Australian Government | COAG Energy Council

NATIONAL HYDROGEN STRATEGY

Issues paper series

1. Hydrogen at scale
2. Attracting hydrogen investment
3. Developing a hydrogen export industry
4. Guarantees of origin
5. Understanding community concerns for safety and the enviornment
6. Hydrogen in the gas network
7. **Hydrogen to support electricity systems**
8. Hydrogen for transport
9. Hydrogen for industrial users

This issues paper explores the interplay between hydrogen production and electricity system operation and the opportunities for clean hydrogen to contribute to the resilience of electricity systems.

The role hydrogen can play in supporting gas networks will be discussed in *Hydrogen in the gas network*. Similarly, the role for clean hydrogen in the transport sector is considered in *Hydrogen for transport*.

A list of questions is presented at the end seeking further input from interested stakeholders.

Hydrogen to support electricity systems

This paper has been informed by submissions to the *Request for Information* released in March this year, as well as:

- targeted visits to countries that have already started to develop hydrogen technologies and markets
- the stakeholder roundtables that were held throughout May and June

The COAG Energy Council Hydrogen Working Group would like to thank industry and community members for their engagement in the strategy development process.

In this paper, unless otherwise indicated, 'hydrogen' refers to 'clean hydrogen,' defined as being produced using renewable energy or using fossil fuels with carbon capture and storage (CCS). This definition reflects the principle of technology neutrality set by COAG Energy and Resources Ministers when they commissioned the Working Group to a comprehensive and ambitious strategy for the development of an Australian hydrogen industry.

Background

How hydrogen production unfolds may have significant, positive or negative, implications for current electricity systems. With multiple production pathways and an emerging market, there is uncertainty regarding exactly how hydrogen will be produced – decentralised or centralised, large or small-scale, using existing network infrastructure or purpose built – and how it will be used. Hydrogen can be produced locally at the end-use site with grid electricity, centrally with grid electricity with the hydrogen transported to an end-use location, remotely using off-grid electricity with the hydrogen transported to the end-use location or remotely at the end-use site using off-grid electricity.[1] Different production methods have varying implications for current electricity systems. As discussed later in this paper, hydrogen production may accelerate the need to address broader electricity market issues, and hydrogen production may also provide some solutions to ensuring the electricity grid remains secure and reliable.

Benefits and opportunities

Hydrogen can support electricity systems in three main ways.[2]

- First, hydrogen can be stored and used to generate electricity when needed, for instance for seasonal storage or demand response purposes.
- Second, electrolysers can rapidly respond to variations in generation output, acting as flexible loads consuming excess renewable energy when it is available and deferring to other loads when generation output is low. This can enable more renewable energy generation on the system, as well as providing an off-take for otherwise curtailed energy.

- Third, electrolysers as large electrical loads can be rapidly ramped up and down to provide frequency control services and other system services for electricity systems. The extent to which hydrogen production supports Australia's electricity systems will depend on whether energy market frameworks and incentives allow or disallow these benefits to be exploited.

Storing and generating electricity

Both the Australian Energy Market Operator (AEMO)[3] and the Australian Energy Regulator (AER) have identified the growing role of storage in Australian Energy Markets.[4] The Independent Review into the Future Security of the National Electricity Market (Finkel Review) also identified a need for increased investments in dispatchable generation and storage at grid-scale as more renewable energy generation is commissioned.[5] To date, there is no explicit market mechanism in the national electricity market to value storage.

Energy storage may emerge as a primary use of hydrogen in the electricity sector, because it offers long-term storage of large amounts of energy and can complement other storage technologies.[6] The benefits of storage include reducing requirements on future transmission and distribution networks and providing a grid-firming product for electricity generators. Using hydrogen as a form of storage, potentially complementing other storage such as batteries, could help improve utilisation of existing network assets and manage network congestion. This could reduce the need for 'over-build' of generation while also enabling larger renewable energy projects than the electricity system could otherwise support by providing an off-take for the excess electricity.

There have been a number of small-scale demonstrations around the world showcasing hydrogen for renewable energy storage, but it is still currently expensive.[7] In Australia, stand-alone power systems (SAPs) are usually diesel, solar photovoltaic with batteries, or diesel-solar-hybrid systems. Hydrogen SAPs are financially competitive with diesel-solar-hybrid and solar-battery systems[8] and could be commercially competitive with diesel equivalents before 2025.[9] In 2018, the Australian Renewable Energy Agency (ARENA) released a report stating that bulk underground hydrogen storage has one of the lowest costs per megawatthour of storage capacity.[10]

There may be opportunities in remote areas of Australia that are currently being served by distribution businesses where it could be economically feasible to develop hydrogen trials, as the costs to serve these communities through diesel generation are high. The Australian Government recently announced support for one such project in Queensland's Daintree region.[11] As the costs of hydrogen production reduce there should be increasing opportunities to demonstrate this method of storage and dispatchable generation at grid scale.

The use of hydrogen in gas turbines to produce electricity is being investigated. There are technical challenges with burning 100% hydrogen in a gas turbine, but it is believed to be technically possible.[12] General Electric has installed over 70 gas turbines capable of burning fuels containing some hydrogen to generate electricity.[13] In addition to electricity production, using hydrogen in this manner would also provide inertia and system strength support.

Hydrogen fuel cells can be used for stationary power generation for back-up and emergency power, including for hospitals, data centres and others who needed continuous and reliable power. The US has installed over 250 MW of stationary fuel cell power.[14]

Allowing greater value from renewable energy

The International Renewable Energy Agency (IRENA) states that hydrogen produced from renewable energy can enable the integration of significant levels of renewable energy and serve as a potential pipeline of power purchase agreements for renewable energy generators.[15] Hydrogen can keep demand close to the generation source which limits marginal loss factors and assists in potentially alleviating network congestion. As jurisdictions introduce or modify their renewable energy targets, the ability to effectively integrate new renewable energy generation without effecting the stability of the electricity system becomes critical to ensuring the practicality of policy objectives. Hydrogen production could potentially help to manage any network congestion from significant penetration of distributed renewables (such as rooftop photovoltaics) in electricity distribution networks.

Providing security and reliability system services

To maintain grid security and reliability, AEMO, and network operators must ensure the power system provides electricity as needed and within its physical limits for a range of factors, such as: voltage, system strength and frequency. Power system security refers to the operation of the power system within safe technical parameters, while reliability refers to the probability of supplying all consumer energy needs with the existing generation capacity and network capability.

Hydrogen producers will want to maximise electrolyser utilisation to produce as much hydrogen as possible, but they may be prepared to modify production levels if incentives exist for the producer to participate in and derive revenue from demand management and ancillary services. The extent to which the load is controllable and what market incentives exist will drive how hydrogen producers participate in the market. Where incentivised, electrolysers can potentially provide a flexible load that can be curtailed during electricity system peaks.

Ancillary services, such as voltage and frequency control, are used by AEMO to manage power system safety and security by maintaining the key physical requirements of the system. In 2018, the AEMC identified frequency control as a current system security challenge.[16] Prior to 2016, the value of the Frequency Control Ancillary Services (FCAS) markets in the National Electricity Market (NEM) was less than $50 million per year, but it has since experienced a rapid increase to now approximately $200 million per year.[17] This is still a relatively small market and the role, if any, that hydrogen production will play in this market is uncertain.

The ability for hydrogen producers to ramp electrolysers up and down will depend on the intended purpose of hydrogen production. For example, integrating a green hydrogen plant into an existing ammonia plant will require continuous production, which means switching on and off and ramping will not be feasible unless hydrogen storage is built into the plant design. Electrolyser technology will continue to evolve, with pilots and demonstrations at grid-scale needed to best understand all the potential opportunities for how hydrogen production can provide security and reliability services to electricity systems.

In the early scaling up of domestic hydrogen production, additional revenue streams like FCAS participation will have a dual benefit of supporting a more resilient power system and assisting the business case for hydrogen production.

Risks and barriers

The electrolysers used for hydrogen production can contribute to electricity system resilience in the presence of high levels of renewable energy generation. However, significant, uncoordinated on-grid hydrogen production could exacerbate constraints and cause other negative impacts to the electricity system and consumers. The Working Group has identified a key risk to be poor asset placement and planning, and the main barrier to be enabling market frameworks. These were also raised by stakeholders through consultations to date.

Poor asset placement and planning

The three main cost components for producing hydrogen are: electricity costs, electrolyser costs and the capacity factor.[18] Using grid connected electricity results in the lowest levelised cost of hydrogen because the electrolysis capacity factor will be high, but this may be dependent on the location of the end-use for the hydrogen and the network charges (both connection and ongoing).[19] From a commercial perspective, it appears likely in the short term that most hydrogen production will occur on-grid.

This presents challenges and risks for electricity systems across Australia, as electrolysers can use large amounts of energy. Poor asset placement and planning could have adverse impacts for electricity system security and reliability, constraints, and electricity costs. There must be strategic consideration of placement of large numbers of electrolysers to ensure the long-term interest of all electricity consumers is balanced against commercial considerations. The large loads electrolysers may add to electricity systems could have adverse effects if the hydrogen production is not responsive to the needs of the system. For example, the additional demand created by hydrogen production could drive large levels of renewable energy generation in fringe of grid areas where renewable energy sources are strong, but network infrastructure is not. There are economic signals, such as connection costs and marginal loss factors, that influence asset location decisions, but these may be inadequate to provide optimal locations from a whole-of-system perspective in the scaling up of hydrogen production. This is because these present quite static cost signals. Ramping hydrogen production concerns dynamic, real-time energy flows and constraints in the system.[20]

Electricity supply capacity and price should be driving factors for selecting the location of electrolysers, in addition to the end-use of the hydrogen. Hydrogen could enable more renewable energy generation by offering large behind-the-meter demand for the energy or by absorbing otherwise curtailed energy to address network constraints. If network capacity and other vital information is not clearly presented to investors and hydrogen producers to enable them to identify optimal locations for hydrogen production, from a whole-of-system perspective, then commercial decisions might not be aligned with the long-term interest of consumers.

There is already acknowledgement through AEMO's Integrated System Plan that optimal renewable energy generation locations are not necessarily matched to existing network infrastructure, however hydrogen production has not been considered in AEMO's identification of renewable energy zones (REZs). REZs should not be assumed to be the optimum location for electrolysers, as they were identified without criteria that might be important to the hydrogen economy. The Working Group is currently undertaking analysis of hydrogen production zones to help improve information needed for optimal siting.

Hydrogen production may be added to new or existing generation projects or could be developed separately. Scaling up hydrogen production for export will require significant electricity, and purpose-built networks may be developed to serve large electrolysers with no direct interaction with current electricity systems. This is not inherently negative, but could be a lost opportunity to improve the reliability, security and affordability of existing electrical systems and markets. Consideration should be given to optimising hydrogen production to secure the most economic benefits.

Utilisation of existing network and gas infrastructure to the extent feasible should also be optimised. Ideally, customers should not have to pay for additional network infrastructure to support industry development unless they also share in benefits. The capital costs of transmission and distribution infrastructure are significant and careful consideration will be needed to ensure hydrogen production does not adversely affect electricity costs; these are the same considerations that are occurring regarding development of new generation assets. The current commercial drivers in the market and regulatory frameworks may be insufficient to scale hydrogen production most effectively. Challenges to scaling up an industry are further discussed in the *Hydrogen at scale* paper, which provides a case study on the lessons learned from the growth of Australia's LNG industry.

Enabling market frameworks

As new technologies continue to be developed and integrated with electricity systems the value of the services these technologies can offer must be fully understood to ensure they can be properly remunerated and incentivised through market frameworks. For example, the FCAS market arrangements currently pay a price per MW of enabled service without regard to the quality of the service.[21] The Hornsdale battery energy storage system demonstrated that different technologies can deliver a different quality of service that may have additional value to the system.[22] Understanding how new technologies can deliver valuable services, both existing and future, and enabling these services with adequate market frameworks is critical to managing changing electricity systems. This is not a hydrogen-specific issue but rather the nature of new and emerging technologies and dramatically changing electricity systems that have evolving demands and requirements.

Hydrogen production may be able to offer a number of services that currently exist or that may be needed in a future grid, such as different frequency control services, simulated inertia, and grid firming. It is important that the services and value to electricity systems of hydrogen production are understood. For example, as a grid firming product hydrogen can store energy for days, week or months whereas other technologies are only able to last hours. The market frameworks will need to continue to adapt to the new requirements of the changing electricity systems. There is significant work underway in managing this transition, including the Energy Security Board's post-2025 market design work for the NEM.

Actions to ensure effective integration with electricity systems

The Working Group, through the consultation to date, has identified the two main areas where actions are needed to ensure hydrogen production is effectively integrated with electricity systems: market and regulatory reforms and pilots and demonstrations. However, the Working Group is interested in receiving stakeholder feedback on whether these are the right priorities.

Market and regulatory reforms

Markets frameworks and signals will drive whether and the extent to which hydrogen production and use, and associated renewable energy growth, will drive electricity system benefits or cause challenges.

Hydrogen enables energy to flow between the electricity, gas, and transport systems that, if done optimally, can create value for consumers. IRENA stated that hydrogen can facilitate sector coupling,[23] and this was also raised in the stakeholder forum. As noted in other issue papers, hydrogen and other market changes can create new linkages between the exports, electricity, gas and transport sectors in Australia.

Stakeholders raised the need to better harmonise the National Electricity and Gas Objectives, Laws and Rules given that hydrogen could play a role in both markets. It was noted that the markets are each separately optimised in the long-term interest of consumers and in the future, hydrogen may enable a choice between building gas or electricity infrastructure to deliver renewable energy to demand centres. The roundtable also noted there may be challenges to this integration as the gas and electricity markets are quite different in operation.

Hydrogen entering and influencing these sectors will increase the interactions and interdependencies between the sectors. Done effectively, sector coupling offers the potential for more efficient delivery of energy to consumers through co-optimised use of energy networks and markets. This may require regulatory changes to enable this increased interaction, as market frameworks will drive whether, and to what extent, coupling and benefits occur.

Stakeholders also noted that increased use of electrolysers and renewable energy generation may need to be considered in future market reforms for:

- arrangements for connection of electrolysers
- demand response mechanisms
- investment coordination (such as the Coordination of Generation and Transmission Investment Review)
- transparency of network system strength and likely future congestion
- management of Distributed Energy Resources (DER).

It is impossible to know what the future grid will look like as it changes from large-scale synchronous generation to new and emerging generation, storage and demand management technologies.[24] The role of governments is not to prescribe what future electricity systems should look like, but instead optimise market settings in the long-term interest of all consumers. Critical to this is providing policy certainty and enabling regulatory frameworks to allow timely and efficient investment decisions to be made.

Energy market regulatory bodies are already undertaking a significant reform work program. Current and future changes to the electricity and gas market rules should consider hydrogen production to future-proof reforms and identify any hydrogen-specific reforms that will also need to be addressed.

Some of the current reforms are relevant to hydrogen production. For example, in April 2019, the AEMC released a consultation paper on transparency of new projects.[25] The paper responds to significant increases in connection requests to network service providers and considers whether the amount of publicly available information for proposed grid-scale generation and large loads should be increased. Should it proceed, this rule change would enable producers to identify future generation locations more easily.

Hydrogen producers could also benefit from the demand management reforms proposed or currently underway, such as changes to provide network service providers with financial incentives and funding to develop non-network solutions, proposed changes to wholesale market demand management, and proposed changes to remove existing barriers that prevent distribution businesses from providing SAPS as a regulated service.[26] Hydrogen technologies can be used in stand-alone power systems and better enabling the use of those systems may provide a demand for hydrogen.

AEMO is currently undertaking work to allow for better integration of distributed energy resources. This work should also consider the system impacts of large flexible loads such as electrolysers and ensure they can be included as a distributed energy resource.

The Western Australian Government has stated that the South West Interconnected System (SWIS) is under increasing pressure as the power system modernises. It has established the Energy Transformation Taskforce to focus on power system security and reliability and future market operations. The work of the Taskforce will also consider the role hydrogen may play in the future SWIS.

The National Hydrogen Strategy will include proposed legislative and regulatory changes that might be needed for hydrogen production. The Working Group seeks stakeholder input on specific legislative or regulatory barriers and more information on when changes will be required, as well as how to unlock the value of sector coupling to deliver consumer benefits.

Pilots and demonstrations

Pilots and demonstrations are needed to better understand the characteristics of hydrogen production systems and their potential interactions with electricity systems. They provide valuable learnings in the scaling up of hydrogen production and enable a test environment for how the technologies react in a real environment. These learnings are crucial to better understanding the services and value new technologies can provide to electricity systems. They can also help inform future planning and investment decisions by market participants and design of market signals and frameworks by market bodies and governments. To optimise project learnings, pilot or demonstration projects should have clear performance goals, which are aligned with promoting energy and climate policy objectives and enabling economic benefits. This in turn will help to improve the design and cost of hydrogen electrolysers, fuel cells and turbines and the market and regulatory frameworks in which they operate.

There are hydrogen production plants currently being developed or considered across Australia. The Port Lincoln Green Hydrogen Plant announced by the South Australian (SA) Government in 2018 will be Australia's first clean hydrogen plant, which will produce hydrogen using a grid connected 15 MW electrolyser and includes a 10 MW hydrogen turbine, 5 MW fuel cell and a distributed green ammonia facility.[27] CSIRO has stated that projects of this size or larger could be commonplace by 2025.[28]

There is also a feasibility study underway for a $600 million 50 MW Hydrogen Super hub at Crystal Brook, SA, which would be the world's largest co-located wind, solar, battery and hydrogen facility, able to produce up to 9,000 tonnes of hydrogen per annum.[29]

Off-grid systems also provide an opportunity for learnings that are necessary to build the industry. CSIRO has identified SAPs as an early targeted application based on market competitiveness.[30] CSIRO has also identified remote mining operations as key demonstration targets due to the ability for hydrogen to service multiple operations on a single site.[31] The Australian mining sector consumes approximately 500 Petajoules per year for transport and power generation with 41 per cent coming from diesel.[32] Replacing diesel could be a significant early market demand if the cost reductions can be realised. SAPS may also be able to provide the hydrogen needed for vehicle refuelling in remote areas. The economics of the SAPS may enable more hydrogen technology trial opportunities and demand, especially in the short-term.

Roles for government

The Working Group is seeking stakeholder feedback on how governments can most effectively and efficiently support the actions needed to ensure that hydrogen's integration with electricity systems produces shared economic benefits for Australians. As discussed above, stakeholders have raised the need for government to establish enabling market frameworks that reflect how hydrogen interacts with different sectors and allow hydrogen production to be appropriately compensated for the value it can provide to electricity systems.

The other area stakeholders identified as a priority for government action is in supporting pilots and demonstrations in the lead up to a hydrogen project being a bankable asset without support. Pilots and demonstrations are currently funded through national and state programs and can be facilitated through a range of mechanisms including reverse auctions, competitive grants, support for power purchase agreements, and enabling more innovation by distribution network service providers for non-network solutions. There is also action governments can take to provide more information for investors and hydrogen producers, including complementing the Australian Renewable Mapping Infrastructure with additional mapping of hydrogen production opportunities.

Table 1 below is a list of actions and timing for stakeholder consideration. The Working Group is seeking feedback on this list of actions and associated timings.

Table 1: List of actions and timing for stakeholder consideration

2020-2023	2023-2025	2025-2030
• Conduct hydrogen research, development and demonstration (RD&D), leveraging from CSIRO's hydrogen RD&D report and international activities • Identify suitable pilots and demonstrations that are needed to fully understand hydrogen production, including at grid-scale • Work with market bodies and operators to understand the scaling of hydrogen production needed by 2030 and impacts on the systems • Develop a method for mapping opportunities for hydrogen production that produce the best outcomes for electricity systems and consumers • Identify the legislative and regulatory changes that are needed along with the priority/timeframe • Investigate and understand the potential revenue streams for hydrogen producers flowing from delivering system services • Develop a 2050 sector coupling vision setting out a strategic vision for the integration of hydrogen in all relevant sectors • Determine different business cases for hydrogen production, including whether and to what extent large-scale production should connect to current electricity systems	• Finalise all legislative and regulatory changes that are required to enable the scaling of hydrogen production • Continue with pilots and demonstrations and capture learnings from completed pilots and demonstrations • Monitor the integration and impact of electrolysers on electricity systems • Continue hydrogen R&D work	• Assess any future network issues in relation to continuing to scale up hydrogen production over the 2030-2040 period • Refresh the 2050 sector coupling vision • Capture lessons and learnings from the 2020-30 scaling of hydrogen production and determine scaling needed for 2040 and beyond

Questions

The National Hydrogen Taskforce is seeking responses to the questions below. You can submit your comments via the Department of Industry, Innovation and Science's consultation Hub: https://consult.industry.gov.au/national-hydrogen-strategy-taskforce/national-hydrogen-strategy-issues-papers

1. *How can hydrogen production best be integrated with current electricity systems (for instance, should large-scale hydrogen production be connected to current electricity systems)? Are there barriers or risks to integration that need be addressed in the Strategy?*

2. *What, if any, future legislative, regulatory and market reforms are needed to ensure hydrogen supports, rather than hinders, electricity system operation and delivers benefits for consumers (for example by reducing demand during high price events)? What is the timeframe, and priority, for these changes?*

3. *Do current market frameworks incentivise the potential value of hydrogen to support electricity systems? What initiatives or changes required?*

4. *Do current market frameworks allow for sector coupling and interactions between different markets that may result from hydrogen production (such as the interplay between gas, electricity, and transport sectors)? If not, what changes are required?*

5. *What factors should be considered when selecting pilot and demonstration projects? How can government best support pilots and demonstrations?*

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[6] ARENA (2018), 'Comparison of Dispatchable Renewable Electricity Options: Technologies for an Orderly Transition', 146.

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[10] CSIRO (2018), National Hydrogen Roadmap, xii.

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[12] CSIRO (2018), National Hydrogen Roadmap, 38.

[13] https://www.ge.com/reports/hydrogen-generation-gas-turbines-can-run-abundant-element-universe/

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[15] IRENA (2018), Hydrogen from renewable Power: technology outlook for the energy transition, 7-8

[16] AEMC, Frequency control frameworks review, Final Report, 26 July 2018, ii.

[17] AEMO, https://www.aemo.com.au/-/media/Files/Media_Centre/2019/QED-Q4-2018.pdf

[18] CSIRO (2018), National Hydrogen Roadmap, 14.

[19] CSIRO (2018), National Hydrogen Roadmap, 15.

[20] Marginal loss factors represent the losses caused by the electrical resistance of transmission lines, and appropriately reward generators that make use of lower resistance flow-paths to load centres. However, they do not factor in the effects of binding constraints that arise in the system that cause generation to be curtailed. Connection costs can reflect the cost of augmenting the network to allow new connections, but cannot guarantee that connected generators will be dispatched if constraints still arise in the system. The NEM's regional pricing design means that abundance of energy supply in constrained locations within regions will not necessarily be reflected in low pool prices accessible by customers in those locations.

[21] AEMO, Initial operation of the Hornsdale Power Reserve Battery Energy Storage System, 2018, 8-9. See also Minter Ellison, A hydrogen industry for Australia – coming soon, 2018. That is available upon request to Minter Ellison.

[22] AEMO, Initial operation of the Hornsdale Power Reserve Battery Energy Storage System, 2018, 8-9.

[23] IRENA (2018), Hydrogen from renewable power: Technology outlook for the energy transition, 16.

[24] Hydrogen Strategy Group (2018), Hydrogen for Australia's future: a briefing paper for COAG Energy Council, 29-30.

[25] AEMC, Transparency of new projects, Consultation paper, 18 April 2019, 1.

[26] See AEMC for further information on relevant rule change requests.

[27] South Australian Government (2019): http://www.renewablessa.sa.gov.au/topic/hydrogen/hydrogen-projects

[28] CSIRO (2018), National Hydrogen Roadmap, 57.

[29] SA Government, http://www.renewablessa.sa.gov.au/topic/hydrogen/hydrogen-projects

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[32] ARENA/Sunshift (2017), Renewable Energy in the Australian Mining Sector – White Paper, 4.