

ELECTROLYSIS SOAKING VARIABLE RENEWABLE GENERATION ON A SUNNY DAY

DAILY TEMPERATURE LOW: 14.4 C HIGH: 22.4 C

South Australian household energy demand (electricity and gas) is lower on mild, sunny days.

This can result in lower and often negative electricity prices, such as on 18 October 2022 when the daily average was $49.23 AUD/MWh (weighted by operational demand).

Figure 2 demonstrates how HyP SA harnessed low and negative pricing occasions driven by excess solar and wind electricity generation to produce 218.8kg at a weighted average price of -$195.31.

FIGURE 2: ***NEM PRICING AND HYP SA PRODUCTION (18/10/22)***

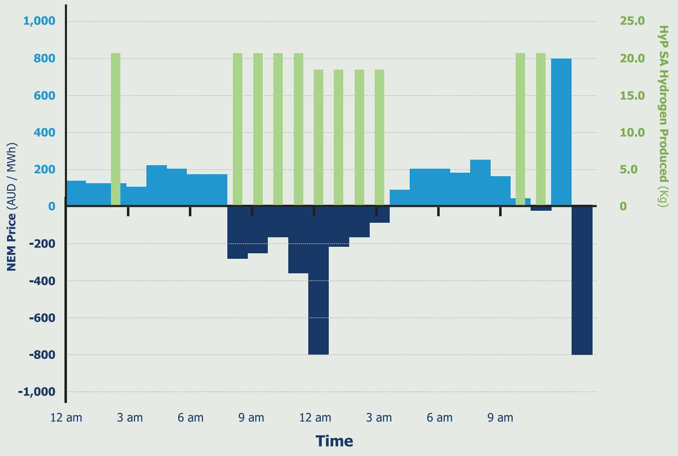
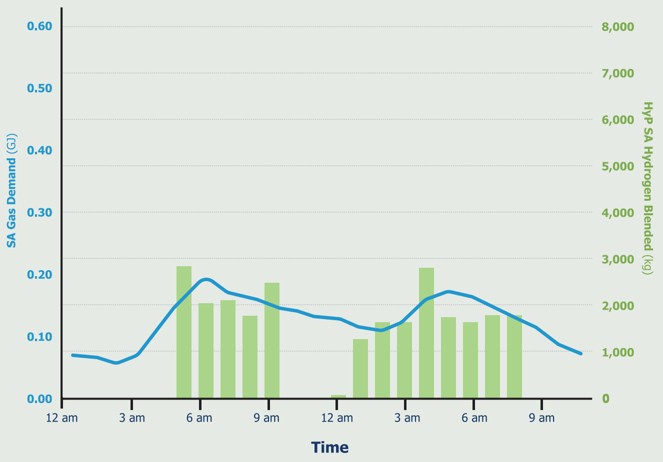


Figure 3 demonstrates that, by design, HyP SA's blending operations automatically shut off between 10am and 12pm when very low demand to the existing 700 homes was experienced.

The majority of hydrogen produced was instead directed to on-site storage and to tube trailers for industrial supply.

FIGURE 3: ***HOURLY BLENDING VOLUMES AND ADELAIZE DISTRIBUTED GAS DEMAND (18/10/22)***



GAS BLENDING ON A COLD WINTER DAY

DAILY TEMPERATURE LOW: 6.4 C HIGH: 16.8 C

South Australian household energy demand (electricity and gas) is higher on cold winter days.

This can result in high electricity prices, such as on 21 July 2022, the electricity spot market averaged $310.20 AUD /MWh (weighted by operational demand), with a morning peak price of $473.52 (6am to 9am) and evening peak price of $334.17 (6pm to 9pm).

Figure 4 demonstrates HyP SA did not further constrain the electricity grid during peak times on this day, instead harnessing a short window of low to negative pricing during the middle of the day to produce 41.4 kg of hydrogen at a weighted average price of $11 AUD/MWh.

FIGURE 4: ***NEM PRICING AND HYP SA PRODUCTION (21/7/22)***

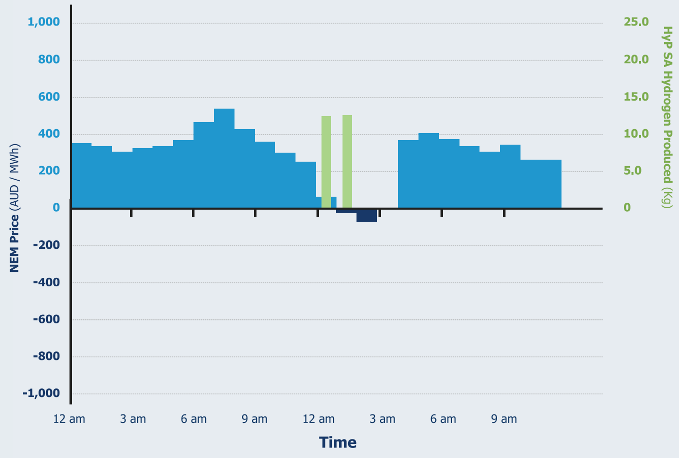
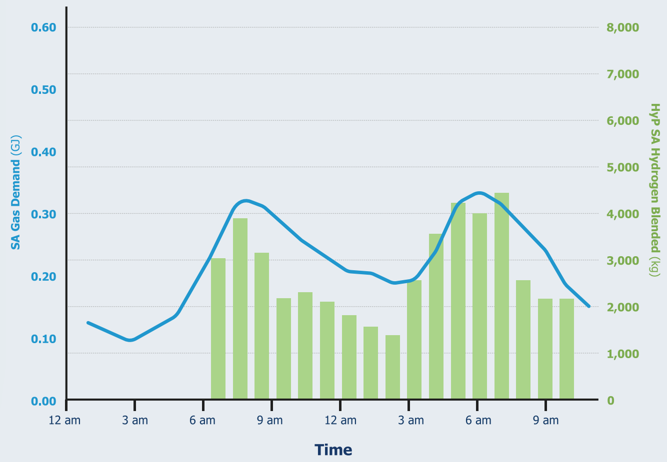


Figure 5 demonstrates HyP SA's blending equipment responds in real time to higher seasonal network demand, as well as intra-day peaks during mornings and evenings.

FIGURE 5: ***HOURLY BLENDING VOLUMES AND ADELAIDE DISTRIBUTED GAS DEMAND (21/07/2022)***



> "Water needs for 100% hydrogen in networks is no more than 0.3% of the physical water use of South Australia and Victoria in 2019-20."

SUSTAINABLE WATER SOURCING

Current electrolysis technology requires water that is purified at site to what commonly referred to as 'ultra-pure water'. This means hydrogen production does not necessarily require high quality water supply to begin with and can avoid competition with existing demands for these sources by drawing on lower quality options, including seawater, and recycled wastewater.

Taking account for sustainable sourcing of water, the AHC assumed a conservative consumption ratio of 20 litres of water per kilogram of hydrogen produced, to account for different water qualities supplied to individual production facilities.

The water consumption for hydrogen production to meet demand in 2030 and 2050 for 10% and 100% is shown in Table 2.

TABLE 2: ***WATER CONSUMPTION FOR HYDROGEN PRODUCTION BY INTERVAL AND STATE***

	10%		100%	
	South Australia	Victoria	South Australia	Victoria
Quantity of hydrogen required (t)	5,150	28,000	270,000	1,300,000
Water consumption (ML)	103	560	5,400	26,000

The cost of using lower quality water sources for hydrogen production is factored into the overall cost stack-up modelled for this Report on page 25, and further detailed in the full State-wide reports.

HYDROGEN STORAGE BENEFITS AND TECHNOLOGIES

One of the main advantages of gas infrastructure is its ability to store vast amounts of energy. This storage helps balance the daily supply of natural gas with fluctuating demand throughout the day and allows seasonal variations in demand to be met.

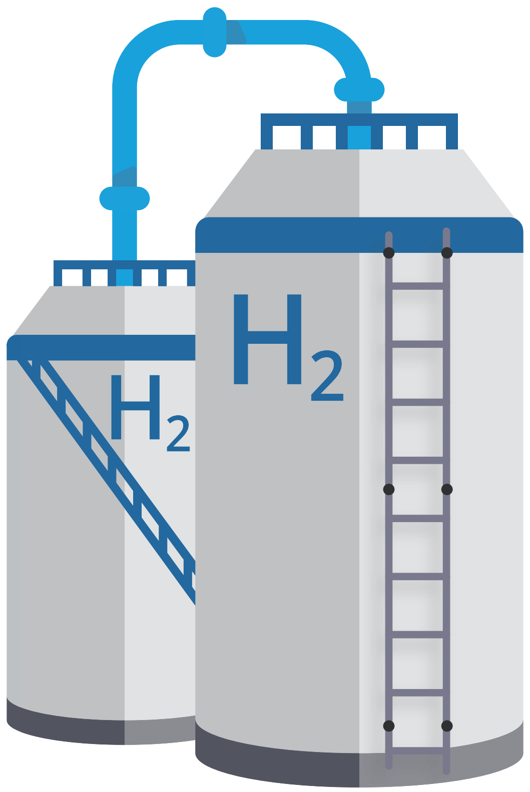
The AHC considered how much storage capacity would be needed to provide the same level of energy security at 10% and 100% renewable hydrogen in networks, while also allowing increased utilisation of renewable electricity availability by shifting the load to times of day and year when renewable electricity supply is high, and demand is low.

Intra-day storage co-located with hydrogen production is needed to balance daily peaks to achieve 10% hydrogen networks, later bolstered by new hydrogen pipelines connecting large-scale hydrogen supply to demand centres to deliver 100% hydrogen in networks.

Long-term 'interseasonal' hydrogen storage is key to efficient delivery of 100% hydrogen because it:

- ensures there is sufficient hydrogen to meet demand during daily and seasonal peaks;
- balances electricity generation capacity and electrolyser capacity needed to produce hydrogen across the year; and
- enables electrolysers to operate efficiently when electricity prices are low or negative.

Further work is required to determine the most suitable technology for long-term storage.



RENEWABLE HYDROGEN TRANSMISSION SYSTEM

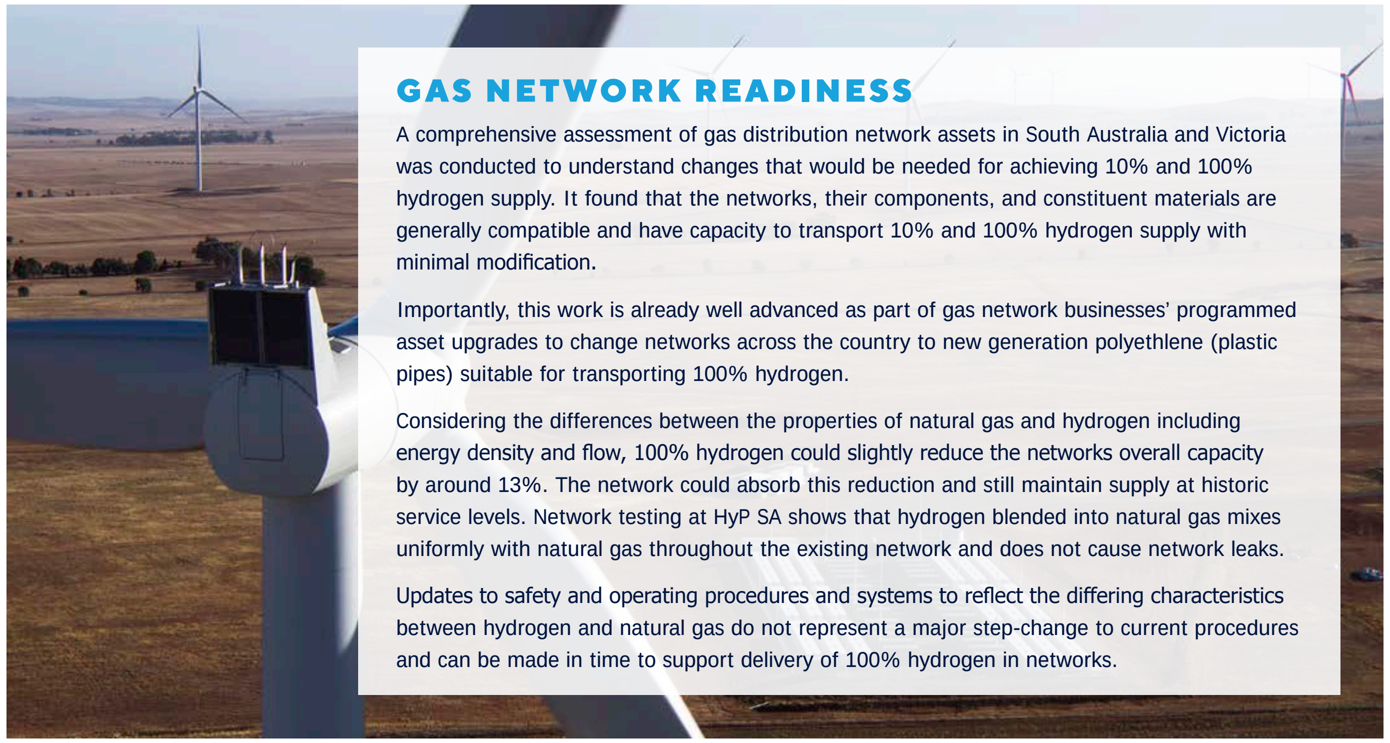
Because renewable hydrogen integrates electricity and gas systems, the AHC considered transmission concepts that could either be gas pipelines from upstream hydrogen production delivering to market, or a 'poles and wires' transmission system to supply electricity to downstream hydrogen production.

Because renewable electricity would be supplied from the existing grid and connected directly to electrolysers for 10% hydrogen, no new electricity or gas transmission systems would be required.

Analysis for the AHC found newly constructed pipelines connecting hydrogen production facilities in REZ to storage and demand centres to be the preferred solution considering distance, capacity, and performance.

This would be complementary to existing and planned electricity and gas transmission infrastructure, with that infrastructure to be leveraged to the greatest extent possible to deliver 10% and ultimately 100% hydrogen.

Technical and Regulatory Feasibility



GAS NETWORK READINESS

A comprehensive assessment of gas distribution network assets in South Australia and Victoria was conducted to understand changes that would be needed for achieving 10% and 100% hydrogen supply. It found that the networks, their components, and constituent materials are generally compatible and have capacity to transport 10% and 100% hydrogen supply with minimal modification.

Importantly, this work is already well advanced as part of gas network businesses' programmed asset upgrades to change networks across the country to new generation polyethlene (plastic pipes) suitable for transporting 100% hydrogen.

Considering the differences between the properties of natural gas and hydrogen including energy density and flow, 100% hydrogen could slightly reduce the networks overall capacity by around 13%. The network could absorb this reduction and still maintain supply at historic service levels. Network testing at HyP SA shows that hydrogen blended into natural gas mixes uniformly with natural gas throughout the existing network and does not cause network leaks.

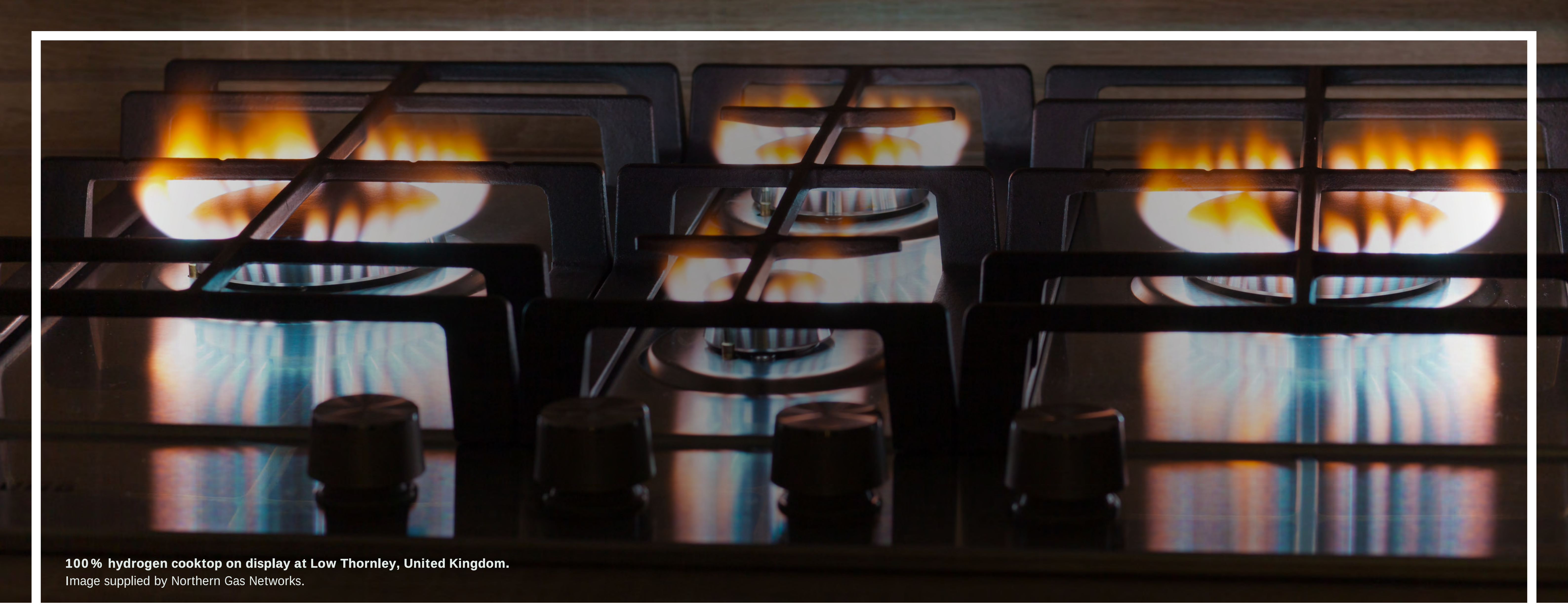
Updates to safety and operating procedures and systems to reflect the differing characteristics between hydrogen and natural gas do not represent a major step-change to current procedures and can be made in time to support delivery of 100% hydrogen in networks.

TABLE 3: GAS DISTRIBUTION INFRASTRUCTURE AND OPERATIONS CHANGES FOR BLENDED GAS AND HYDROGEN SUPPLY

	10% HYDROGEN	100% HYDROGEN
INFRASTRUCTURE		
Network capacity	A 2-4% reduction in capacity caused by 10% blended gas supply, to be absorbed by the existing network.	A 13% reduction in capacity due to 100% hydrogen supply, to be absorbed by the existing network.
Distribution licensed pipelines	162 of 178 distribution licensed pipelines are suitable for 10% and 100% hydrogen supply. Potential minor modification of 16 pipelines if research proves them unsuitable.	
Distribution piping	No changes required. All distribution piping in Victoria and South Australia is suitable for 10% blended gas and 100% hydrogen supply.	
Joint types	No changes required.	Most joints are suitable with 100% hydrogen supply. Potential replacement of some specific joints if further testing proves them unsuitable.
Metal components	Most components are suitable for 10% and 100% hydrogen supply. Potential replacement of some specific components if further testing proves them unsuitable. Any changes are expected to be able to take place as part of planned upgrades.	
Plastic components	Most components are suitable for 10% and 100% hydrogen supply, with potential replacement of some specific components such as elastomer sub-components if further testing proves them unsuitable. Any changes are expected to be able to take place as part of planned upgrades.	
Facility piping	Stress analysis of piping layouts at each facility should be undertaken. Some field regulators may benefit from modification of pipe supports.	
OPERATIONS		
Operational Procedures	Some potential changes should be considered; these would not be major step changes to current procedures. A list for each scenario can be found in the full State-wide reports.	

Table 3 outlines the key changes required to different aspects of gas network infrastructure in 10% and 100% hydrogen scenarios. The AHC calculated a cost of less than $100 million per network to upgrade them for 100% hydrogen, representing a small fraction of current asset value and able to be conducted as part of existing programmed asset upgrades already underway.

This is covered in more detail in the full State-wide reports.



100 % hydrogen cooktop on display at Low Thornley, United Kingdom.
Image supplied by Northern Gas Networks.

CONSUMER APPLIANCES ASSESSMENT

It is generally accepted that 10 % volumes of hydrogen blended with natural gas is compatible with most existing consumer appliances, with work underway to determine the maximum upper limit.

Research to confirm the compatibility of bespoke commercial and industrial appliances at 10% hydrogen is well progressed supported by practical demonstrations such as HyP SA and Hydrogen Park Gladstone.

These projects are key to providing a pathway for relevant approvals and show that existing home appliances can work safely, reliably, and effectively with up to 10% hydrogen blends and potentially even higher - with international projects supply up to 20% hydrogen blends.

When receiving 100% renewable hydrogen gas, new appliances or burner parts may be required. 100% hydrogen appliances and hydrogen-ready appliances are being developed in Australia and overseas, for example AGIG has a number of Australian-made 100% hydrogen barbecues it uses at community events and is developing a 100% hydrogen home featuring a range of common household appliances.

At present, these appliances are niche products while the market establishes itself. Appliance manufacturers are already working to supply these products at scale, which are expected to be made available at a similar cost to existing gas appliances.

Work is underway to develop Australian Standards for these appliances, which would enable testing requirements to be prepared and manufacturers to begin producing appliances for the Australian market.

This is an important enabler as it allows customers to retain their choice of energy supply with confidence it is future-proofed for a net zero scenario. It also paves the way for a smoother transition at the time of 100% implementation which is detailed at Page 23.

The United Kingdom is actively consulting on mandating 'hydrogen ready' boilers be installed from 2026 as part of a low-regrets action for consumers.

The AHC calculated the capital expenditure of appliance conversions across both states as follows:

- $483 million (2021 dollars) for conversion of appliances in Victoria.
- $102 million (2021 dollars) for conversion of appliances in South Australia.

While material, appliance changeover is required under any net-zero transition, and is relatively small when compared with the expected capital expenditure for upstream production, transmission, and storage. This is covered in more detail in the full State-wide Reports.

REGULATORY AND LEGAL ASSESSMENT

There is significant work underway to develop a regulatory and legal environment at the state and federal levels which enables blended gas and hydrogen supply. This includes recognition of hydrogen in regulatory frameworks, compliance with gas specifications and standards, and regulatory changes needed for the sale of a 'renewable gas' product.

The full State-wide reports provide an assessment of 'no regret' regulatory and legal considerations; timing of these potential changes was also considered in an indicative ideal timeline in those reports.

Policy and regulatory reforms that incentivise the production and supply of renewable gas are likely to develop a competitive market environment. Such market design could leverage the experience of Australia's successful Renewable Energy Target, which surpassed its target of encouraging an additional 20% renewable electricity generation by 2020 compared with 1997 levels. This would enable the market to define least cost decarbonisation across the electricity and gas sectors.

Policy considerations that would support the implementation of hydrogen-ready appliances include:

- A dual-fuel or hydrogen-ready appliance mandate by 2030 or earlier;
- A customer rebate program for hydrogen-ready appliances ahead of 2030 (or earlier); and
- A requirement for businesses with Type B appliances to have conversion plans prepared by an approved consultant or appliance supplier/manufacturer.

IMPLEMENTATION PLAN

(Illustrated on page 20 and 21)

Considering the production, storage, supply and end-use activities highlighted in this report, the AHC developed a detailed implementation plan outlining the key actions to achieve 10 % and 100 % hydrogen.

A summary timeline depicting the electrolyser build out over time and key activities to deliver this concept is shown below. The plan shows the key activities required for phased implementation of 10% blending.

Switching from 10% to 100% hydrogen could take place from the mid-2030s, leveraging lessons from similar programs such as existing mains replacement and the move from towns gas to natural gas.

This activity represents a transformational shift in the energy system impacting gas, electricity and transport sectors alike to achieve the challenge and opportunity represented by common net zero goals and requires strong coordination between government and industry.

IMPLEMENTATION PLAN

FOUNDATIONAL ACTIVITIES

Establish renewable gas market framework		Ongoing
Planning, procurement, and delivery of hydrogen production and storage projects informed by earlier demonstration projects		Ongoing
Land acquisition	Up to 2 years per project	Ongoing
Environmental approvals and licensing	Up to 2 years per project	Ongoing
Public knowledge and acceptance programs		Ongoing

STAGE 1 PLANNING ACTIVITIES

Complete hydrogen blending demonstrations	2017-2023
Regulatory, legislative, and policy changes to support blending and conversion	2017-2025
Government supported 100 % conversion study program for Type B appliances	2022-2027
Standards and testing of gas appliances to allow 100 % hydrogen conversion; hydrogen-ready appliances available to purchase by 2028	2019-2028
Safety management documentation and approval to operate 100 % hydrogen gas network	2022-2028

PHASED IMPLEMENTATION OF 10% HYDROGEN

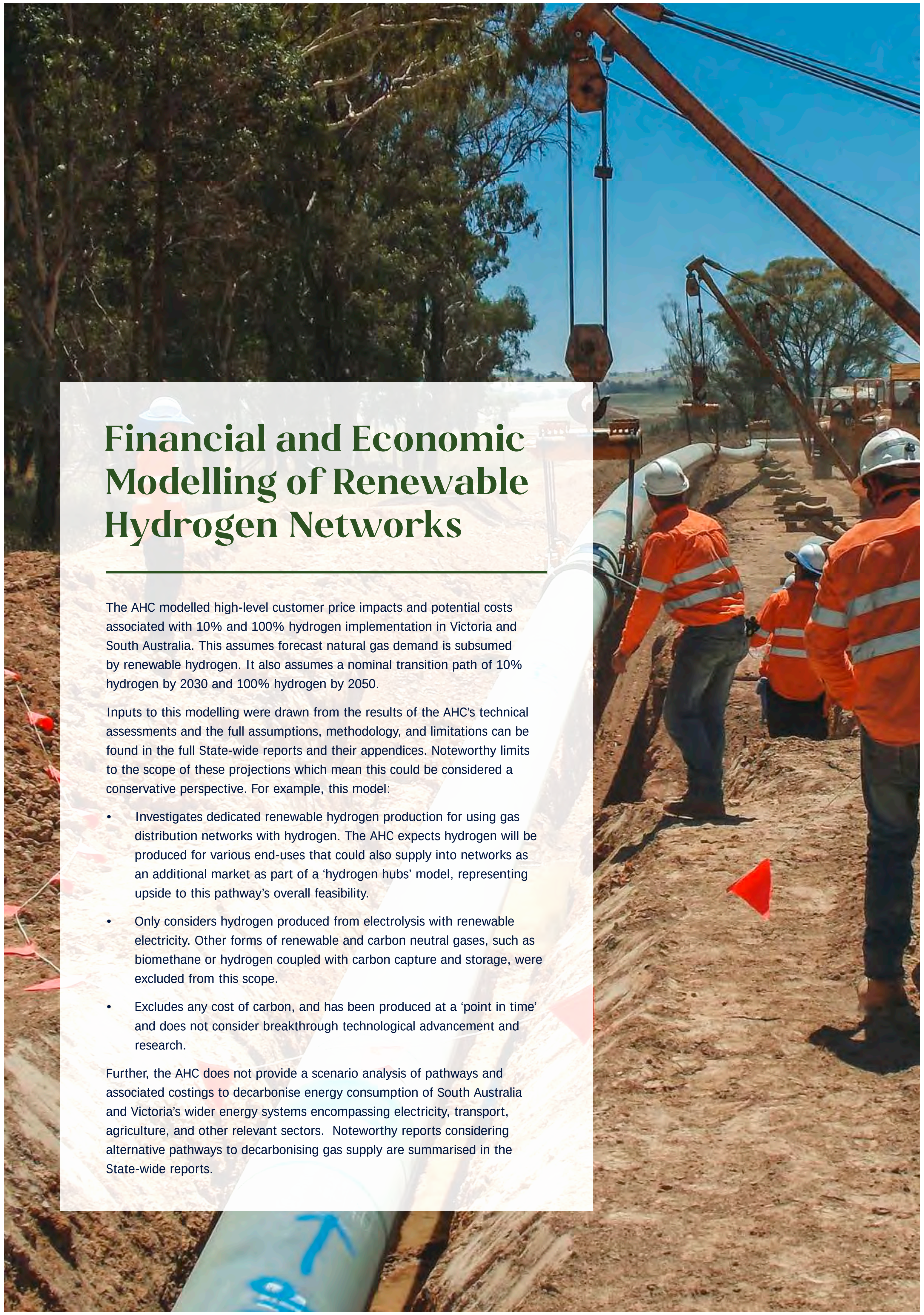
STAGE 2 PLANNING ACTIVITIES

Construction of electrolyser, water infrastructure, electricity transmission line and equipment procurement		2031-2045
Gas-fitting training and licensing requirements	4 years prior to conversion	2033-2035
Appliance conversion and responsibility strategy	5 years prior to conversion	2033-2035

STAGE 3 ACTIVITIES

Hydrogen-ready appliance roll-out completed		2030-2042
Construction of hydrogen transmission pipelines	4 to 6 years construction per unit	2030-2045
Construction of hydrogen storage and conversion facilities	Up to 2 years per project	2030-2045
Distribution network conversion strategy completed & responsibilities identified	4 years per project	2031-2050

PHASED TRANSITION OF GAS NETWORKS TO 100% HYDROGEN



Financial and Economic Modelling of Renewable Hydrogen Networks

The AHC modelled high-level customer price impacts and potential costs associated with 10% and 100% hydrogen implementation in Victoria and South Australia. This assumes forecast natural gas demand is subsumed by renewable hydrogen. It also assumes a nominal transition path of 10% hydrogen by 2030 and 100% hydrogen by 2050.

Inputs to this modelling were drawn from the results of the AHC's technical assessments and the full assumptions, methodology, and limitations can be found in the full State-wide reports and their appendices. Noteworthy limits to the scope of these projections which mean this could be considered a conservative perspective. For example, this model:

- Investigates dedicated renewable hydrogen production for using gas distribution networks with hydrogen. The AHC expects hydrogen will be produced for various end-uses that could also supply into networks as an additional market as part of a 'hydrogen hubs' model, representing upside to this pathway's overall feasibility.
- Only considers hydrogen produced from electrolysis with renewable electricity. Other forms of renewable and carbon neutral gases, such as biomethane or hydrogen coupled with carbon capture and storage, were excluded from this scope.
- Excludes any cost of carbon, and has been produced at a 'point in time' and does not consider breakthrough technological advancement and research.

Further, the AHC does not provide a scenario analysis of pathways and associated costings to decarbonise energy consumption of South Australia and Victoria's wider energy systems encompassing electricity, transport, agriculture, and other relevant sectors. Noteworthy reports considering alternative pathways to decarbonising gas supply are summarised in the State-wide reports.

FINANCIAL MODELLING

METHODOLOGY

Projections to 2050 were produced for capital expenditure (capex) profiles, operating cost (opex) profiles including costs of renewable electricity, and revenue from the sale of hydrogen.

These projections were then compared to the natural gas price with no future cost of carbon added for each year to 2050 to illustrate the financial and customer bill impacts of transitioning to 100% renewable hydrogen supply over time.

Capex Profile: Hydrogen production facilities, storage, and transmission

There will be significant and ongoing capex required in production facilities in both states as the blending rate increases towards 100%. This investment ramps up across both states as the required capacity increases but is offset by falling electrolyser unit costs as larger scale production facilities are built. Significant capex from the mid-2030's to the early 2040's is driven by the development of pipeline and long-term storage infrastructure to connect significant hydrogen production projects coming online.

FIGURE 6: **VICTORIAN ESTIMATED CAPEX PROFILE FOR HYDROGEN PRODUCTION FACILITIES, TRANSMISSION, AND LONG-TERM STORAGE**

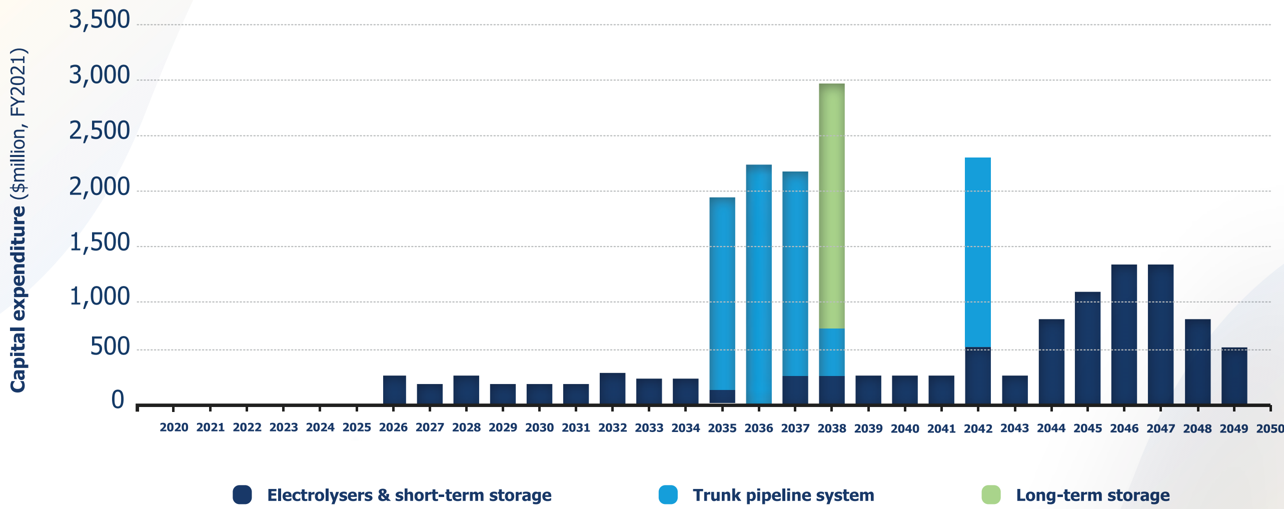
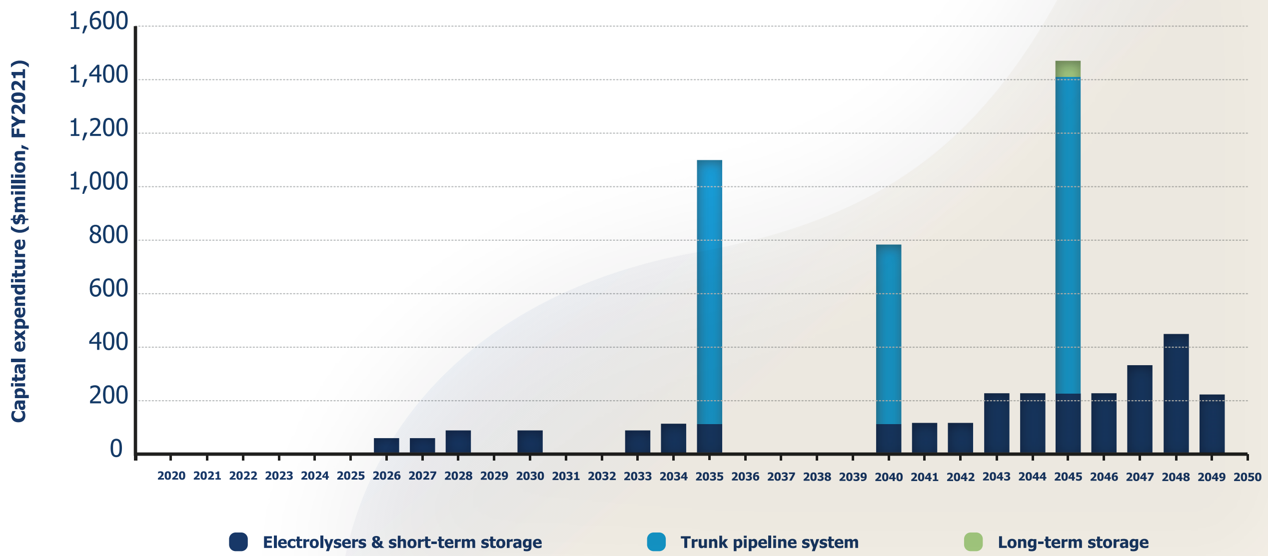


FIGURE 7: **SOUTH AUSTRALIAN ESTIMATED CAPEX PROFILE FOR HYDROGEN PRODUCTION FACILITIES, TRANSMISSION, AND LONG-TERM STORAGE**



Opex Profile: hydrogen production facilities, storage, and transmission

There is significant and ongoing opex required as hydrogen production increases, mostly for hydrogen production (including renewable electricity, water, and general opex.)

FIGURE 8: **VICTORIAN ESTIMATED OPEX PROFILE FOR HYDROGEN PRODUCTION FACILITIES, TRANSMISSION, AND LONG-TERM STORAGE**

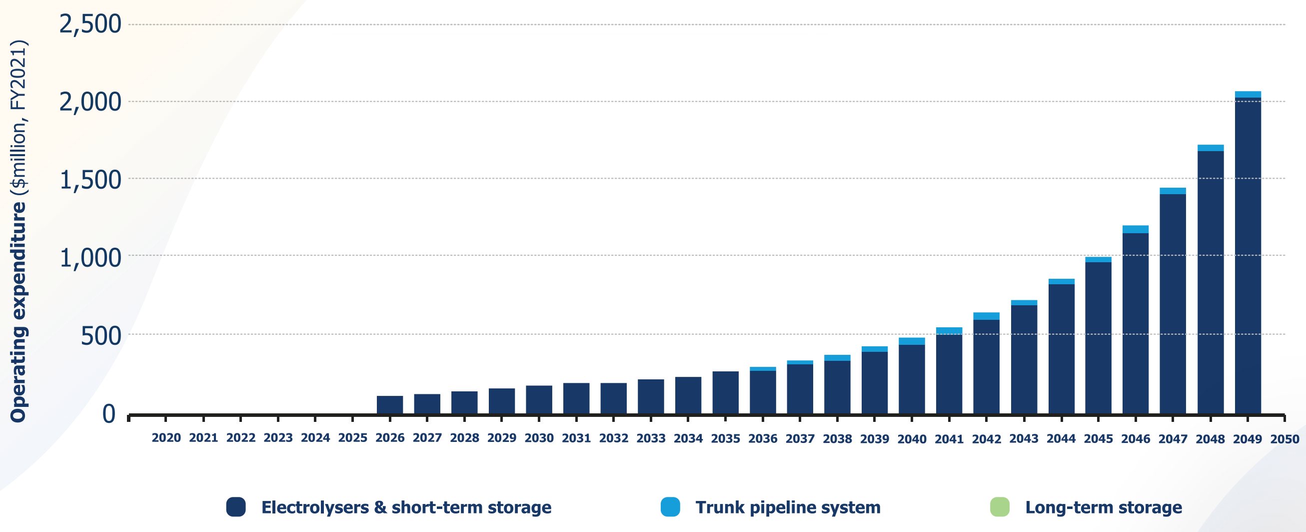
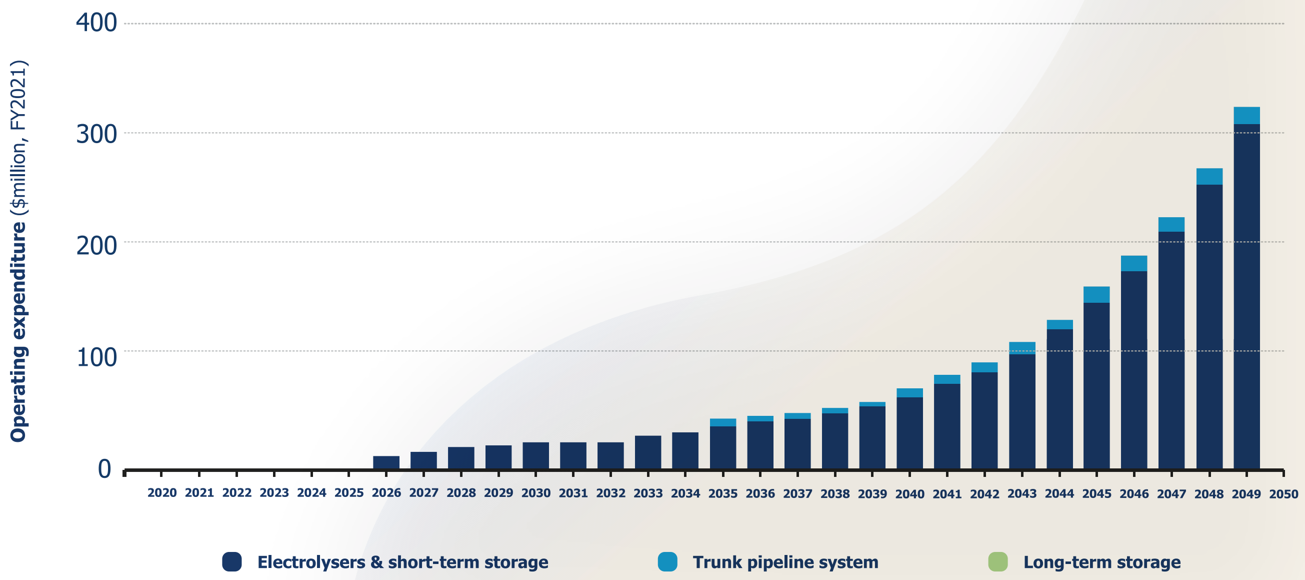


FIGURE 9: **SOUTH AUSTRALIAN ESTIMATED OPEX PROFILE FOR HYDROGEN PRODUCTION FACILITIES, TRANSMISSION, AND LONG-TERM STORAGE**



Opex Profile: Electrolysers

Most of the opex is for electrolysers and hydrogen storage is for the cost of electricity. Water costs and general opex constitute a much smaller proportion.

FIGURE 10: **VICTORIAN ESTIMATED HYDROGEN PRODUCTION OPEX PROFILE BY COST CATEGORY**

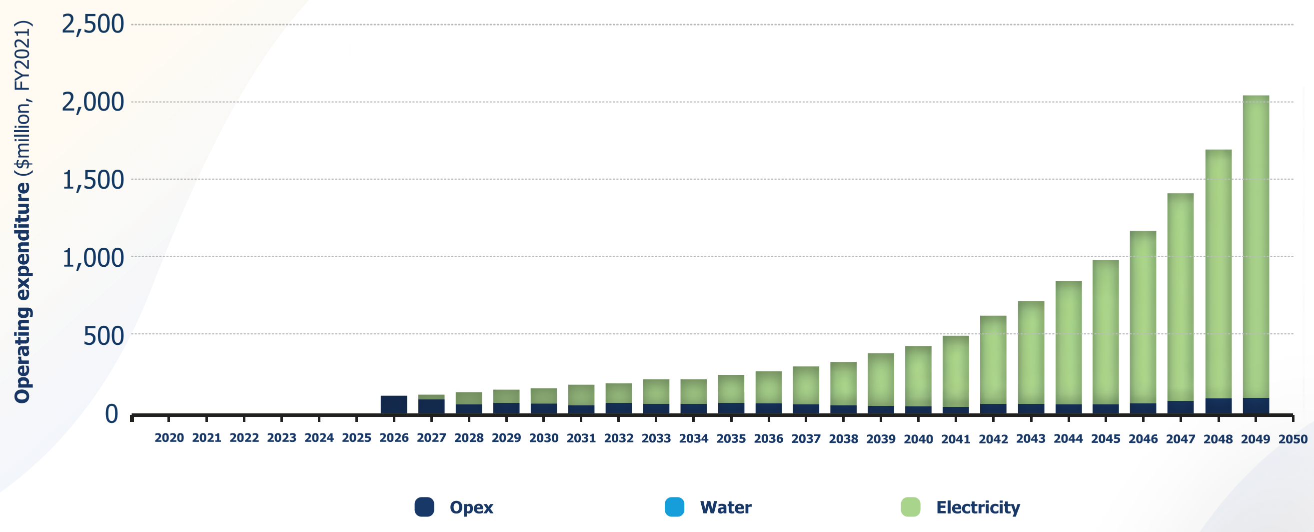
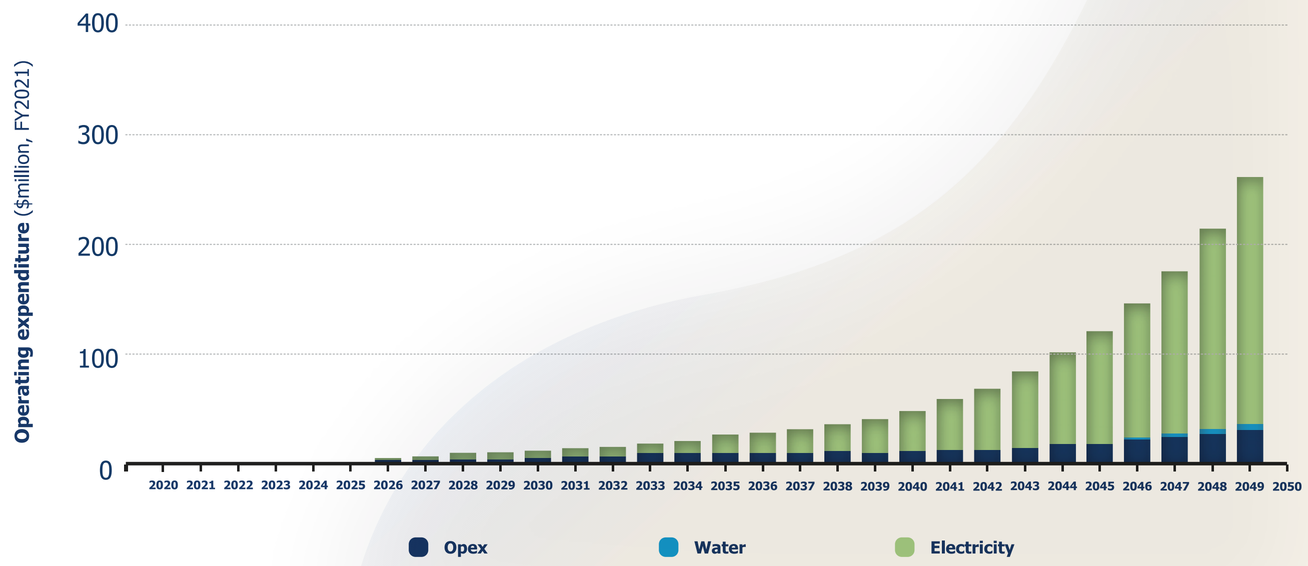


FIGURE 11: **SOUTH AUSTRALIAN ESTIMATED HYDROGEN PRODUCTION OPEX PROFILE BY COST CATEGORY**



REVENUE REQUIREMENT FROM THE SALE OF HYDROGEN

The annual revenue requirement when the gas distribution network is 100% renewable hydrogen is estimated to be $2.9 billion for Victoria and $0.56 billion for South Australia. Much of this covers electricity costs for operating electrolysers, and return of capex for producing, storing, and transporting hydrogen.

Wholesale costs of hydrogen for use in the gas distribution network is also affected by the assumption that hydrogen infrastructure constructed will also supply to the mobility market from 2040 to support emissions reductions in the transport sector. The opex of producing hydrogen for this market is assumed to be recovered entirely from its customers, and that these custmers will also contributie to the capex of the infrastructure used in common with hydrogen production for gas supply. This has the effect of lowering the capex that must be recovered from customers on the gas distribution network. It is assumed that the contribution to common capex of customers in the mobility market is:

- On average, 25% of the total capex during the period 2040-2050 in Victoria.
- On average, 45% of the total capex during the period 2040-2050 in South Australia.

FIGURE 12: VICTORIAN ANNUAL REVENUE REQUIREMENT FROM THE SALE OF HYDROGEN

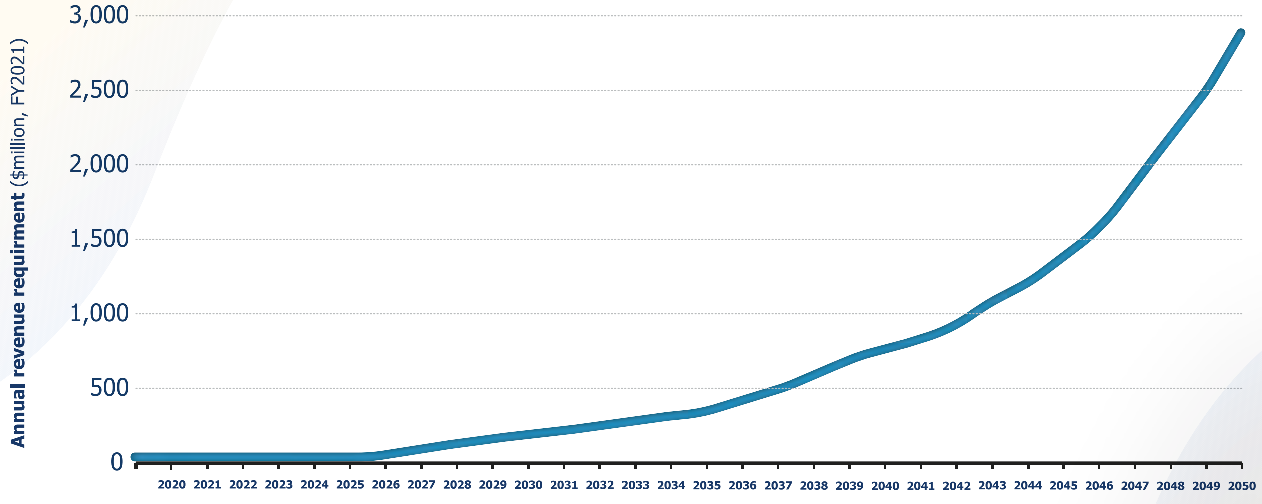
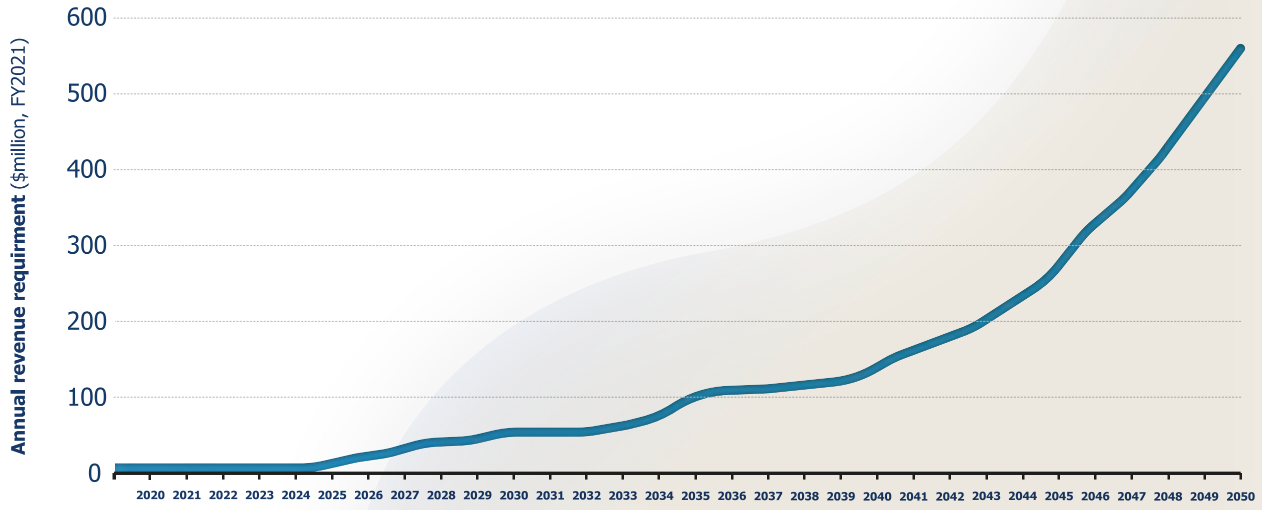


FIGURE 13: SOUTH AUSTRALIAN ANNUAL REVENUE REQUIREMENT FROM THE SALE OF HYDROGEN



PROJECTED CUSTOMER BILL IMPACT

The AHC then took a standard retail building block approach to model the change to customer bills over time by switching to renewable hydrogen supply.

The individual cost components in this approach include:

- Wholesale cost of energy;
- Distribution costs;
- Retail operating costs and margin.

The capex for network and appliance conversions across both states is relatively small when compared with the expected capital expenditure by gas distribution businesses over the period to 2050. These costs have been assumed to be recovered in the same way as network costs i.e. incurred by network businesses, treated as capex and recovered through a return on and return of these costs, consistent with the way capex is generally recovered.

These are conservative models, produced to reflect the uncertainty of future costs of electricity, hydrogen, carbon, and associated infrastructure. A detailed methodology and breakdown for each state and scenario can be found in the full reports.

FIGURE 14: TOTAL BILL FOR AN AVERAGE VICTORIAN RESIDENTIAL GAS CUSTOMER BY COST COMPONENT

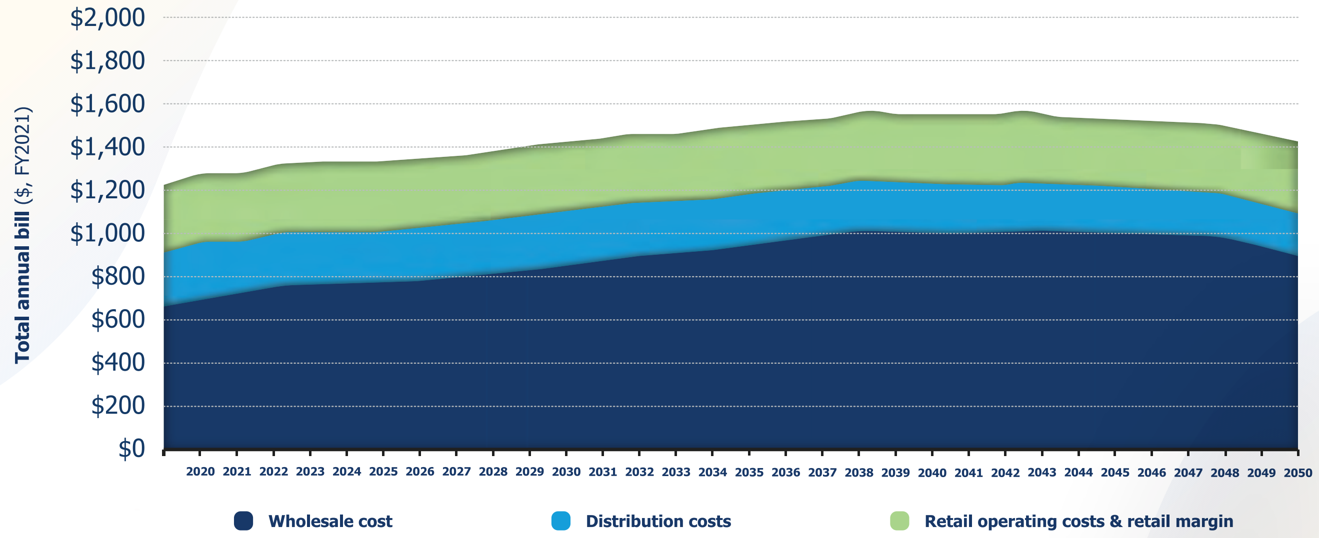
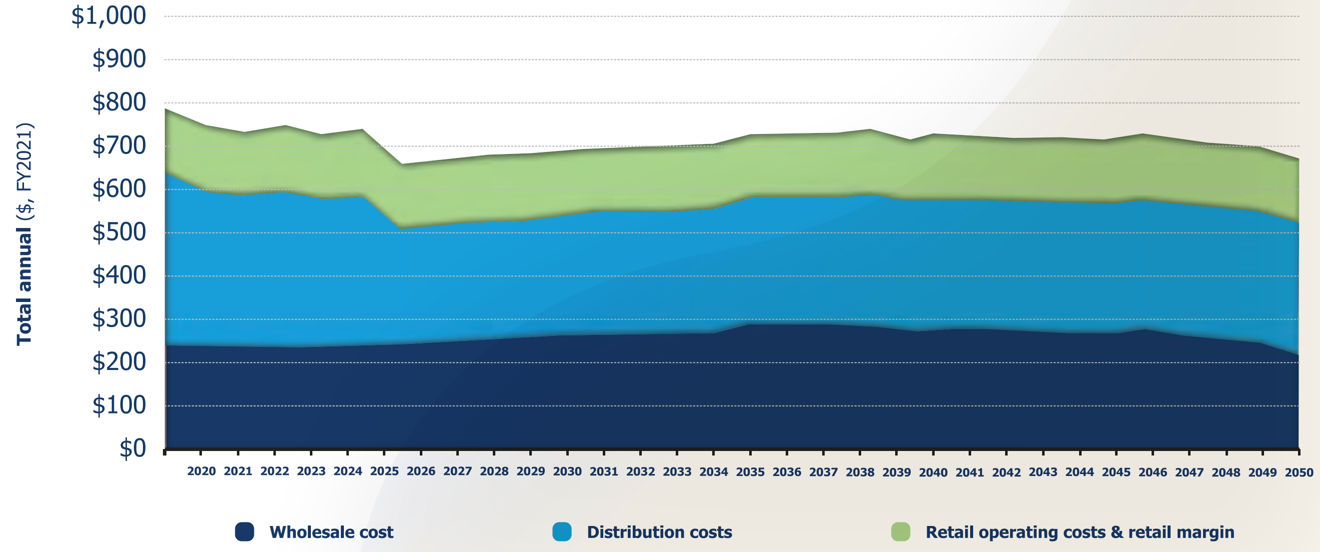


FIGURE 15: TOTAL BILL FOR AN AVERAGE SOUTH AUSTRALIAN RESIDENTIAL GAS CUSTOMER BY COST COMPONENT



REVENUE REQUIREMENT FROM THE SALE OF HYDROGEN

The results enabled the change for an average customer in Victoria and South Australia to be modelled through to 2050 and compared to a benchmark 'without hydrogen' case.

Compared to the 'without hydrogen' case, these projections show minimal disruption to customer bills in Victoria and South Australia with hydrogen. Indeed, an average customer in South Australia would experience a slight improvement.

Hydrogen hubs and other new infrastructure developed for adjacent markets may further improve customer bill projections, as would anticipated technology breakthroughs in hydrogen production, and the introduction of other forms of renewable and carbon neutral gas into supply.

FIGURE 16: **TOTAL BILL FOR AN AVERAGE VICTORIAN RESIDENTIAL GAS CUSTOMER COMPARED TO NATURAL GAS**

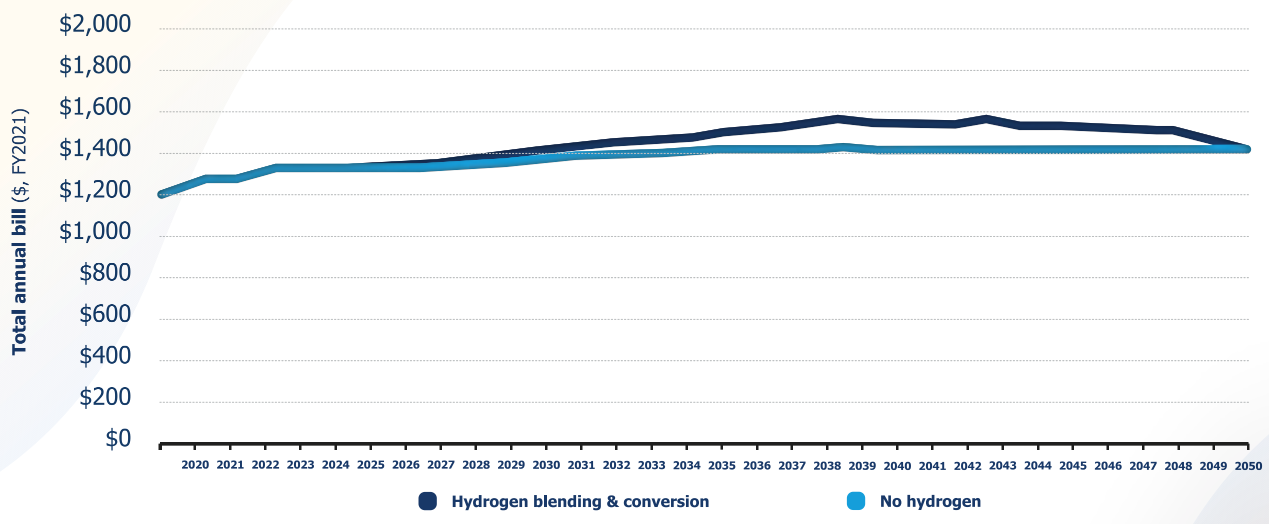
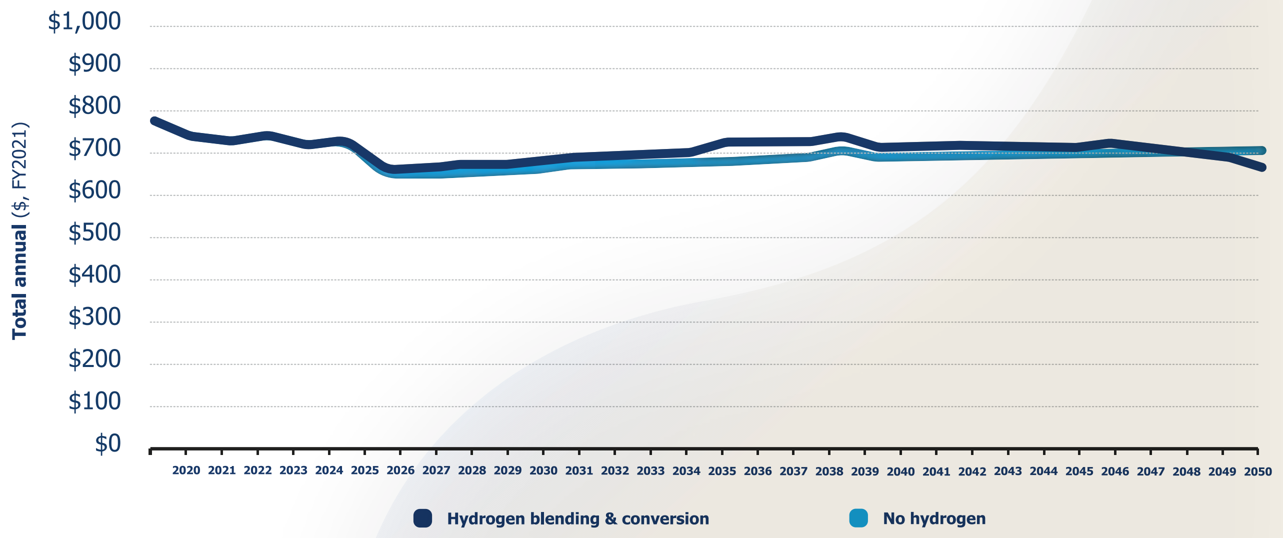


FIGURE 17: **TOTAL BILL FOR AN AVERAGE SOUTH AUSTRALIAN RESIDENTIAL GAS CUSTOMER COMPARED TO NATURAL GAS**



ECONOMIC BENEFITS AND OPPORTUNITIES

The AHC commissioned separate Economic Impact Assessment (EIA) to understand the broader economic impacts of decarbonising gas networks in Victoria and South Australia with renewable hydrogen.

The EIA measured the expected change in key economic indicators expected to occur as a result of the project – job creation, Gross State Product (GSP), and value-add to the economy. A range of assumptions and parameters applied across the scope of the analysis can be found in the full State-wide reports.

This projected that the construction and operational phases would generate a range of direct and indirect economic benefits.

The assessment found the full construction program would deliver a significant boost to the building and trades sector in both states, and additional benefits would be expected across the rest of Australia.

TABLE 4: **ECONOMIC IMPACT SUMMARY**

	DIRECT	INDIRECT	TOTAL
10% HYDROGEN – Construction (per year, over 5 years)			
Output ($M)	$126.19	$106.7	$232.89
Employment (FTE)	295	430	725
Value added ($M)	$40.52	$40.99	$94.32
100% HYDROGEN – Construction (per year, over 20 years)			
Output ($B)	$2.19	$1.83	$4.02
Employment (FTE)	5,102	7,405	12,50
Value added ($B)	$0.77	$0.75	$0.15
10% HYDROGEN – Operational phase (annual)			
Output ($M)	$41.62	$39.69	$81.31
Employment (FTE)	55	110	165
Value added ($M)	$14.11	$16.74	$30.85
100% HYDROGEN – Operational phase (annual)			
Output ($B)	$1.58	$1.51	$3.10
Employment (FTE)	2,08	4,166	6,255
Value added ($B)	$0.53	$0.64	$1.17

Conclusion

Victoria's and South Australia's gas distribution networks are an integral part of today's energy system, providing a reliable supply to millions of residential, commercial, and industrial customers. Supported by a range of independent technical studies, the AHC considered a range of fundamental questions to determine how a 100 % renewable hydrogen distribution system could optimally be achieved, including:

- Key actions and their timing to 2050 to implement 10 % and 100 % hydrogen supply;
- Compatibility and capacity of the existing gas distribution network.
- New production, storage and transmission infrastructure needed, and how this could be coupled with other emerging markets including renewable electricity and hydrogen mobility.
- Compatibility of existing appliances and required steps to achieve full hydrogen readiness.
- Regulatory and legal considerations for producing, distributing, and encouraging the uptake of renewable hydrogen.
- Overall cost of producing and supplying renewable hydrogen.
- Broader economic benefits and opportunities of pursuing and delivering renewable hydrogen distribution networks.

In addressing these challenges and opportunities, the AHC's work has demonstrated that it is technically and economically feasible to continue to use existing infrastructure to achieve a 100 % renewable hydrogen disribution system and support Australia's economy including households, businesses and industry.

Importantly, the reports provide a better understanding of the opportunity to access Australia's world-class gas distribution infrastructure to unlock its hydrogen opportunity whilst retaining energy security and affordability, and identifies a range of low-regret enablers that could trigger coordinated action by government and industry.


Australian
Hydrogen Centre