Australian Government

COAG Energy Council

NATIONAL HYDROGEN STRATEGY

Issues paper series

This issues paper explores the benefits, challenges and issues related to introducing hydrogen into Australia's gas distribution networks. It explores the actions needed to commence blending of hydrogen into these networks.

The COAG Energy Council Hydrogen Working Group seeks feedback on the proposed actions to introduce hydrogen into Australian gas networks.

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

Hydrogen in the gas network

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 a comprehensive and ambitious strategy for the development of an Australian hydrogen industry.

Background

Hydrogen has been identified as an option to decarbonise heat demand. As it is a combustible gas, it can be used in similar ways to natural gas, using much of the same infrastructure and providing many of the same benefits.[1] Energy Networks Australia's 2050 Gas Vision sets a vision '*for Australia to turn its gas resources into products and services that will enhance national prosperity while achieving carbon neutrality'*.[2] Hydrogen is one way to make this vision a reality.

There is considerable interest within the gas sector to consider use of hydrogen in Australia's gas networks. In submissions to the COAG Hydrogen Working Group and through consultations, stakeholders have raised further benefits of using hydrogen in gas networks. These include:

- *Helping to build a hydrogen export industry* – skills and experience gained in using hydrogen domestically will build volume and help drive costs down the learning curve, leading to faster development of a competitive export industry. It will also build the knowledge, and the handling and technical expertise needed for an export industry to operate safely and effectively.

- *Improving energy security and resilience*– hydrogen could be an important substitute form of energy for use in the gas distribution networks. It may be a better option than full electrification as a path to decarbonisation. With appropriate market incentives, it can also strengthen the energy security and reliability of electricity systems and diversify fuel supply options for transport. These benefits are discussed further in the *Hydrogen to Support Electricity Systems* and *Hydrogen for Transport* issues papers.

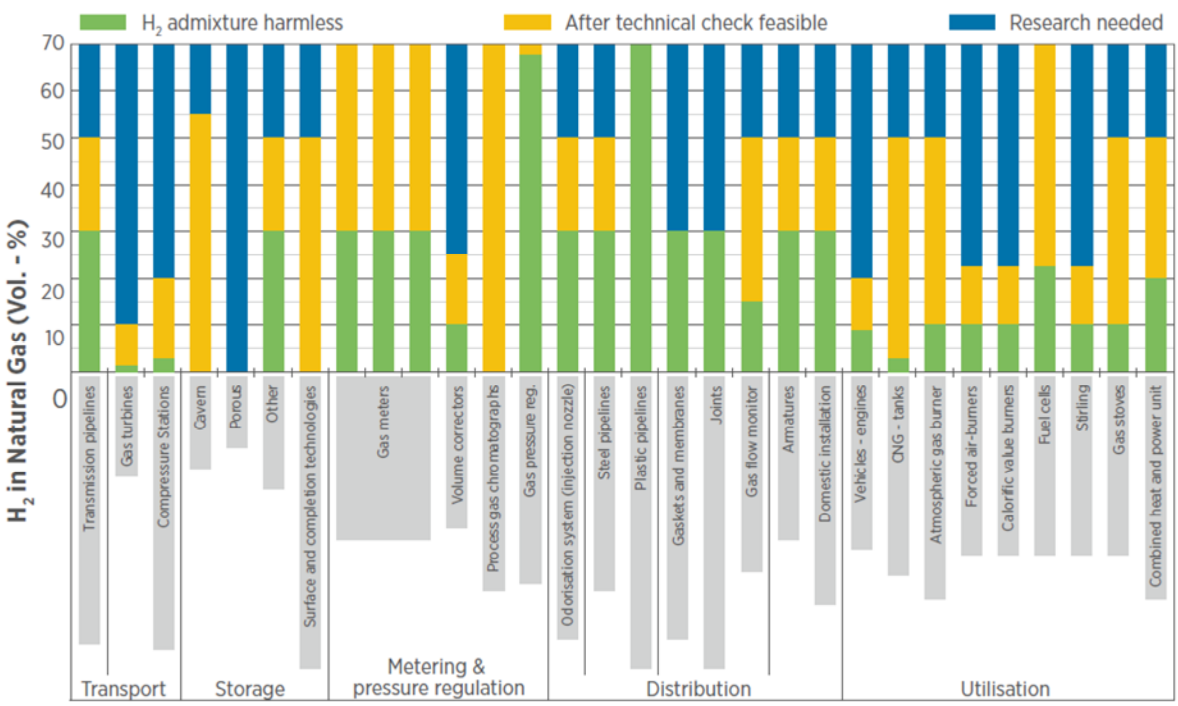
- *Unlocking value in energy markets* – because hydrogen can be used in the transport, electricity and gas sectors it creates the potential for investment in one sector to reduce costs in another.[3] For example, co-optimised construction of gas pipelines and electricity infrastructure to support hydrogen could unlock more renewable energy resources and deliver more flexible, dynamic and efficient market operation (see the *Hydrogen to Support Electricity Systems* issues paper for more discussion of this topic).

However, hydrogen's physical properties mean it does not behave exactly as natural gas does when in natural gas infrastructure. Materials science research to date indicates that injecting hydrogen into the high-tensile steel used in high-pressure transmission pipelines can cause hydrogen embrittlement (where hydrogen being absorbed into the metal makes the pipe brittle and prone to failure).[4] Consistent with these findings, the Working Group is not considering use of hydrogen in Australia's gas transmission networks at this time.

With regards to introducing hydrogen into gas distribution networks, the UK Sustainable Gas Institute concludes that '*there is limited real-world evidence on the capability of low-pressure gas networks to transport 100% hydrogen streams effectively*'.[5] However it is worth noting that there are networks globally that already have high proportions of hydrogen operating in their distribution networks. For example hydrogen gas currently comprises approximately 50% of the gas distributed in networks in Singapore and parts of China, where manufactured town gas is used.[6] Nonetheless, in order to ensure consumer safety and to minimise disruption to gas users, moves towards using hydrogen for decarbonising heat have focussed on blending small amounts of hydrogen with natural gas in distribution networks.

Studies have shown that at low blending concentrations, there is little or no change to natural gas infrastructure required (Figure 1).[7] Optimal blending concentrations will depend on the characteristics of the existing network, natural gas composition and end-use applications. Further, existing studies show that, generally, blending at relatively low hydrogen concentrations (up to 10-20% in volume), may not require major investment or modification to infrastructure. [8]

Figure 1: Hydrogen tolerance of gas infrastructure components[9]



Trials of hydrogen blending to a safe upper limit into the gas distribution networks are underway internationally as well as domestically. For example, the Irons Mains Project (Northern Gas Networks) in Leeds[10] England, with support from the Leeds City Council, is investigating blending in the Leeds gas distribution network as a step towards using 100% hydrogen.[11] In Australia, companies are also piloting blending. Announced projects include; the Hydrogen Park SA (Hyp SA) project in Adelaide, Jemena's Power to Gas trial and ATCO's Clean Energy Innovation Hub in Perth. [12] [13] [14]

Challenges, barriers and risks

Blending hydrogen with natural gas initially then switching in the long term to solely use hydrogen in the gas distribution network to realise the benefits outlined above, and elsewhere, raises three questions: Is Australia's gas infrastructure physically suitable? Will consumers accept it? And is it achievable at a reasonable cost?

Suitability of gas infrastructure

Gas infrastructure impacted by hydrogen blending includes the distribution network itself, consumer piping, which carries gas from meters to appliances, and gas appliances in homes and businesses.

Early findings to date from Australian trials indicate that existing gas distribution networks should be able to accept the blending of some hydrogen.[15] The Australian Gas Infrastructure Group (AGIG) noted in its submission that progressive replacement of existing cast iron distribution pipelines with high-density polyethylene (HDPE) pipe, which is suitable for transporting hydrogen (i.e. 'hydrogen ready'), is already well underway across Australia. The replacement program is being undertaken primarily for safety and operational reasons. The replacement of existing cast iron pipelines with HDPE is expected to be completed in Victoria by 2033 and the program is expected to be largely completed by 2035.[16] As noted by the Future Fuel Cooperative Research Centre (CRC) at the roundtable, there may be areas of pipeline within the gas distribution network or stand-alone systems that could safely have much higher concentrations. For example, newer networks in the ACT and in Tasmania are already HDPE based. As a first step in trials, the South Australian (Hyp SA) project is aiming to blend 5% hydrogen into the gas distribution network to 770 customers by mid-2020. [17]

Consumer piping used to deliver gas from the outlet of the gas billing meter to consumers (which can be to the home or to industrial sites) can be made from a variety of materials, including copper, steel, PVC, polyamides, and multi-layered metal and synthetic piping. Stakeholders, such as Energy Safe Victoria, have advised the Working Group that the low delivery pressure in consumer piping would mean there should not be pressure-related technical issues that would pose significant barriers to the safe delivery of hydrogen gas. However at this stage checks have not yet occurred to confirm that all Australian consumer piping materials are hydrogen ready. The Future Fuels CRC has advised the Working Group it is proposing future work to complete these checks.

Metering is another consideration. If the distribution network were to contain a blended gas, then metering would need to be calibrated for the calorific value, and tested to ensure it provided an accurate way of estimating the volume of gas passing through the network.[18]

Alternatively, if blending was consistent, bills could be adjusted through the billing system without adjusting each meter separately.

Many existing residential gas appliances are tested to operate under limited conditions with hydrogen at levels of 13%.[19] This limit was selected factoring a safety margin well above the likely naturally occurring levels of hydrogen in natural gas and so is not meant to represent a safe upper limit for general appliance operation. Work by the Energy Pipelines CRC has found a blend of around 5% has no effects, but that minor modifications may be required to some appliances with blends of up to 30%.[20] The ability of industrial appliances to accept gas containing hydrogen may be more complex. These devices are individually certified and may require recertification.

Another factor to be considered is the potential effect on industries that use natural gas as both an input feedstock and source of industrial process energy. In some cases, hydrogen may act as a contaminant that would need to be removed, or otherwise dealt with before the natural gas can be used. In the roundtable, Chemistry Australia emphasised the need to investigate this thoroughly to inform the National Strategy. Consideration is needed of whether these users are connected to the gas transmission or distribution systems and how to manage industry feedstock contaminations. In the roundtable, Chemistry Australia emphasised the need to investigate this thoroughly to inform the National Strategy.

Case Study: Kick-start project on hydrogen in gas networks

Work is well underway to identify any technical or regulatory barriers to blending 10% hydrogen (by volume) into the domestic gas distribution network through a project commissioned by COAG Energy Council and led by the South Australian Government, in conjunction with the Future Fuels CRC.

Effects on gas composition, blending, network materials, downstream appliances, and risk and safety are under consideration. Preliminary results indicate that there are small changes needed in each of these areas. The project has found that further work is required before 10% by volume of hydrogen is injected into the gas distribution network, including a desktop review of relevant studies and practical testing considering:

- suitability of pipeline materials (both steel and plastic)
- suitability of industrial appliances
- injection location and impacts on distribution capacity
- accuracy of metering equipment
- suitability of gas chromatographs

These findings will guide the Future Fuels CRC's forward work program.

Consumer acceptance

Consumer research by the University of Queensland reveals that safety is consumers' primary concern when it comes to hydrogen use in homes and in the community. However, most of those surveyed indicated they trusted there would be adequate safety precautions in place should hydrogen use become widespread.[21] People rated safety in the home as extremely important. They wanted more information about the costs of appliance upgrades. Most people interviewed, however, were unconcerned about blends of up to 10% hydrogen by volume.[22]

Consumers currently trust that regulation will keep them safe, which points to the need to make sure that regulation keeps pace with industry development. Several submissions in response to the *Request for Input* noted that hydrogen is already being produced and stored safely using well-established methods and that the fundamental safety regime in Australia should be able to accommodate the unique safety issues posed by hydrogen. Experience overseas suggests that while hydrogen has some unique safety hazards, these should be able to be managed with an effective safety regime. Australian regulation can build on this experience to ensure regulation is in place when needed.

Safe widespread use of hydrogen in gas networks will require skills and training for associated trades and for others who are likely to work on or near gas distribution networks. This need has already been recognised by the ACT Government and Evoenergy, who are working with the Canberra Institute of Technology's 100% hydrogen test facility. The aim is to understand how hydrogen behaves in distribution networks and appliances, and apply these findings to associated trade curriculums.[23] Training for emergency services will also be important. The *Understanding community concerns for safety and the environment* issues paper discusses this issue in more detail.

One interesting finding of University of Queensland survey was that people wanted to be able to choose whether to participate in a hydrogen blending trial. However, the only way to accommodate this desire for choice would be to remove individual homes from the gas distribution network (and electrify their current gas appliances) for the duration of the trial – which would add complexity and of difficulty to any such trial. This finding highlights that gas distribution companies and retailers still have much work to do in educating the community ahead of trials of hydrogen blending.

The inability to opt out will also likely mean that greater reassurance over safety and economic impacts will be required. Roundtable participants noted that demonstration projects would require the people participating to be confident that their safety and interests would be protected. Energy Consumers Australia suggested that this might mean demonstration projects being guaranteed support for 10 to 15 years. The projects would also need to be reversible if it was unsuccessful.

There was consensus among roundtable participants that failing to earn social acceptance would pose a significant barrier to blending hydrogen into gas distribution networks. The University of Queensland survey indicates that support for hydrogen technologies is directly related to the level of consumer knowledge about hydrogen.[24] This suggests it will be important to transparently provide information and data to consumers to give comfort on the safety, reliability and environmental benefits of hydrogen.

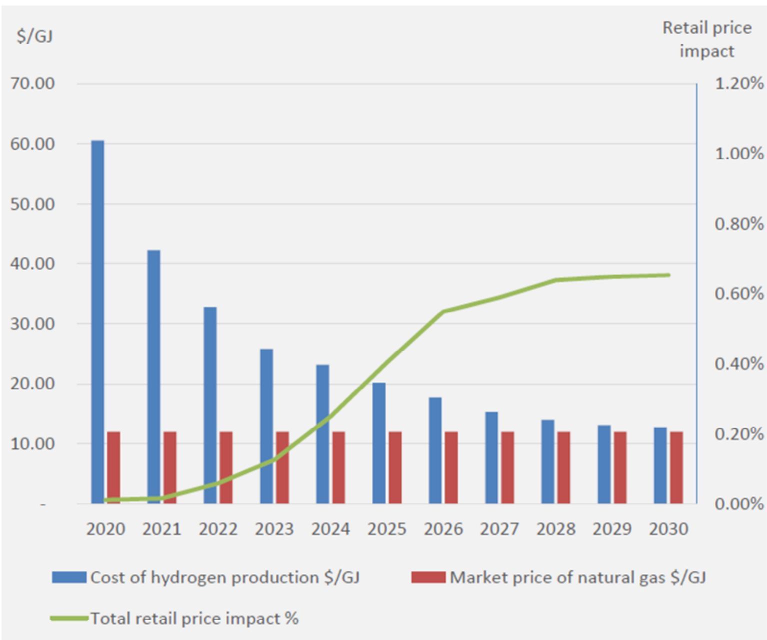
Multiple stakeholders suggested that it was important to raise the public profile of hydrogen. Hydrogen powered public transport and hydrogen using appliances in public places (for example BBQs) were mentioned as options, as were other demonstration projects.

Economics, investment, costs and incentives

The consumer focus groups conducted by University of Queensland researchers revealed cost would be a key issue for consumers. The report states 'less than half of the survey sample would be willing to pay more for hydrogen technologies even if there were clear environmental benefits'. Willingness to pay did vary significantly with age, income, location and knowledge.[25] There were also some concerns expressed around costs raised in individual submissions such as, refitting of distribution networks to take hydrogen, the capacity to produce low-cost hydrogen, uncertainty of additional costs hydrogen may add to current gas supply and if those costs would be applied more generally even to non-gas users.

Hydrogen production costs are currently high but do have the potential for reduction. AGIG's submission suggests a cost curve showing costs for hydrogen production (assuming that initially existing infrastructure will have capacity to transport this production, while acknowledging that additional infrastructure may be needed towards the end of the time period) potentially reaching price parity with domestic natural gas markets that are exposed to global markets by 2030. This cost curve is included at Figure 2. The cost curve combines analysis from manufacturers of electrolysers, CSIRO and Morgan Stanley, but does not include any costs of infrastructure such as transmission lines or new pipelines. However, if it is indicative of the likely cost reduction of hydrogen compared to natural gas, then blending of hydrogen with natural gas could follow this cost reduction to minimise retail price impacts.[26]

Figure 2 - AGIG estimate of hydrogen and natural costs and retail price effects for a 10% renewable gas [27]



However, individual impacts on the consumption portion of gas bills are only one part of the story. When the economics of blending hydrogen into the gas distribution network, it is important to consider costs and benefits across the whole system. Gas consumers are also electricity consumers and transport users. Considering the costs and benefits across these three sectors (which are increasingly coupled together) could unlock extra value for consumers and offset some of the costs of moving to blending. Jemena argued in its submission that the biggest value of hydrogen comes from its ability to drive this sector coupling, '*allowing energy and value flows to move between electricity and gas, and between the energy sector and the transportation sector in a manner that creates value for all the sectors'*. [28] Further study is also required of the potential economic benefits that can be provided by sector coupling.[29]

AGIG with input from Deloitte has modelled two pathways to decarbonise the whole of Victoria's gas consumption based on 2017 energy consumption data– full conversion to renewable electricity for existing uses of electricity and natural gas, and the use of hydrogen as a means of decarbonising gas use. This study has suggested that utilising hydrogen for existing natural gas use with existing infrastructure may be up to 40% less expensive than full electrification. However, as noted in *Hydrogen for Australia's Future*, the modelling assumes that changeover is effectively instantaneous, and priced on projected 2030 costs from the Australian Electricity Market Operator. In reality, both pathways will take several decades to complete in an orderly fashion, so the actual costs will benefit from normal replacements, further experience-driven cost reductions, digitalisation of the grid operation, demand response and improved efficiency.[30]

Moving from theory to reality

Internationally, significant research and many studies have been undertaken to understand the type and breadth of challenges of hydrogen blending, much of which is expected to apply to the Australian context. As Figure 1 shows, at levels of 10% or less, infrastructure is known to be compatible or easily confirmed with technical checks.

However, Australian regulators need to satisfy themselves that international experience is applicable here. The *Hydrogen in the Gas Networks Kick-start Project* commissioned by COAG Energy Ministers is a first step in providing this reassurance. Work underway in the Future Fuels CRC (see case study below) is another. Demonstration projects such as those being undertaken by AGIG, ATCO, Jemena and EvoEnergy will bring important real-world data and experience to the discussion. Standards Australia has already identified the relevant gas standards that may need to be amended.[31]

Stakeholder consultations consistently called for more support for demonstration and pilot projects. Energy Consumers Australia at the roundtable spoke of the need to set up demonstration projects, including potentially a pure hydrogen distribution network in a new sub-division or a regional location. If the demonstration projects showed it was possible to address the key issues identified in this paper, then similar approaches could be progressively rolled out across the gas distribution network. Jemena highlighted the opportunity projects like these gave proponents to begin a meaningful dialogue with stakeholders. Jemena further noted that pilot projects provided the opportunity to test and refine new regulations in a small region before they were rolled out more broadly.

Participants in the roundtable were of the view that regulations and standards should be harmonised to the extent practicable across Australia. There was also a view Australia should be actively involved in the design and harmonisation of international standards and regulations. For example, as a potential world leader, Australia could play an influential role in developing best practice management approaches; educating and informing the public about hydrogen; evolving regulations, technical standards and guidelines; and policy changes to deliver the desired health, safety and environmental outcomes.

Case Study: Future Fuels Cooperative Research Centre research and development to inform hydrogen in gas networks

The Australian Government and the South Australian Government and industry partners are supporting the Future Fuels Co-operative Research Centre to undertake three interdisciplinary research programs:

Research Program 1 focuses on the understanding of the technical, commercial and market barriers to, and opportunities for, the use of hydrogen. Projects include:

- Developing techno-economic models of hydrogen production processes and supply chains to identify major technical or cost hurdles to the commercial uptake of hydrogen.
- Developing network models that incorporate current plans for Australia's energy market and options for sector coupling with the electricity system in order to generate change at the lowest total cost to consumers.
- Research on the properties of hydrogen- natural gas mixtures to determine how they will impact residential, commercial and industrial customers, including a comprehensive appliance test program to determine if appliances can operate on natural gas with a 10% hydrogen by volume blend.

Research Program 2 studies the social and policy context, including public acceptance and safety, for technology and infrastructure associated with hydrogen. Projects include:

- Research to assist industry and government to understand and address community-based issues and develop appropriate engagement solutions around hydrogen infrastructure projects.
- Research focused on regulatory best practice in other jurisdictions and adapting these regulations to the Australian environment.

Research Program 3 identifies and addresses gaps in relevant Australian industry codes and standards associated with design, construction and operation of gas networks. Projects include:

- Research underway to provide knowledge on long term pipe and weld material performance with hydrogen.
- Research into release rates and dispersion characteristics of various hydrogen-natural gas blends after a rupture or venting operation.

Established in 2018, the CRC has a 7 year life, with research findings being made available across this timeframe.

Potential roles for governments

Stakeholders supported measures to introduce hydrogen into gas distribution networks. Their comments included the need for clear policy signals from governments (including long-term commitments to decarbonisation), and a call to be bold so that economies of scale could develop. They noted the challenges of reducing costs, and had a preference for market signals that included the value of decarbonising. However, participants also noted that mandating action would reduce businesses' flexibility, which may lead to more expensive and or less optimal outcomes.

Stakeholders raised various potential policy options to support the blending of hydrogen into gas distribution networks, ranging from allowing blending to take place, through to encouraging it or mandating it. These are summarised in Table 1.

Table 1: Potential policy options to support blending of hydrogen into gas distribution networks

	Options	Description
Allow	Clarify legal requirements	Ensure relevant legislation is unambiguous with respect to allowing hydrogen blending into natural gas distribution systems. Could include establishing a safe upper limit.
	Consumer education	Ensure consumers are informed of the merits and safe use of hydrogen blends for appliances.
Encourage	Access Climate Solutions Funds	Develop Emissions Reduction Fund Method for hydrogen blending projects or guidance that would support proponents to access other existing Methods
	ARENA and CEFC funding of projects	Prioritise hydrogen activities for ARENA's grant funding and CEFC's investment activities.
	Clean gas certification schemes	Establish a certification scheme that allows gas utilities to certify their gas as having lower emissions (than current gas). Could include multiple levels of certification to allow for different levels of blending, and allow gas retailers to sell 'green gas' at a premium to interested consumers.
	Feed-in tariffs	Legislate to pay providers of hydrogen (at suitable blending locations) a premium above the cost of gas for each unit of hydrogen blended into the network, with the cost of paying for this premium spread across all gas consumers.
	Support for appliance switching/modifying	Develop appliance and implementation standards or provide financial assistance.
Mandate	Renewable gas targets	Set target(s) for the amount of hydrogen or biogas to be blended within gas distribution networks. These could be aspirational or mandated targets.
	Hydrogen blending mandates	Mandate hydrogen blends for gas distribution networks.

Potential pathways

Consultation, research, submissions and discussions have confirmed the view that it is too early to commit to 100% hydrogen in Australia's gas networks. This is due to: unknown costs, not knowing if and when costs will be competitive with gas; and the need for a practical demonstration of safety regimes and consumer acceptance. Any decision to move towards 100% hydrogen in gas distribution networks needs to be subject to further analysis of the costs, infrastructure readiness, user needs and competitiveness of other technologies.

It is clear however from Gas Vision 2050 that gas distribution network owners are already moving to future-proof their assets for a low carbon future, in some cases without drivers from emissions reduction regulation or subsidies from government.[32] At a minimum, the Working Group considers it imperative that regulation keeps pace with these actions, so that consumers remain safe and do not bear excessive costs.

To initiate the transition and set the foundation for a hydrogen future, it appears more viable to consider gradual blending of hydrogen into the gas distribution networks. This would not prevent a later move to switch to 100% hydrogen in these networks when more information is available to better assess the economics, consumer acceptance and technical feasibility.

An important early step would be to determine a safe upper limit for the initial blending of hydrogen in gas distribution networks, recognising that it may be different in different networks. The *Hydrogen in the Gas Networks kick-start project* led by the South Australian Government is assessing the regulatory changes and technical standards that would be required for more wide-spread use of hydrogen in the gas distribution networks. This limit could be raised at a later date if more information from trials provides evidence confirming it is safe to do so.

Earlier in the paper, we noted three key issues around gas blending: technical practicality, consumer acceptance, and economics. Governments must be satisfied that all three are answered before implementing any of the above. There are trials underway, as discussed earlier, which will inform the transition and build on what we know. However, there are many 'no regret actions' that can be taken now to lay the foundations for the future while we await trial outcomes. Considering the potential of a gradual introduction of a hydrogen blend into the gas distribution networks, Table 2 below lists some of the actions that the Working Group think can be taken in the short-term and an indicative timeline. The Working Group seeks views on any missing elements and on timings.

Table 2: Proposed timetable of activities to support hydrogen blending in Australian gas distribution networks

2020-2022	2022-2030	Beyond 2030
Technical: • Map and determine suitable hydrogen blending points • Review technical and regulatory challenges and barriers to widespread blending and determine a plan to address them. • Set a timetable to initiate blending of hydrogen into the gas distribution network up to an agreed threshold. • Flag to appliance manufacturers that the blending of hydrogen into gas distribution networks is on the horizon. • Review and harmonise current standards and regulations to safely accommodate hydrogen in the gas distribution networks. • Understand industrial feedstock requirements. • Map out which distribution pipelines in Australia will need to be changed to HDPE (hydrogen ready). • Develop with pipeline operators a timetable to ensure all new gas distribution networks are 'hydrogen ready' for a blends, up to 100%. *Community:* • Design and launch a program to build community understanding of, and support for, hydrogen. • Identify and build the skills needed for a hydrogen industry in Australia.	*Technical:* • Allow hydrogen blending into the gas distribution networks. • Develop with manufacturers a timetable to ensure appliances are 'hydrogen ready' for a range of blends, up to 100%. • Require that all new domestic gas appliances to be 'hydrogen ready' and able to meet safety standards using a range of hydrogen percentages. • Conduct hydrogen RD&D. with a focus on research to support the switch to 100% hydrogen and demonstration projects of up to 100% hydrogen in small gas distribution networks. *Community:* • Support early adopters to adapt or replace end use equipment. • Introduce necessary skills and training programs. • Continue to promote the benefits and social acceptance of hydrogen. *Economic* • Develop links to other sectors of the economy that can utilise the hydrogen gas stream. • Undertake periodic analysis of the costs and benefits of a switch to 100% hydrogen, and communicate timeframes in which it could potentially occur.	• As demand increases, identify and map hydrogen gas infrastructure needs.

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. *Which existing gas distribution networks or stand-alone systems are 'hydrogen ready' and which are not? What safe upper limit applies? Does this readiness include meters, behind-the-meter infrastructure, and appliances?*

2. *What is the potential to have a test project of 100% hydrogen use in a small regional location and where?*

3. *Which standards and regulations can be harmonised across jurisdictions considering the different structures and market settings (e.g. safety, codes of practice)?*

4. *What roles should government and industry play in addressing any consumer concerns and building social acceptance?*

5. *How could the actions included in Table 2 be improved? Are there other actions that should be added?*

References

[1] Hydrogen Strategy Group, 'Hydrogen for Australia's Future', p29

[2] Energy Networks – Gas Vision 2050 report, February 2018 https://www.energynetworks.com.au/sites/default/files/gasvision2050_march2017_0.pdf

[3] Australian Gas Infrastructure Group submission on the National Hydrogen Strategy Discussion Paper, March 2019. https://consult.industry.gov.au/national-hydrogen-strategy-taskforce/national-hydrogen-strategy-request-for-input/consultation/view_respondent?uuId=793798735

[4] Research has demonstrated that a 5% hydrogen mixture by volume in natural gas can have a significant effect on hydrogen embrittlement in X80 steels (the highest strength grade). The authors suggest that no more than 20% hydrogen by volume blending should be done if a design life greater than 50 years is to be maintained. (see Meng, B., Gu, C., Zhang, L., Zhou, C., Li, X., Zhao, Y., Zheng, J., Chen, X. & Han, Y. 2017, "Hydrogen effects on X80 pipeline steel in high-pressure natural gas/hydrogen mixtures", International Journal of Hydrogen Energy, vol. 42, no. 11, pp. 7404-7412.) Much more testing and assessment of Australian infrastructure is needed before blending hydrogen into the existing gas transmission network could be considered.

[5] Sustainable Gas Institute, ICL White Paper, 2017. A Greener Gas Grid: What are the Options?, p.g. vii https://www.sustainablegasinstitute.org/wp-content/uploads/2017/12/SGI-A-greener-gas-grid-what-are-the-options-WP3.pdf?noredirect=1

[6] Deloitte Access Economics report – Decarbonising Australia's gas distribution networks, November 2017pp23 https://www.energynetworks.com.au/sites/default/files/054496_tg_decarbonising_australias_gas_network_final.pdf

[7] International Renewable Energy Agency (IRENA), 2018. Hydrogen from Renewable Power https://www.irena.org/publications/2018/Sep/Hydrogen-from-renewable-power, pg.39

[8] International Renewable Energy Agency (IRENA), 2018. Hydrogen from Renewable Power https://www.irena.org/publications/2018/Sep/Hydrogen-from-renewable-power, pg. 39

[9] International Renewable Energy Agency (IRENA), 2018. Hydrogen from Renewable Power https://www.irena.org/publications/2018/Sep/Hydrogen-from-renewable-power, pg. 39

[10] Northern Gas Networks, Leeds City Gate Project https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf

[11] Sustainable Gas Institute, ICL White Paper, 2017. A Greener Gas Grid: What are the Options? https://www.sustainablegasinstitute.org/wp-content/uploads/2017/12/SGI-A-greener-gas-grid-what-are-the-options-WP3.pdf?noredirect=1

[12] Hydrogen Park of South Australia – Power-to-gas demonstration *http://www.renewablessa.sa.gov.au/topic/hydrogen/hydrogen-projects/hydrogen-park-south-australia*

[13] Jemena's Power to Gas Trial https://jemena.com.au/about/innovation/project-h2go

[14] ATCO – The Clean Energy Innovation Hub The Clean Energy Innovation Hub https://www.atco.com/en-au/projects/clean-energy-innovation-hub.html

[15] Identifying the commercial, technical and regulatory issues for injecting renewable gas in Australian distribution gas networks, Research report by Energy Pipelines CRC, July 2017. https://www.energynetworks.com.au/sites/default/files/epcrc_report_for_ena_-_research_report_-_july_2017_-_final_with_appendix.pdf

[16] Deloitte Access Economics report – Decarbonising Australia's gas distribution networks, November 2017pp79 https://www.energynetworks.com.au/sites/default/files/054496_tg_decarbonising_australias_gas_network_final.pdf

[17] Australian Gas Infrastructure Group. Hydrogen Park of South Australia http://www.renewablessa.sa.gov.au/topic/hydrogen/hydrogen-projects/hydrogen-park-south-australia

[18] Deloitte Access Economics report – Decarbonising Australia's gas distribution networks, November 2017pp33 https://www.energynetworks.com.au/sites/default/files/054496_tg_decarbonising_australias_gas_network_final.pdf

[19] https://www.energynetworks.com.au/sites/default/files/2017_-_decarbonising_networks_final.pdf p5 accessed 10 June 2019

[20] https://www.energynetworks.com.au/sites/default/files/2017_-_decarbonising_networks_final.pdf p5 accessed 10 June 2019

[21] The Australian public's perception of hydrogen for energy, UQ, December 2018pp13-14 https://arena.gov.au/assets/2018/12/the-australian-publics-perception-of-hydrogen-for-energy.pdf

[22] The Australian public's perception of hydrogen for energy, UQ, December 2018pp33-34. https://arena.gov.au/assets/2018/12/the-australian-publics-perception-of-hydrogen-for-energy.pdf

[23] Hydrogen Test Facility – CIT Fyshwick https://www.evoenergy.com.au/emerging-technology/hydrogen-test-facility

[24] Lambert, V., and Ashworth, P., 2018, The Australian public's perception of hydrogen for energy, p11 https://arena.gov.au/assets/2018/12/the-australian-publics-perception-of-hydrogen-for-energy.pdf

[25] The Australian public's perception of hydrogen for energy, ARENA, December 2018, p16 https://arena.gov.au/assets/2018/12/the-australian-publics-perception-of-hydrogen-for-energy.pdf

[26] AGIG submission to the National Hydrogen Strategy Discussion Paper https://consult.industry.gov.au/national-hydrogen-strategy-taskforce/national-hydrogen-strategy-request-for-input/consultation/view_respondent?show_all_questions=0&sort=submitted&order=ascending&_q__text=australian+gas+infrastructure+group&uuId=793798735

[27] AGIG submission to the National Hydrogen Strategy Discussion Paper https://consult.industry.gov.au/national-hydrogen-strategy-taskforce/national-hydrogen-strategy-request-for-input/consultation/view_respondent?show_all_questions=0&sort=submitted&order=ascending&_q__text=australian+gas+infrastructure+group&uuId=793798735

[28] Jemena submission on the National Hydrogen Strategy Discussion Paper, April 2019 https://consult.industry.gov.au/national-hydrogen-strategy-taskforce/national-hydrogen-strategy-request-for-input/consultation/view_respondent?show_all_questions=0&sort=submitted&order=ascending&_q__text=jemena&uuId=528925245

[29] Jemena's NHS Discussion Paper submission https://consult.industry.gov.au/national-hydrogen-strategy-taskforce/national-hydrogen-strategy-request-for-input/consultation/view_respondent?show_all_questions=0&sort=submitted&order=ascending&_q__text=jemena&uuId=528925245

[30] Hydrogen Strategy Group, 'Hydrogen for Australia's Future', p30

[31] https://www.standards.org.au/getmedia/2d89a05c-9dd0-4878-90f8-d1c228306d5b/D-1368-Hydrogen-discussion-paper.pdf.aspx , p13 accessed 10 June 2019

[32] Energy Networks Australia, https://www.energynetworks.com.au/gas-vision-2050